HydrauCalc 2025a

Components description

(www.hydraucalc.com)

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1. About...

Software for Fluid Flow and Pressure Loss Calculations

in Pipes and Piping Elements such as

Bends, Reducers, Tees, Valves, Orifices and more.

Brief description:

HydrauCalc is a software application that allows accurate modelling and calculating of stabilized flows in pipes and piping elements (laminar and turbulent flow).

Friction Loss is calculated using the Darcy-Weisbach method, which provides accurate results for non-compressible fluids (liquids). This method also provides satisfactory results of reasonable accuracy for compressible fluids (gases) when the Mach number is less than 0.2 - equivalent to 70 m/s for air at normal temperature and pressure (ref: Internal Flow System, Second Edition, D.S. Miller).

Friction Factors can be calculated using various formulations: Colebrook-White, Swamee-Jain Equation... and more than 40 other correlations published by recognized scientists (for the purpose of comparison of results).

HydrauCalc runs on the Windows environment and has an intuitive interface.

The software comes with its own databases (liquid and gaseous fluids, standard diameters and pipe roughness). Users can also add their own fluid characteristics and pipe diameters.

Units can be selected individually or by unit systems. More than 300 units commonly used in hydraulic calculations are integrated with HydrauCalc. The unit conversion engine is dynamic and automatically converts the values when modifying the units.

Quality Assurance:

HydrauCalc comes with a document that provides a comparison of the results of the software with a series of examples published in well-known and respected references. Examples of hydraulic analysis include calculations of flow, pressure drop and pipe sizing for compressible and incompressible fluids.

The HydrauCalc results data compares very favorably with the published results.

Interface Languages:

The interfaces are available in English, French and Spanish.

Saving a calculation:

For each piping element, the calculation data can be saved and reused later.

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2. Components description

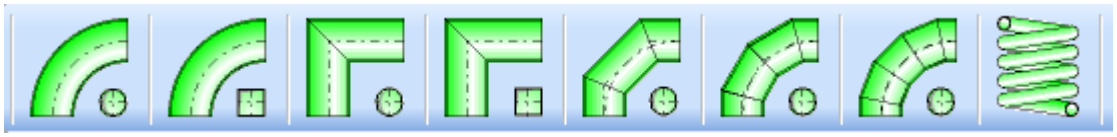
Components

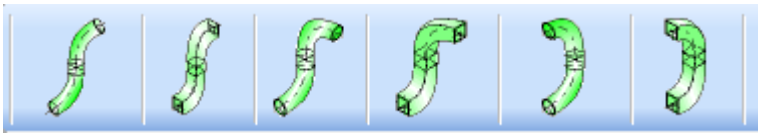
This section describes each of the components or elements that can be modeled and calculated.

Components are grouped by component type in subsections. These subsections are organized in the same order as in the Component Bar:

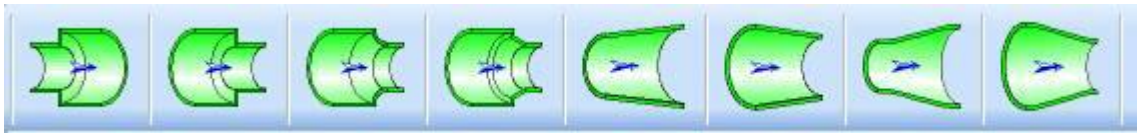
- Straight Pipes

- Bends, Elbows





- Transitions



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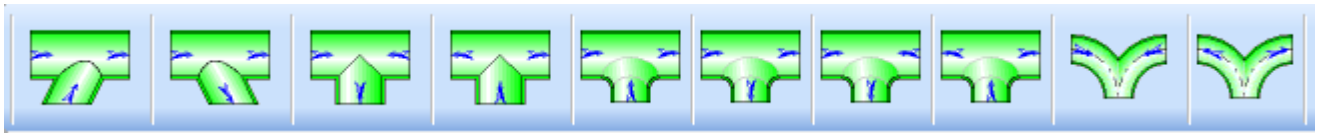

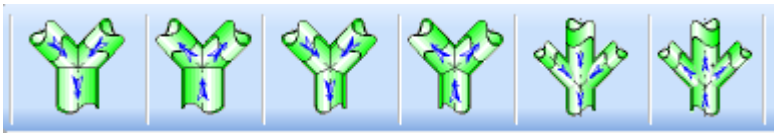

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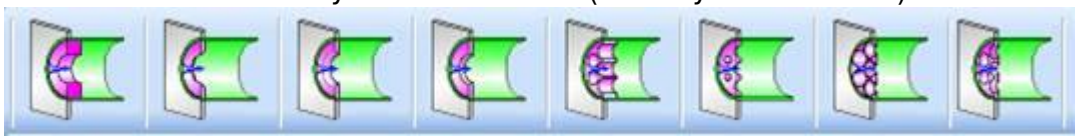
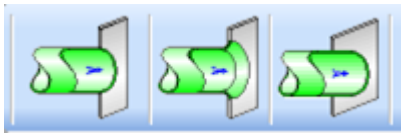
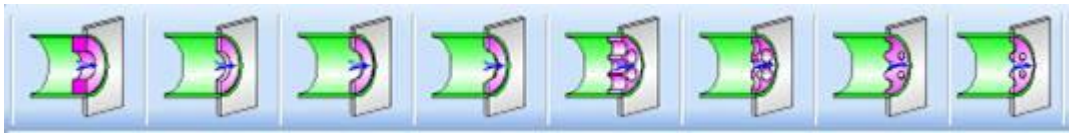
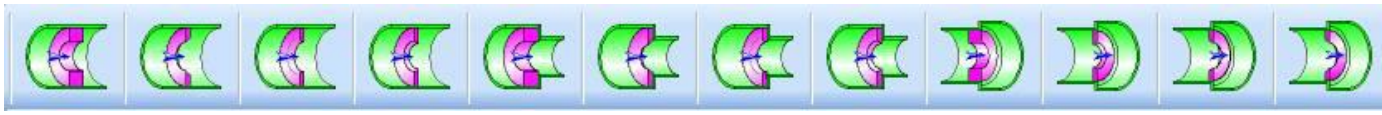


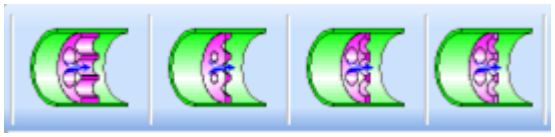
- Piping Discharge



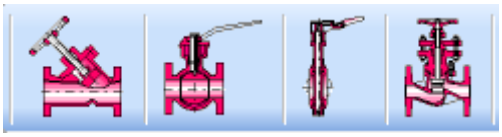


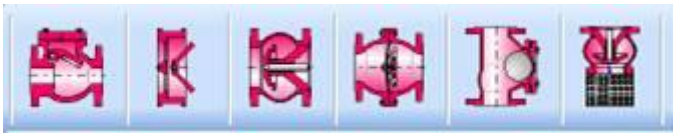
- Orifices, Perforated Plates and Flowmeters

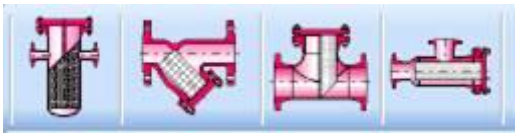




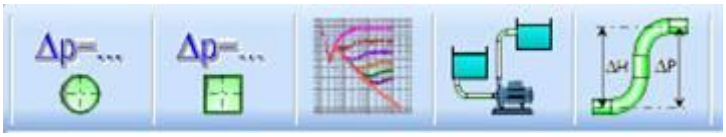
- Valves, Check Valves, Strainers and Sprinklers







- Miscellaneous



Components are called by using the [Component Bar].

In general, each component has several calculation methods that are derived from different reference works. For all components, each calculation method is detailed and includes:

- A description of the method used
- The mathematical formulation of the model
- The nomenclature used for equations
- The validity range of the formulation
- An application example
- The bibliographic reference (s) used for modeling

This section will use, as much as possible, the notation for the cited references.

2.1 Straight pipes

This subsection regroups the set of straight pipes that can be modeled and calculated. The types of straight pipe available are:

- Straight Pipe - Circular Cross-Section

- Straight Pipe - Rectangular Cross-Section

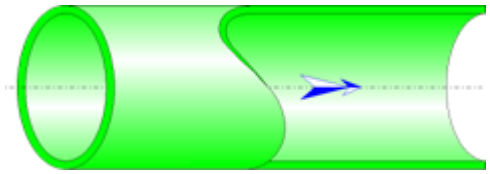
- Straight Pipe - Triangular Cross-Section

- Straight Pipe - Annular Cross-Section

2.1.1 Straight pipe - Circular cross-section

Straight Pipe

Circular Cross-section



To calculate the pressure losses by friction in straight pipes, Darcy Weisbach's equation is used for all proposed calculation methods, except for the HAZEN-WILLIAMS method.

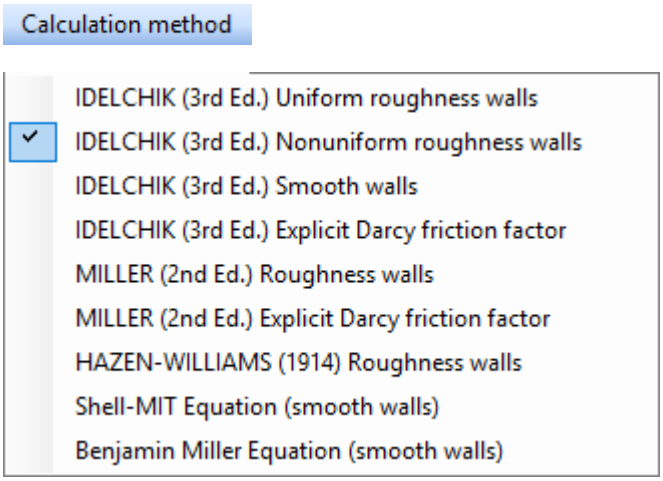
For the calculation of the friction factor, the user can choose from one of the 7 available relationships, depending on the roughness of the inner walls:

- Homogeneous roughness piping (uniform roughness - pipe used by Nikuradse for its experimental data) - Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Heterogeneous roughness piping (industrial type piping) - Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipes with smooth walls - Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipes with roughness walls - Internal Flow System, 2nd Edition, D.S. Miller
- Pipes with roughness walls - Hazen-Williams
- Pipes with smooth walls - Shell-MIT Equation
- Pipes with smooth walls - Benjamin Miller Equation

It is also possible to explicitly specify the value of the friction factor. This is available in case you are looking for results with another formulation of the friction factor (Haaland equation for example). The friction factor is available for the following references:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "Pipes with nonuniform roughness"

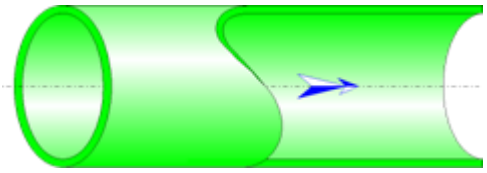


2.1.1.1 IDELCHIK (uniform roughness walls)

Straight Pipe

Circular Cross-Section and Uniform Roughness Walls

(IDELCHIK)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of circular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula. The roughness of the inner walls of the pipe is supposed uniform (pipe used by Nikuradse for its experimental data).

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille (independent of the value of relative roughness),
- for turbulent flow regime by the Nikuradse equation (dependent of the value of relative roughness),
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\bar{\Delta} = \frac{\Delta}{D_h}$$

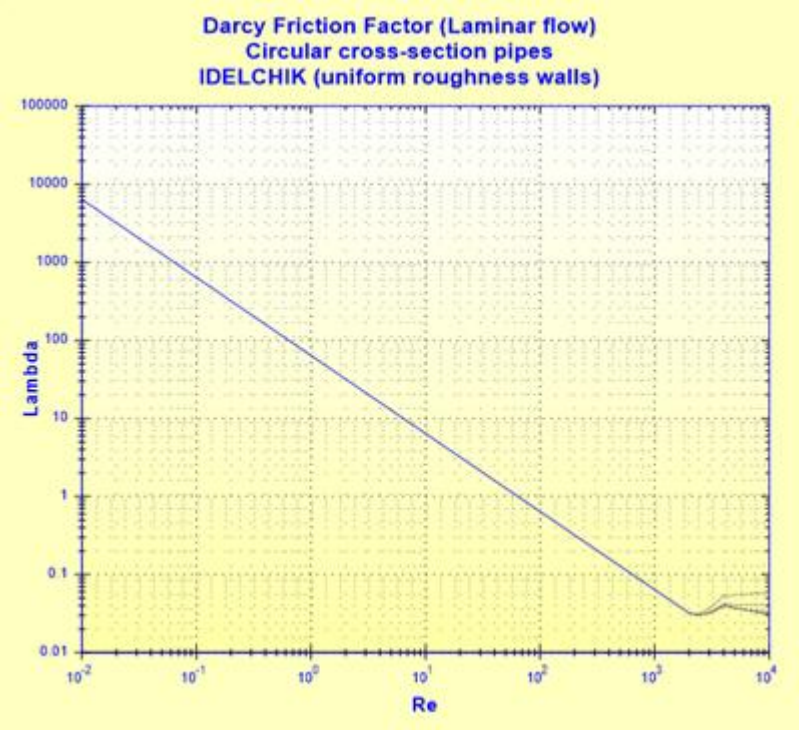
Darcy friction factor:

- laminar flow regime ($Re \leq 2000$):

  Hagen-Poiseuille law

$$\lambda = \frac{64}{Re}$$

([1] diagram 2.1)



■ turbulent flow regime – transition region and complete turbulence region (Re ≥ 4000):

Nikuradze equation

$$\lambda = \frac{1}{\left[a_1 + b_1 \cdot \log(Re \cdot \sqrt{\lambda}) + c_1 \cdot \log(\overline{\Delta})\right]^2}$$

([1] diagram 2.2)

where the values of a_1, b_1 and c_1 are given below:

$\overline{\Delta} \cdot Re \cdot \sqrt{\lambda}$	a_1	b_1	c_1
3.6 - 10	-0.800	2.000	0.000
10 - 20	0.068	1.130	-0.870
20 - 40	1.538	0.000	-2.000
40 - 191.2	2.471	-0.588	-2.588
> 191.2	1.138	0.000	-2.000

Reynolds number at which pipe cease to be hydraulically smooth:

$$Re'_{lim} = \frac{26.9}{\overline{\Delta}^{1.143}}$$

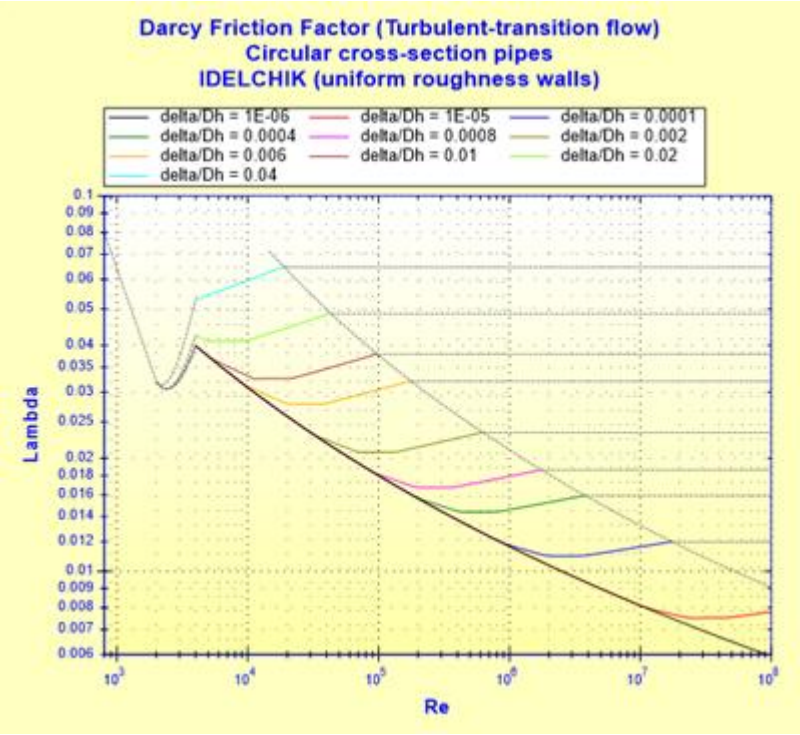
([1] §2.17)

Reynolds number corresponding to the beginning of complete turbulence:

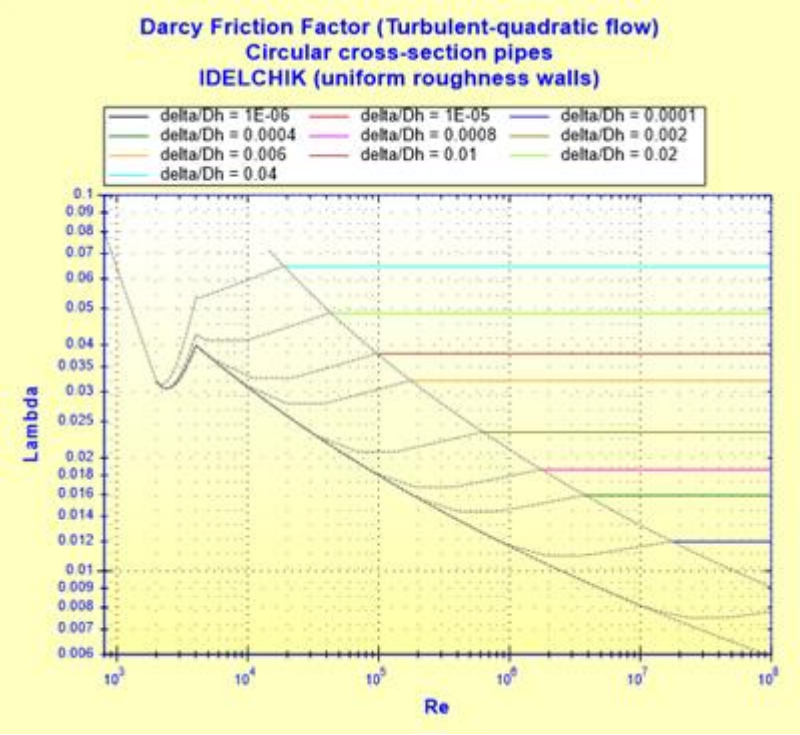
$$Re''_{lim} = \frac{217.6 - 382.4 \cdot \log(\bar{\Delta})}{\bar{\Delta}}$$

([1] diagram 2.2)

Transition region



Complete turbulence region



■ critical flow regime (2000 < Re < 4000):

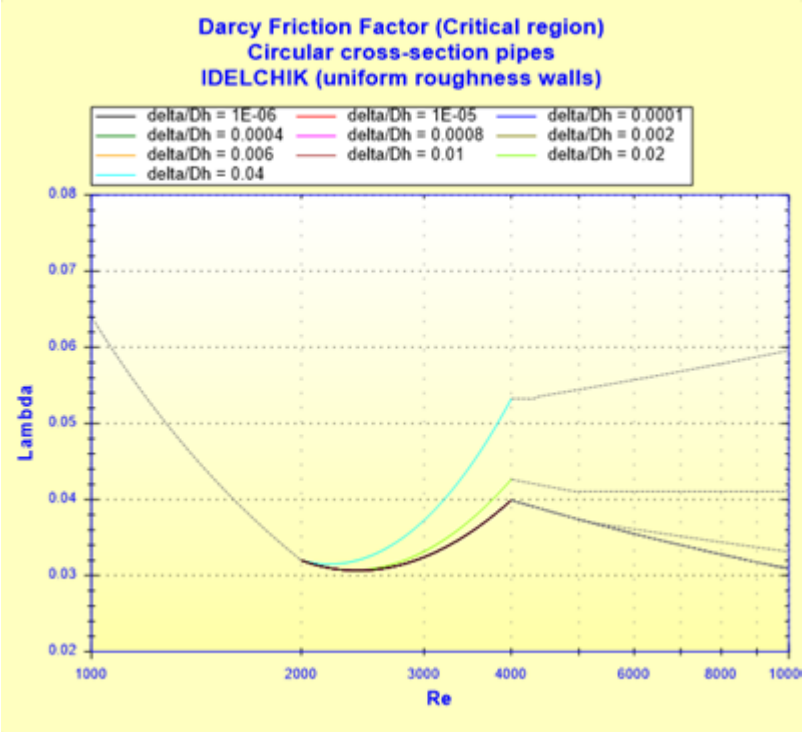
linear interpolation

$$\lambda = \lambda_L \cdot \left(1 - \frac{Re - 2000}{2000}\right) + \lambda_T \cdot \left(\frac{Re - 2000}{2000}\right)$$

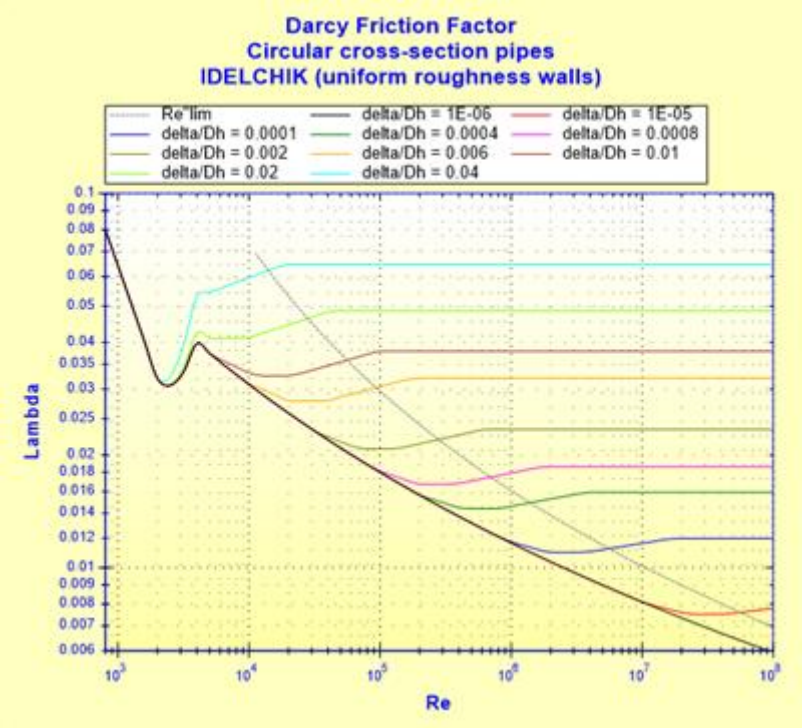
with:

λ_L = laminar friction coefficient obtained with Re = 2000

λ_T = turbulent friction coefficient obtained with Re = 4000



■ all flow regimes:



Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \lambda \cdot \frac{l}{D_h}$$

([1] equation 2-2)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

([1] equation 2-2)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h Hydraulic diameter (m)

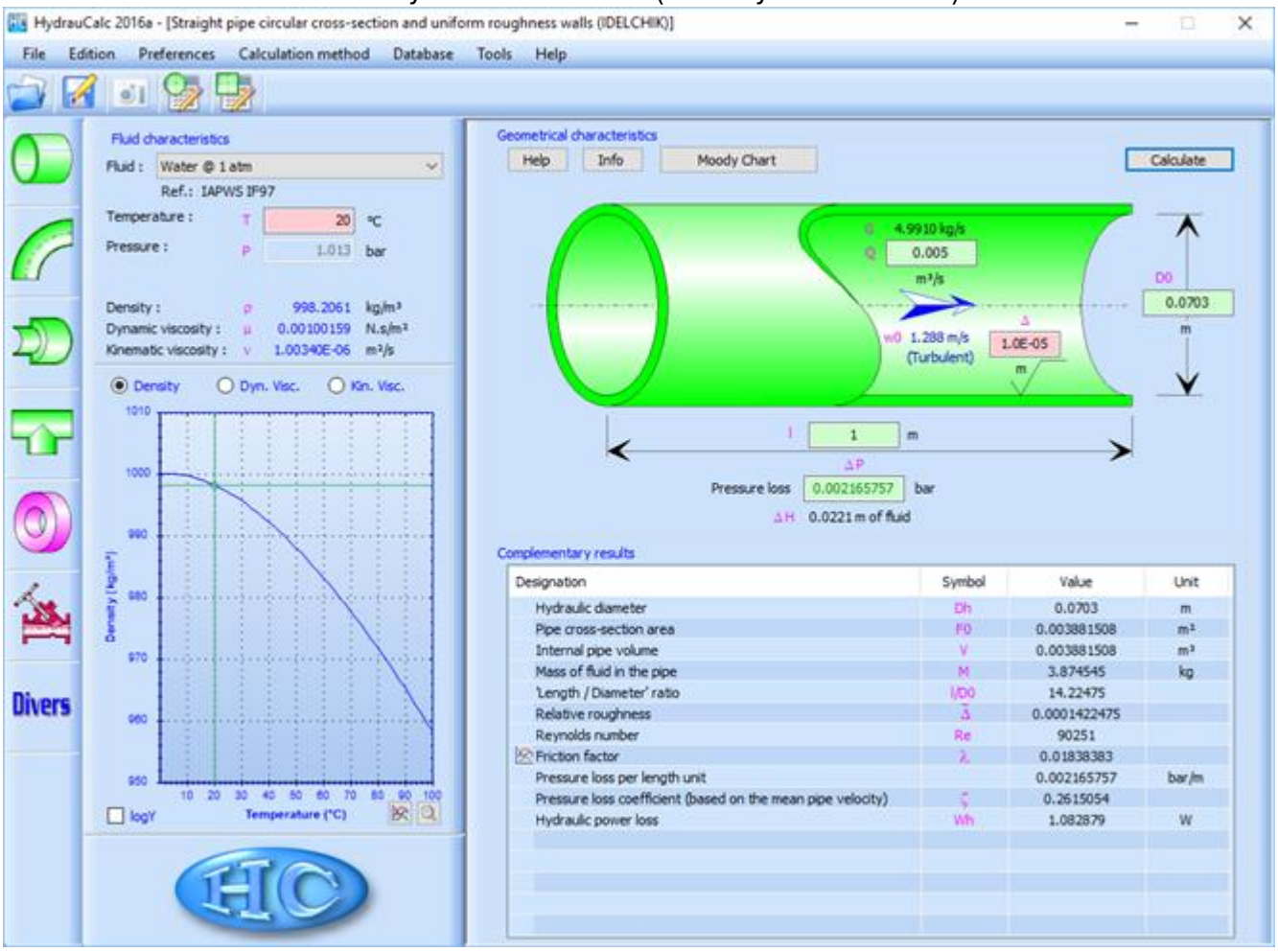
D_0 Internal diameter (m)

F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity (m/s)
l	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
Re'_{lim}	Limiting Reynolds number for hydraulically smooth law ()
Re''_{lim}	Limiting Reynolds number for quadratic law ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()
λ	Darcy friction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
- $\bar{\Delta} \leq 0.05$
- stabilized flow

Example of application:



References:

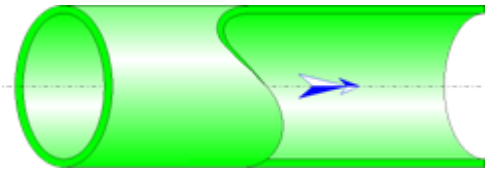
[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.1.2 IDELCHIK (nonuniform roughness walls)

Straight Pipe

Circular Cross-Section and Nonuniform Roughness Walls

(IDELCHIK)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of circular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula. The roughness of the inner walls of the pipe is supposed nonuniform (commercial pipe).

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille (independent of the value of relative roughness),
- for turbulent flow regime by the implicit Colebrook-White equation (dependent of the value of relative roughness),
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\overline{\Delta} = \frac{\Delta}{D_h}$$

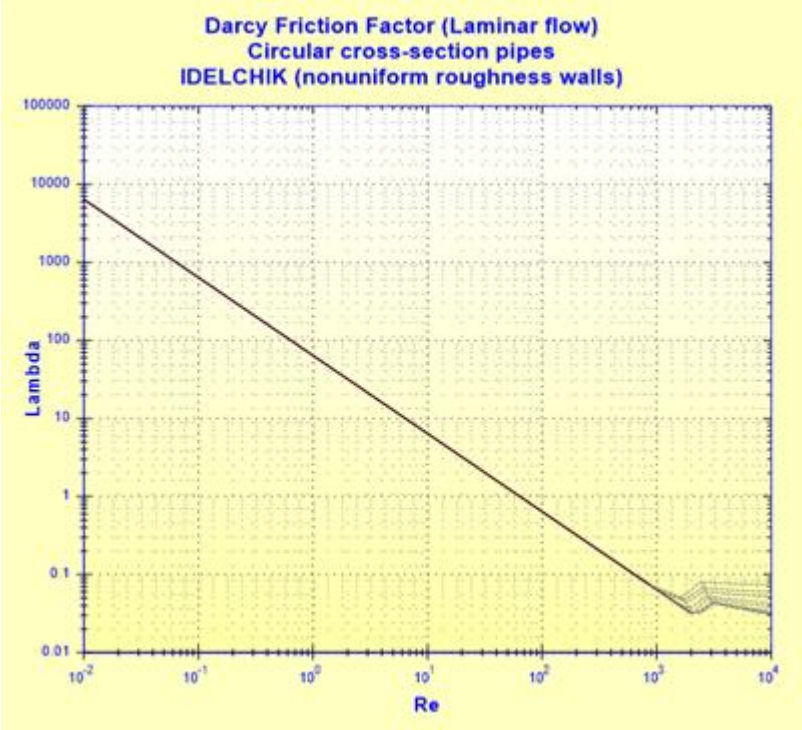
Darcy friction factor:

- laminar flow regime ($Re \leq Re_0$):

  Hagen-Poiseuille law

$$\lambda = \frac{64}{Re}$$

([1] diagram 2.1)



■ turbulent flow regime – transition region and complete turbulence region ($Re \geq Re_2$):

Colebrook-White equation

$$\lambda = \frac{1}{\left[2 \cdot \log\left(\frac{2.51}{Re \cdot \sqrt{\lambda}} + \frac{\overline{\Delta}}{3.7}\right)\right]^2}$$

([1] diagram 2.4)

Reynolds number at which pipe cease to be hydraulically smooth:

$$Re'_{lim} = \frac{15}{\overline{\Delta}}$$

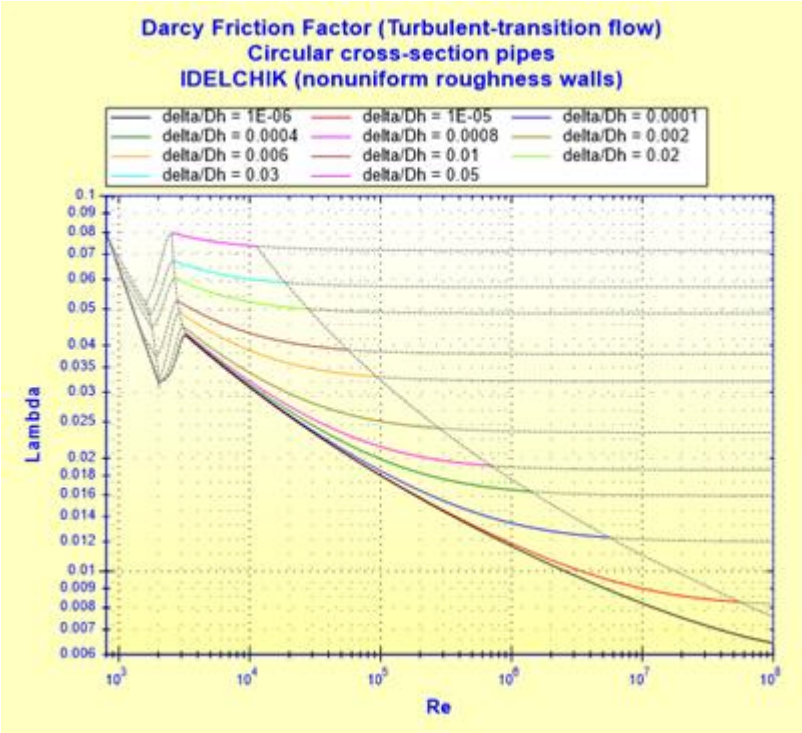
([1] §2.23)

Reynolds number corresponding to the beginning of complete turbulence:

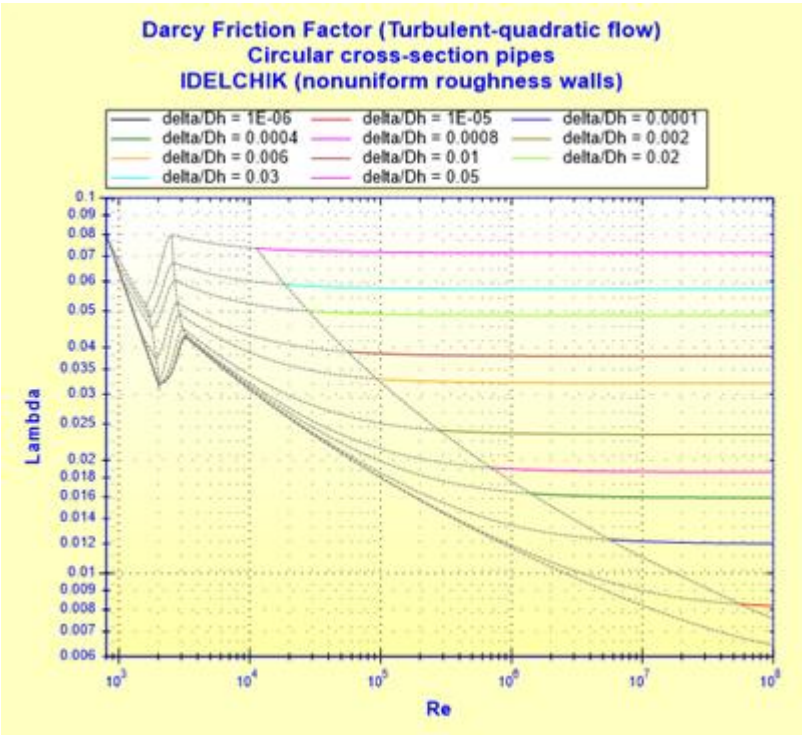
$$Re''_{lim} = \frac{560}{\overline{\Delta}}$$

([1] diagram 2.4)

Transition region



Complete turbulence region



■ critical flow regime ($Re_0 < Re < Re_2$):

$$\lambda = f(\mathrm{Re}, \overline{\Delta})$$

([1] diagram 2.3)

Reynolds number of start of critical zone:

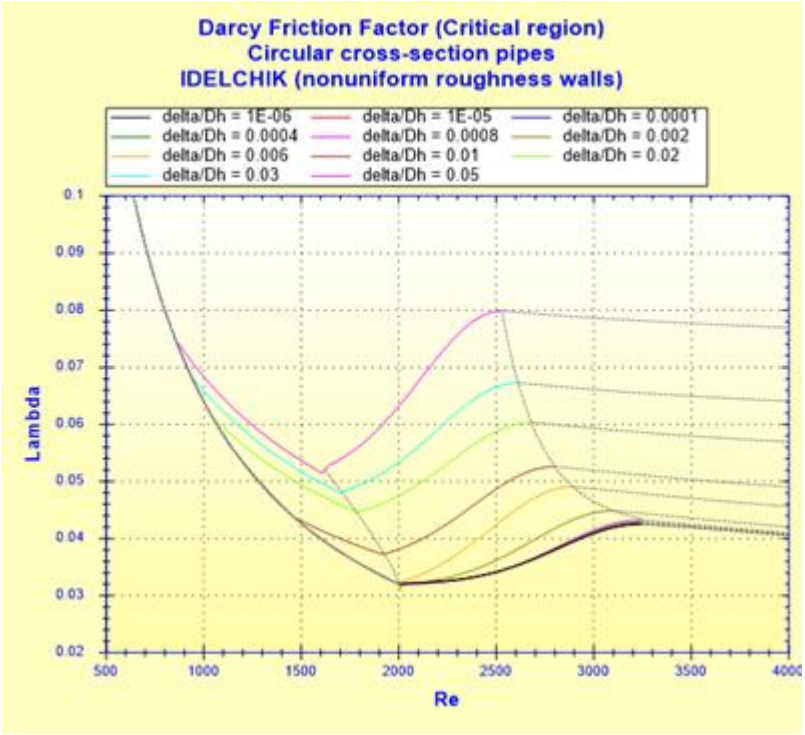
$$Re_0 = 754 \exp\left(\frac{0.0065}{\Delta}\right)$$

([1] §2.21)

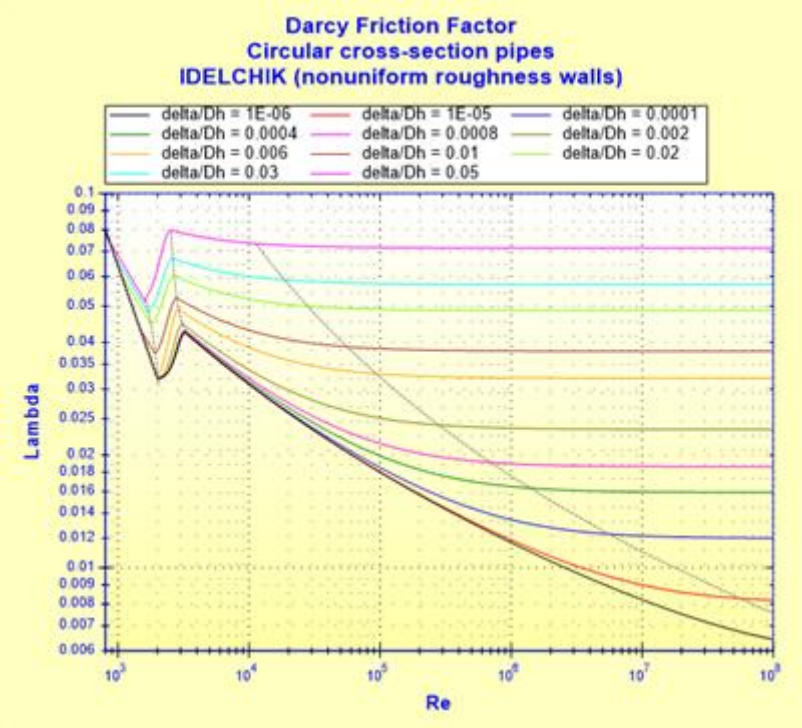
Reynolds number at end of critical zone:

$$Re_2 = 2090\left(\frac{1}{\Delta}\right)^{0.0635}$$

([1] §2.22)



■ all flow regimes:



Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \lambda \cdot \frac{l}{D_h}$$

([1] equation 2-2)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

([1] equation 2-2)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h Hydraulic diameter (m)

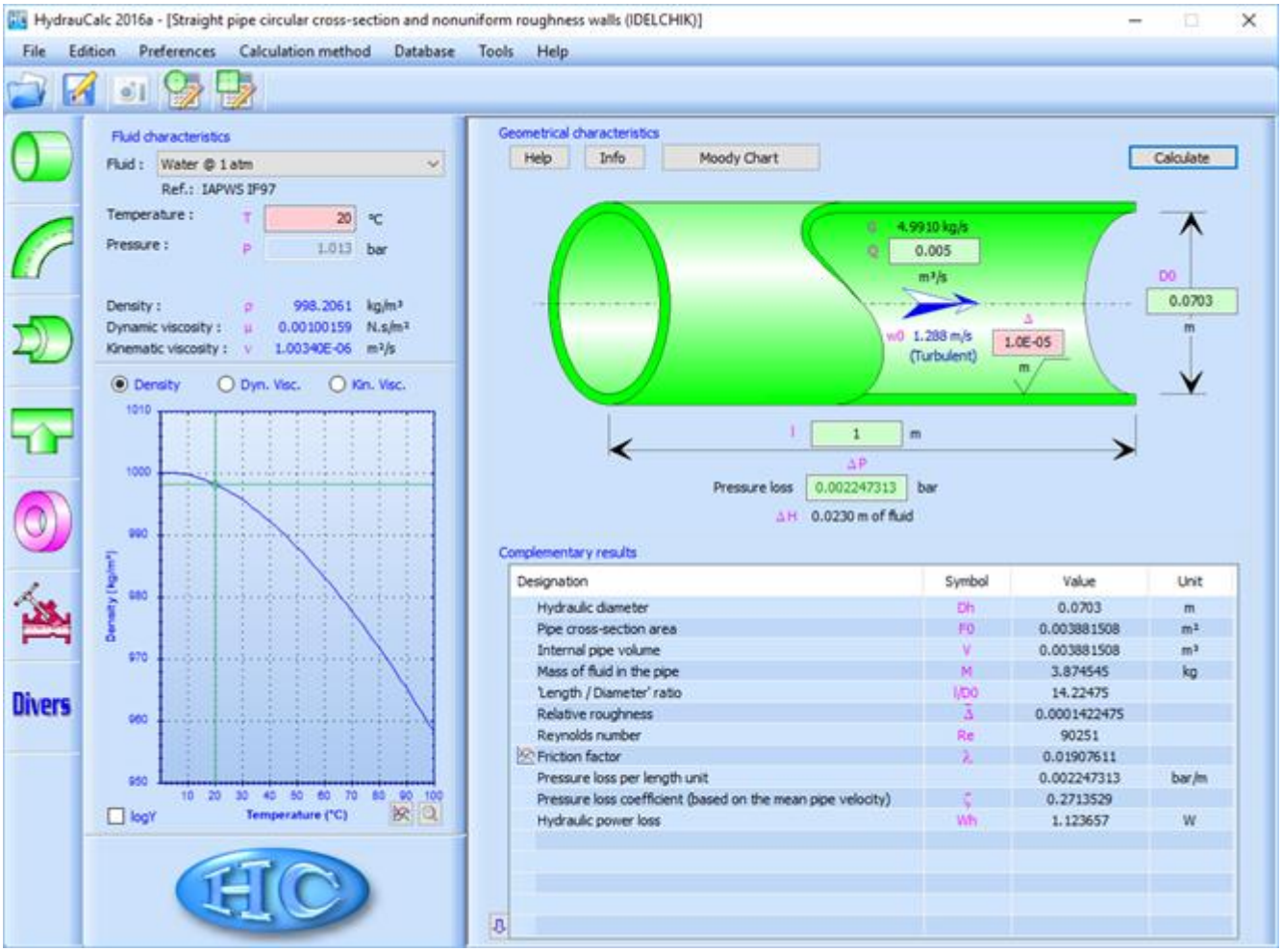
D_0 Internal diameter (m)

F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity (m/s)
l	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
Re_0	Reynolds number of start of critical zone ()
Re_2	Reynolds number at end of critical zone ()
Re'_{lim}	Limiting Reynolds number for hydraulically smooth law ()
Re''_{lim}	Limiting Reynolds number for quadratic law ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()
λ	Darcy friction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
- $\bar{\Delta} \leq 0.05$
- stabilized flow

Example of input data and results:



References:

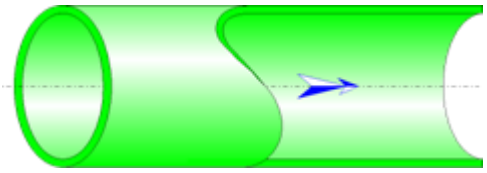
[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.1.3 IDELCHIK (smooth walls)

Straight Pipe

Circular Cross-Section and Smooth Walls

(IDELCHIK)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of circular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula. The inner wall of the piping is supposed to completely smooth (without roughness).

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille,
- for turbulent flow regime by the explicit Filonenko and Althsul equation,
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

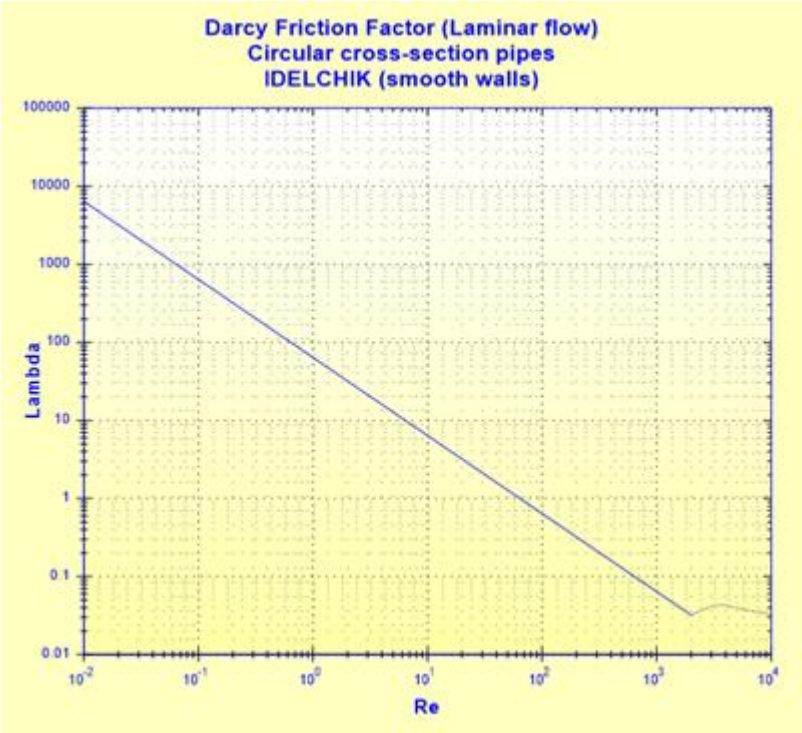
$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Darcy friction factor:

- laminar flow regime ($Re \leq 2000$):

  Hagen-Poiseuille law

  $$\lambda = \frac{64}{Re}$$ ([1] diagram 2.1)

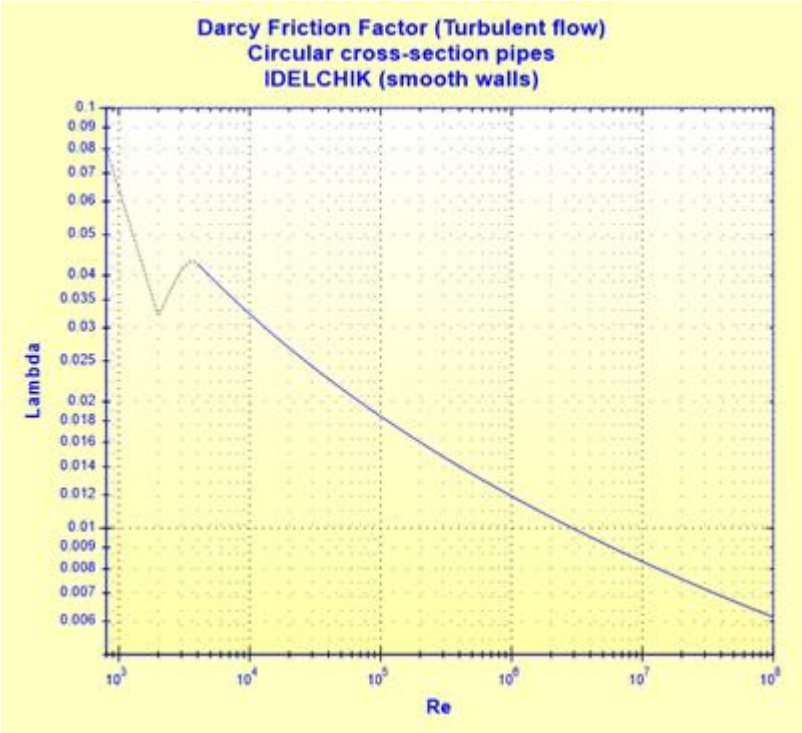


■ turbulent flow regime (Re ≥ 4000):

Filonenko and Althsul Equation

$$\lambda = \frac{1}{[1.8 \cdot \log(\mathrm{Re}) - 1.64]^2}$$

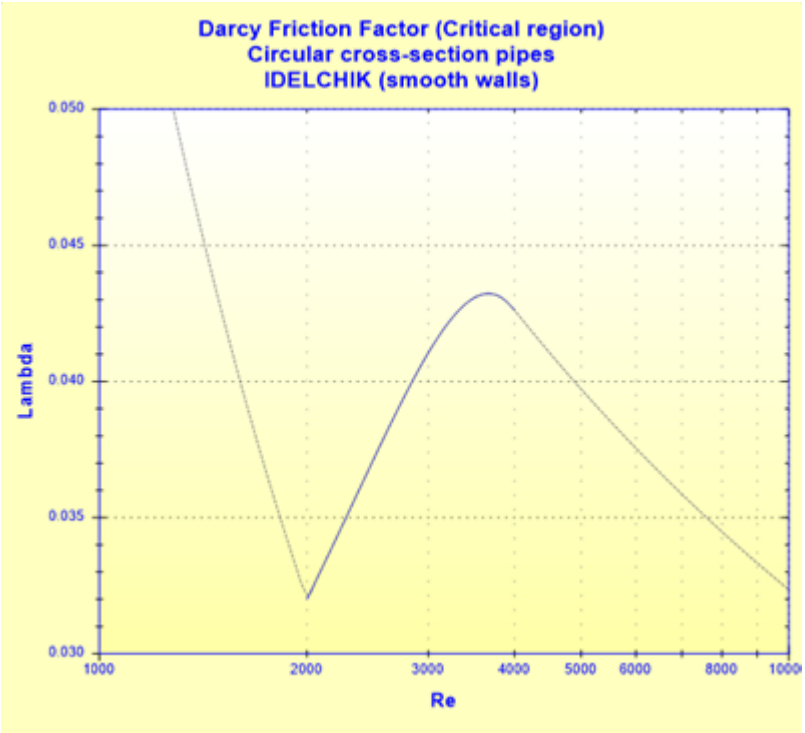
([1] diagram 2.1)



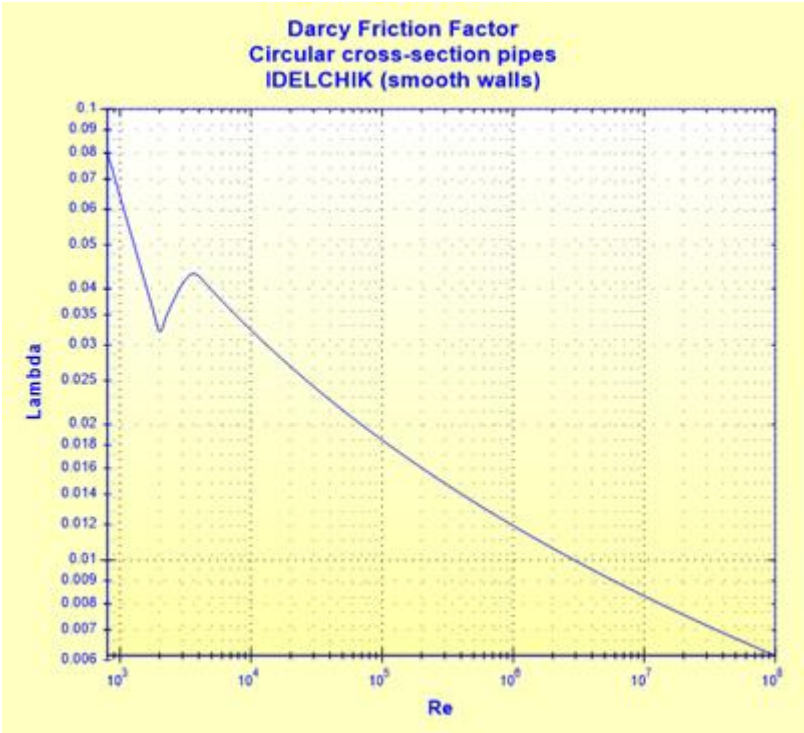
■ critical flow regime (2000 < Re < 4000):

interpolation between laminar and turbulent flows

$\lambda = f(\mathrm{Re})$ ([1] diagram 2.1)



■ all flow regimes:



Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \lambda \cdot \frac{l}{D_h}$$

([1] equation 2-2)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot w_0^2}{2}$$

([1] equation 2-2)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{w_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_0	Internal diameter (m)
F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity (m/s)
l	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
λ	Darcy friction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m^3)

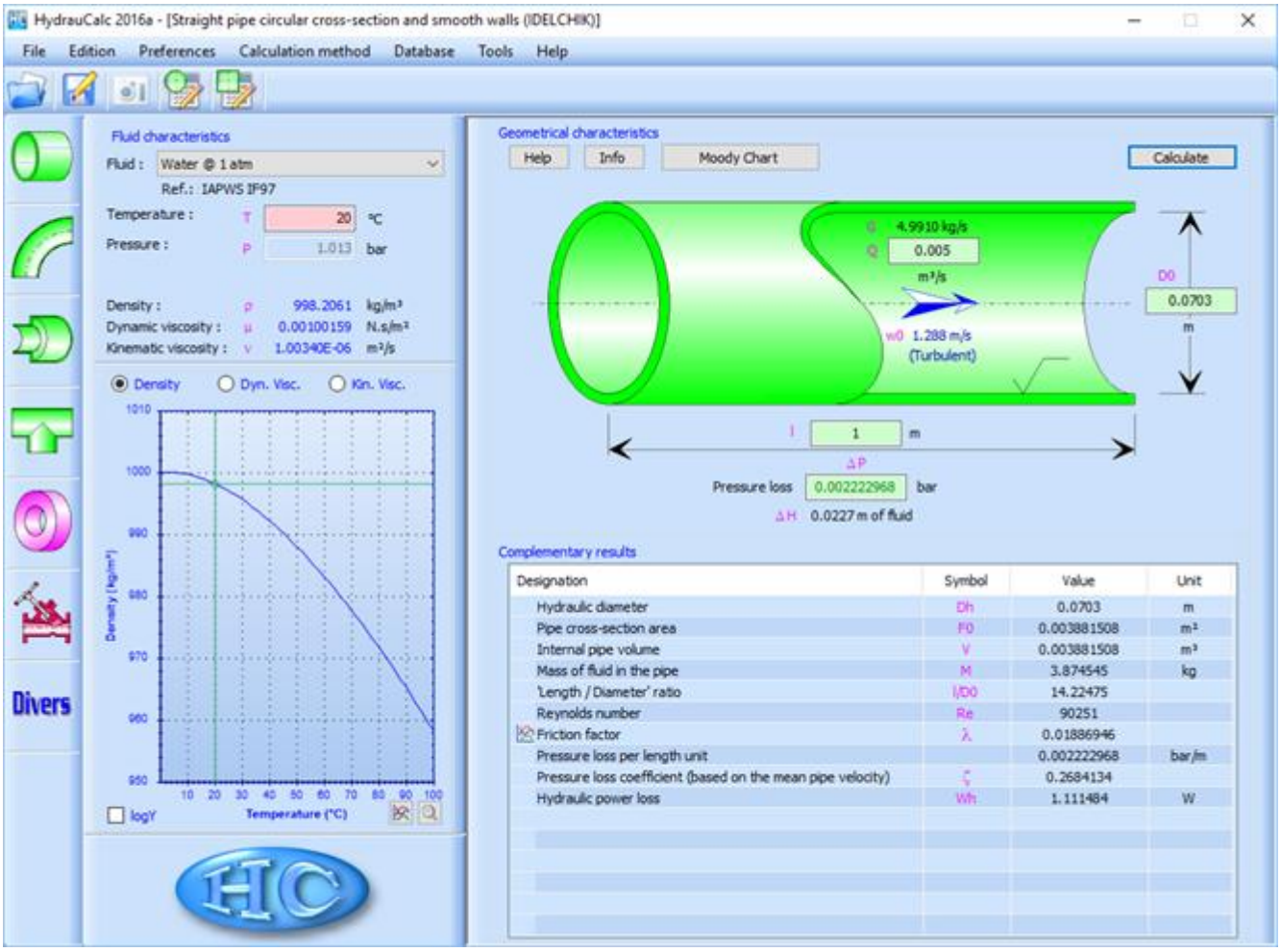
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
- stabilized flow

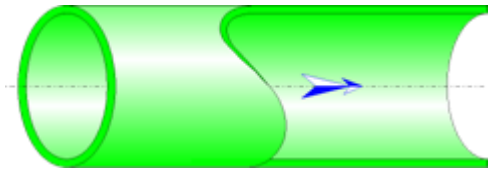
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.1.4 IDELCHIK (explicit Darcy friction factor)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of circular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula.

In this model Darcy friction factor is filled explicitly.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \lambda \cdot \frac{l}{D_h}$$

([1] equation 2-2)

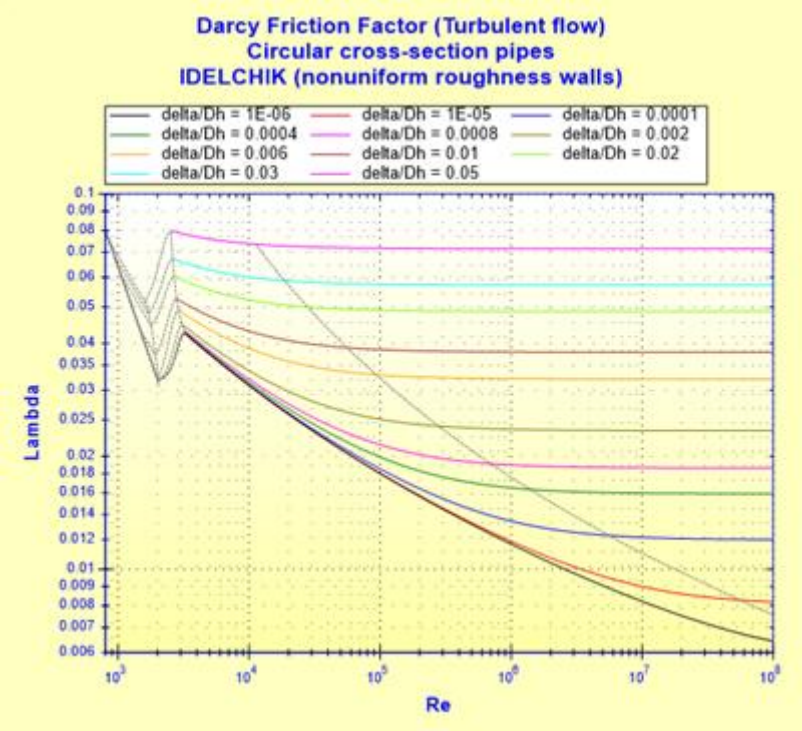
Equivalent relative roughness (turbulent regime - Re ≥ 4000):

Colebrook-White equation

$$\lambda = \frac{1}{\left[2 \cdot \log\left(\frac{2.51}{Re \cdot \sqrt{\lambda}} + \frac{\bar{\Delta}}{3.7}\right)\right]^2}$$

([1] diagram 2.4)

where $\bar{\Delta}$ is calculated by solving the equation.



Equivalent absolute roughness (m):

$$\Delta = \overline{\Delta} \cdot D_h$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

([1] equation 2-2)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h Hydraulic diameter (m)

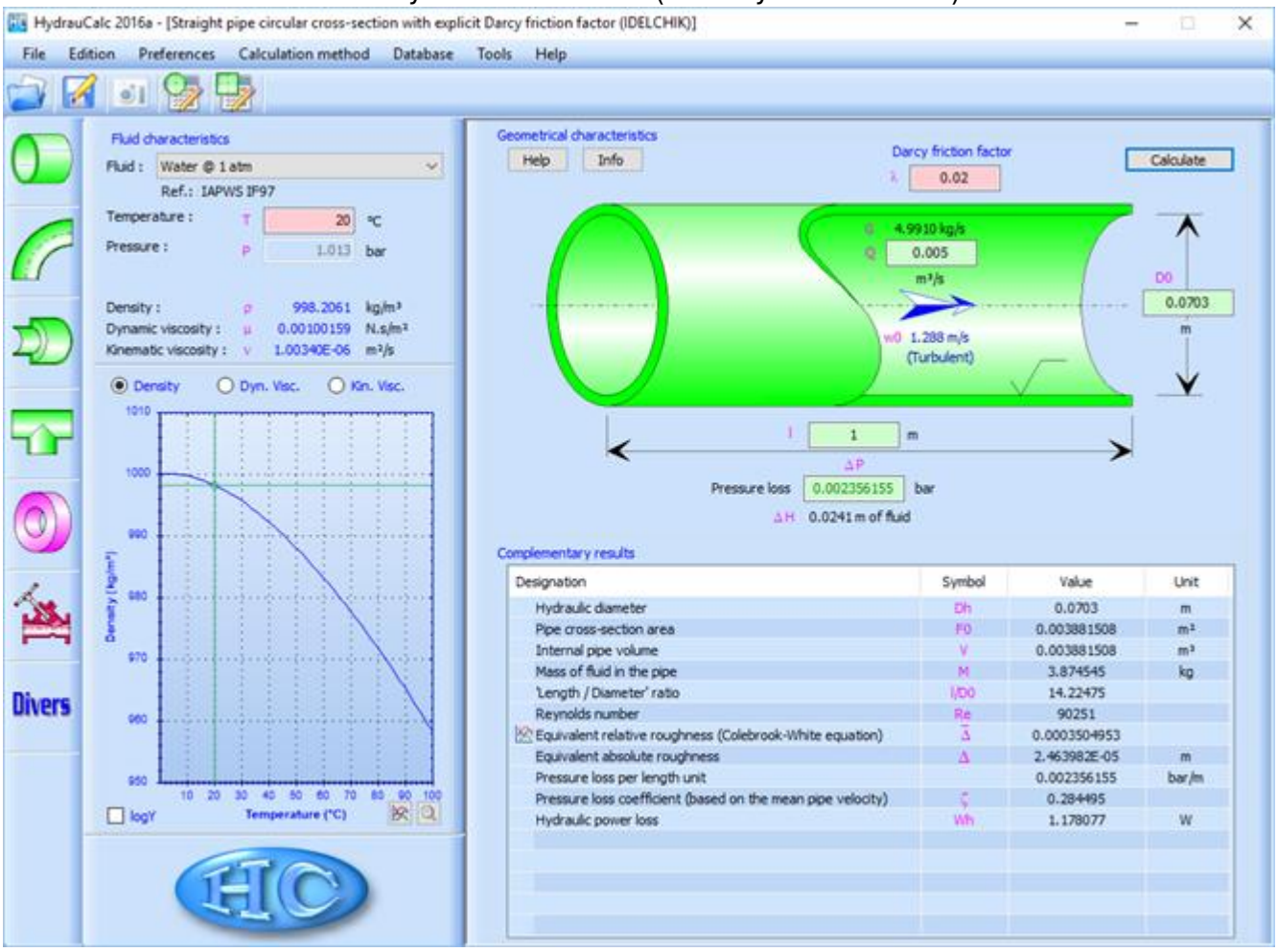
D_0 Internal diameter (m)

F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity (m/s)
l	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
λ	Darcy friction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
Δ	Equivalent absolute roughness of walls (m)
$\bar{\Delta}$	Equivalent relative roughness of walls ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- critical and turbulent flow regime ($2\ 10^3 \leq Re \leq 10^8$)
- stabilized flow

Example of application:



References:

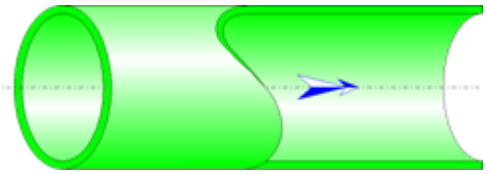
[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.1.5 MILLER (roughness walls)

Straight Pipe

Circular Cross-Section and Roughness Walls

(MILLER)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of circular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula.

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille (independent of the value of relative roughness),
- for turbulent flow regime by the explicit Swamee-Jain equation (dependent of the value of relative roughness), the explicit Swamee-Jain equation is a Colebrook-White equation approximation,
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Hydraulic diameter (m):

$$D = d$$

Cross-section area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$m = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = A \cdot L$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

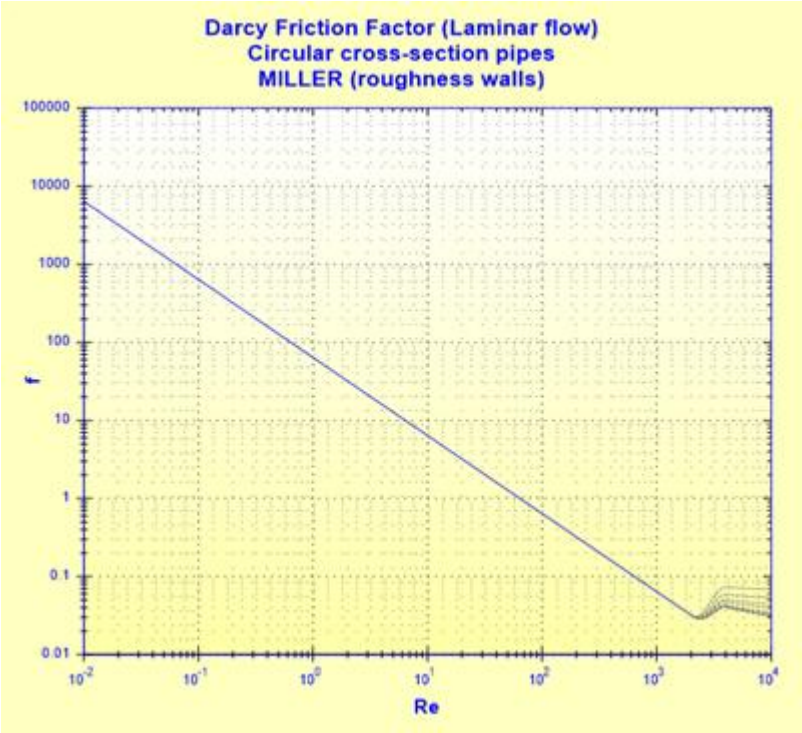
Darcy friction factor:

- laminar flow regime ($Re \leq 2000$):

  Hagen-Poiseuille law

$$f = \frac{64}{Re}$$

([1] equation 8.7)



■ turbulent flow regime – transition region and complete turbulence region (Re ≥ 4000):

Swamee-Jain equation (Colebrook-White equation approximation)

$$f = \frac{0.25}{\left[\log\left(\frac{k}{3.7 \cdot D} + \frac{5.74}{\mathrm{Re}^{0.9}}\right)\right]^2}$$

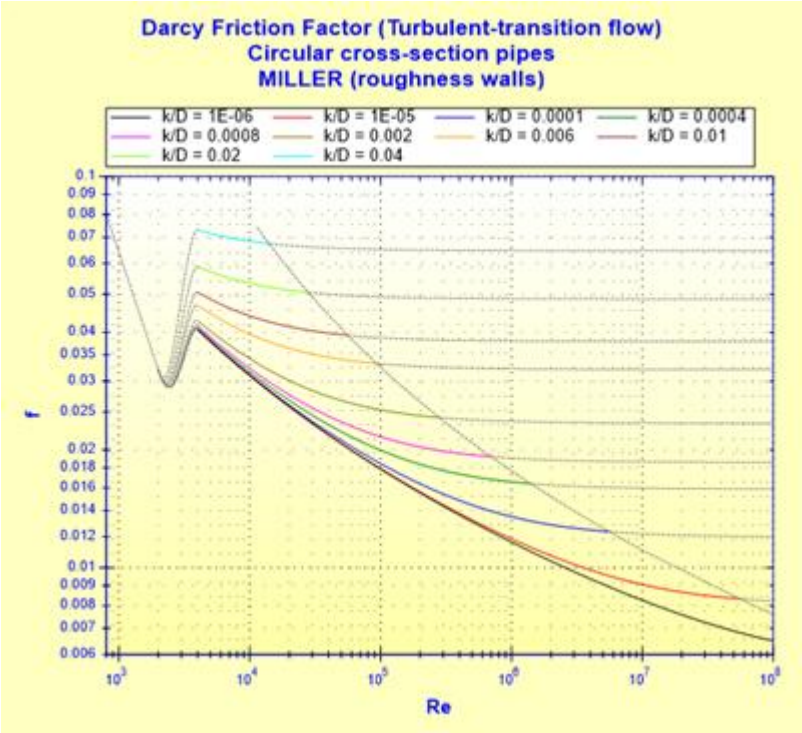
([1] equation 8.4)

Reynolds number corresponding to the beginning of complete turbulence:

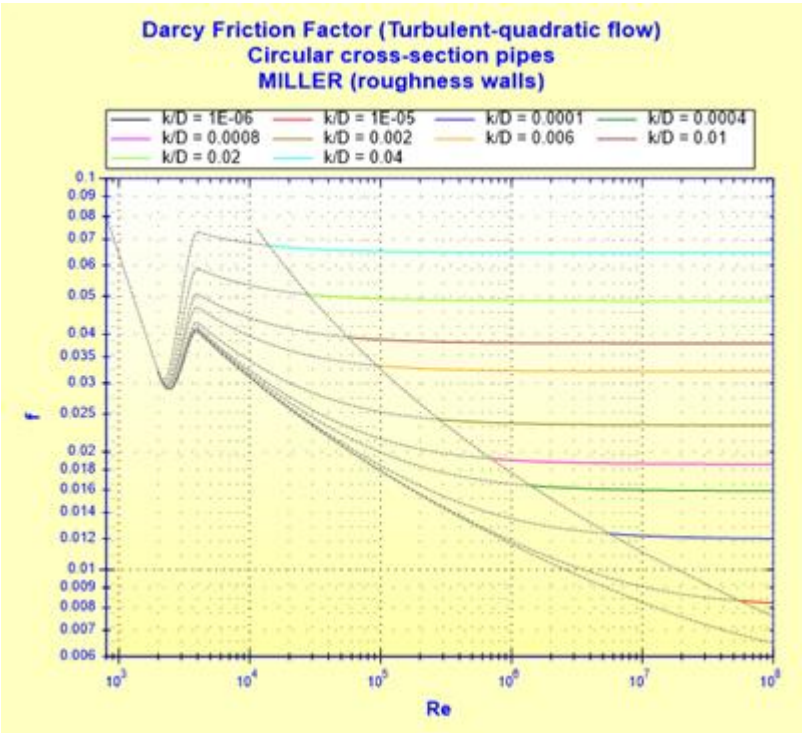
$$\mathrm{Re''}_{lim} = \frac{560}{\Delta}$$

([2] diagram 2.4)

Transition region



Complete turbulence region



■ critical flow regime (2000 < Re < 4000):

cubic interpolation

$$f = (X1 + R \cdot (X2 + R \cdot (X3 + X4)))$$ ([3])

with:

$$R = \frac{Re}{2000}$$

$$X1 = 7 \cdot FA - FB$$

$$X2 = 0.128 - 17 \cdot FA + 2.5 \cdot FB$$

$$X3 = -0.128 + 13 \cdot FA - 2 \cdot FB$$

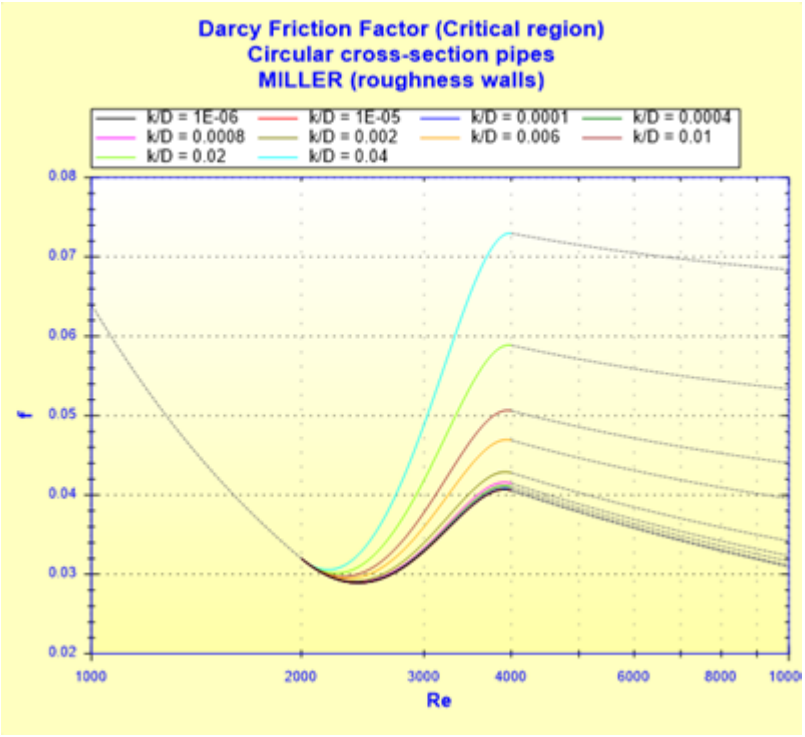
$$X4 = R \cdot (0.032 - 3 \cdot FA + 0.5 \cdot FB)$$

$$FA = Y3^{-2}$$

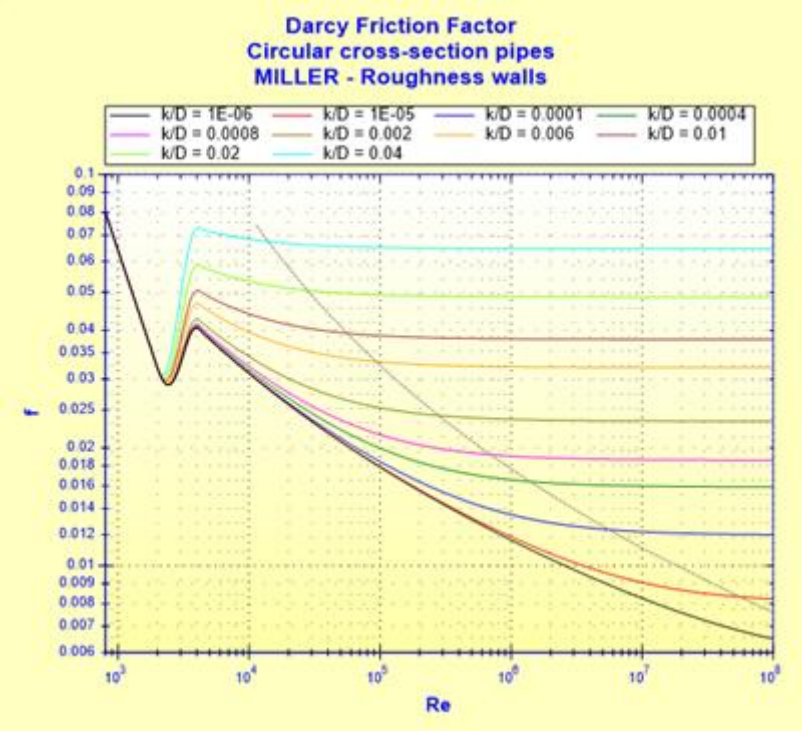
$$FB = FA \cdot \left(2 - \frac{0.00514215}{Y2 \cdot Y3}\right)$$

$$Y2 = \frac{k}{3.7 \cdot D} + \frac{5.74}{Re^{0.9}}$$

$$Y3 = -0.86859 \cdot ln\left(\frac{k}{3.7 \cdot D} + \frac{5.74}{4000^{0.9}}\right)$$



■ all flow regimes:



Friction pressure loss coefficient:

$$K_f = f \cdot \frac{L}{D}$$

([1] equation 8.3)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_f$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

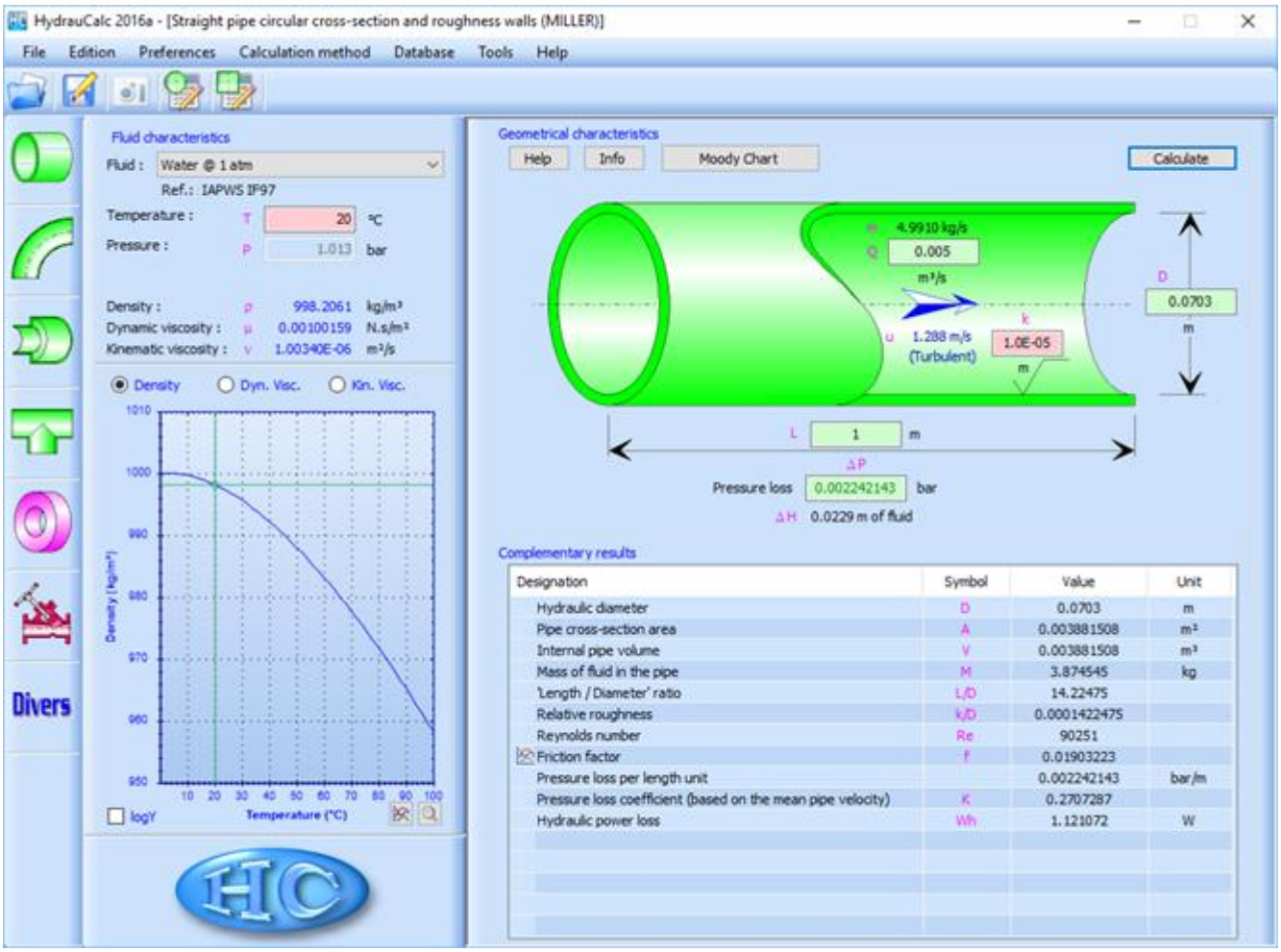
D	Hydraulic diameter (m)
d	Internal diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
m	Mass flow rate (kg/s)
U	Mean velocity (m/s)
L	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
Re''_{lim}	Limiting Reynolds number for quadratic law ()
k	Absolute roughness of walls (m)
f	Darcy friction factor ()
K_f	Friction pressure loss coefficient ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
- $k/D \leq 0.05$

- stabilized flow

Example of application:



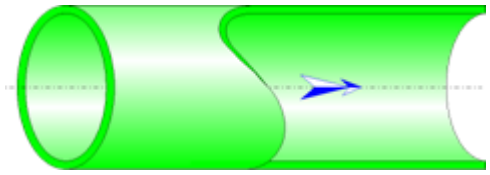
References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

[2] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

[3] Dunlop (1991)

2.1.1.6 MILLER (explicit Darcy friction factor)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of circular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula.

In this model Darcy friction factor is filled explicitly.

Model formulation:

Hydraulic diameter (m):

$$D = d$$

Cross-section area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$m = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = A \cdot L$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

Friction pressure loss coefficient:

$$K_f = f \cdot \frac{L}{D}$$ ([1] equation 8.3)

Total pressure loss coefficient (based on the mean pipe velocity):

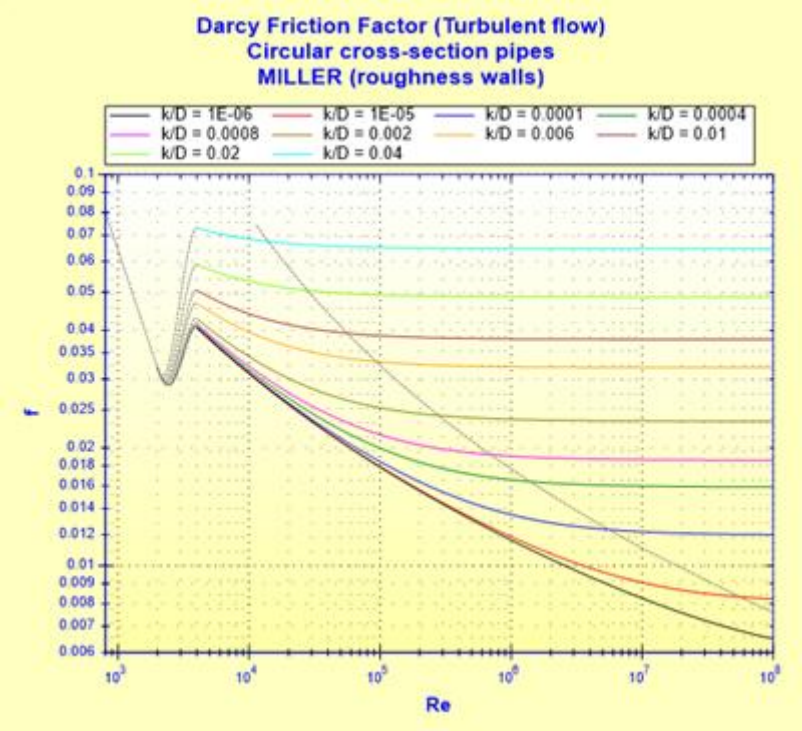
$$K = K_f$$

Equivalent absolute roughness (turbulent regime- Re ≥ 4000):

Swamee-Jain equation (Colebrook-White equation approximation)

$$f = \frac{0.25}{\left[\log\left(\frac{k}{3.7 \cdot D} + \frac{5.74}{Re^{0.9}}\right)\right]^2}$$ ([1] equation 8.4)

where k is calculated by solving the equation.



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

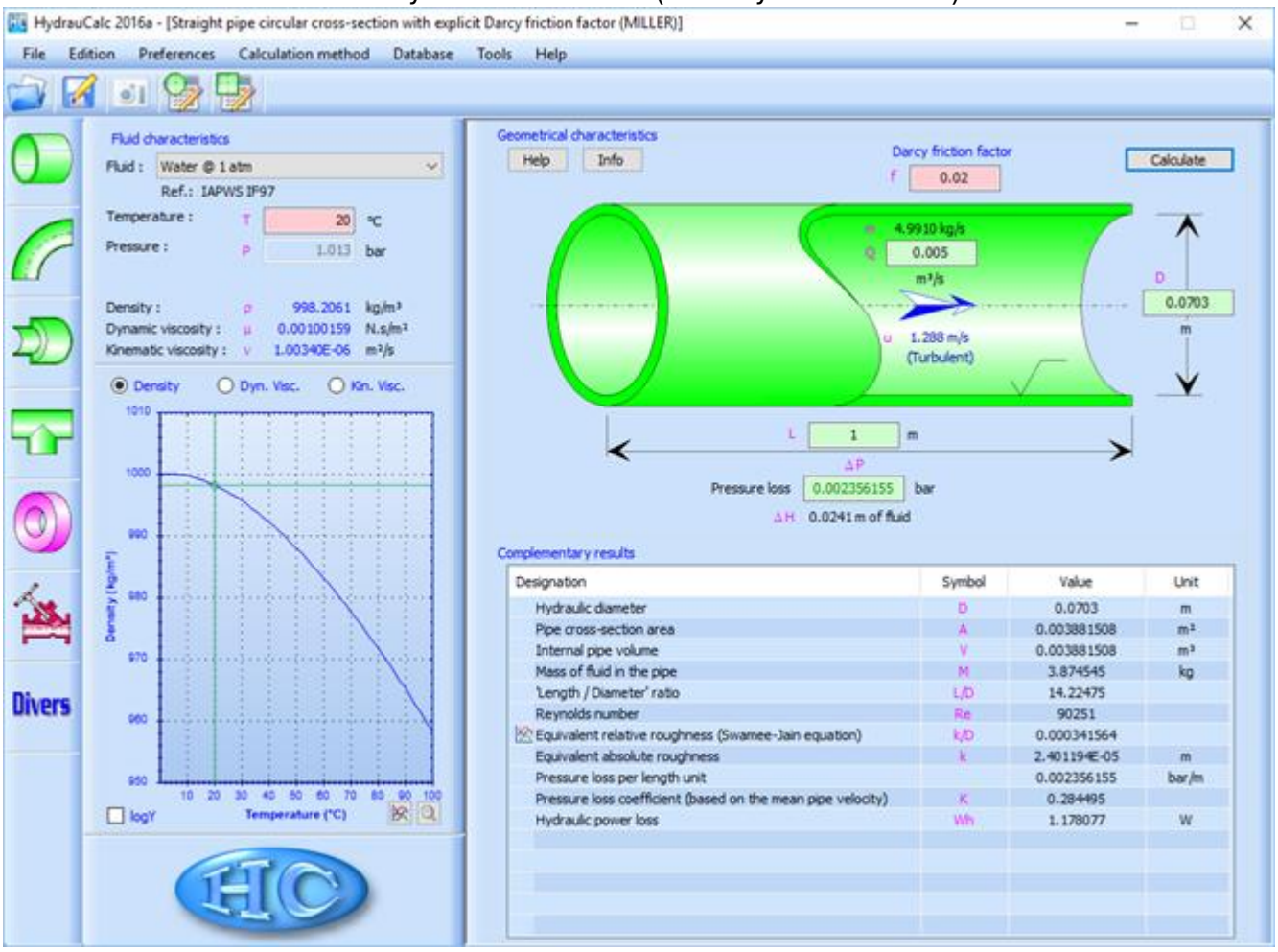
D	Hydraulic diameter (m)
d	Internal diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
m	Mass flow rate (kg/s)

U	Mean velocity (m/s)
L	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
f	Darcy friction factor ()
K_f	Friction pressure loss coefficient ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
k	Equivalent absolute roughness of walls (m)
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- critical and turbulent flow regime ($2\ 10^3 \leq Re \leq 10^8$)
- stabilized flow

Example of application:



References:

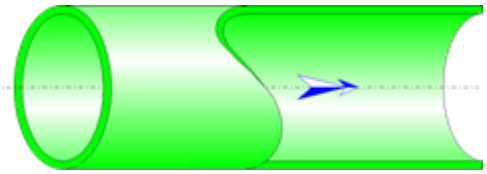
[1] Internal Flow System, Second Edition, D.S. Miller (1990)

2.1.1.7 HAZEN-WILLIAMS (roughness walls)

Straight Pipe

Circular Cross-Section and Roughness Walls

(HAZEN-WILLIAMS)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of circular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Hazen-Williams equation.

The Hazen-Williams equation is an empirical relationship which relates the flow of water in a pipe with the physical properties of the pipe and the pressure drop caused by friction. It is used in the design of water pipe systems such as fire sprinkler systems, water supply networks, and irrigation systems.

The Hazen-Williams equation has the advantage that the coefficient C is not a function of the Reynolds number, but it has the disadvantage that it is only valid for water. Also, it does not account for the temperature or viscosity of the water.

Model formulation:

Hydraulic diameter (m):

$$D_h = D$$

Cross-section area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$V = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$m = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V_{ol} = A \cdot L$$

Fluid mass in the pipe (kg):

$$M = V_{ol} \cdot \rho$$

Reynolds number:

$$Re = \frac{V \cdot D}{\nu}$$

Head loss of fluid (m):

$$H_f = L \cdot \left[\frac{V}{\left(0.849 \cdot C_{HW} \cdot \left(\frac{D}{4} \right)^{0.63} \right)} \right]^{\frac{1}{0.54}}$$

Note: this equation is derived from the following Hazen-Williams relationship adapted to SI units:

$$V = 0.849 \cdot C_{HW} \cdot R_h^{0.63} \cdot S^{0.54}$$ ([1])

with:

$$R_h = \frac{D}{4}$$

and:

$$S = \frac{H_f}{L}$$

Pressure loss coefficient:

$$K = H_f \cdot \frac{2 \cdot g}{V^2}$$

Pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot V^2}{2}$$

Equivalent Darcy friction factor:

$$f = K \cdot \frac{D}{L}$$

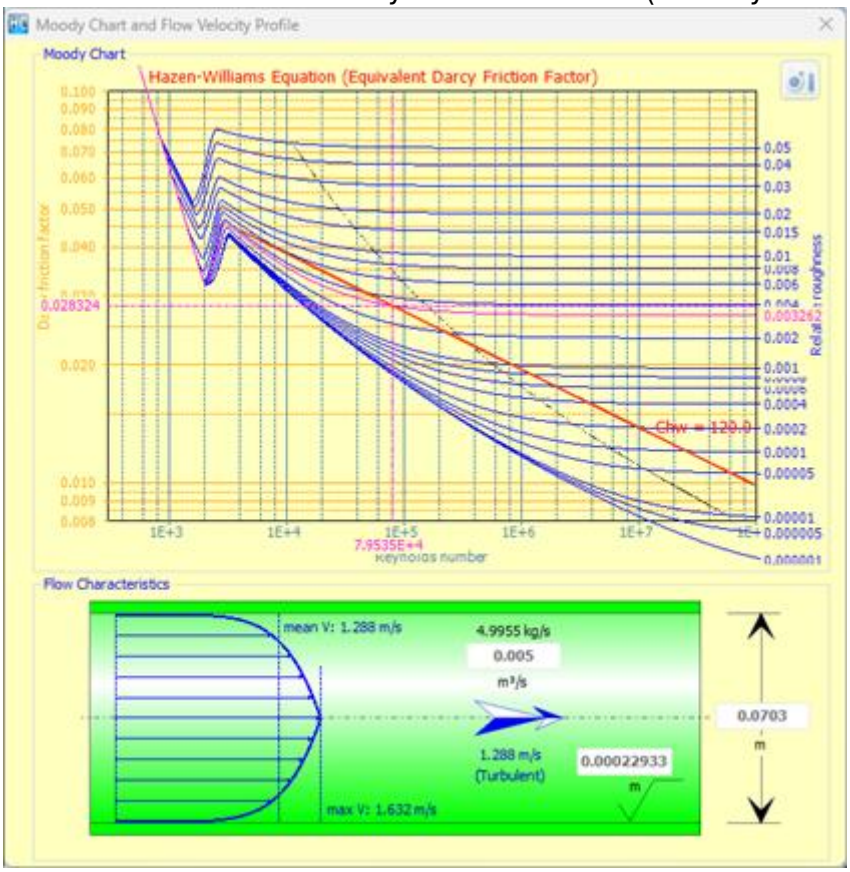
Equivalent relative roughness (turbulent regime - Re ≥ 4000):

Colebrook-White equation

$$f = \frac{1}{\left[2 \cdot \log\left(\frac{2.51}{Re \cdot \sqrt{f}} + \frac{k}{3.7 \cdot D}\right)\right]^2}$$

where k is calculated by solving the equation.

Example of plotting the Hazen-Williams roughness coefficient in the Moody diagram (for CHW = 120)



Equivalent absolute roughness (m):

$$\varepsilon = k \cdot D$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
D_h	Hydraulic diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
V	Mean velocity (m/s)
m	Mass flow rate (kg/s)
L	Pipe length (m)

V_{ol} Fluid volume in the pipe (m^3)

M Fluid mass in the pipe (kg)

Re Reynolds number ()

C_{HW} Hazen-Williams roughness coefficient ($m^{0.37}/s$)

H_f Head loss of fluid (m)

R_h Hydraulic radius (m)

S Head loss per unit length of the pipe ()

K Pressure loss coefficient (based on the mean pipe velocity) ()

ΔP Pressure loss (Pa)

f Equivalent Darcy friction factor ()

k Equivalent relative roughness of walls (m)

ε Equivalent absolute roughness of walls (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m^3)

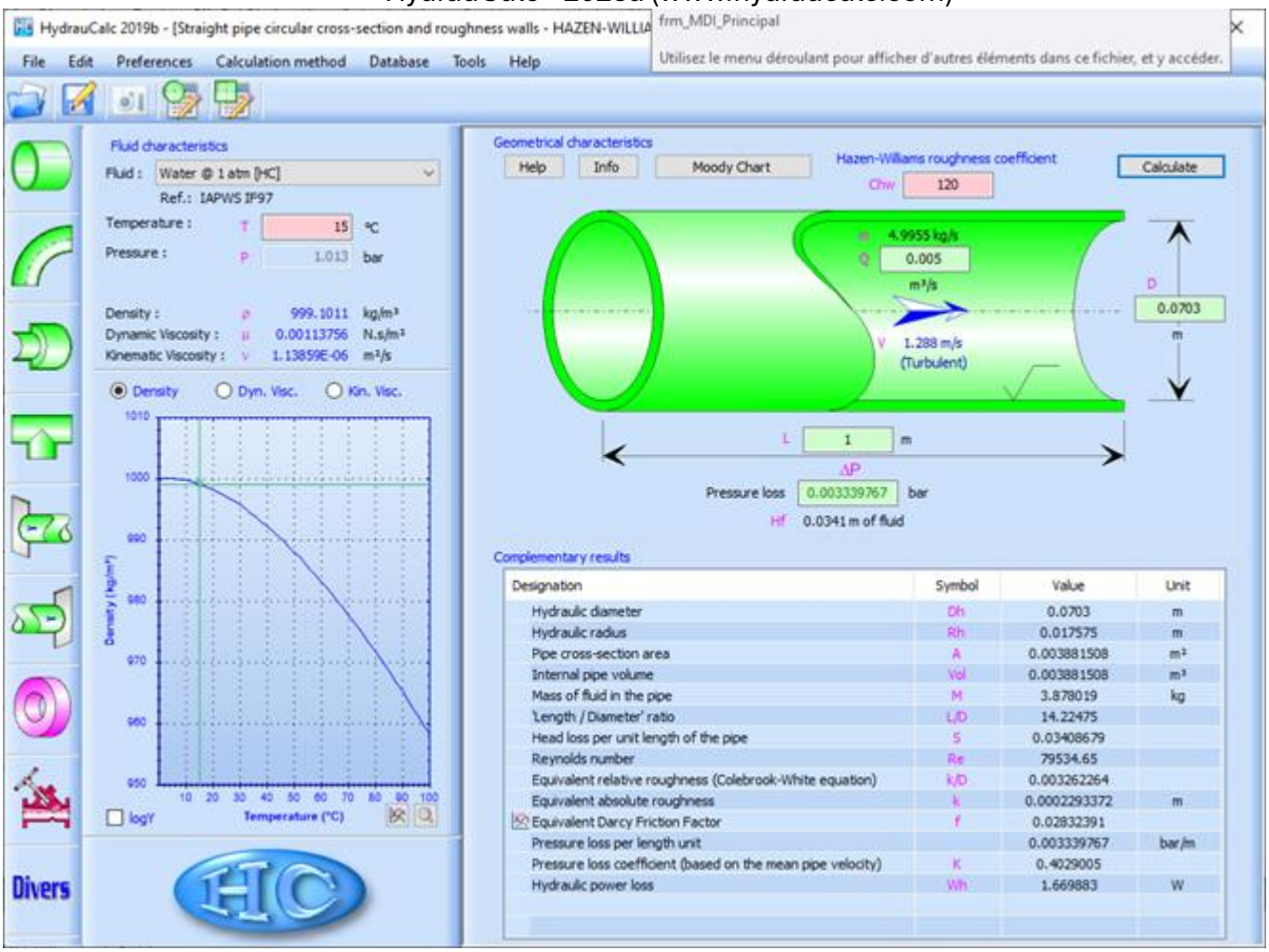
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($4 \cdot 10^3 \leq Re \leq 1 \cdot 10^8$)
- mean velocity lower than or equal to 3 m/s ($V \leq 3$ m/s)
- internal diameter of pipe between 0.05 m and 1.85 m ($0.05\ m \leq D \leq 1.85\ m$)
- valid only for fresh water close to 15 ° C with a kinematic viscosity of approximately $1.13 \cdot 10^{-6}\ m^2/s$
- stabilized flow

Example of application:



References:

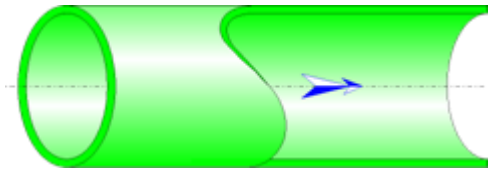
[1] G. Williams & A. Hazen; "Hydraulic Tables. The elements of gagings and the friction of water flowing in pipes, aqueducts, sewers, etc." (1914)

2.1.1.8 Shell-MIT equation (smooth walls)

Straight Pipe

Circular Cross-Section and Smooth Walls

(Shell-MIT equation)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of circular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Shell-MIT equation.

Model formulation:

Cross-section area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$V = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V_f = A \cdot L$$

Fluid mass in the pipe (kg):

$$M_f = V_f \cdot \rho$$

Reynolds number:

$$R = \frac{V \cdot D}{\nu}$$

Modified Reynolds number:

$$R_m = \frac{R}{7742}$$ ([1] equation 6.69)

Friction factor:

- laminar flow regime ($Re \leq 2000$):

$$f = \frac{0.00207}{R_m}$$ ([1] equation 6.70)

- turbulent flow regime ($Re \geq 4000$):

$$f = 0.0018 + 0.00662 \cdot \left(\frac{1}{R_m}\right)^{0.355}$$ ([1] equation 6.71)

- critical flow regime ($2000 < Re < 4000$):

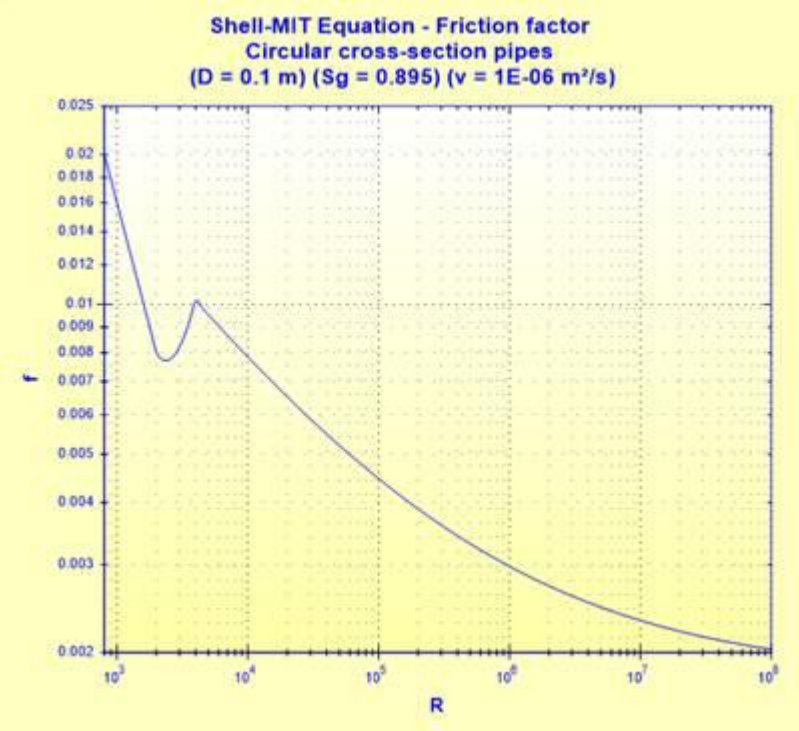
  linear interpolation

$$f = f_L \cdot \left(1 - \frac{R - 2000}{2000}\right) + f_T \cdot \left(\frac{R - 2000}{2000}\right)$$

  with:

  f_L = laminar friction coefficient obtained with R = 2000

  f_T = turbulent friction coefficient obtained with R = 4000



Fluid specific gravity ():

$$Sg = \frac{\rho}{1000}$$

Linear pressure loss (psi/mi):

$$Pm_{[psi/mi]} = 0.241 \cdot \frac{f \cdot Sg \cdot Q_{[bbl/day]}^{2}}{D_{[in]}^{5}}$$

([1] equation 6.72)

Total pressure loss (Pa):

$$\Delta P = Pm \cdot 4.28420 \cdot L$$

Total head loss of fluid (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

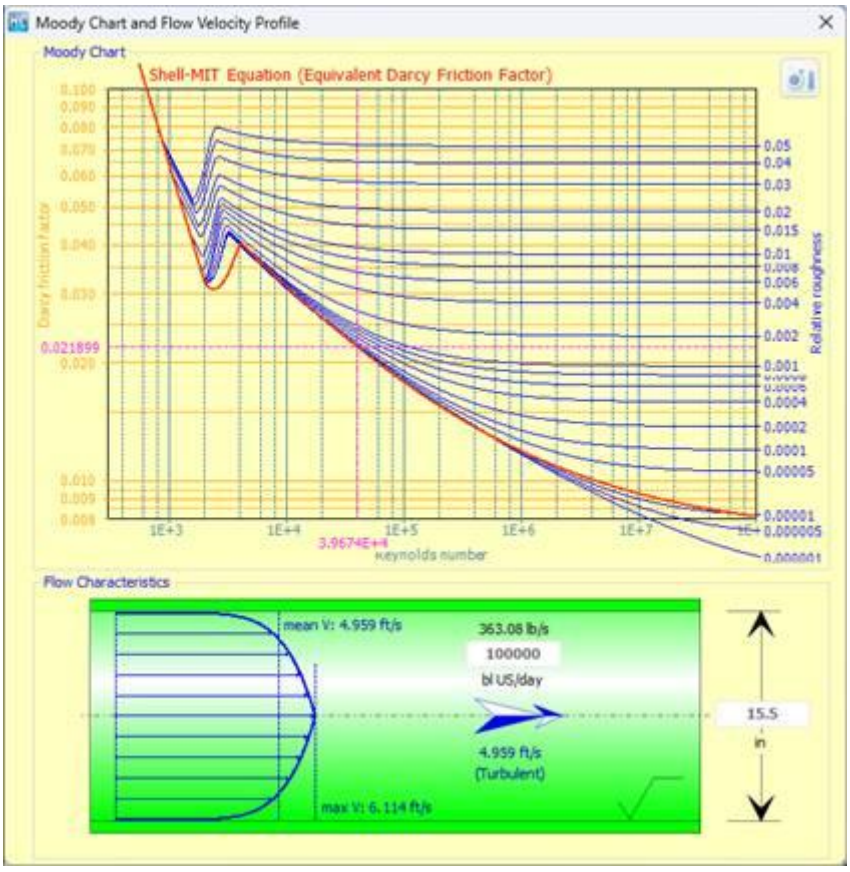
Pressure loss coefficient (based on the mean pipe velocity):

$$K = \Delta P \cdot \frac{2}{\rho \cdot V^2}$$

Equivalent Darcy friction factor:

$$fd = K \cdot \frac{D}{L}$$

Example of plotting the equivalent Darcy friction factor in the Moody diagram (for Sg = 0.895)



Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

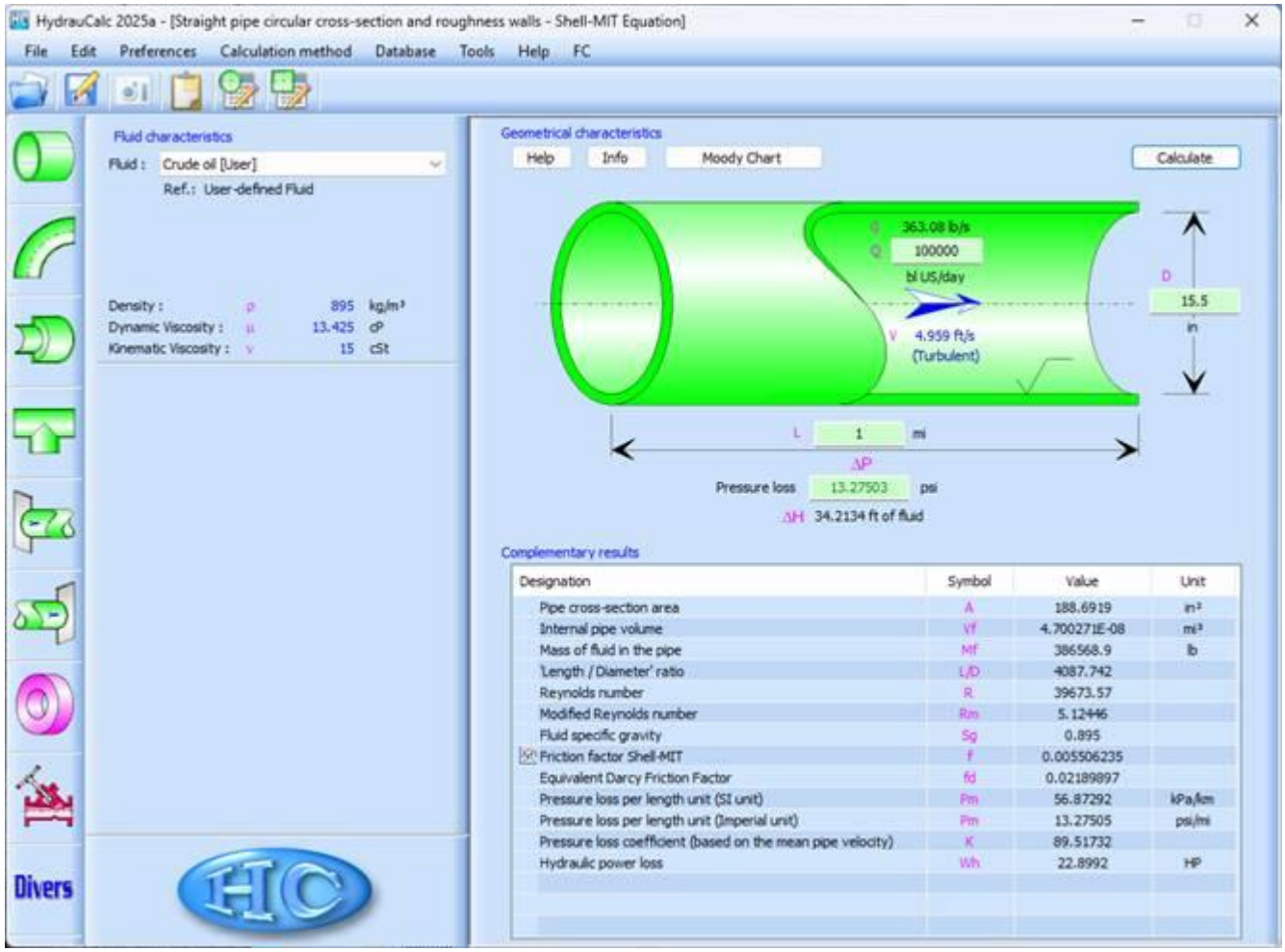
D	Internal diameter (m)
A	Cross-sectional area of pipe (m^2)

Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V	Mean velocity (m/s)
L	Pipe length (m)
V_f	Fluid volume in the pipe (m^3)
M_f	Fluid mass in the pipe (kg)
Sg	Fluid specific gravity (water = 1.00) ()
R	Reynolds number ()
Rm	Modified Reynolds number ()
f	Friction factor ()
Pm	Pressure drop (psi/mi)
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
K	Pressure loss coefficient ()
fd	Equivalent Darcy friction factor ()
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar, critical and turbulent
- stabilized flow
- The Shell-MIT equation is used specifically in the petroleum industry to calculate the pressure drop in heavy crude oil and heated pipelines. It is only suitable for heavy crude oil and high pour fuel oils.

Example of application:



References:

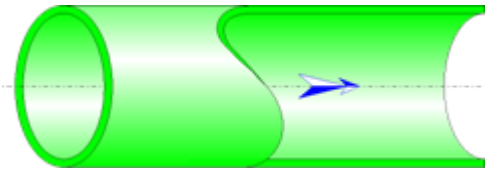
[1] Piping Calculations Manual - McGraw-Hill (2005)

2.1.1.9 Benjamin Miller equation (smooth walls)

Straight Pipe

Circular Cross-Section and Smooth Walls

(Benjamin Miller equation)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of circular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Benjamin Miller equation.

Model formulation:

Cross-section area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$V = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V_f = A \cdot L$$

Fluid mass in the pipe (kg):

$$M_f = V_f \cdot \rho$$

Reynolds number:

$$R = \frac{V \cdot D}{\nu}$$

Fluid specific gravity ():

$$Sg = \frac{\rho}{1000}$$

Linear pressure loss (psi/mi):

$$Pm_{[psi/mi]} = 0.0607 \cdot \frac{\left(Q_{[bbl/day]} / M\right)^2 \cdot Sg}{D_{[in]}^5}$$

([1] équation 6.65)

with :

$$M = \log_{10}\left(\frac{D_{[in]}^3 \cdot Sg \cdot Pm_{[psi/mi]}}{\nu^2}\right) + 4.35$$

([1] équation 6.64)

Total pressure loss (Pa):

$$\Delta P = Pm \cdot 4.28420 \cdot L$$

Total head loss of fluid (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

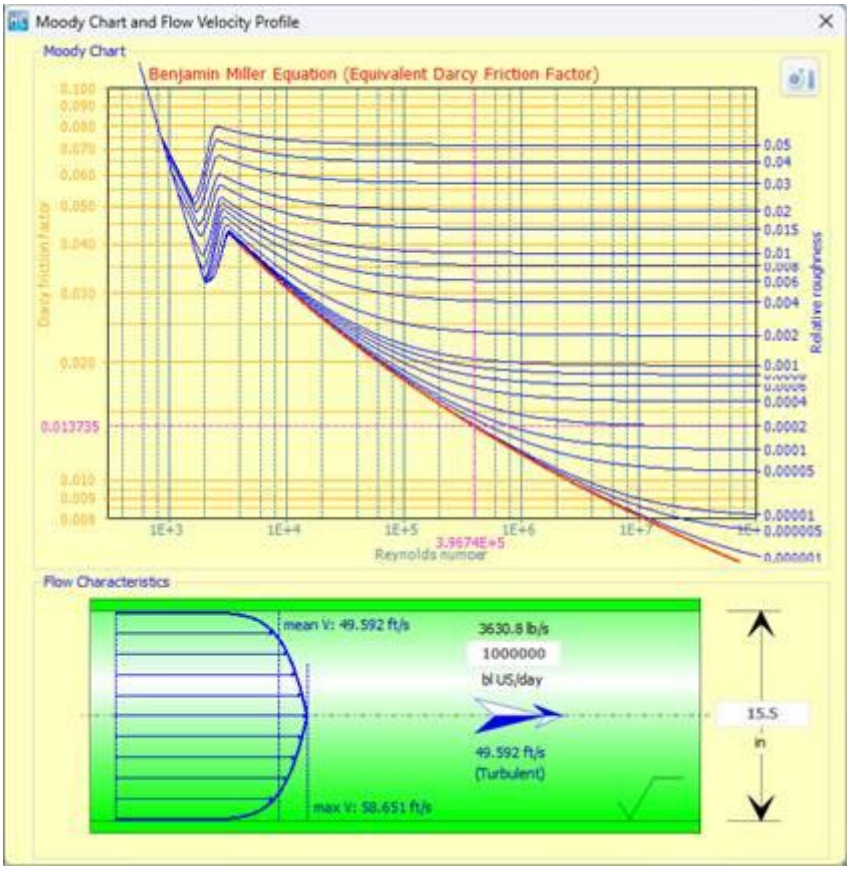
Pressure loss coefficient (based on the mean pipe velocity):

$$K = \Delta P \cdot \frac{2}{\rho \cdot V^2}$$

Equivalent Darcy friction factor:

$$fd = K \cdot \frac{D}{L}$$

Example of plotting the equivalent Darcy friction factor in the Moody diagram (for Sg = 0.895 and ν = 15 cSt)



Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

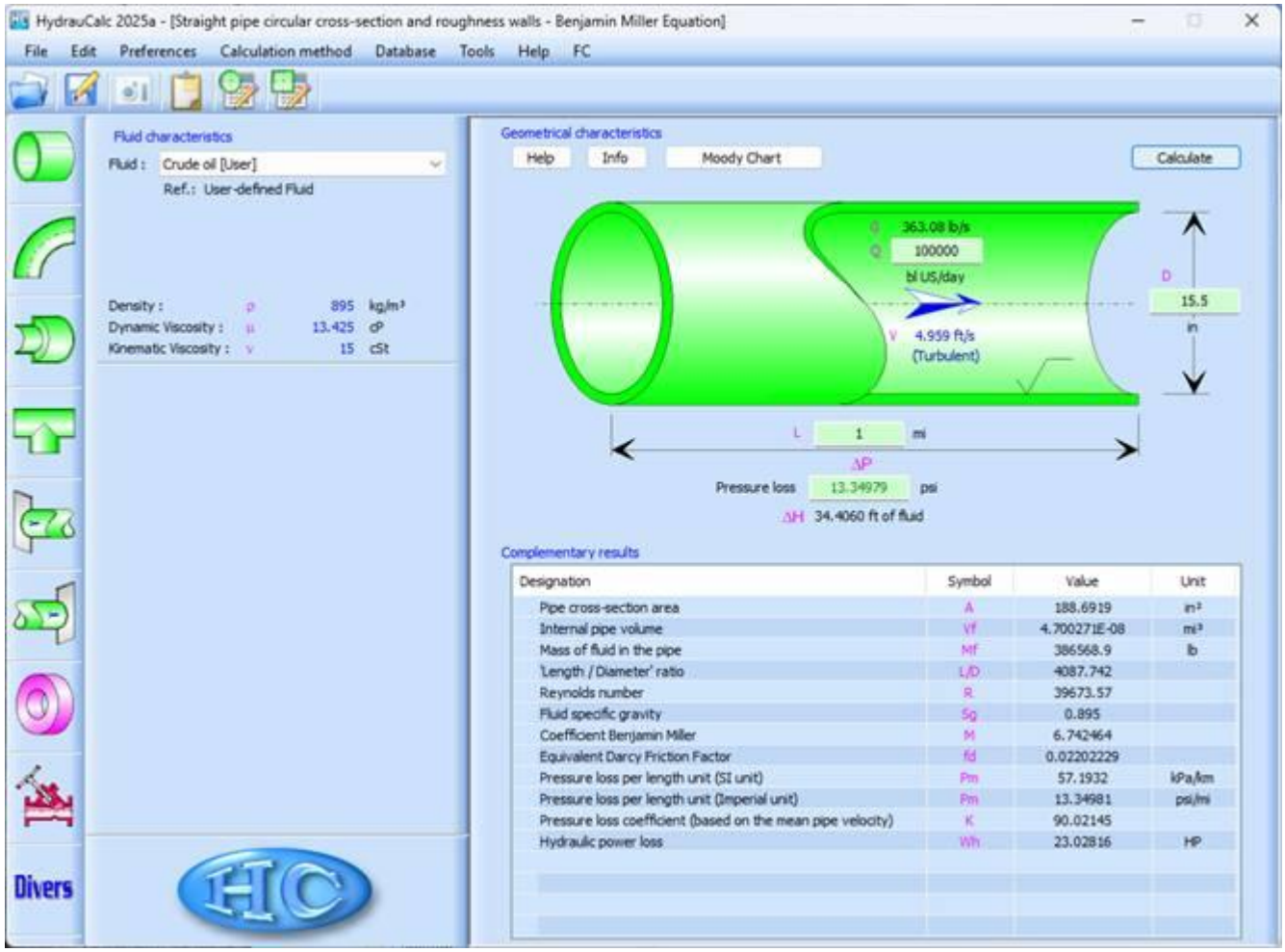
D Internal diameter (m)

A	Cross-sectional area of pipe (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V	Mean velocity (m/s)
L	Pipe length (m)
V_f	Fluid volume in the pipe (m^3)
M_f	Fluid mass in the pipe (kg)
Sg	Fluid specific gravity (water = 1.00) ()
R	Reynolds number ()
M	Parameter ()
Pm	Pressure drop (psi/mi)
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
K	Pressure loss coefficient ()
fd	Equivalent Darcy friction factor ()
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- flow regime: turbulent
- stabilized flow
- The Benjamin Miller equation is used specifically in the petroleum industry to calculate the pressure drop in heavy crude oil and heated pipelines. It is only suitable for heavy crude oil and high pour fuel oils.

Example of application:



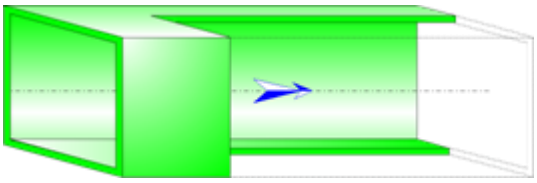
References:

[1] Piping Calculations Manual - McGraw-Hill (2005)

2.1.2 Straight pipe - Rectangular cross-section

Straight Pipe

Rectangular Cross-section



To calculate the pressure losses by friction in straight pipes, Darcy Weisbach's equation is used.

For the calculation of the friction factor, the user can choose from one of the 4 available relationships, depending on the roughness of the inner walls:

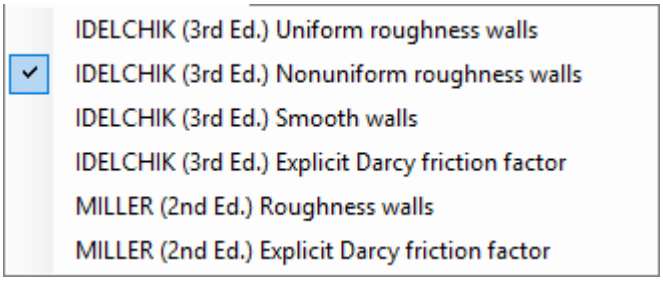
- Homogeneous roughness piping (uniform roughness - pipe used by Nikuradse for its experimental data) - Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Heterogeneous roughness piping (industrial type piping) - Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipes with smooth walls - Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipes with roughness walls - Internal Flow System, 2nd Edition, D.S. Miller

It is also possible to explicitly specify the value of the friction factor. This is available in case you are looking for results with another formulation of the friction factor (Haaland equation for example). The friction factor is available for the following references:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "Pipes with nonuniform roughness"

Calculation method

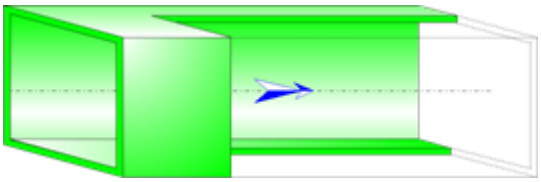


2.1.2.1 IDELCHIK (uniform roughness walls)

Straight Pipe

Rectangular Cross-Section and Uniform Roughness Walls

(IDELCHIK)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of square or rectangular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula. The roughness of the inner walls of the pipe is supposed uniform (pipe used by Nikuradse for its experimental data).

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille (independent of the value of relative roughness),
- for turbulent flow regime by the Nikuradse equation (dependent of the value of relative roughness),
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Hydraulic diameter (m):

$$D_h = \frac{2 \cdot a_0 \cdot b_0}{a_0 + b_0}$$ ([1] diagram 2.6)

Cross-section area (m^2):

$$F_0 = a_0 \cdot b_0$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

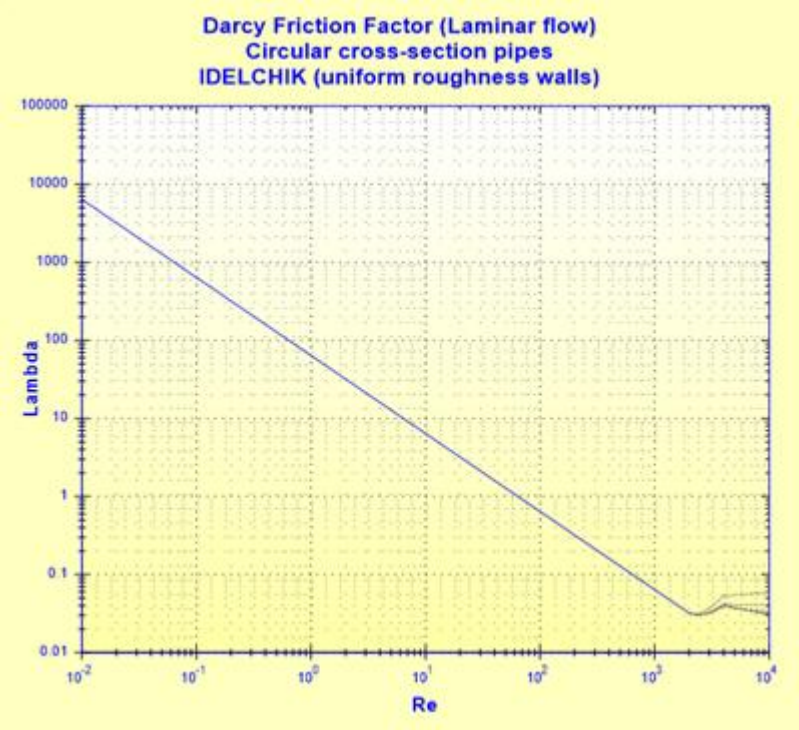
$$\overline{\Delta} = \frac{\Delta}{D_h}$$

Darcy friction factor for circular cross-section:

- laminar flow regime ($Re \leq 2000$):

  Hagen-Poiseuille law

$$\lambda = \frac{64}{Re}$$ ([1] diagram 2.1)



■ turbulent flow regime – transition region and complete turbulence region (Re ≥ 4000):

Nikuradze equation

$$\lambda = \frac{1}{\left[a_1 + b_1 \cdot \log(Re \cdot \sqrt{\lambda}) + c_1 \cdot \log(\overline{\Delta})\right]^2}$$ ([1] diagram 2.2)

where the values of a_1, b_1 and c_1 are given below:

$\overline{\Delta} \cdot Re \cdot \sqrt{\lambda}$	a_1	b_1	c_1
3.6 - 10	-0.800	2.000	0.000
10 - 20	0.068	1.130	-0.870
20 - 40	1.538	0.000	-2.000
40 - 191.2	2.471	-0.588	-2.588
> 191.2	1.138	0.000	-2.000

Reynolds number at which pipe cease to be hydraulically smooth:

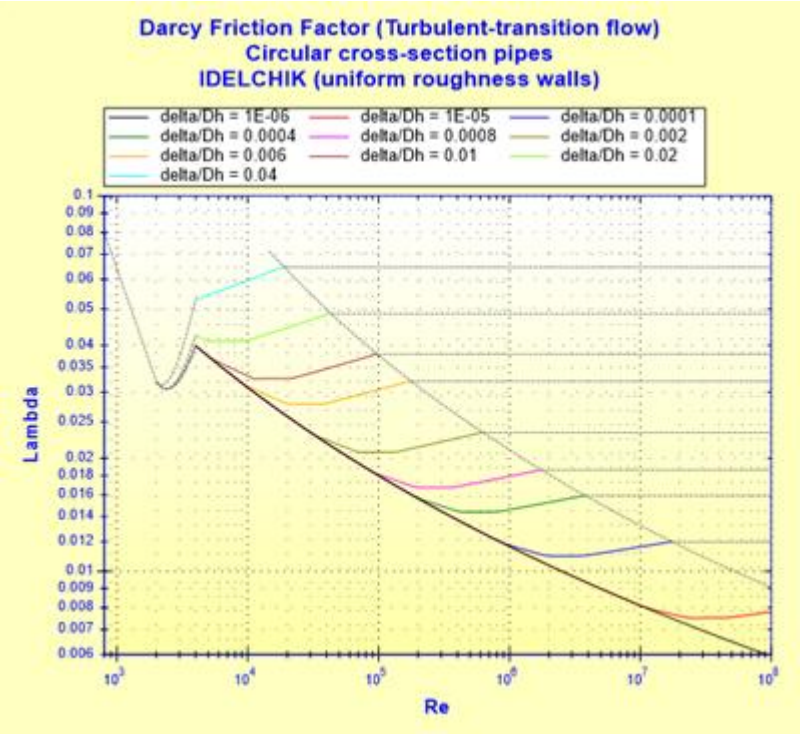
$$Re'_{lim} = \frac{26.9}{\overline{\Delta}^{1.143}}$$ ([1] §2.17)

Reynolds number corresponding to the beginning of complete turbulence:

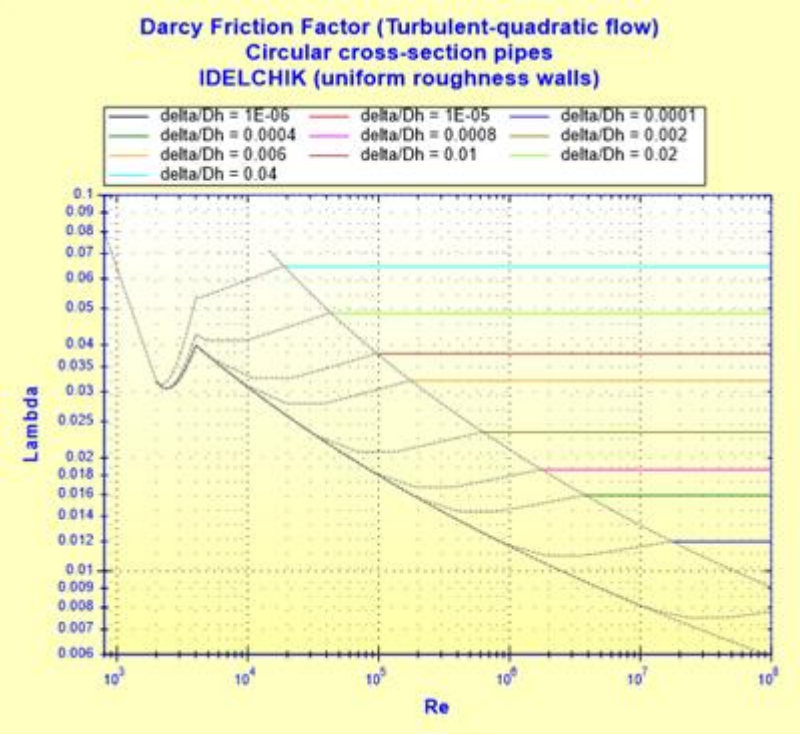
$$Re''_{lim} = \frac{217.6 - 382.4 \cdot \log(\bar{\Delta})}{\bar{\Delta}}$$

([1] diagram 2.2)

Transition region



Complete turbulence region



■ critical flow regime (2000 < Re < 4000):

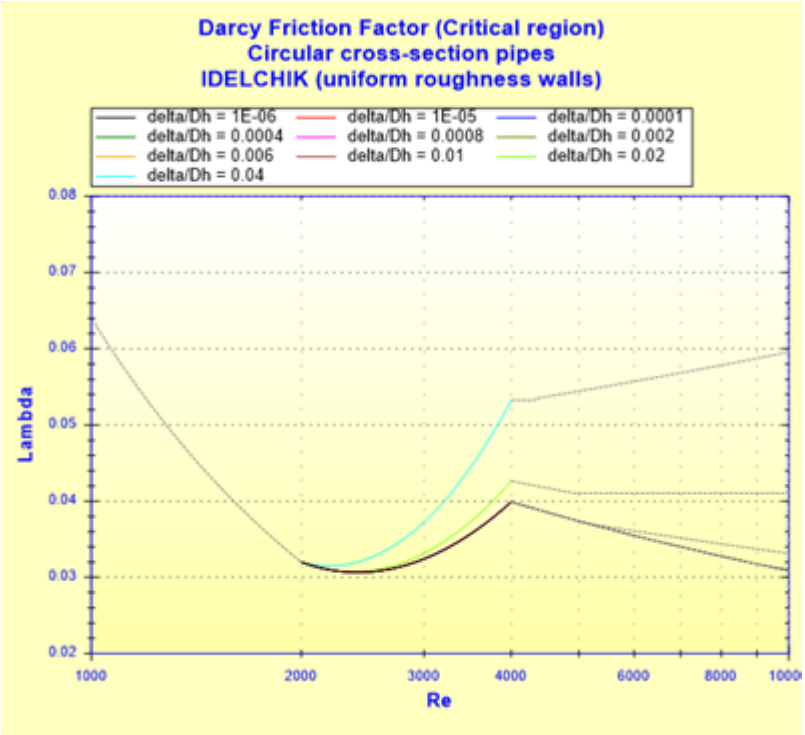
linear interpolation

$$\lambda = \lambda_L \cdot \left(1 - \frac{Re - 2000}{2000}\right) + \lambda_T \cdot \left(\frac{Re - 2000}{2000}\right)$$

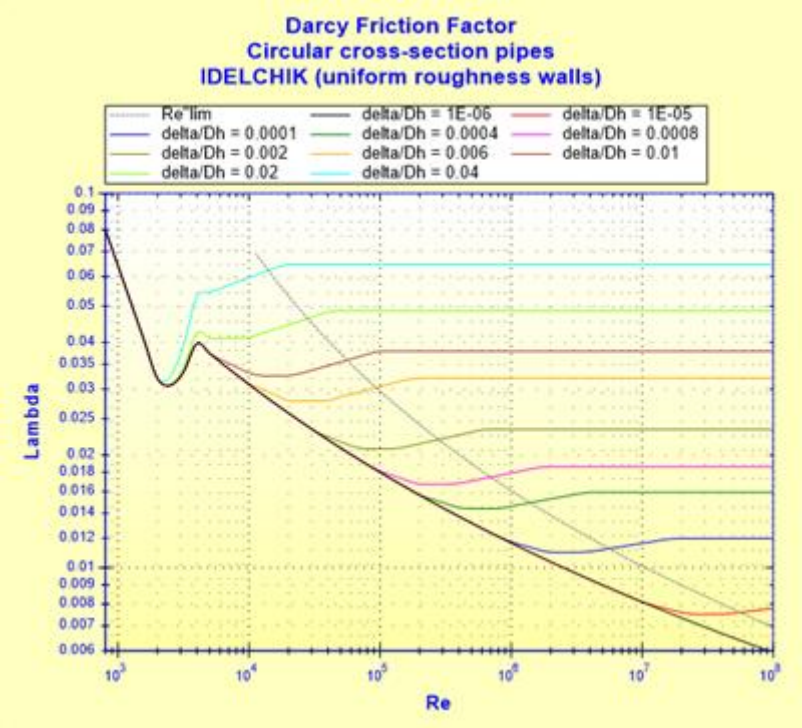
with:

λ_L = laminar friction coefficient obtained with Re = 2000

λ_T = turbulent friction coefficient obtained with Re = 4000



■ all flow regimes:



Correction for Darcy friction factor for noncircular cross-section:

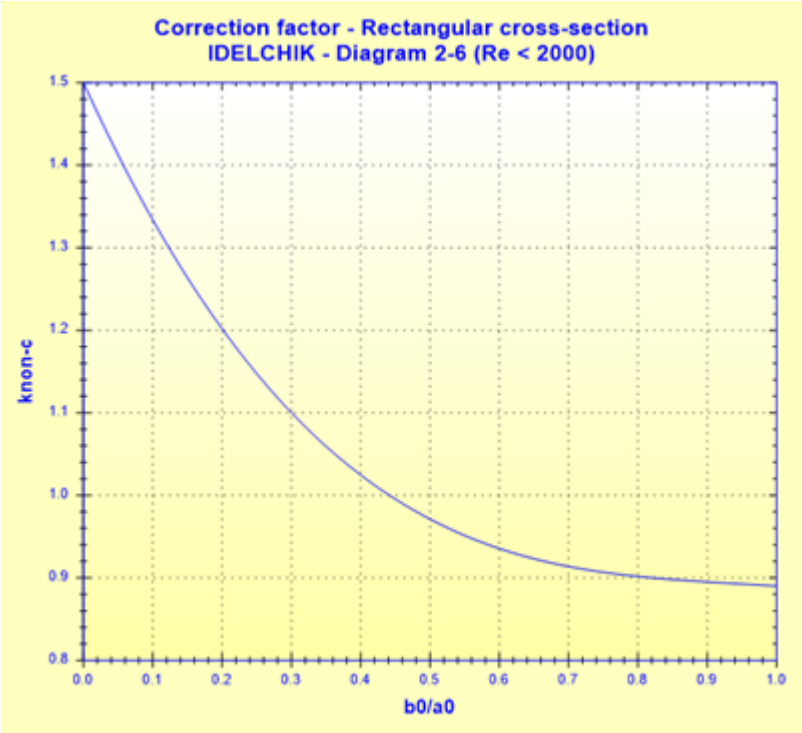
- $a_0 \geq b_0$

$$k_{non-c} = f(b_0/a_0)$$ ([1] diagram 2.6)

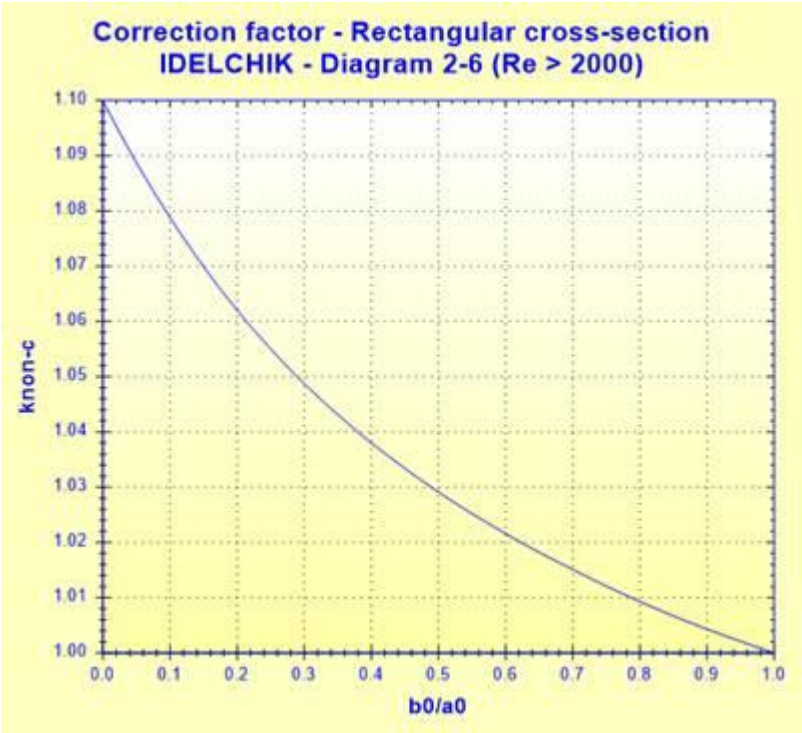
- $a_0 < b_0$

$$k_{non-c} = f(a_0/b_0)$$ ([1] diagram 2.6)

■ laminar flow (Re ≤ 2000):



■ turbulent flow (Re > 2000):



Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \lambda \cdot k_{non-c} \cdot \frac{l}{D_h}$$

([1] diagram 2.6)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$ ([1] diagram 2.6)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

a_0	Rectangular cross-section width (m)
b_0	Rectangular cross-section height (m)
D_h	Hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity (m/s)
l	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
Re'_{lim}	Limiting Reynolds number for hydraulically smooth law ()
Re''_{lim}	Limiting Reynolds number for quadratic law ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()
λ	Darcy friction factor for circular cross-section ()

k_{non-c} Correction for Darcy friction factor for noncircular cross-section ()

ζ Pressure loss coefficient (based on the mean pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

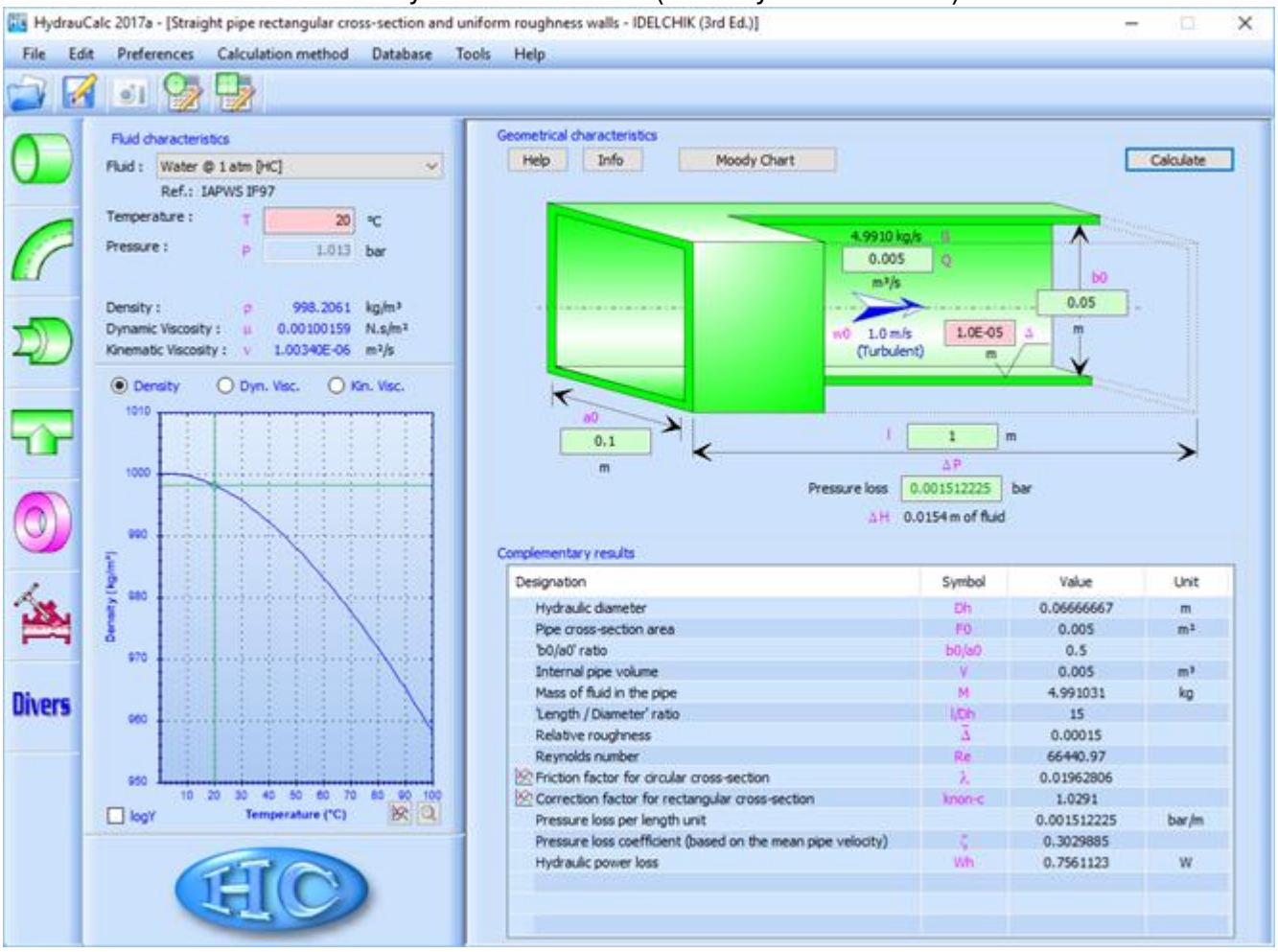
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
- $\overline{\Delta} \leq 0.05$
- stabilized flow

Example of application:



References:

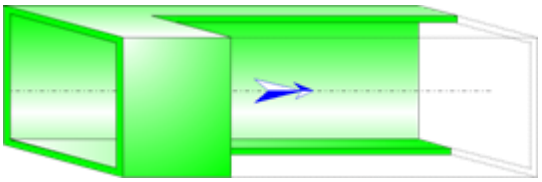
[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.2.2 IDELCHIK (nonuniform roughness walls)

Straight Pipe

Rectangular Cross-Section and Nonuniform Roughness Walls

(IDELCHIK)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of square or rectangular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula. The roughness of the inner walls of the pipe is supposed nonuniform (commercial pipe).

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille (independent of the value of relative roughness),
- for turbulent flow regime by the implicit Colebrook-White equation (dependent of the value of relative roughness),
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Hydraulic diameter (m):

$$D_h = \frac{2 \cdot a_0 \cdot b_0}{a_0 + b_0}$$ ([1] diagram 2.6)

Cross-section area (m^2):

$$F_0 = a_0 \cdot b_0$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

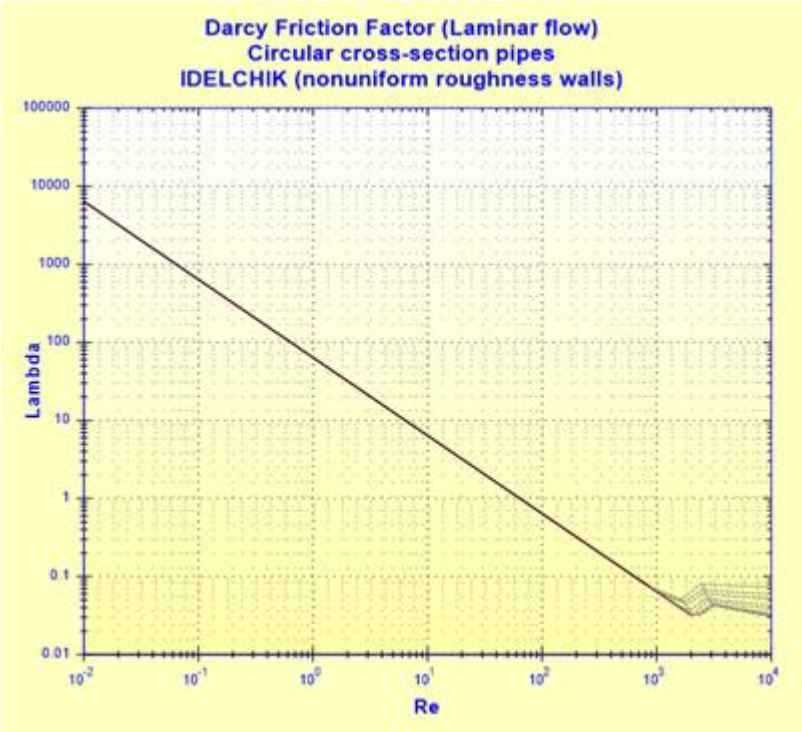
$$\bar{\Delta} = \frac{\Delta}{D_h}$$

Darcy friction factor for circular cross-section:

- laminar flow regime ($Re \le Re_0$):

  Hagen-Poiseuille law

$$\lambda = \frac{64}{Re}$$ ([1] diagram 2.1)



■ turbulent flow regime – transition region and complete turbulence region ($Re \geq Re_2$):

Colebrook-White equation

$$\lambda = \frac{1}{\left[2 \cdot \log\left(\frac{2.51}{Re \cdot \sqrt{\lambda}} + \frac{\overline{\Delta}}{3.7}\right)\right]^2}$$ ([1] diagram 2.4)

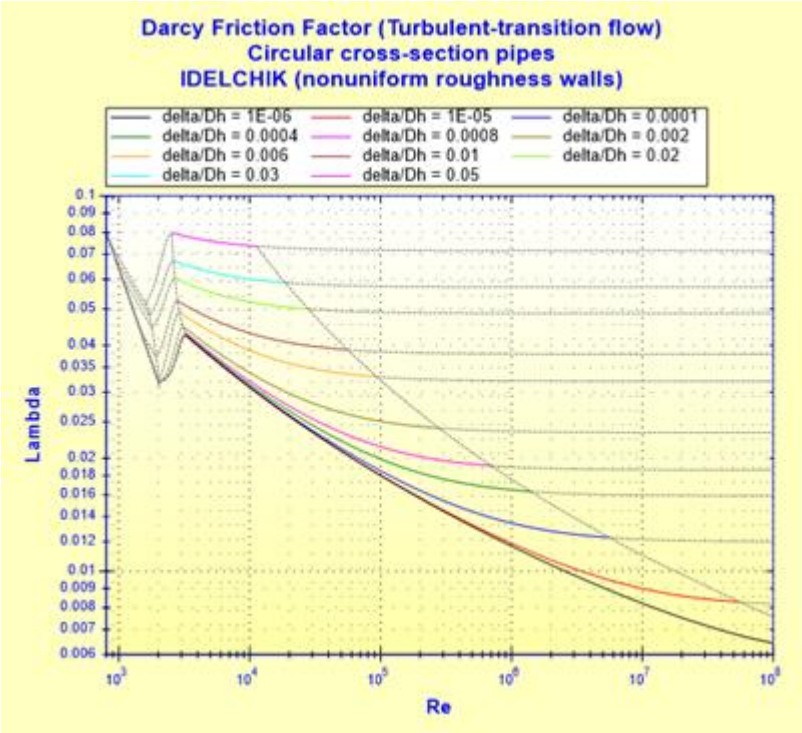
Reynolds number at which pipe cease to be hydraulically smooth:

$$Re'_{lim} = \frac{15}{\overline{\Delta}}$$ ([1] §2.23)

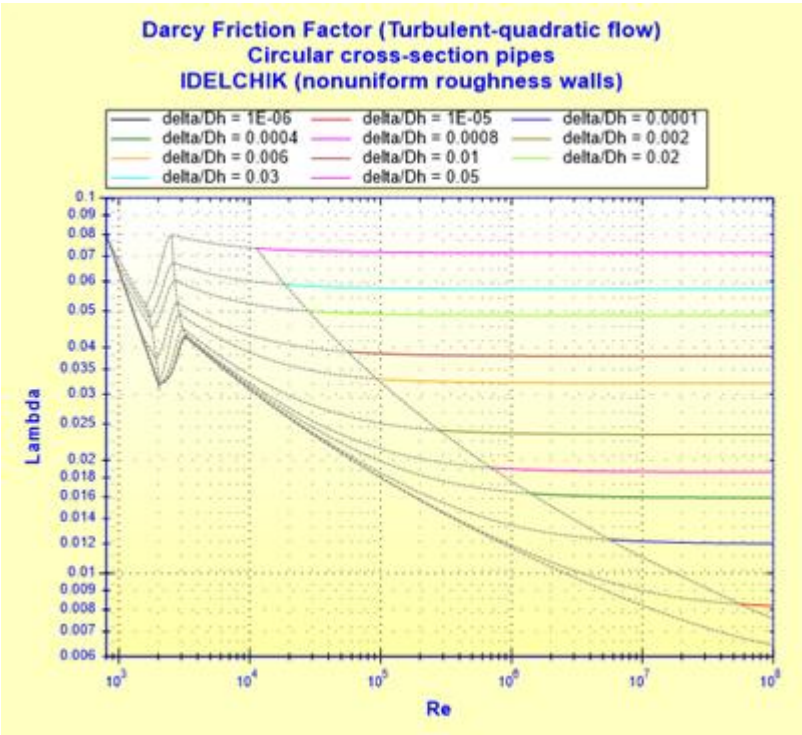
Reynolds number corresponding to the beginning of complete turbulence:

$$Re''_{lim} = \frac{560}{\overline{\Delta}}$$ ([1] diagram 2.4)

Transition region



Complete turbulence region



■ critical flow regime ($Re_0 < Re < Re_2$):

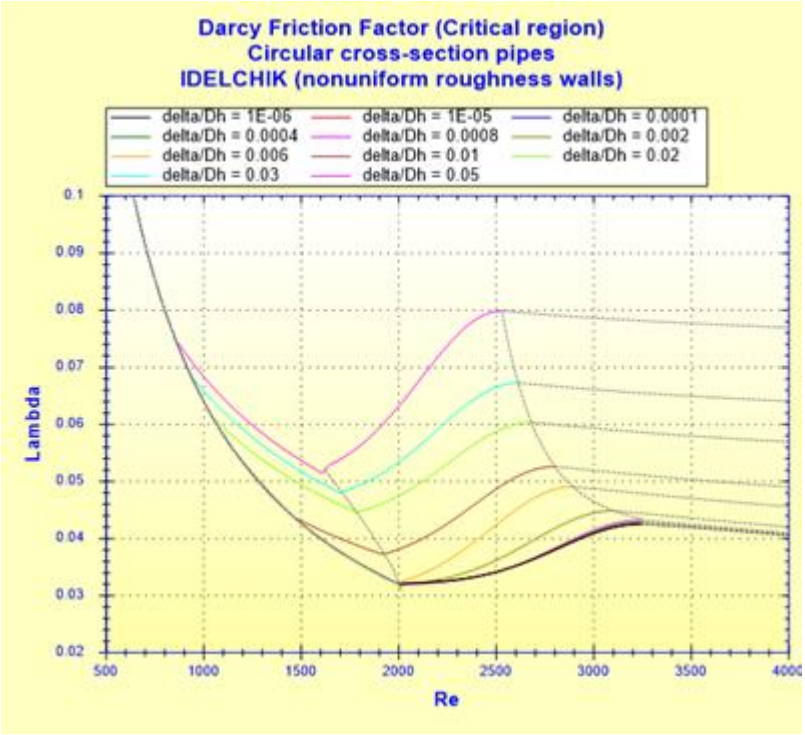
$$\lambda = f(\mathrm{Re}, \overline{\Delta})$$ ([1] diagram 2.3)

Reynolds number of start of critical zone:

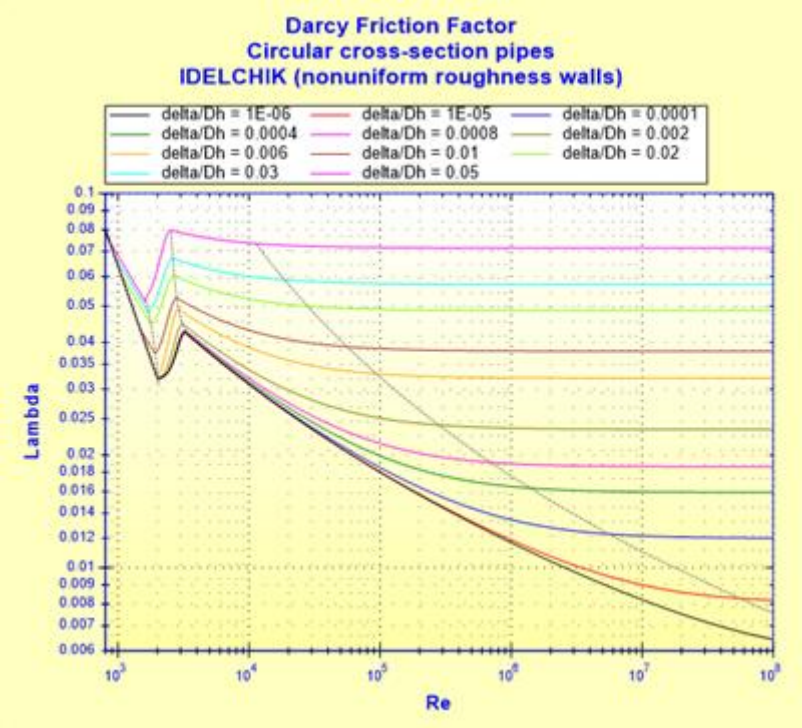
$$Re_0 = 754 \exp\left(\frac{0.0065}{\overline{\Delta}}\right)$$ ([1] §2.21)

Reynolds number at end of critical zone:

$$Re_2 = 2090\left(\frac{1}{\overline{\Delta}}\right)^{0.0635}$$ ([1] §2.22)



■ all flow regimes:



Correction for Darcy friction factor for noncircular cross-section:

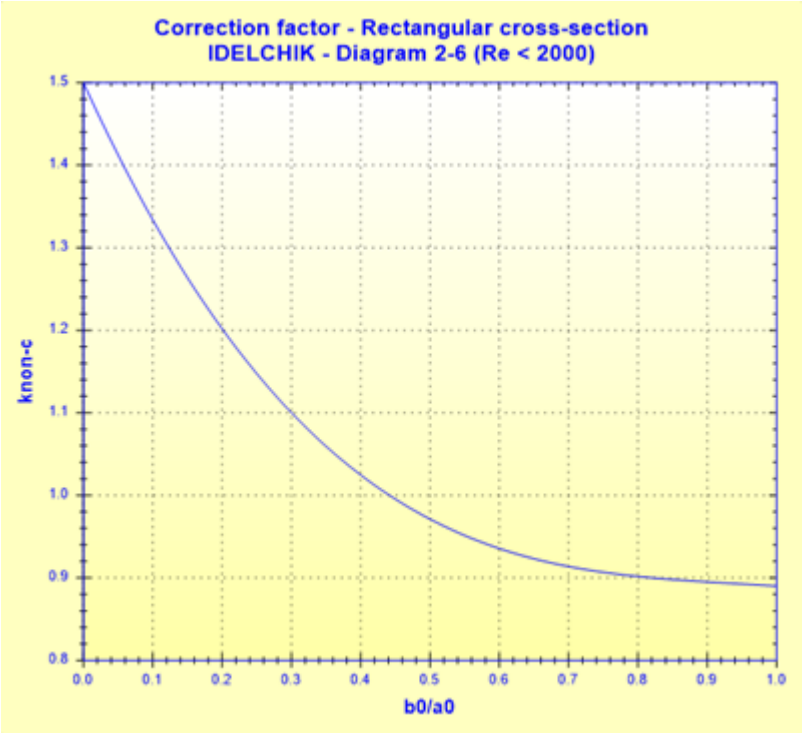
- $a_0 \geq b_0$

$$k_{non-c} = f(b_0/a_0)$$ ([1] diagram 2.6)

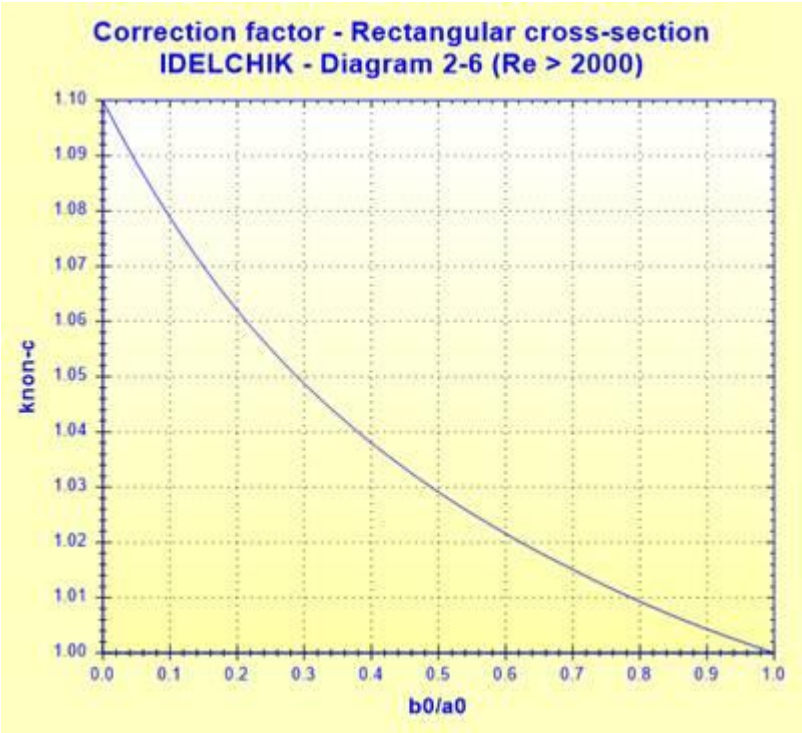
- $a_0 < b_0$

$$k_{non-c} = f(a_0/b_0)$$ ([1] diagram 2.6)

■ laminar flow (Re ≤ 2000):



■ turbulent flow (Re > 2000):



Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \lambda \cdot k_{non-c} \cdot \frac{l}{D_h}$$

([1] diagram 2.6)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$

([1] diagram 2.6)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

a_0	Rectangular cross-section width (m)
b_0	Rectangular cross-section height (m)
D_h	Hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity (m/s)
l	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
Re_0	Reynolds number of start of critical zone ()
Re_2	Reynolds number at end of critical zone ()
Re'_{lim}	Limiting Reynolds number for hydraulically smooth law ()
Re''_{lim}	Limiting Reynolds number for quadratic law ()
Δ	Absolute roughness of walls (m)

$\bar{\Delta}$ Relative roughness of walls ()

λ Darcy friction factor for circular cross-section ()

k_{non-c} Correction for Darcy friction factor for noncircular cross-section ()

ζ Pressure loss coefficient (based on the mean pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m^3)

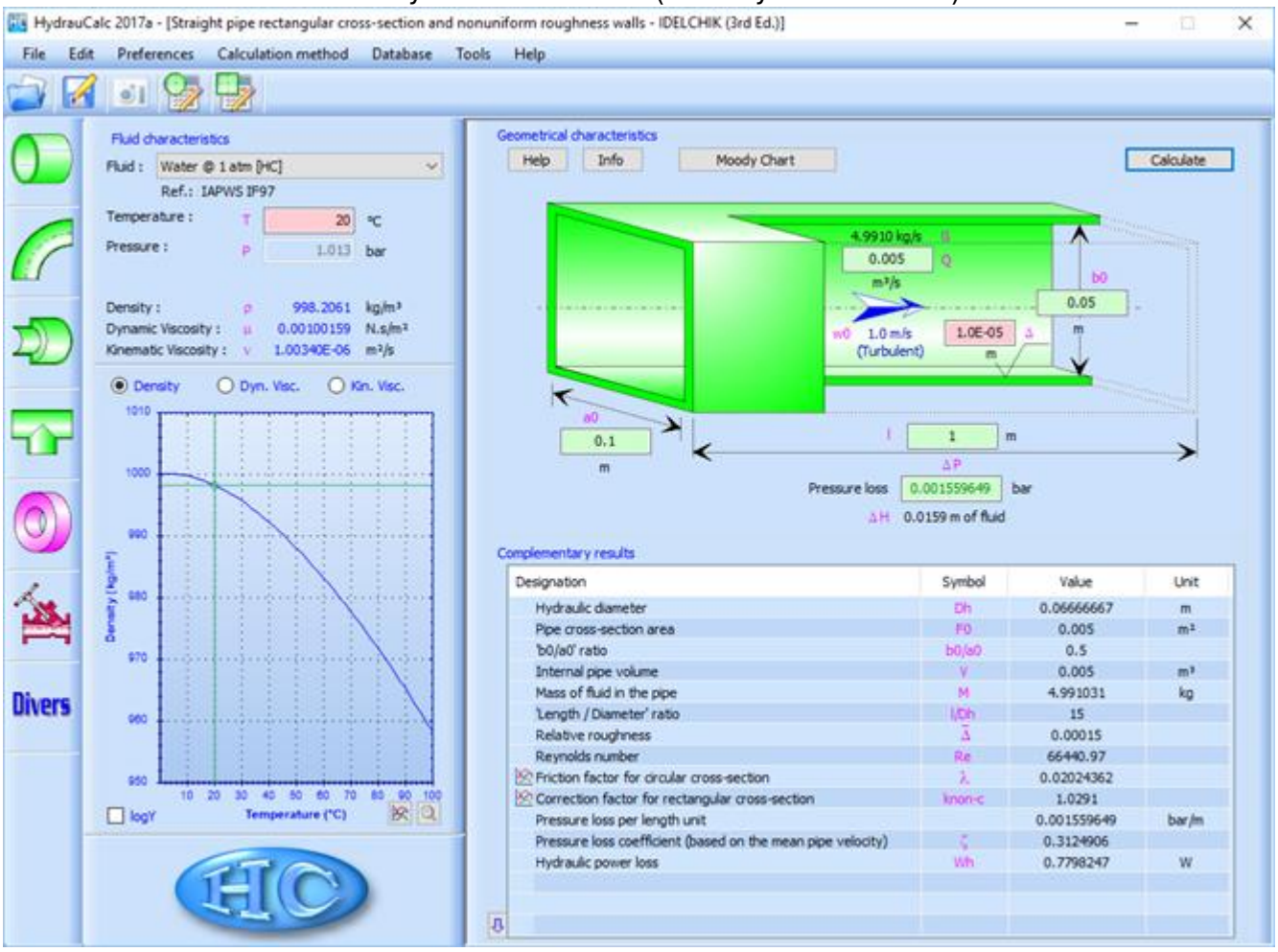
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
- $\bar{\Delta} \leq 0.05$
- stabilized flow

Example of application:



References:

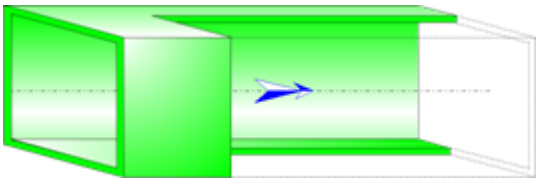
[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.2.3 IDELCHIK (smooth walls)

Straight Pipe

Rectangular Cross-Section and Smooth Walls

(IDELCHIK)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of square or rectangular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula. The inner wall of the piping is supposed to completely smooth (without roughness).

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille,
- for turbulent flow regime by the explicit Filonenko and Althsul equation,
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Hydraulic diameter (m):

$$D_h = \frac{2 \cdot a_0 \cdot b_0}{a_0 + b_0}$$ ([1] diagram 2.6)

Cross-section area (m^2):

$$F_0 = a_0 \cdot b_0$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

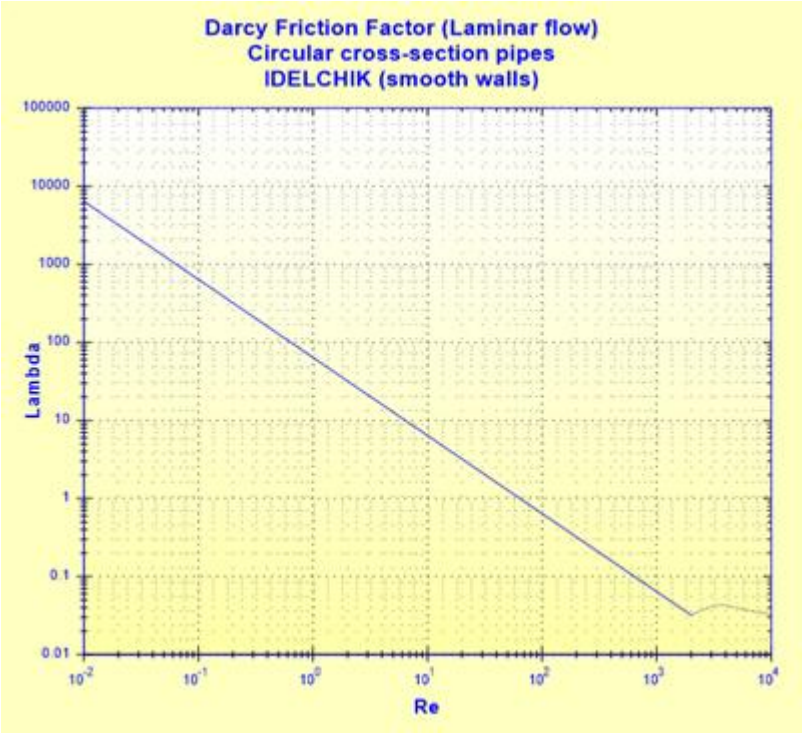
$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Darcy friction factor for circular cross-section:

- laminar flow regime ($Re \leq 2000$):

  Hagen-Poiseuille law

  $$\lambda = \frac{64}{Re}$$ ([1] diagram 2.1)

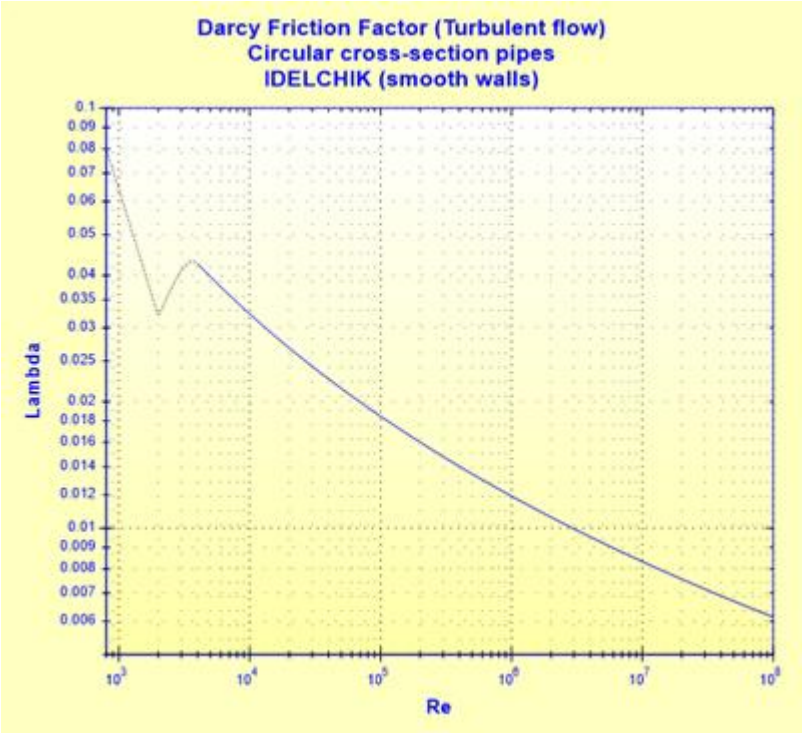


■ turbulent flow regime (Re ≥ 4000):

Filonenko and Althsul Equation

$$\lambda = \frac{1}{[1.8 \cdot \log(Re) - 1.64]^2}$$

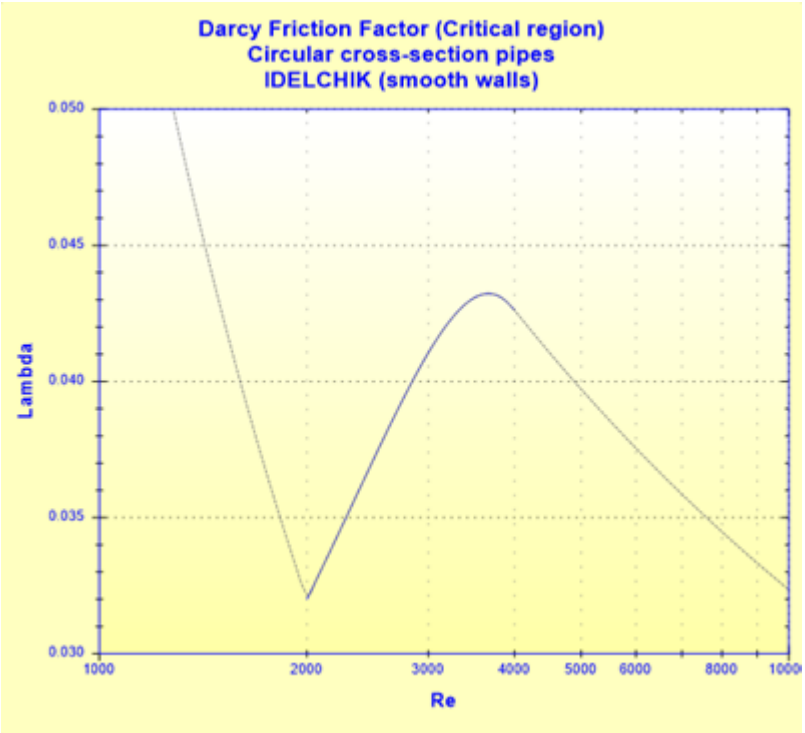
([1] diagram 2.1)



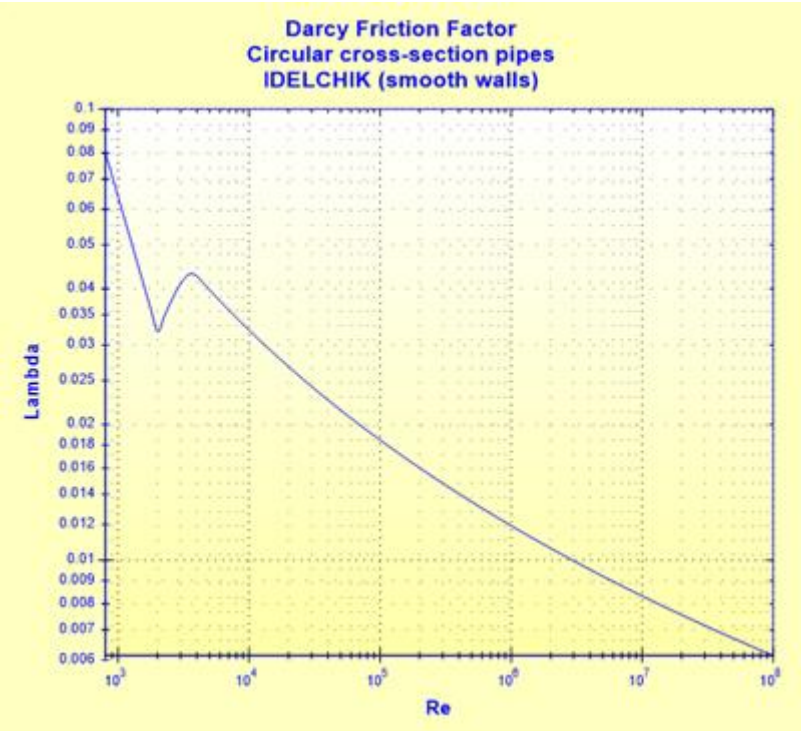
■ critical flow regime ($2000 < Re < 4000$):

interpolation between laminar and turbulent flows

$\lambda = f(\mathrm{Re})$ ([1] diagram 2.1)



■ all flow regimes:



Correction for Darcy friction factor for noncircular cross-section:

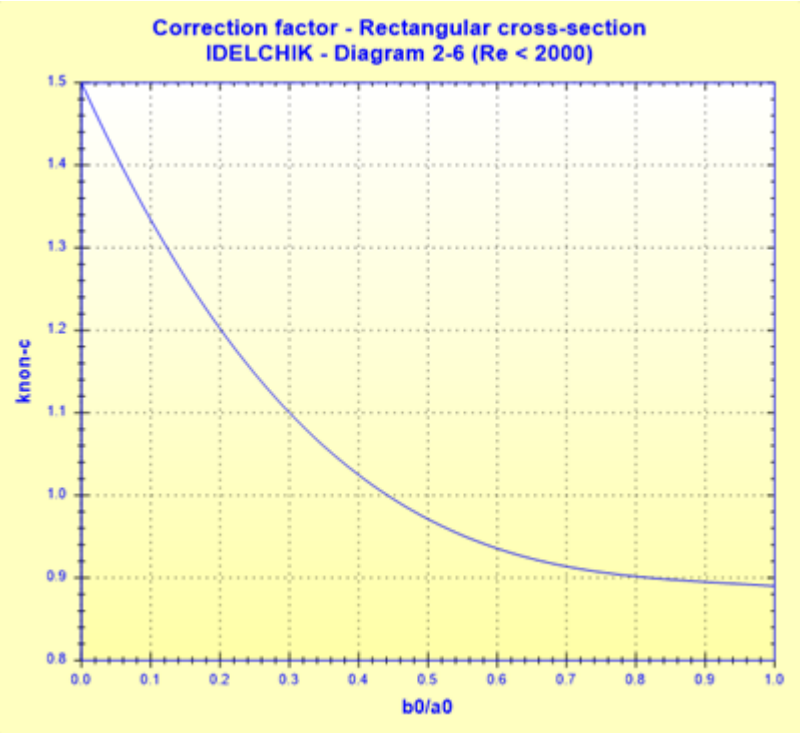
- $a_0 \geq b_0$

$$k_{non-c} = f(b_0/a_0)$$ ([1] diagram 2.6)

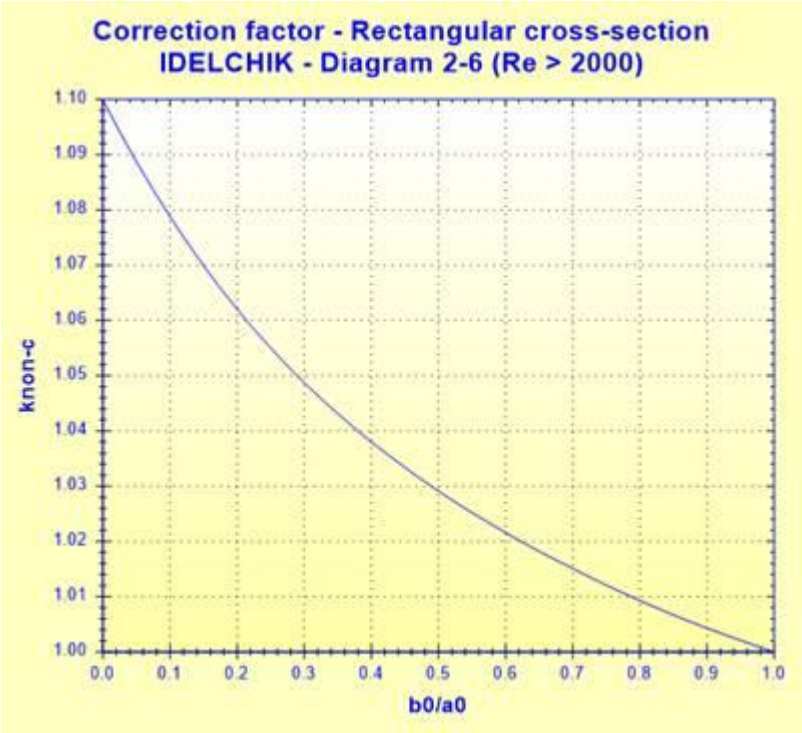
- $a_0 < b_0$

$$k_{non-c} = f(a_0/b_0)$$ ([1] diagram 2.6)

■ laminar flow (Re ≤ 2000):



■ turbulent flow (Re > 2000):



Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \lambda \cdot k_{non-c} \cdot \frac{l}{D_h}$$

([1] diagram 2.6)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

([1] diagram 2.6)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

a_0 Rectangular cross-section width (m)

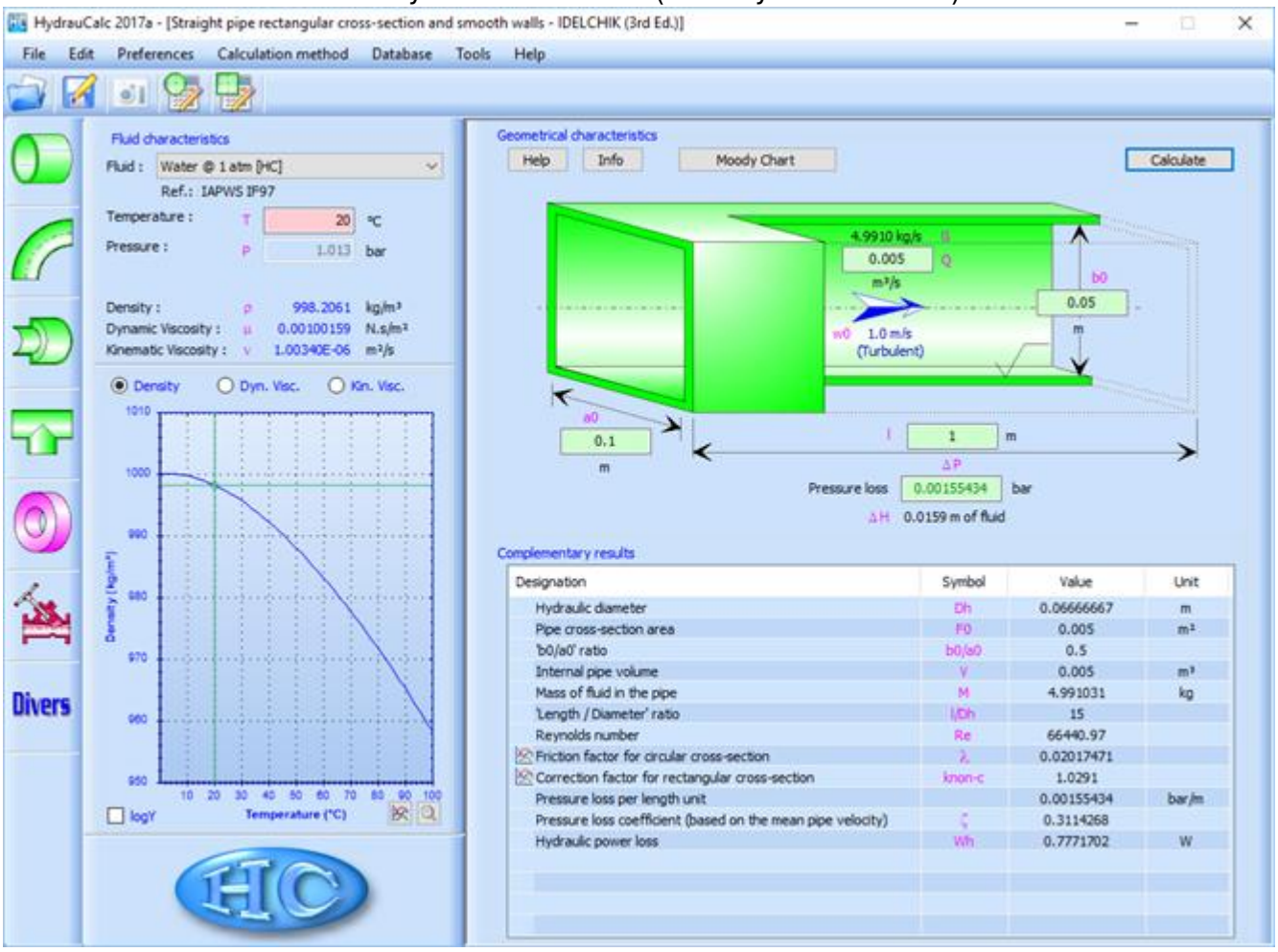
b_0 Rectangular cross-section height (m)

D_h	Hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity (m/s)
l	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
λ	Darcy friction factor for circular cross-section ()
k_{non-c}	Correction for Darcy friction factor for noncircular cross-section ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
- stabilized flow

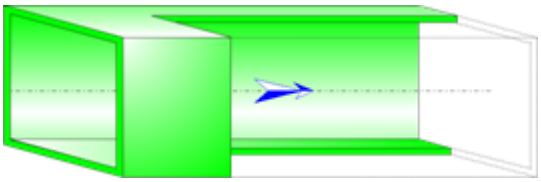
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.2.4 IDELCHIK (explicit Darcy friction factor)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of square or rectangular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula.

In this model Darcy friction factor is filled explicitly.

Model formulation:

Hydraulic diameter (m):

$$D_h = \frac{2 \cdot a_0 \cdot b_0}{a_0 + b_0}$$ ([1] diagram 2.6)

Cross-section area (m^2):

$$F_0 = a_0 \cdot b_0$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Correction for Darcy friction factor for noncircular cross-section:

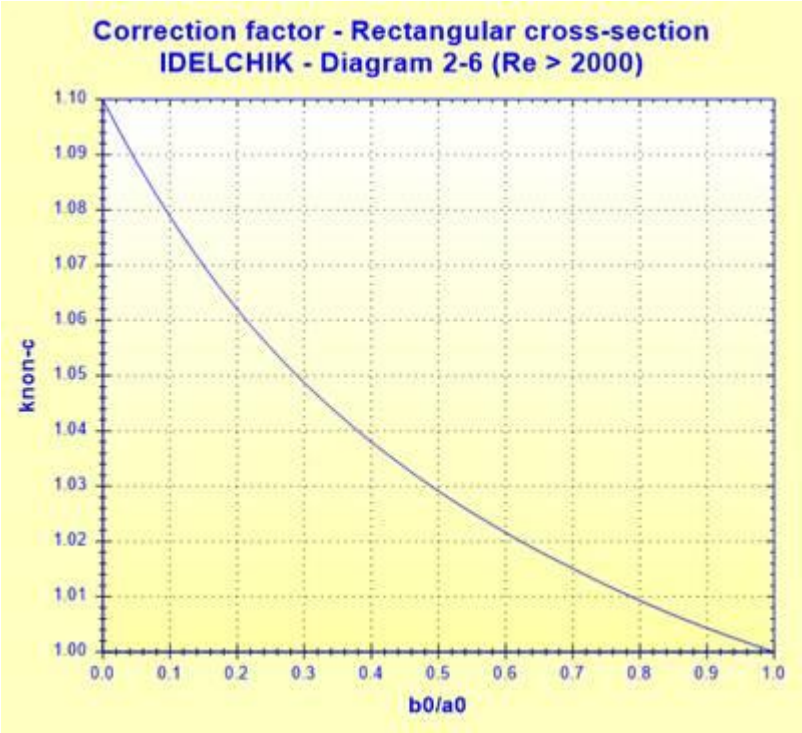
- $a_0 \geq b_0$

  $$k_{non-c} = f(b_0/a_0)$$ ([1] diagram 2.6)

- $a_0 < b_0$

  $$k_{non-c} = f(a_0/b_0)$$ ([1] diagram 2.6)

- turbulent flow (Re > 2000):



Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \lambda \cdot k_{non-c} \cdot \frac{l}{D_h}$$

([1] diagram 2.6)

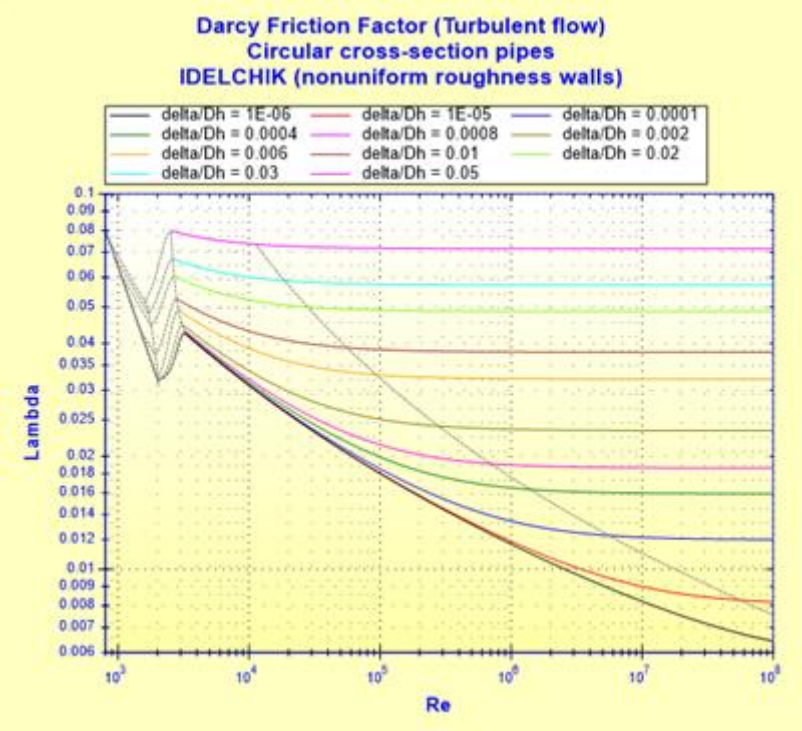
Equivalent relative roughness (turbulent regime - Re ≥ 4000):

Colebrook-White equation

$$\lambda = \frac{1}{\left[2 \cdot \log\left(\frac{2.51}{Re \cdot \sqrt{\lambda}} + \frac{\overline{\Delta}}{3.7}\right)\right]^2}$$

([1] diagram 2.4)

where $\overline{\Delta}$ is calculated by solving the equation.



Equivalent absolute roughness (m):

$$\Delta = \overline{\Delta} \cdot D_h$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

([1] diagram 2.6)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

a_0 Rectangular cross-section width (m)

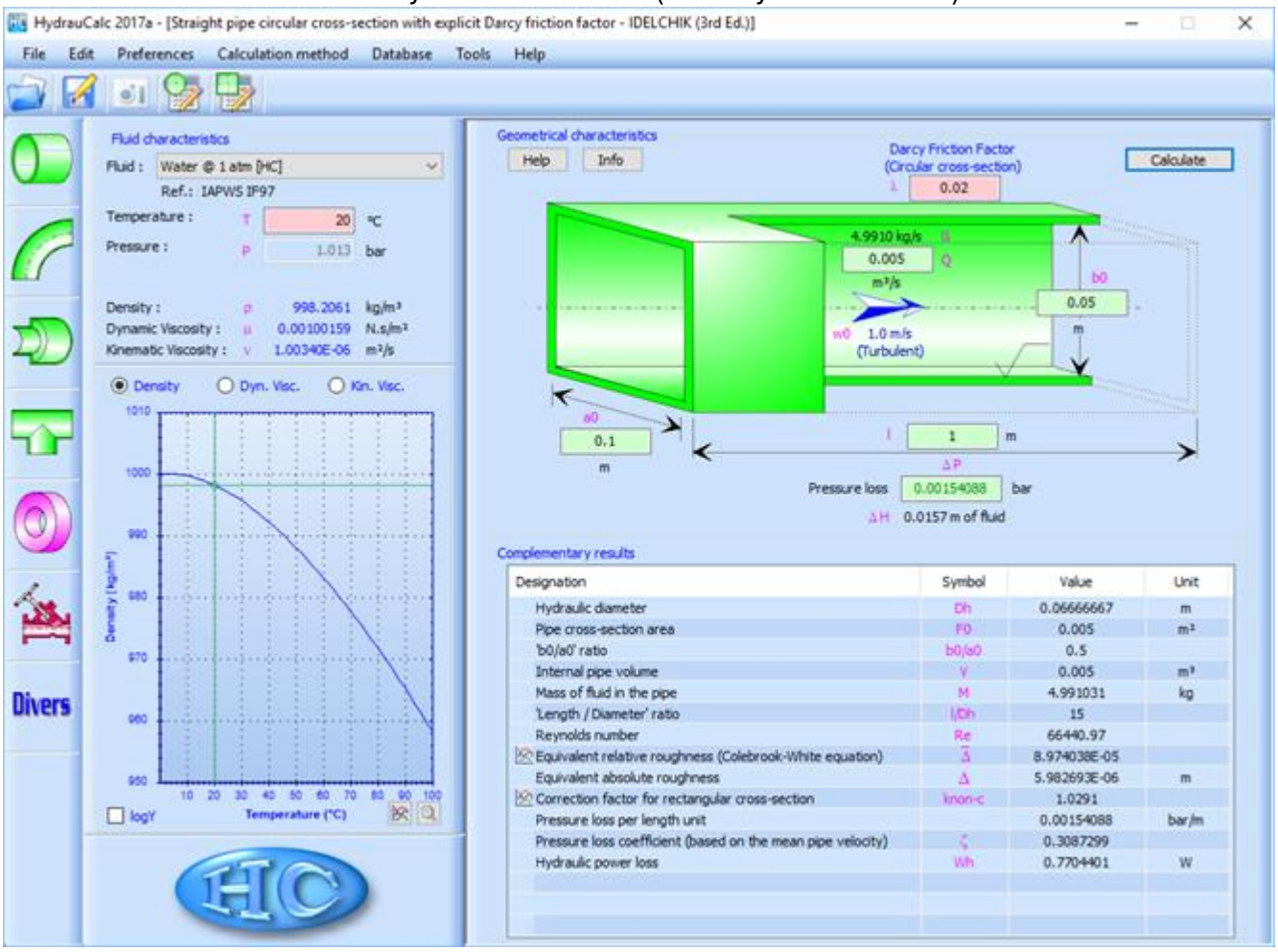
b_0 Rectangular cross-section height (m)

D_h	Hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity (m/s)
l	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
λ	Darcy friction factor for circular cross-section ()
k_{non-c}	Correction for Darcy friction factor for noncircular cross-section ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
Δ	Equivalent absolute roughness of walls (m)
$\bar{\Delta}$	Equivalent relative roughness of walls ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- critical and turbulent flow regime ($2\ 10^3 \leq Re \leq 10^8$)
- stabilized flow

Example of application:



References:

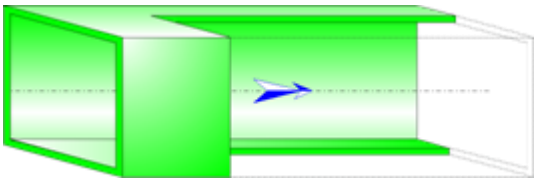
[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.2.5 MILLER (roughness walls)

Straight Pipe

Rectangular Cross-Section and Roughness Walls

(MILLER)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of square or rectangular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula.

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille (independent of the value of relative roughness),
- for turbulent flow regime by the explicit Swamee-Jain equation (dependent of the value of relative roughness), the explicit Swamee-Jain equation is a Colebrook-White equation approximation,
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Hydraulic diameter (m):

$$D = \frac{2 \cdot b \cdot W}{b + W}$$

Cross-section area (m^2):

$$A = b \cdot W$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$m = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = A \cdot L$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

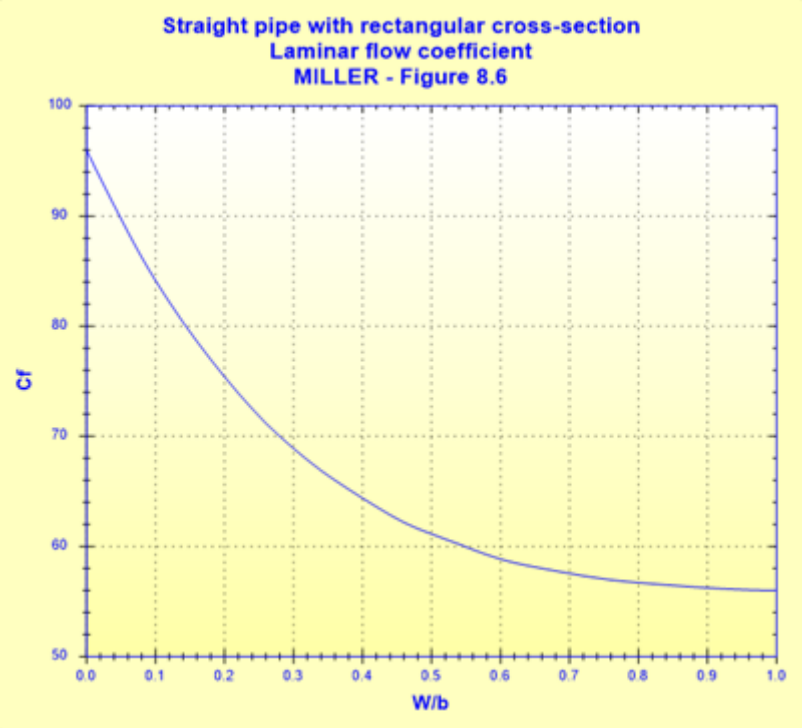
Laminar flow coefficient:

- $b \geq W$

  $$Cf = f(W/b)$$ ([1] figure 8.6)

- $b < W$

  $$Cf = f(b/W)$$ ([1] figure 8.6)

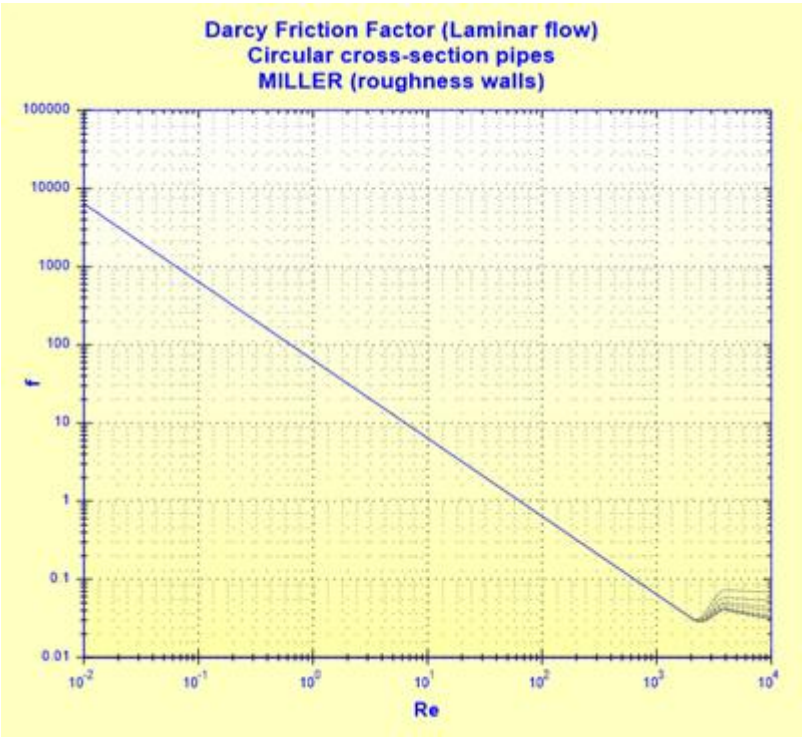


Darcy friction factor:

- laminar flow regime (Re ≤ 2000):

  Hagen-Poiseuille law

  $$f = \frac{Cf}{Re}$$ ([1] equation 8.7)



■ turbulent flow regime – transition region and complete turbulence region (Re ≥ 4000):

Swamee-Jain equation (Colebrook-White equation approximation)

$$f = \frac{0.25}{\left[\log\left(\frac{k}{3.7 \cdot D} + \frac{5.74}{\mathrm{Re}^{0.9}}\right)\right]^2}$$

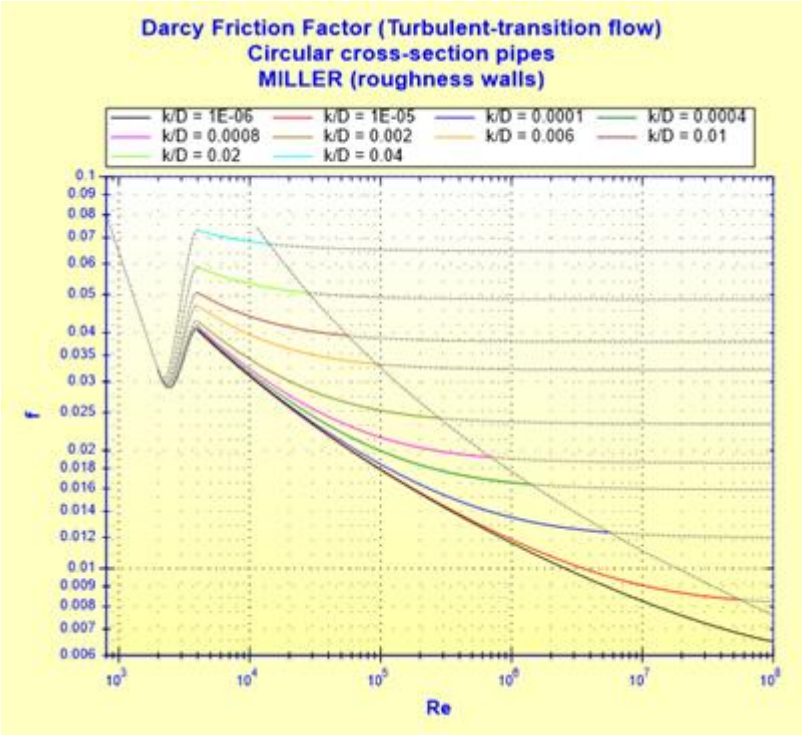
([1] equation 8.4)

Reynolds number corresponding to the beginning of complete turbulence:

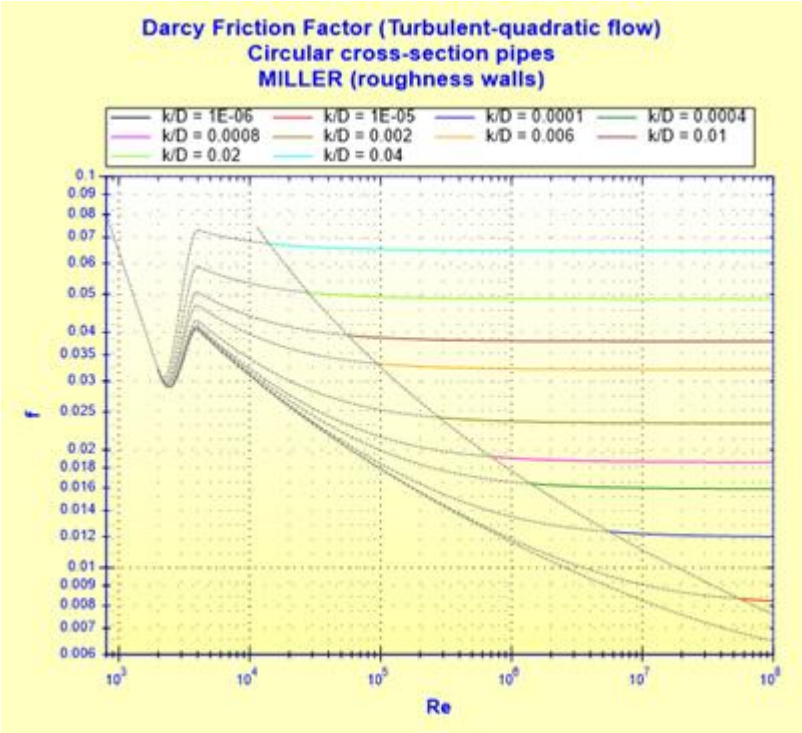
$$\mathrm{Re''}_{lim} = \frac{560}{\Delta}$$

([2] diagram 2.4)

Transition region



Complete turbulence region



■ critical flow regime (2000 < Re < 4000):

cubic interpolation

$$f = (X1 + R \cdot (X2 + R \cdot (X3 + X4)))$$ ([3])

with:

$$R = \frac{Re}{2000}$$

$$X1 = 7 \cdot FA - FB$$

$$X2 = 0.128 - 17 \cdot FA + 2.5 \cdot FB$$

$$X3 = -0.128 + 13 \cdot FA - 2 \cdot FB$$

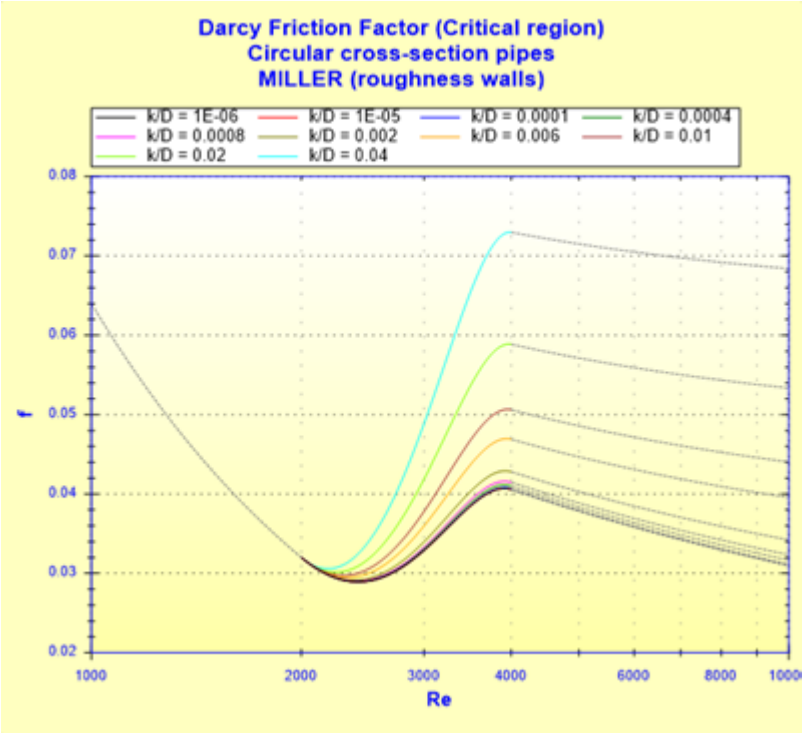
$$X4 = R \cdot (0.032 - 3 \cdot FA + 0.5 \cdot FB)$$

$$FA = Y3^{-2}$$

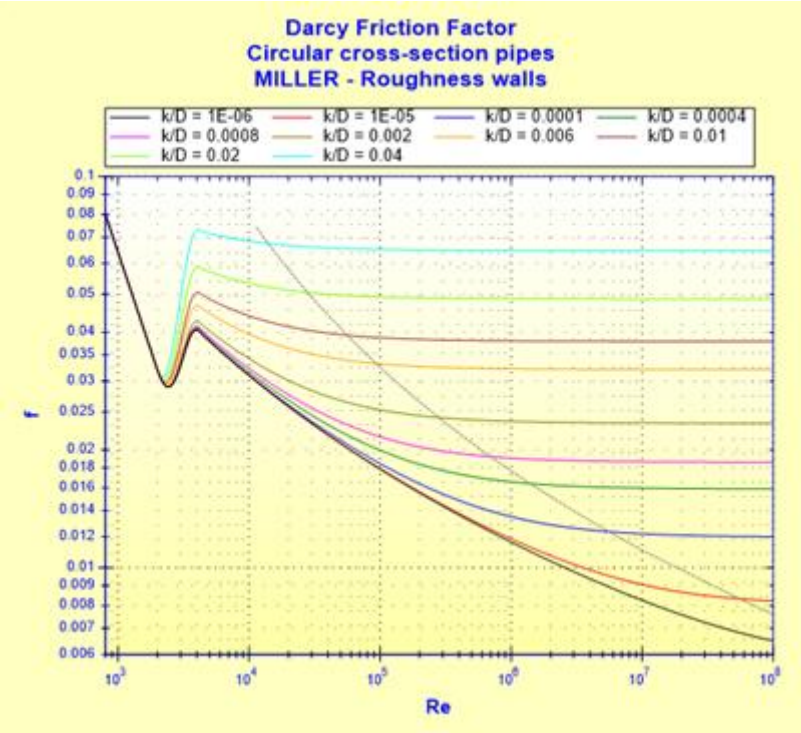
$$FB = FA \cdot \left(2 - \frac{0.00514215}{Y2 \cdot Y3}\right)$$

$$Y2 = \frac{k}{3.7 \cdot D} + \frac{5.74}{Re^{0.9}}$$

$$Y3 = -0.86859 \cdot ln\left(\frac{k}{3.7 \cdot D} + \frac{5.74}{4000^{0.9}}\right)$$



■ all flow regimes:



Friction pressure loss coefficient:

$$K_f = f \cdot \frac{L}{D}$$

([1] equation 8.3)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_f$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

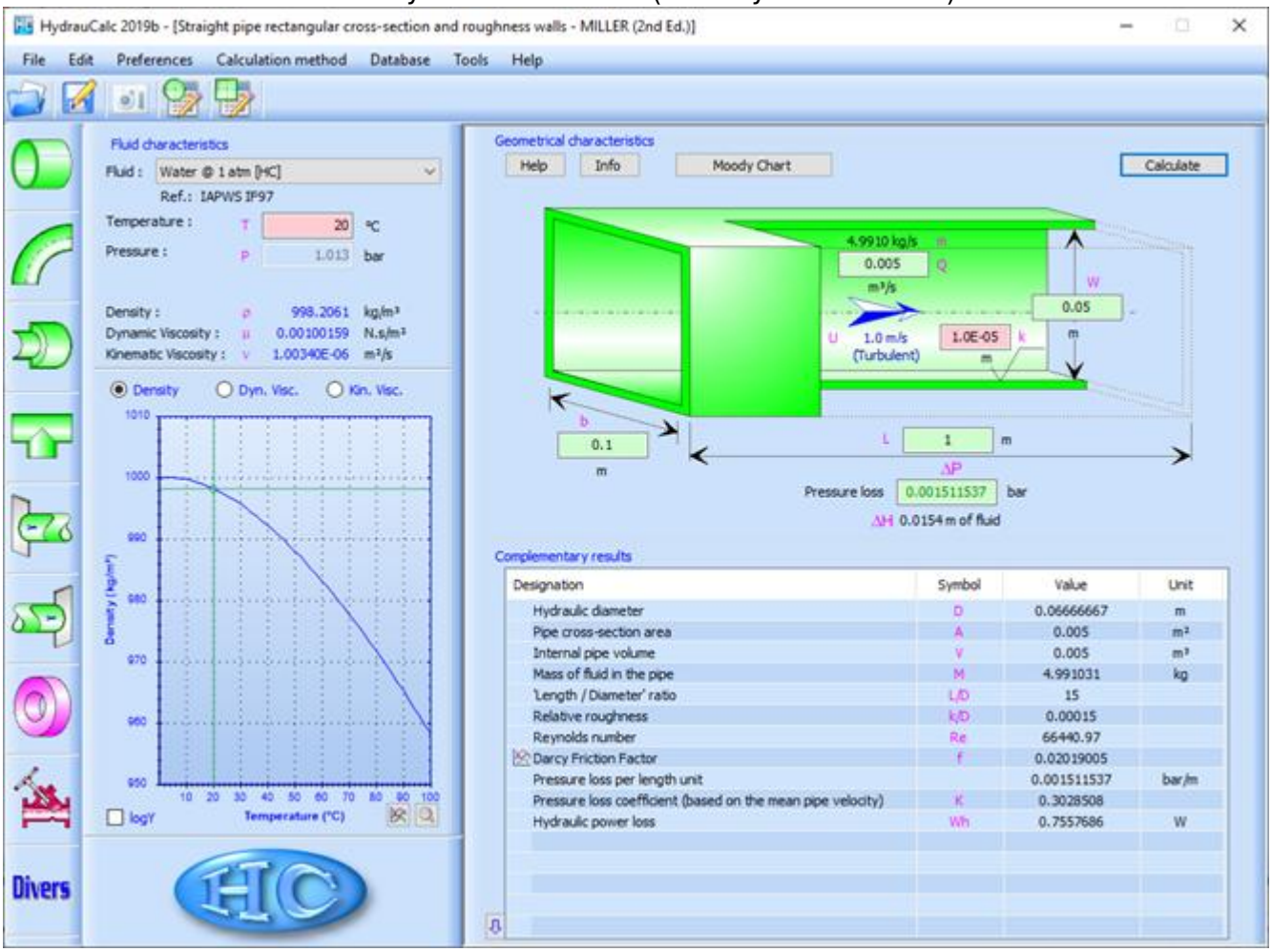
b	Cross-section width (m)
W	Cross-section height (m)
D	Hydraulic diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
m	Mass flow rate (kg/s)
U	Mean velocity (m/s)
L	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
Re''_{lim}	Nombre de Reynolds correspondant au début de la turbulence complète ()
Cf	Laminar flow coefficient ()
k	Absolute roughness of walls (m)

f	Darcy friction factor ()
K_f	Friction pressure loss coefficient ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
- $k/D \leq 0.05$
- stabilized flow

Example of application:



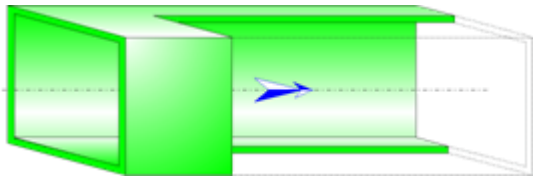
References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

[2] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

[3] Dunlop (1991)

2.1.2.6 MILLER (explicit Darcy friction factor)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of square or rectangular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula.

In this model Darcy friction factor is filled explicitly.

Model formulation:

Hydraulic diameter (m):

$$D = \frac{2 \cdot b \cdot W}{b + W}$$

Cross-section area (m^2):

$$A = b \cdot W$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$m = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = A \cdot L$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

Friction pressure loss coefficient:

$$K_f = f \cdot \frac{L}{D}$$ ([1] equation 8.3)

Total pressure loss coefficient (based on the mean pipe velocity):

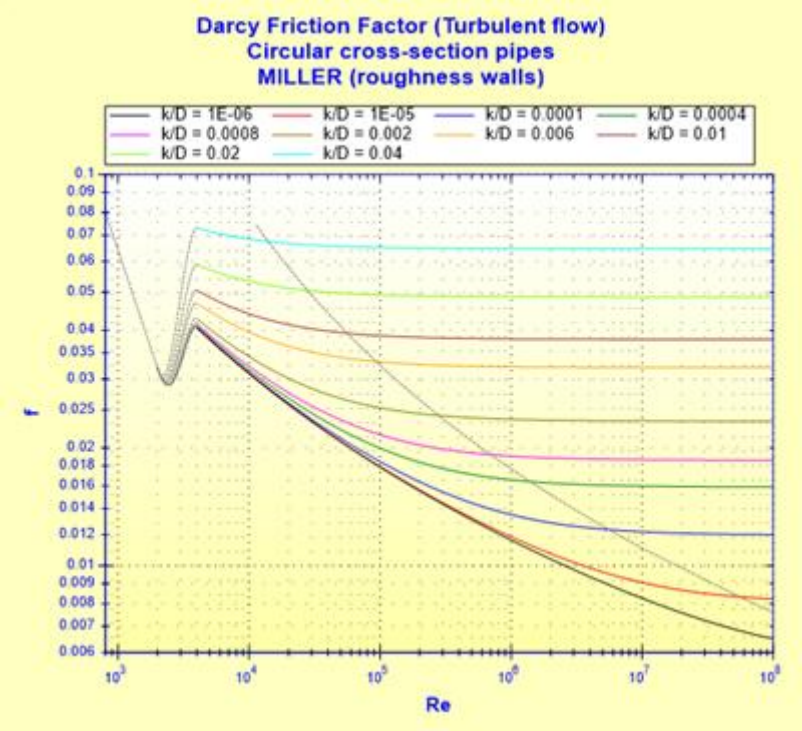
$$K = K_f$$

Equivalent absolute roughness (turbulent regime - Re ≥ 4000):

Swamee-Jain equation (Colebrook-White equation approximation)

$$f = \frac{0.25}{\left[\log\left(\frac{k}{3.7 \cdot D} + \frac{5.74}{Re^{0.9}}\right)\right]^2}$$ ([1] equation 8.4)

where k is calculated by solving the equation.



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

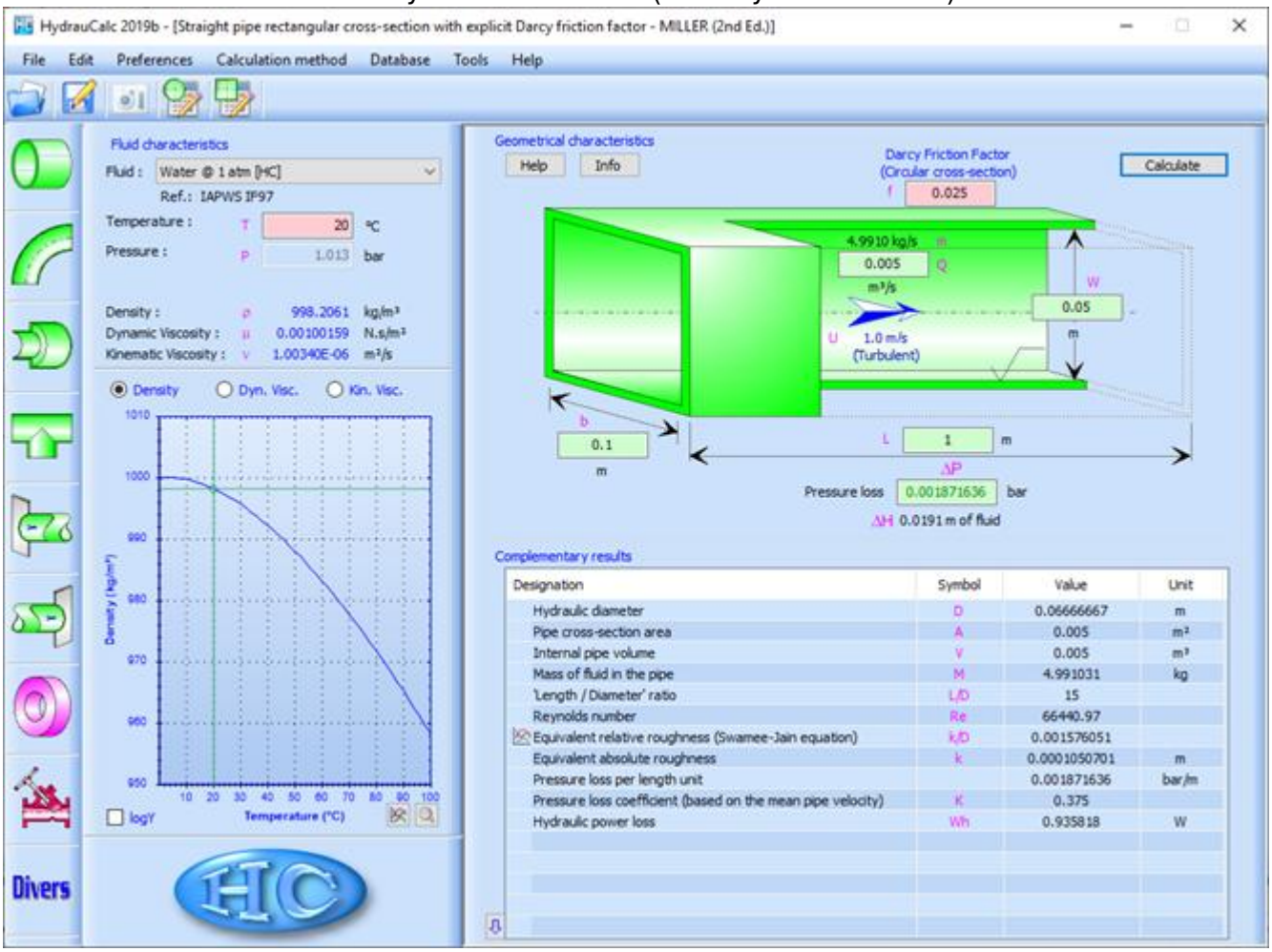
b	Cross-section width (m)
W	Cross-section height (m)
D	Hydraulic diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)

m	Mass flow rate (kg/s)
U	Mean velocity (m/s)
L	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
f	Darcy friction factor ()
K_f	Friction pressure loss coefficient ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
k	Equivalent absolute roughness of walls (m)
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- critical and turbulent flow regime ($2\ 10^3 \leq Re \leq 10^8$)
- stabilized flow

Example of application:



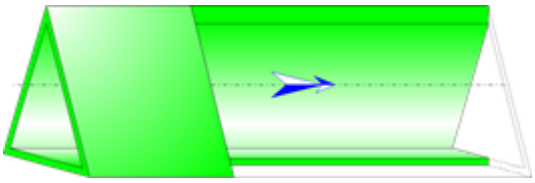
References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

2.1.3 Straight pipe - Triangular cross-section

Straight Pipe

Triangular Cross-section



To calculate the pressure losses by friction in straight pipes, Darcy Weisbach's equation is used.

For the calculation of the friction factor, the user can choose from one of the 4 available relationships, depending on the roughness of the inner walls:

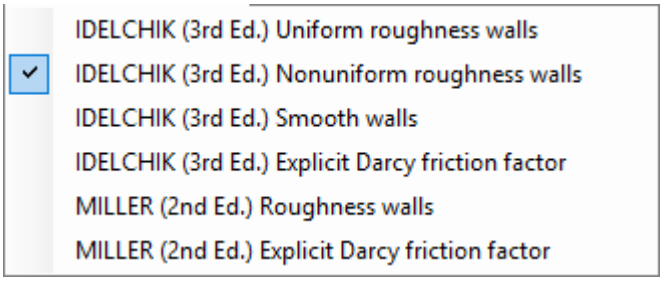
- Homogeneous roughness piping (uniform roughness - pipe used by Nikuradse for its experimental data) - Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Heterogeneous roughness piping (industrial type piping) - Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipes with smooth walls - Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipes with roughness walls - Internal Flow System, 2nd Edition, D.S. Miller

It is also possible to explicitly specify the value of the friction factor. This is available in case you are looking for results with another formulation of the friction factor (Haaland equation for example). The friction factor is available for the following references:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "Pipes with nonuniform roughness"

Calculation method

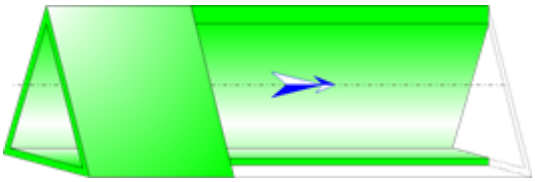


2.1.3.1 IDELCHIK (uniform roughness walls)

Straight Pipe

Triangular Cross-Section and Uniform Roughness Walls

(IDELCHIK)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of triangular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula. The roughness of the inner walls of the pipe is supposed uniform (pipe used by Nikuradse for its experimental data).

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille (independent of the value of relative roughness),
- for turbulent flow regime by the Nikuradse equation (dependent of the value of relative roughness),
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Half top angle (°):

$$\beta = \tan^{-1}\left(\frac{a_0}{2 \cdot h}\right)$$

Hydraulic diameter (m):

$$D_h = \frac{2 \cdot h}{1 + \sqrt{\frac{1}{\tan^2(\beta)} + 1}}$$

Cross-section area (m^2):

$$F_0 = \frac{a_0}{2} \cdot h$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

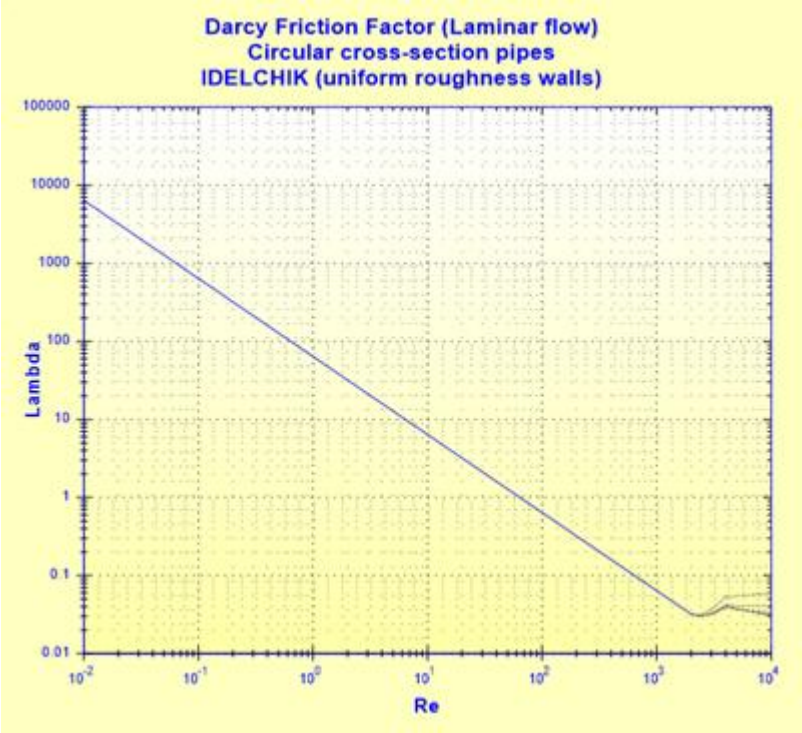
$$\overline{\Delta} = \frac{\Delta}{D_h}$$

Darcy friction factor for circular cross-section:

- laminar flow regime (Re ≤ 2000):

  Hagen-Poiseuille law

  $$\lambda_{circ} = \frac{64}{Re}$$ ([1] diagram 2.1)



- turbulent flow regime – transition region and complete turbulence region (Re ≥ 4000):

  Nikuradse equation

  $$\lambda_{circ} = \frac{1}{\left[a_1 + b_1 \cdot \log(Re \cdot \sqrt{\lambda}) + c_1 \cdot \log(\overline{\Delta})\right]^2}$$ ([1] diagram 2.2)

  where the values of a_1, b_1 and c_1 are given below:

$\bar{\Delta} \cdot Re \cdot \sqrt{\lambda}$	a_1	b_1	c_1
3.6 - 10	-0.800	2.000	0.000
10 - 20	0.068	1.130	-0.870
20 - 40	1.538	0.000	-2.000
40 - 191.2	2.471	-0.588	-2.588
> 191.2	1.138	0.000	-2.000

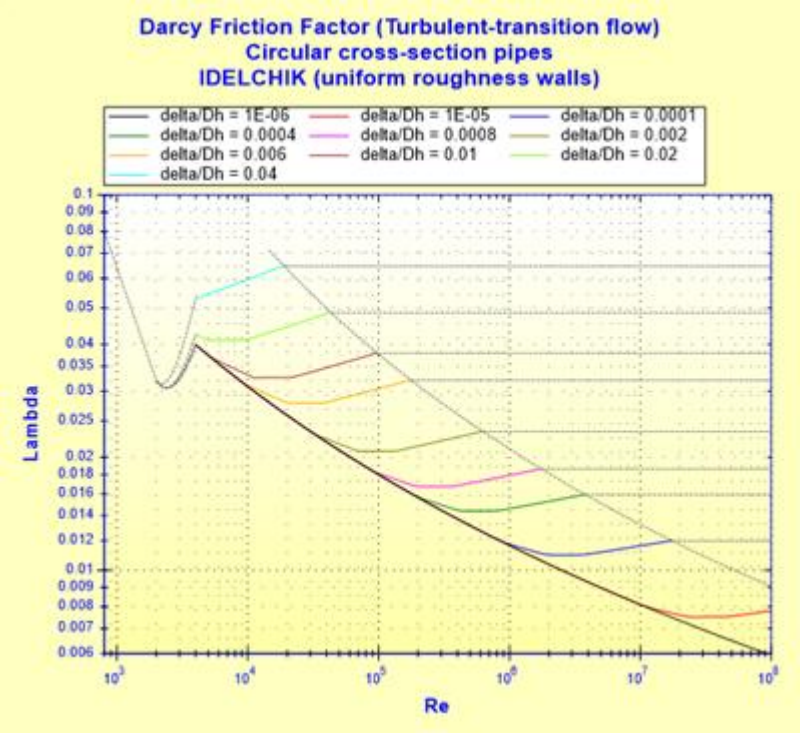
Reynolds number at which pipe cease to be hydraulically smooth:

$$Re'_{lim} = \frac{26.9}{\bar{\Delta}^{1.143}}$$ ([1] §2.17)

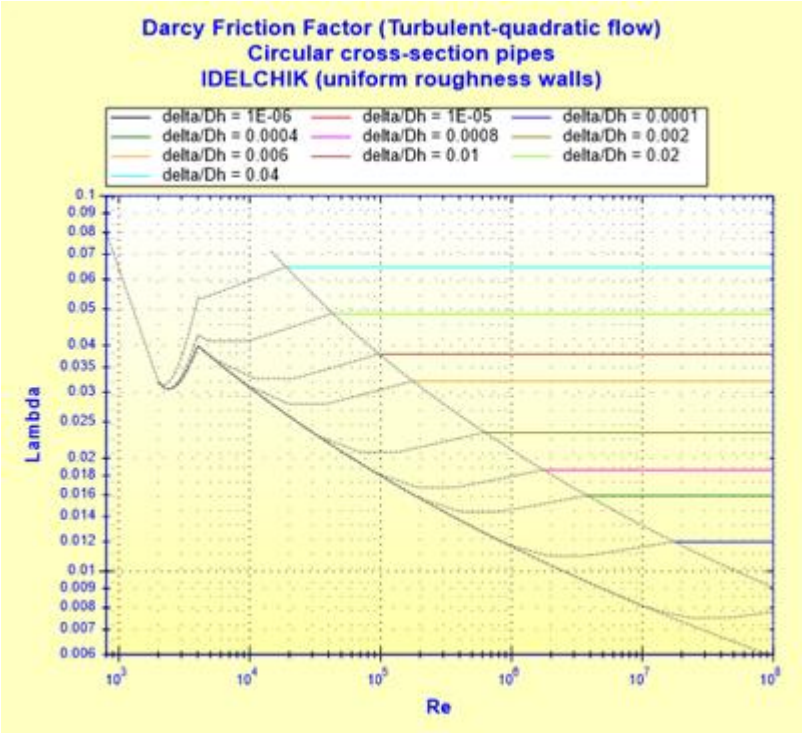
Reynolds number corresponding to the beginning of complete turbulence:

$$Re''_{lim} = \frac{217.6 - 382.4 \cdot \log(\bar{\Delta})}{\bar{\Delta}}$$ ([1] diagram 2.2)

Transition region



Complete turbulence region



■ critical flow regime (2000 < Re < 4000):

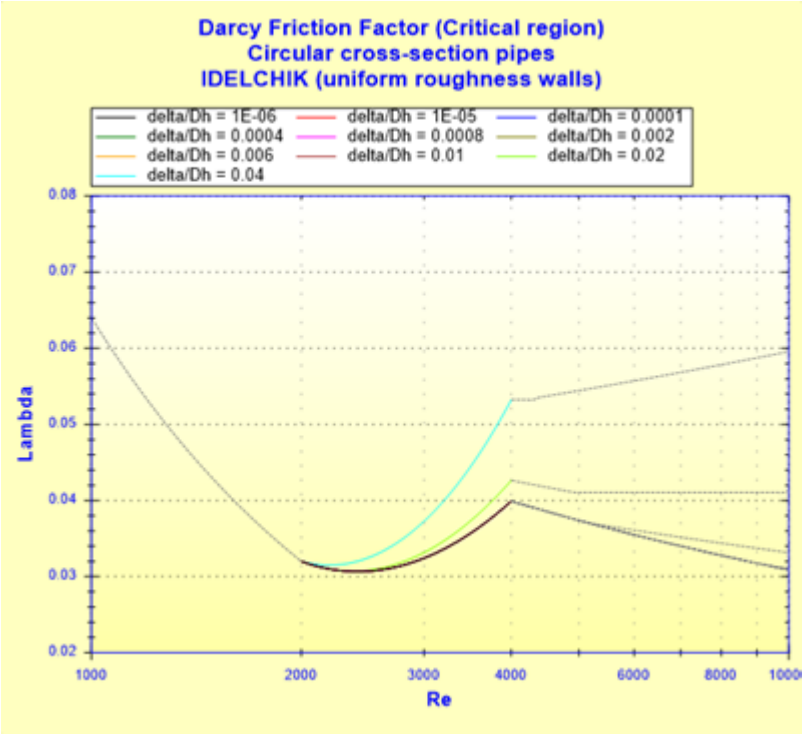
linear interpolation

$$\lambda_{circ} = \lambda_L \cdot \left(1 - \frac{Re - 2000}{2000}\right) + \lambda_T \cdot \left(\frac{Re - 2000}{2000}\right)$$

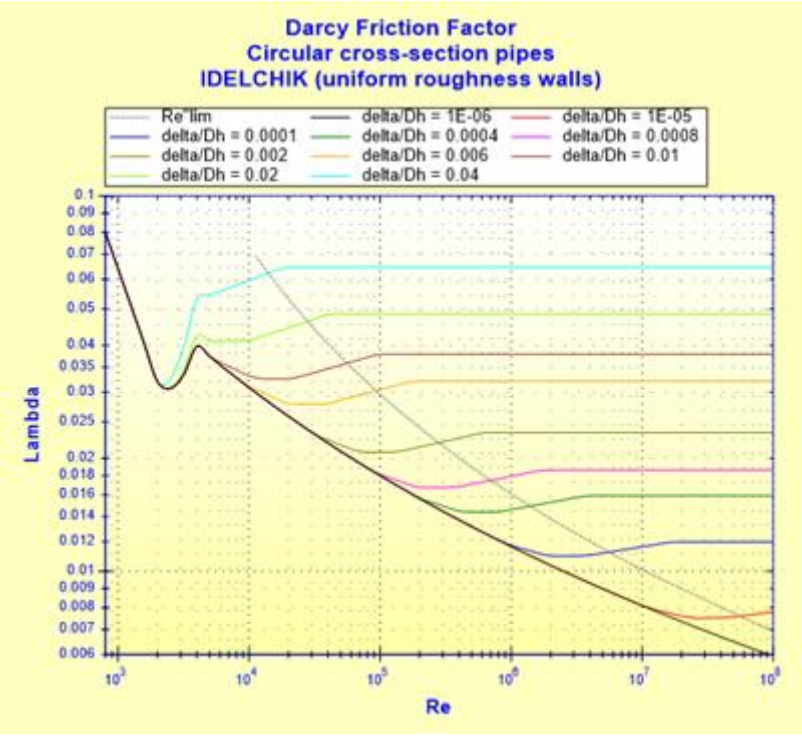
with:

λ_L = laminar friction coefficient obtained with Re = 2000

λ_T = turbulent friction coefficient obtained with Re = 4000



■ all flow regimes:



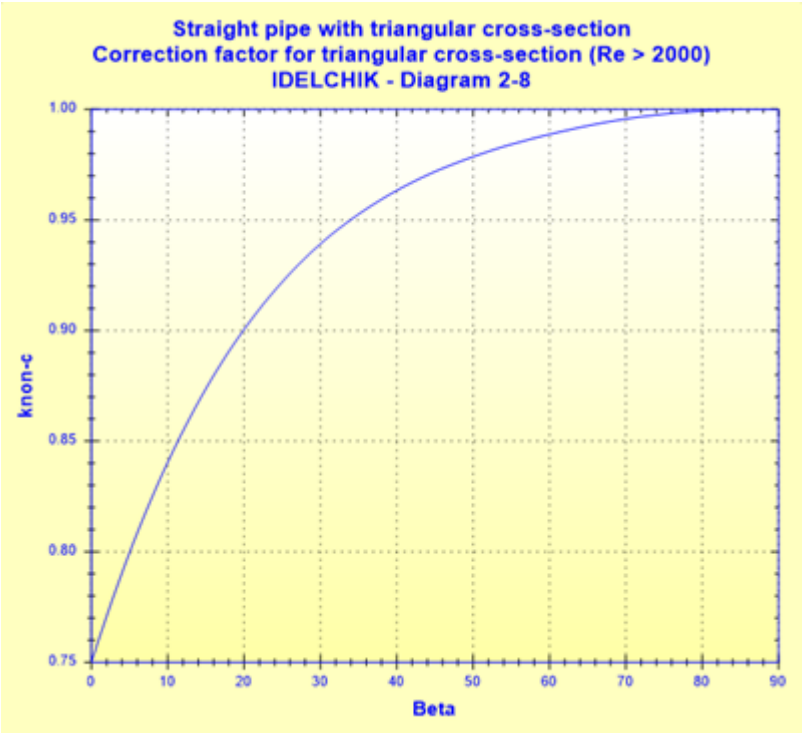
Correction for Darcy friction factor for triangular cross-section:

■ laminar flow (Re ≤ 2000):

$$k_{non-c} = f(\beta)$$ ([1] diagram 2.8)

- turbulent flow (Re > 2000):

$$k_{non-c} = f(\beta)$$ ([1] diagram 2.8)



Darcy friction factor for triangular cross-section:

$$\lambda_{tria} = \lambda_{circ} \cdot k_{non-c}$$ ([1] diagram 2.8)

Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \lambda_{tria} \cdot \frac{l}{D_h}$$ ([1] diagram 2.8)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$ ([1] diagram 2.8)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

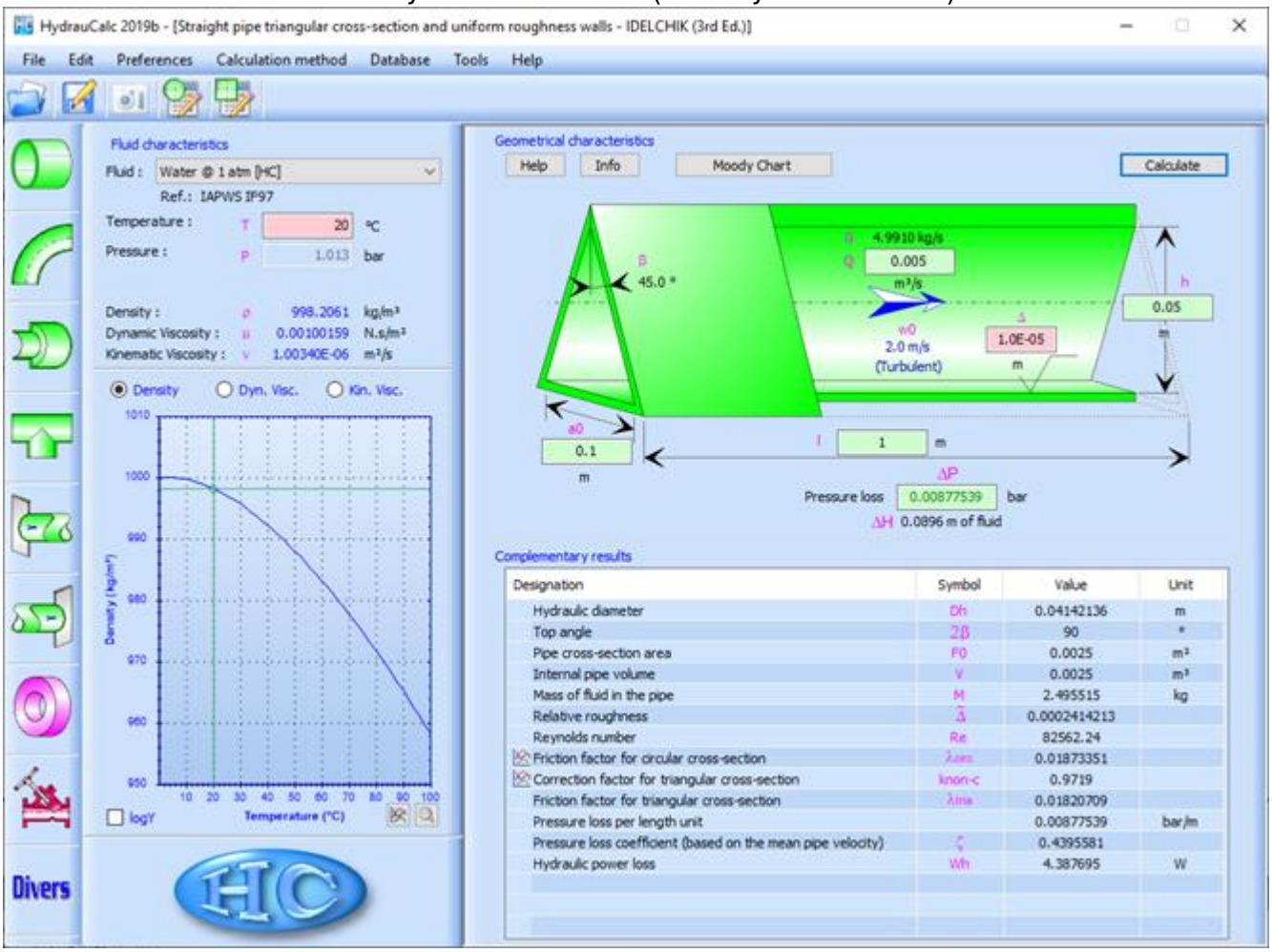
a_0	Cross-section base (m)
h	Cross-section height(m)
β	Half top angle (°)
D_h	Hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
l	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)

Re	Reynolds number ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()
λ_{circ}	Darcy friction factor for circular cross-section ()
Re'_{lim}	Limiting Reynolds number for hydraulically smooth law ()
Re''_{lim}	Limiting Reynolds number for quadratic law ()
k_{non-c}	Correction for Darcy friction factor for triangular cross-section ()
λ_{tria}	Darcy friction factor for triangular cross-section ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
- relative roughness $\bar{\Delta} \leq 0.05$
- stabilized flow

Example of input data and results:



References:

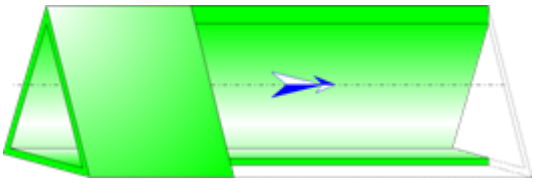
[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.3.2 IDELCHIK (nonuniform roughness walls)

Straight Pipe

Triangular Cross-Section and Nonuniform Roughness Walls

(IDELCHIK)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of triangular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula. The roughness of the inner walls of the pipe is supposed nonuniform (commercial pipe).

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille (independent of the value of relative roughness),
- for turbulent flow regime by the implicit Colebrook-White equation (dependent of the value of relative roughness),
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Half top angle (°):

$$\beta = \tan^{-1}\left(\frac{a_0}{2 \cdot h}\right)$$

Hydraulic diameter (m):

$$D_h = \frac{2 \cdot h}{1 + \sqrt{\frac{1}{\tan^2(\beta)} + 1}}$$

Cross-section area (m^2):

$$F_0 = \frac{a_0}{2} \cdot h$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

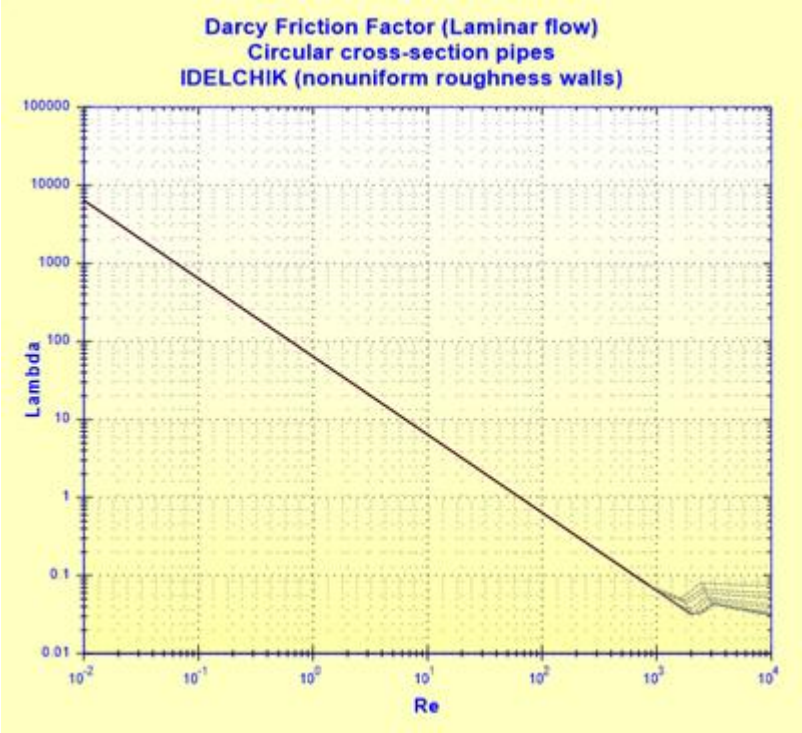
$$\overline{\Delta} = \frac{\Delta}{D_h}$$

Darcy friction factor for circular cross-section:

- laminar flow regime ($Re \leq Re_0$):

  Hagen-Poiseuille law

  $$\lambda_{circ} = \frac{64}{Re}$$ ([1] diagram 2.1)



- turbulent flow regime – transition region and complete turbulence region ($Re \geq Re_2$):

  Colebrook-White equation

  $$\lambda_{circ} = \frac{1}{\left[2 \cdot \log\left(\frac{2.51}{Re \cdot \sqrt{\lambda}} + \frac{\overline{\Delta}}{3.7}\right)\right]^2}$$ ([1] diagram 2.4)

  Reynolds number at which pipe cease to be hydraulically smooth:

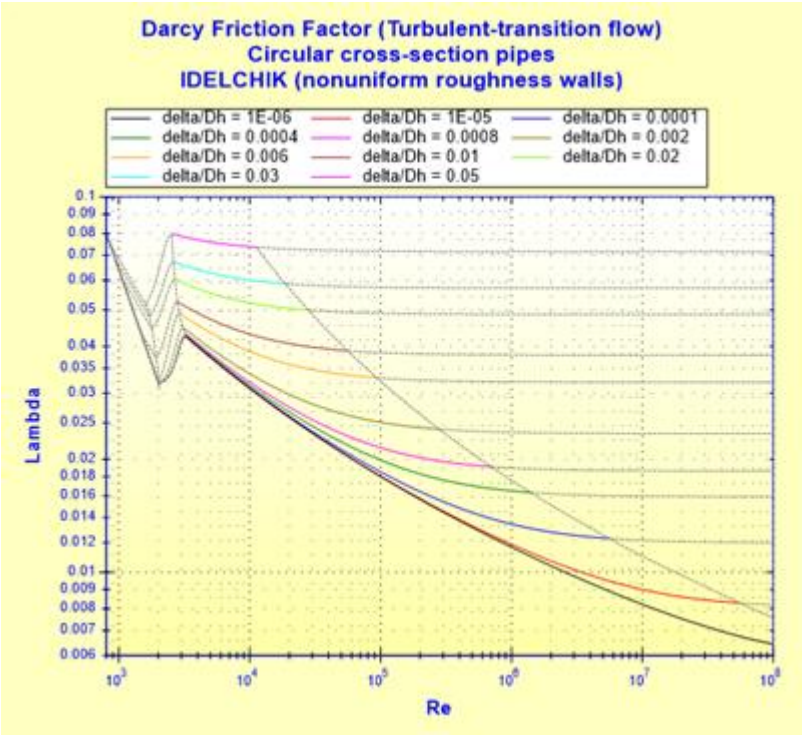
  $$Re'_{lim} = \frac{15}{\overline{\Delta}}$$ ([1] §2.23)

  Reynolds number corresponding to the beginning of complete turbulence:

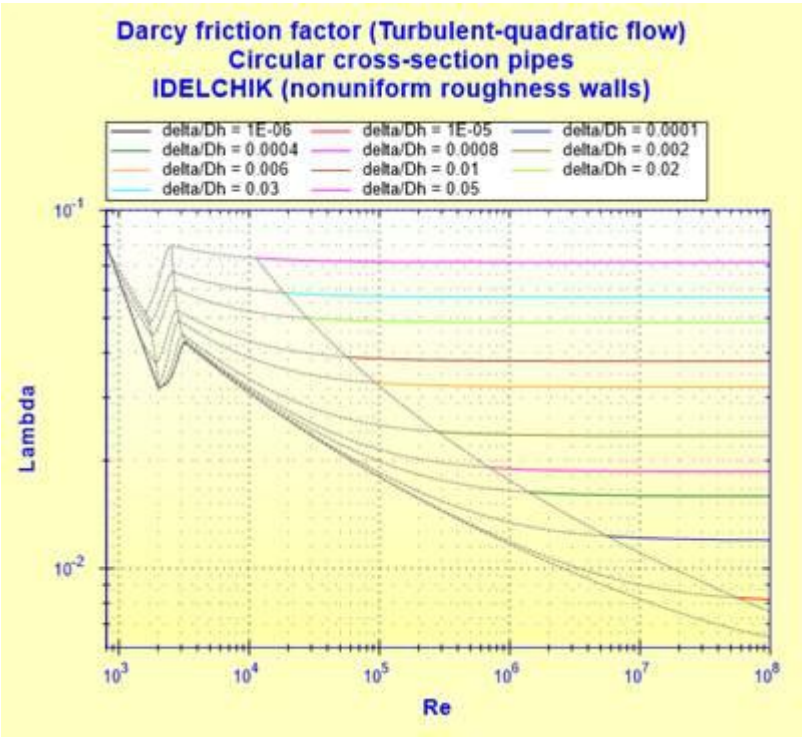
$$Re''_{lim} = \frac{560}{\Delta}$$

([1] diagram 2.4)

Transition region



Complete turbulence region



■ critical flow regime ($Re_0 < Re < Re_2$):

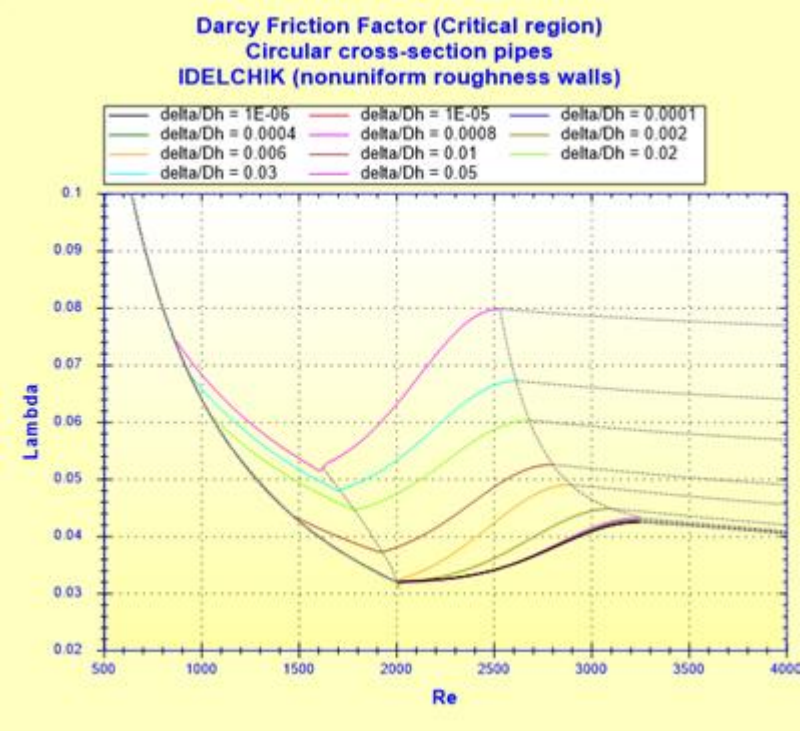
$$\lambda_{circ} = f(Re, \overline{\Delta})$$ ([1] diagram 2.3)

Reynolds number of start of critical zone:

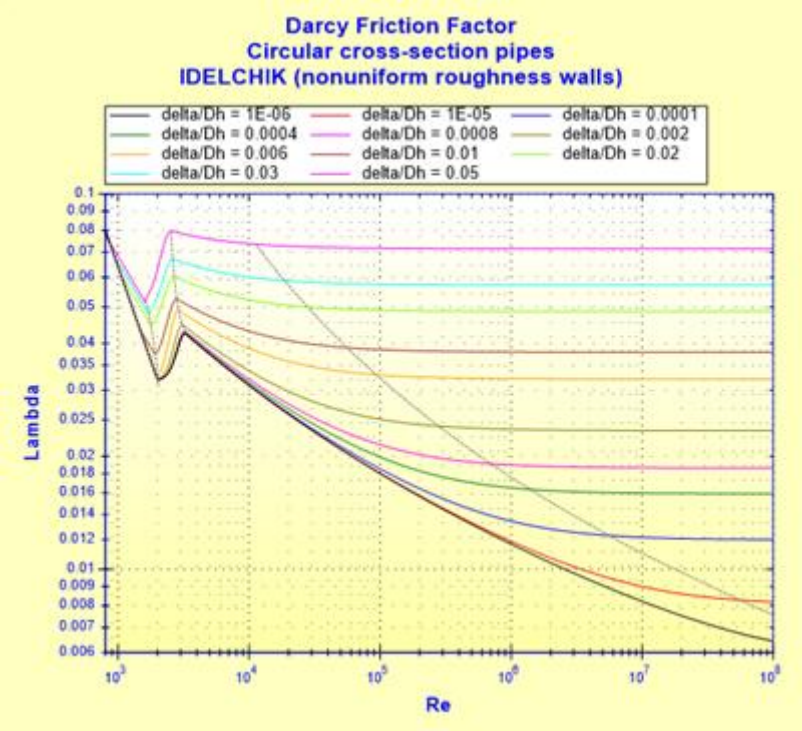
$$Re_0 = 754 \exp\left(\frac{0.0065}{\overline{\Delta}}\right)$$ ([1] §2.21)

Reynolds number at end of critical zone:

$$Re_2 = 2090\left(\frac{1}{\overline{\Delta}}\right)^{0.0635}$$ ([1] §2.22)



■ all flow regimes:



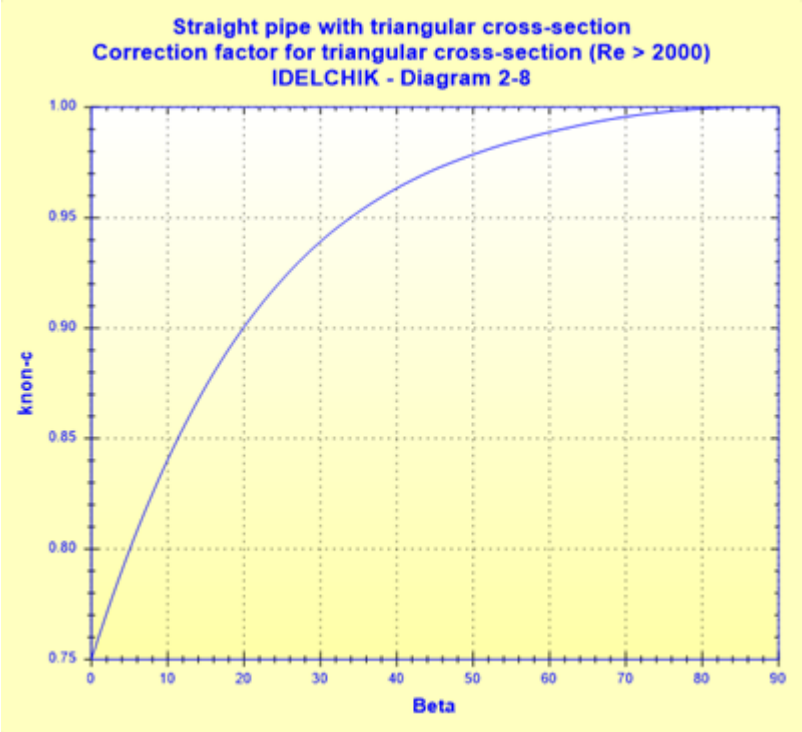
Correction for Darcy friction factor for triangular cross-section:

- laminar flow (Re ≤ 2000):

$$k_{non-c} = f(\beta)$$ ([1] diagram 2.8)

- turbulent flow (Re > 2000):

$$k_{non-c} = f(\beta)$$ ([1] diagram 2.8)



Darcy friction factor for triangular cross-section:

$$\lambda_{tria} = \lambda_{circ} \cdot k_{non-c}$$ ([1] diagram 2.8)

Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \lambda_{tria} \cdot \frac{l}{D_h}$$ ([1] diagram 2.8)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$ ([1] diagram 2.8)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

a_0	Cross-section base (m)
h	Cross-section height(m)
β	Half top angle (°)
D_h	Hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
l	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()
λ_{circ}	Darcy friction factor for circular cross-section ()
Re'_{lim}	Limiting Reynolds number for hydraulically smooth law ()
Re''_{lim}	Limiting Reynolds number for quadratic law ()
Re_0	Reynolds number of start of critical zone ()
Re_2	Reynolds number at end of critical zone ()
k_{non-c}	Correction for Darcy friction factor for noncircular cross-section ()
λ_{tria}	Darcy friction factor for triangular cross-section ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

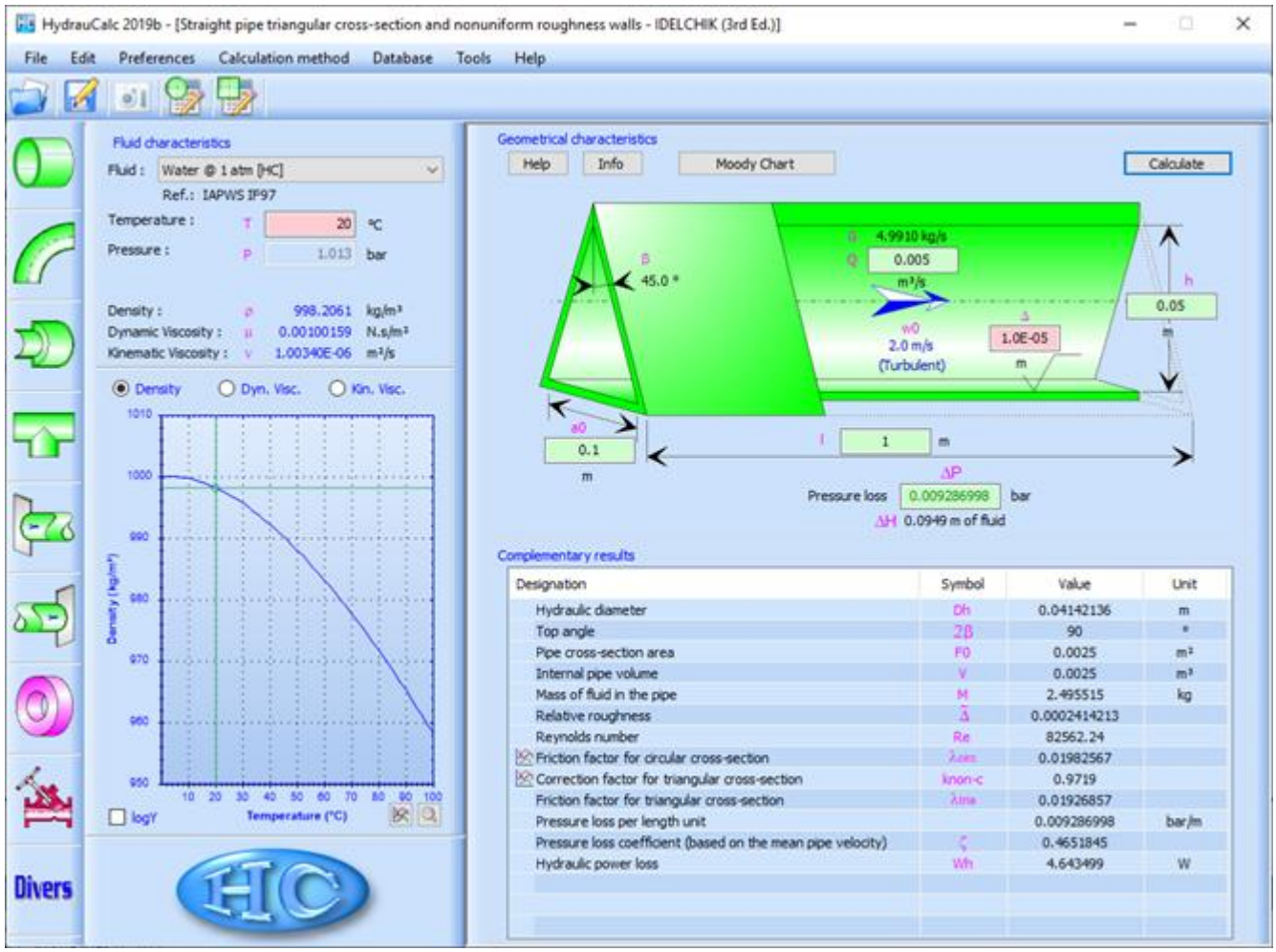
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
- relative roughness $\overline{\Delta} \leq 0.05$
- stabilized flow

Example of input data and results:



References:

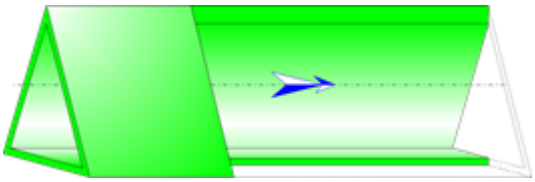
[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.3.3 IDELCHIK (smooth walls)

Straight Pipe

Triangular Cross-Section and Smooth Walls

(IDELCHIK)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of triangular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula. The inner wall of the piping is supposed to completely smooth (without roughness).

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille,
- for turbulent flow regime by the explicit Filonenko and Althsul equation,
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Half top angle (°):

$$\beta = \tan^{-1}\left(\frac{a_0}{2 \cdot h}\right)$$

Hydraulic diameter (m):

$$D_h = \frac{2 \cdot h}{1 + \sqrt{\frac{1}{\tan^2(\beta)} + 1}}$$

Cross-section area (m^2):

$$F_0 = \frac{a_0}{2} \cdot h$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

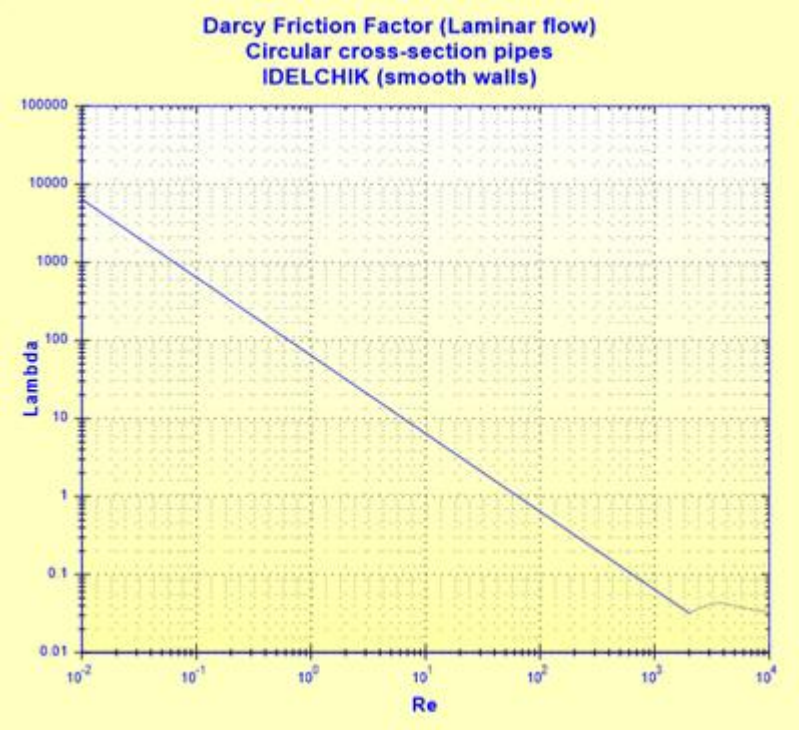
$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Darcy friction factor for circular cross-section:

- laminar flow regime ($Re \leq 2000$):

  Hagen-Poiseuille law

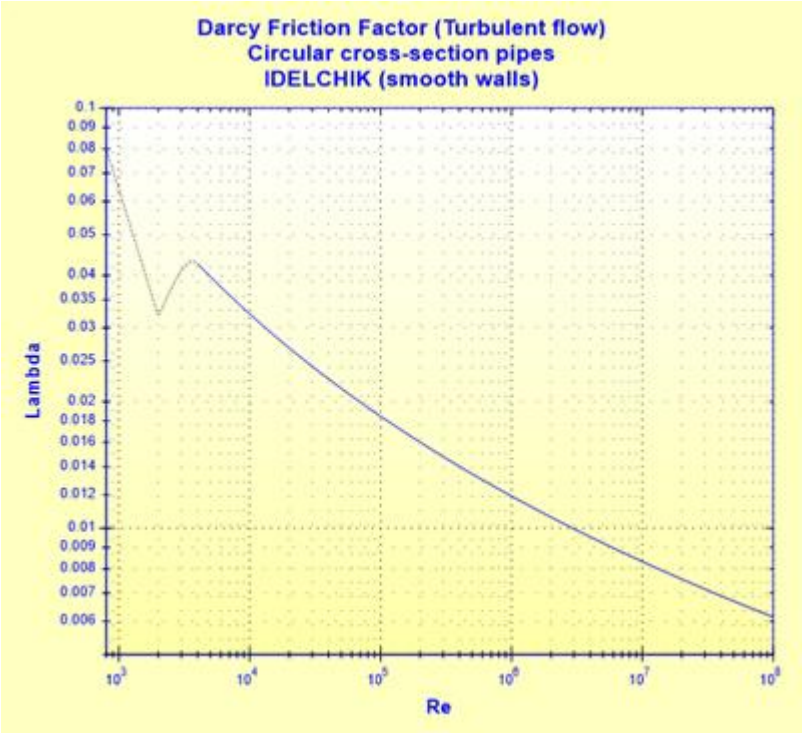
$$\lambda_{circ} = \frac{64}{Re}$$ ([1] diagram 2.1)



■ turbulent flow regime (Re ≥ 4000):

Filonenko and Althsul Equation

$$\lambda_{circ} = \frac{1}{\left[1.8 \cdot \log(Re) - 1.64\right]^2}$$ ([1] diagramme 2.1)

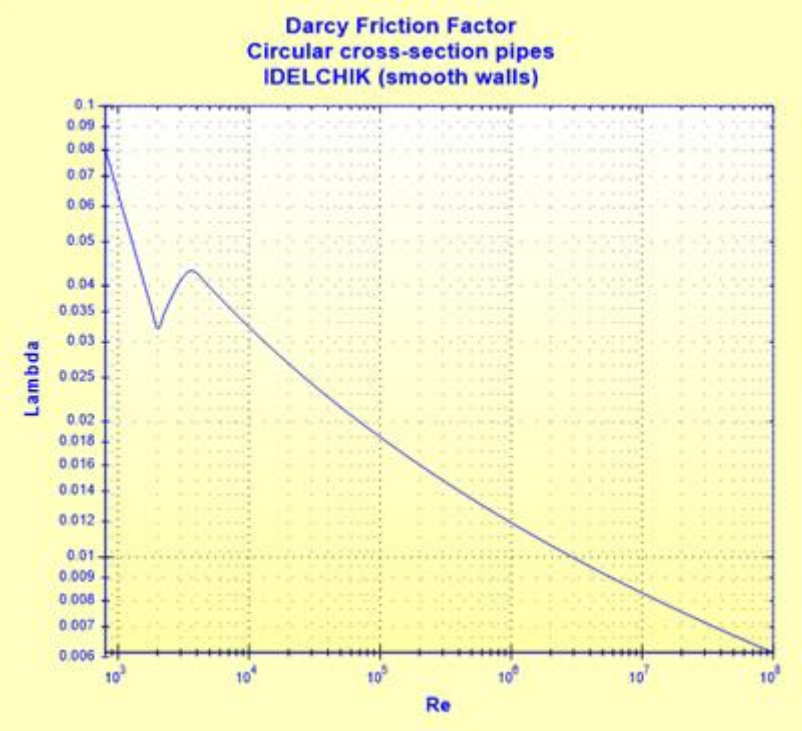


■ critical flow regime (2000 < Re < 4000):

interpolation between laminar and turbulent flows

$\lambda_{circ} = f(\mathrm{Re})$ ([1] diagram 2.1)

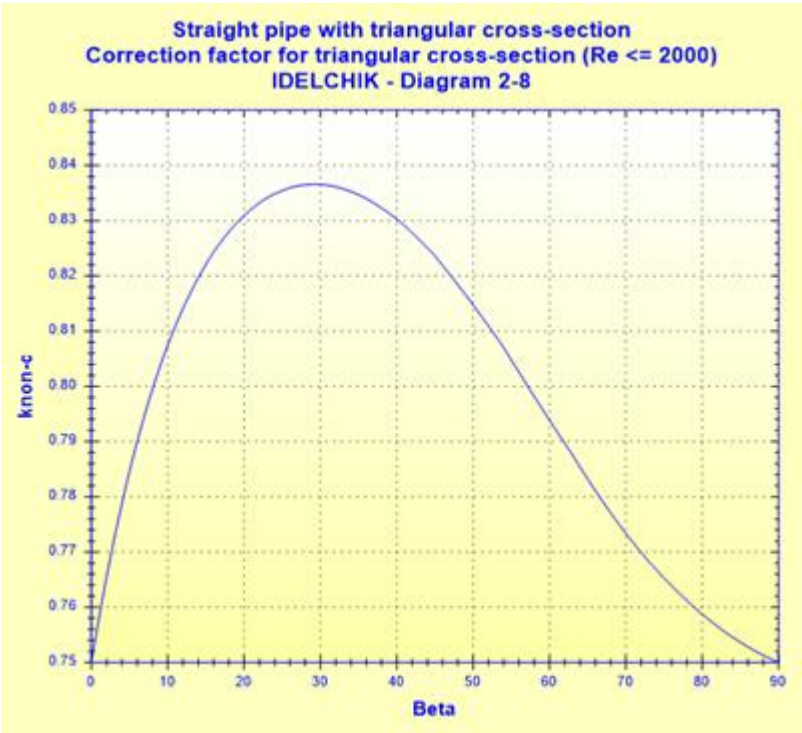
■ all flow regimes:



Correction for Darcy friction factor for triangular cross-section:

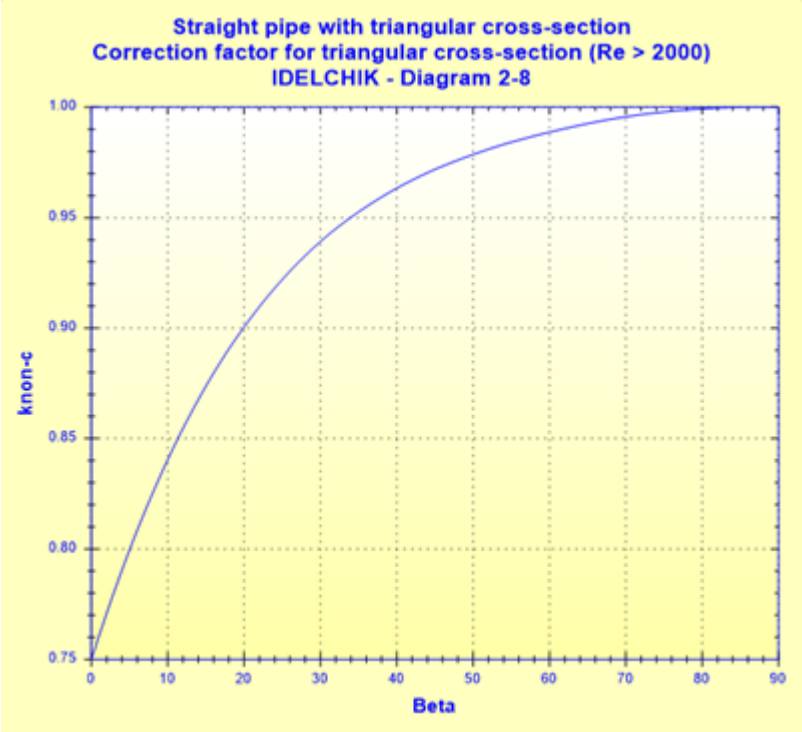
- laminar flow (Re ≤ 2000):

$$k_{non-c} = f(\beta)$$ ([1] diagram 2.8)



- turbulent flow (Re > 2000):

$$k_{non-c} = f(\beta)$$ ([1] diagram 2.8)



Darcy friction factor for triangular cross-section:

$$\lambda_{tria} = \lambda_{circ} \cdot k_{non-c}$$ ([1] diagram 2.8)

Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \lambda_{tria} \cdot \frac{l}{D_h}$$ ([1] diagram 2.8)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$ ([1] diagram 2.8)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

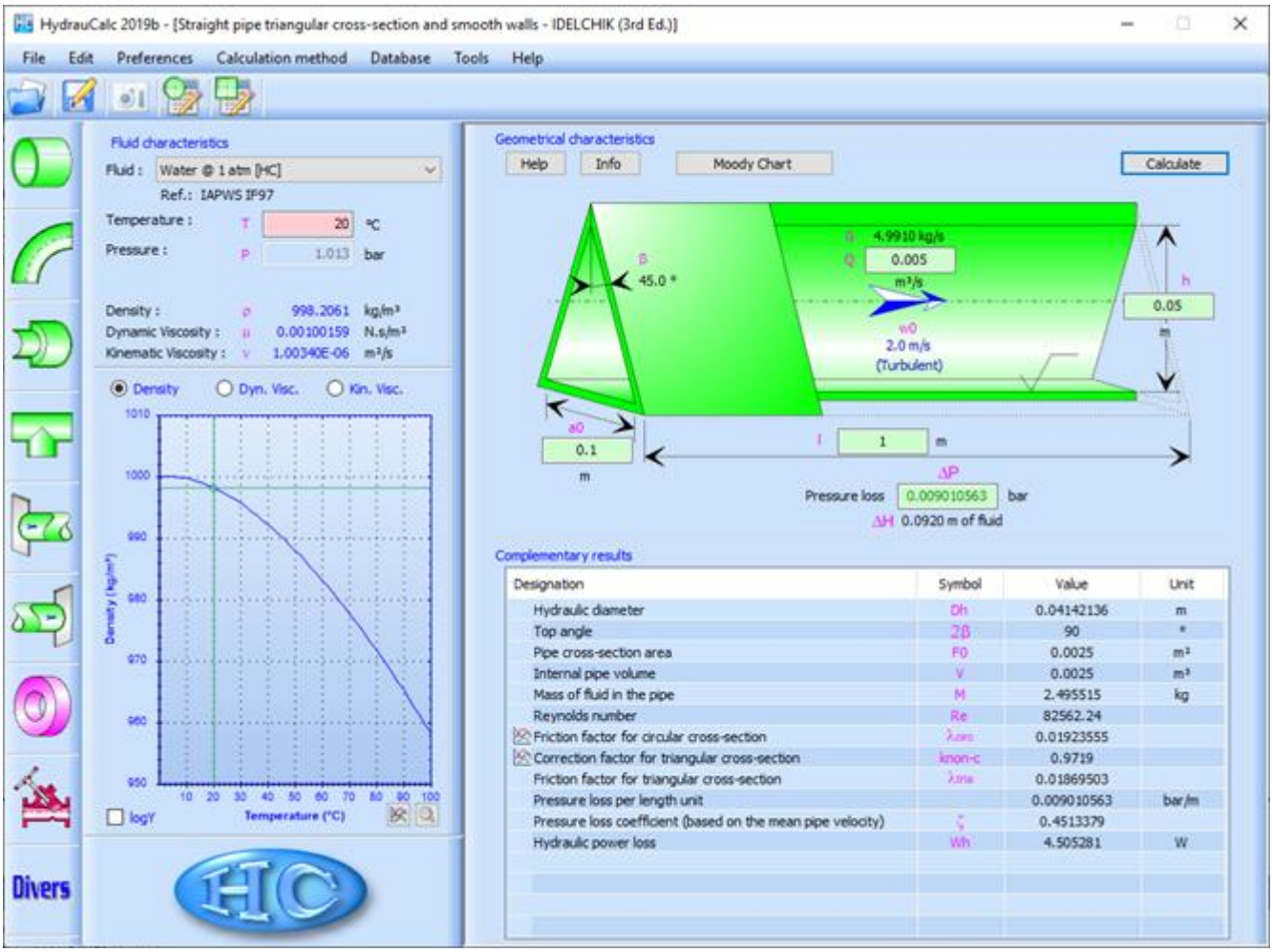
Symbols, Definitions, SI Units:

a_0	Cross-section base (m)
h	Cross-section height(m)
β	Half top angle (°)
D_h	Hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
l	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
λ_{circ}	Darcy friction factor for circular cross-section ()
k_{non-c}	Correction for Darcy friction factor for noncircular cross-section ()
λ_{tria}	Darcy friction factor for triangular cross-section ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
- stabilized flow

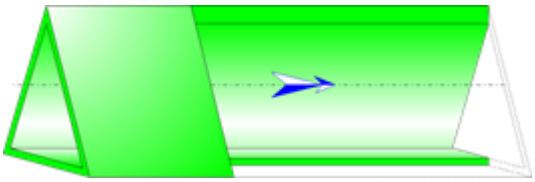
Example of input data and results:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.3.4 IDELCHIK (explicit Darcy friction factor)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of triangular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula.

In this model Darcy friction factor is filled explicitly.

Model formulation:

Top angle (°):

$$\beta = \tan^{-1}\left(\frac{a_0}{2 \cdot h}\right)$$

Hydraulic diameter (m):

$$D_h = \frac{2 \cdot h}{1 + \sqrt{\frac{1}{\tan^2(\beta)} + 1}}$$

Cross-section area (m²):

$$F_0 = \frac{a_0}{2} \cdot h$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

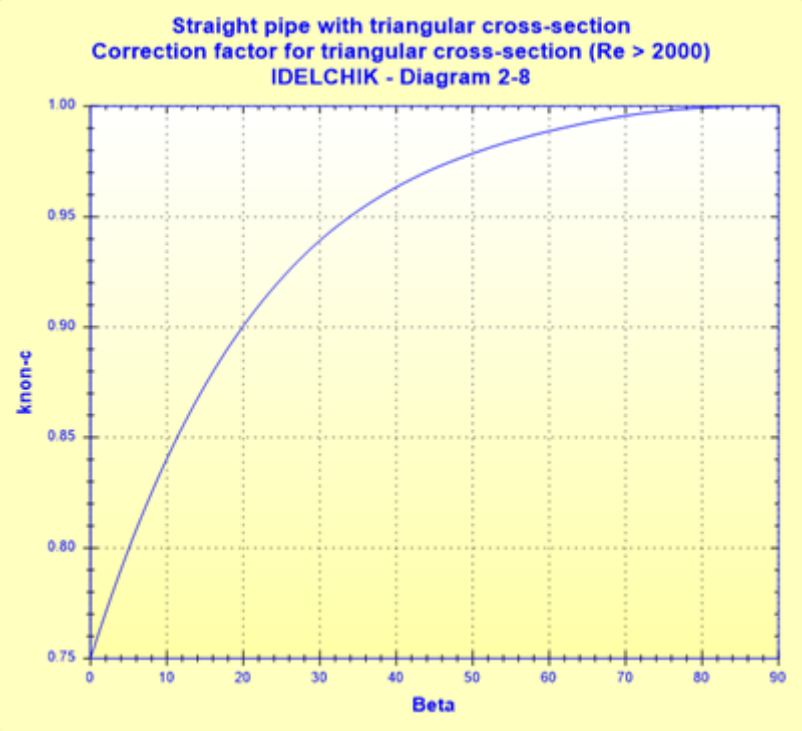
$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Correction for Darcy friction factor for triangular cross-section:

$$k_{non-c} = f(\beta)$$ ([1] diagram 2.8)



Darcy friction factor for triangular cross-section:

$$\lambda_{tria} = \lambda_{circ} \cdot k_{non-c}$$ ([1] diagram 2.8)

Pressure loss coefficient (based on the mean pipe velocity):

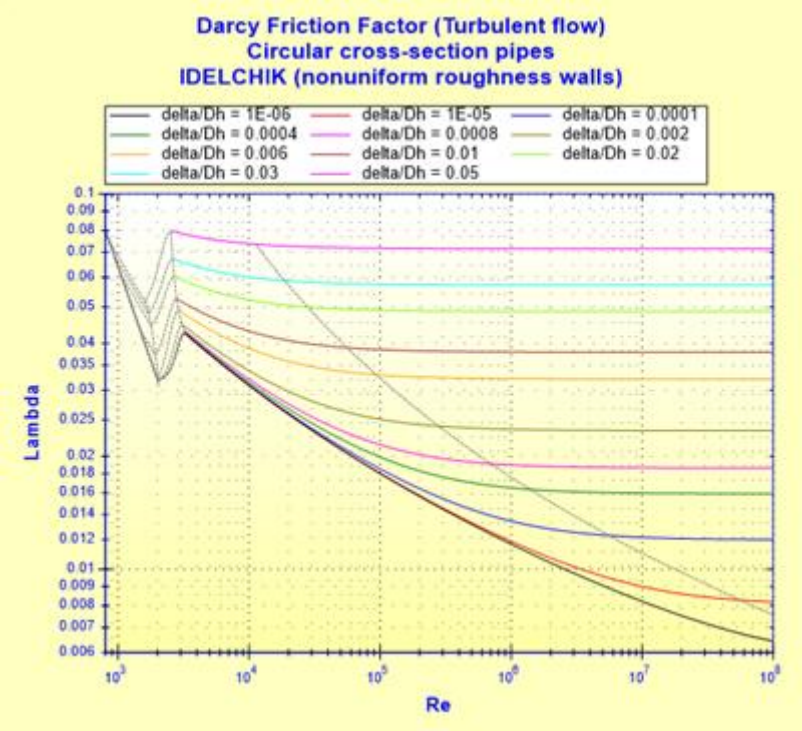
$$\zeta = \lambda_{tria} \cdot \frac{l}{D_h}$$ ([1] diagram 2.8)

Equivalent relative roughness (turbulent regime - Re ≥ 4000):

Colebrook-White equation

$$\lambda_{circ} = \frac{1}{\left[2 \cdot \log\left(\frac{2.51}{Re \cdot \sqrt{\lambda_{circ}}} + \frac{\overline{\Delta}}{3.7}\right)\right]^2}$$ ([1] diagram 2.4)

where $\overline{\Delta}$ is calculated by solving the equation.



Equivalent absolute roughness (m):

$$\Delta = \overline{\Delta} \cdot D_h$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

([1] diagram 2.8)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

a_0	Cross-section base (m)
h	Cross-section height(m)

β□□□□□□□□□□□□□□ Top angle (°)

D_h Hydraulic diameter (m)

F_0 Cross-sectional area (m²)

Q Volume flow rate (m³/s)

w_0 Mean velocity (m/s)

G Mass flow rate (kg/s)

l Pipe length (m)

V Fluid volume in the pipe (m³)

M Fluid mass in the pipe (kg)

Re Reynolds number ()

k_{non-c} Correction for Darcy friction factor for noncircular cross-section ()

λ_{circ} Darcy friction factor for circular cross-section ()

λ_{tria} Darcy friction factor for triangular cross-section ()

ζ Pressure loss coefficient (based on the mean pipe velocity) ()

$\bar{\Delta}$ Equivalent relative roughness of walls ()

Δ Equivalent absolute roughness of walls (m)

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

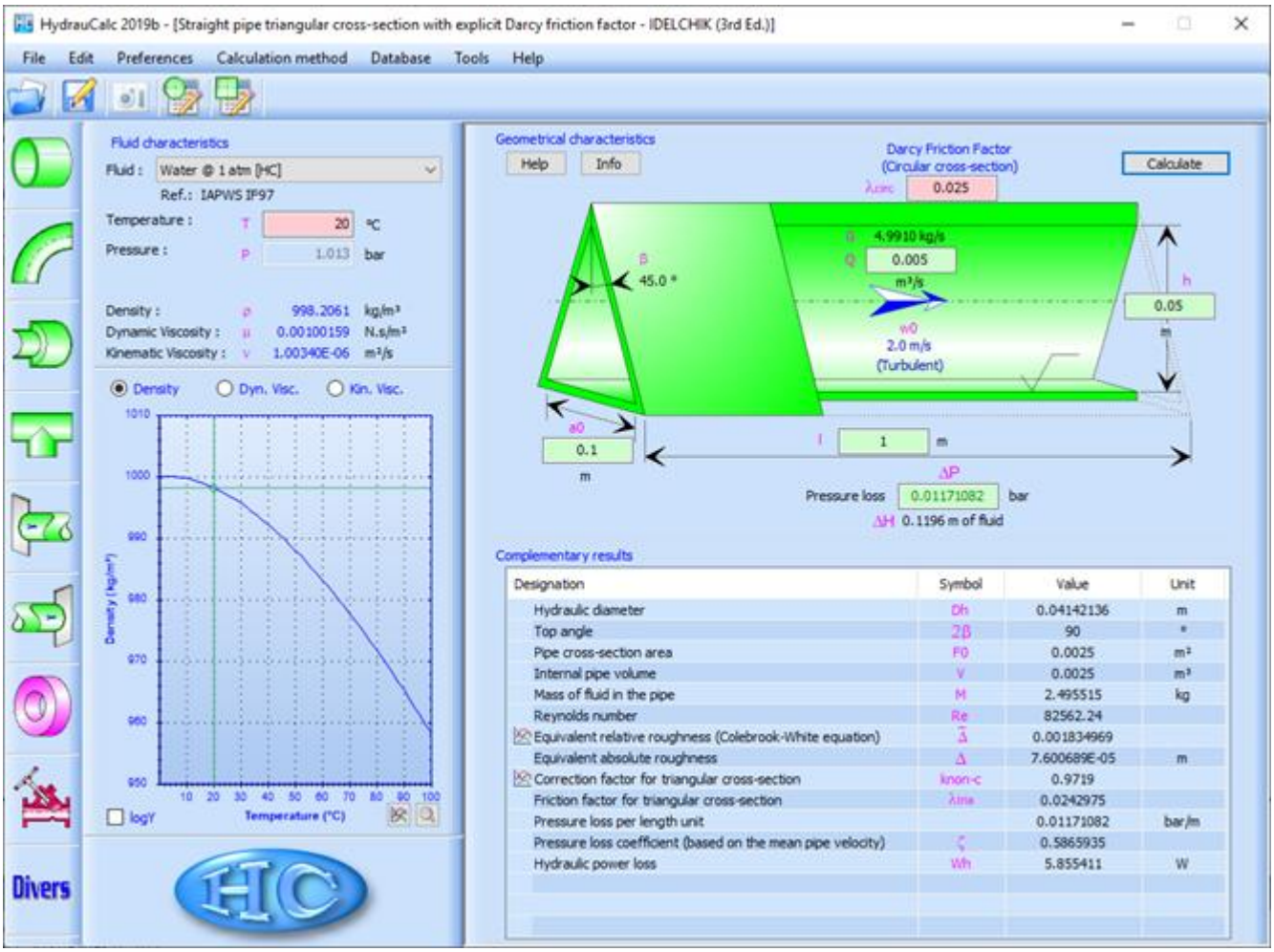
g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($4 \cdot 10^3 \leq Re \leq 10^8$)
- Darcy friction factor for circular cross-section $\lambda_{circ} < 0.1$

- stabilized flow

Example of input data and results:



References:

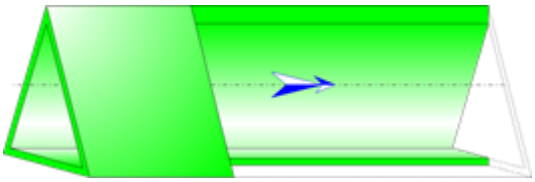
[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.3.5 MILLER (roughness walls)

Straight Pipe

Triangular Cross-Section and Roughness Walls

(MILLER)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of triangular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula.

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille (independent of the value of relative roughness),
- for turbulent flow regime by the explicit Swamee-Jain equation (dependent of the value of relative roughness), the explicit Swamee-Jain equation is a Colebrook-White equation approximation,
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Top angle (°):

$$\theta = 2 \cdot \tan^{-1}\left(\frac{W}{2 \cdot h}\right)$$

Hydraulic diameter (m):

$$D = \frac{2 \cdot h}{1 + \sqrt{\frac{1}{\tan^2\left(\frac{\theta}{2}\right)} + 1}}$$

Cross-section area (m^2):

$$A = \frac{W}{2} \cdot h$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$m = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = A \cdot L$$

Fluid mass in the pipe (kg):

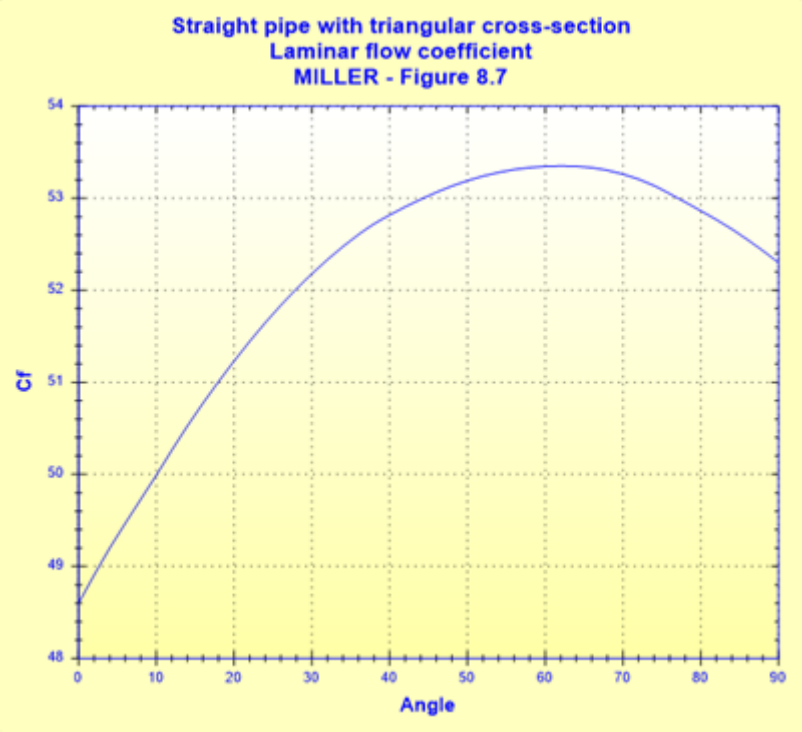
$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

Laminar flow coefficient:

$$Cf = f(\theta)$$ ([1] figure 8.7)

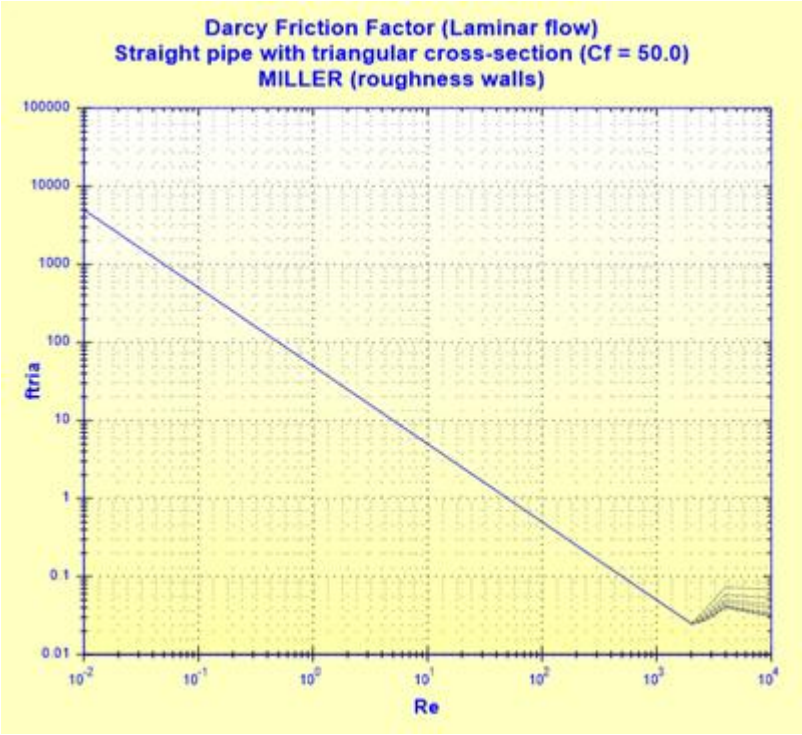


Darcy friction factor:

- laminar flow regime (Re ≤ 2000):

  Darcy friction factor for triangular cross-section:

  $$f_{tria} = \frac{Cf}{Re}$$ ([1] equation 8.7)



([1] equation 8.7with Cf = 50)

■ turbulent flow regime – transition region and complete turbulence region (Re ≥ 4000):

Darcy friction factor for circular cross-section:

Swamee-Jain equation (Colebrook-White equation approximation)

$$f_{clc} = \frac{0.25}{\left[\log\left(\frac{k}{3.7 \cdot D} + \frac{5.74}{\mathrm{Re}^{0.9}}\right)\right]^2}$$

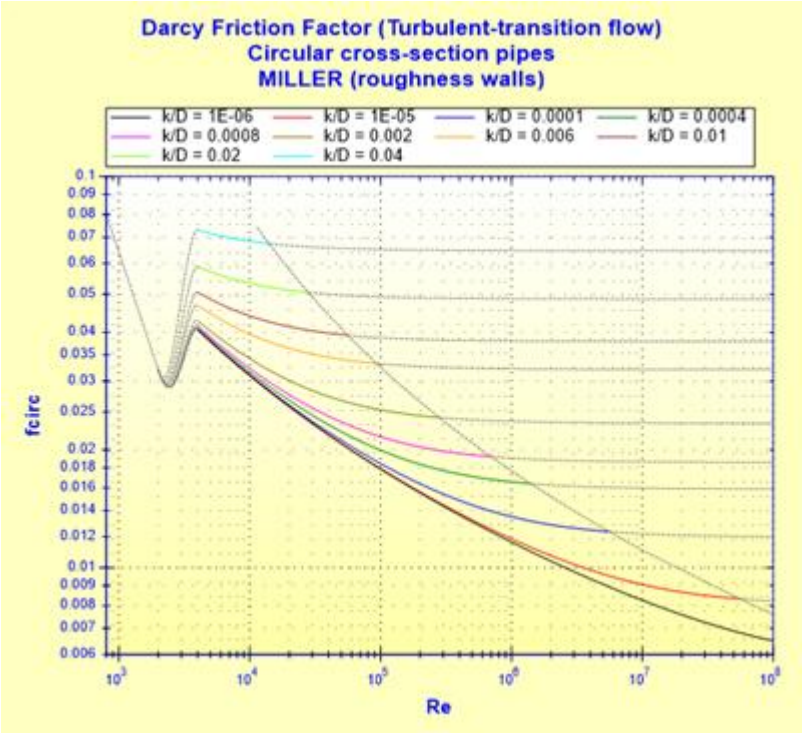
([1] equation 8.4)

Reynolds number corresponding to the beginning of complete turbulence:

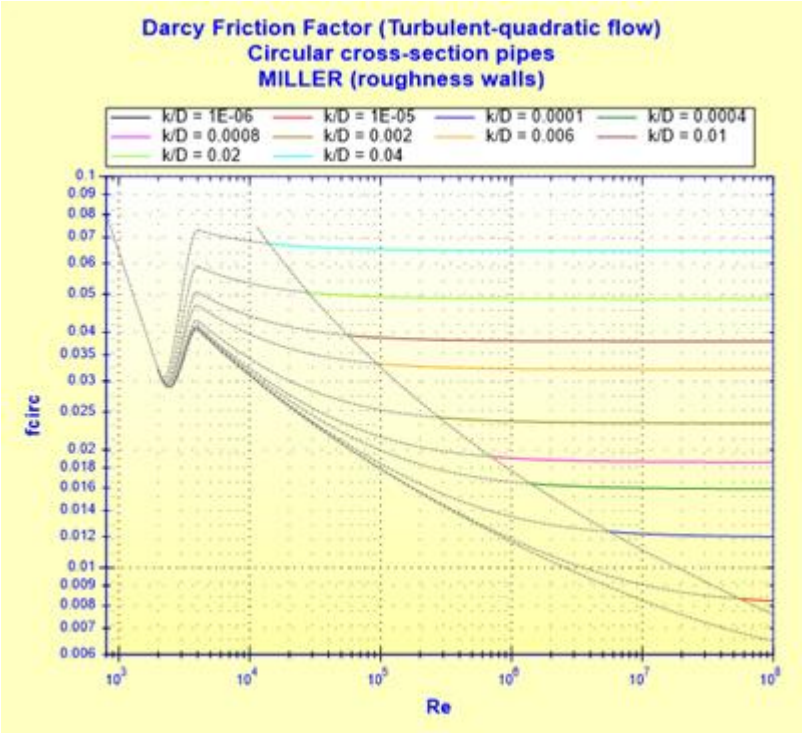
$$\mathrm{Re''}_{lim} = \frac{560}{k/D}$$

([2] diagram 2.4)

Transition region



Complete turbulence region



Darcy friction factor for triangular cross-section:

$$f_{tria} = f_{circ}$$

■ critical flow regime ($2000 < Re < 4000$):

Darcy friction factor for circular cross-section:

cubic interpolation

$$f_{circ} = (X1 + R \cdot (X2 + R \cdot (X3 + X4)))$$ ([3])

with:

$$R = \frac{Re}{2000}$$

$$X1 = 7 \cdot FA - FB$$

$$X2 = 0.128 - 17 \cdot FA + 2.5 \cdot FB$$

$$X3 = -0.128 + 13 \cdot FA - 2 \cdot FB$$

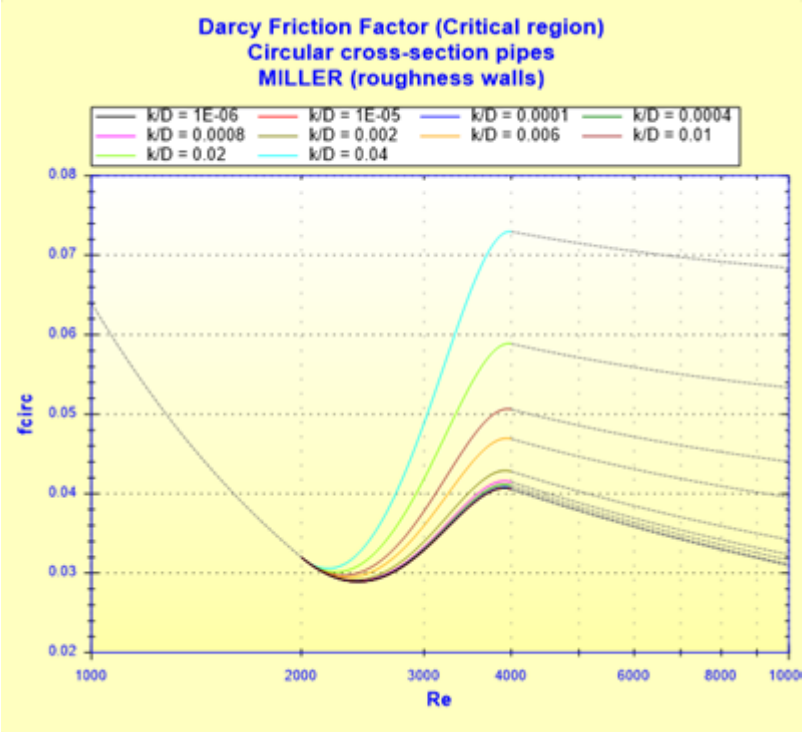
$$X4 = R \cdot (0.032 - 3 \cdot FA + 0.5 \cdot FB)$$

$$FA = Y3^{-2}$$

$$FB = FA \cdot \left(2 - \frac{0.00514215}{Y2 \cdot Y3}\right)$$

$$Y2 = \frac{k}{3.7 \cdot D} + \frac{5.74}{Re^{0.9}}$$

$$Y3 = -0.86859 \cdot ln\left(\frac{k}{3.7 \cdot D} + \frac{5.74}{4000^{0.9}}\right)$$



Darcy friction factor for triangular cross-section:

$$f_{tria} = f_{circ}$$

Friction pressure loss coefficient:

$$K_f = f_{tria} \cdot \frac{L}{D}$$ ([1] equation 8.3)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_f$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

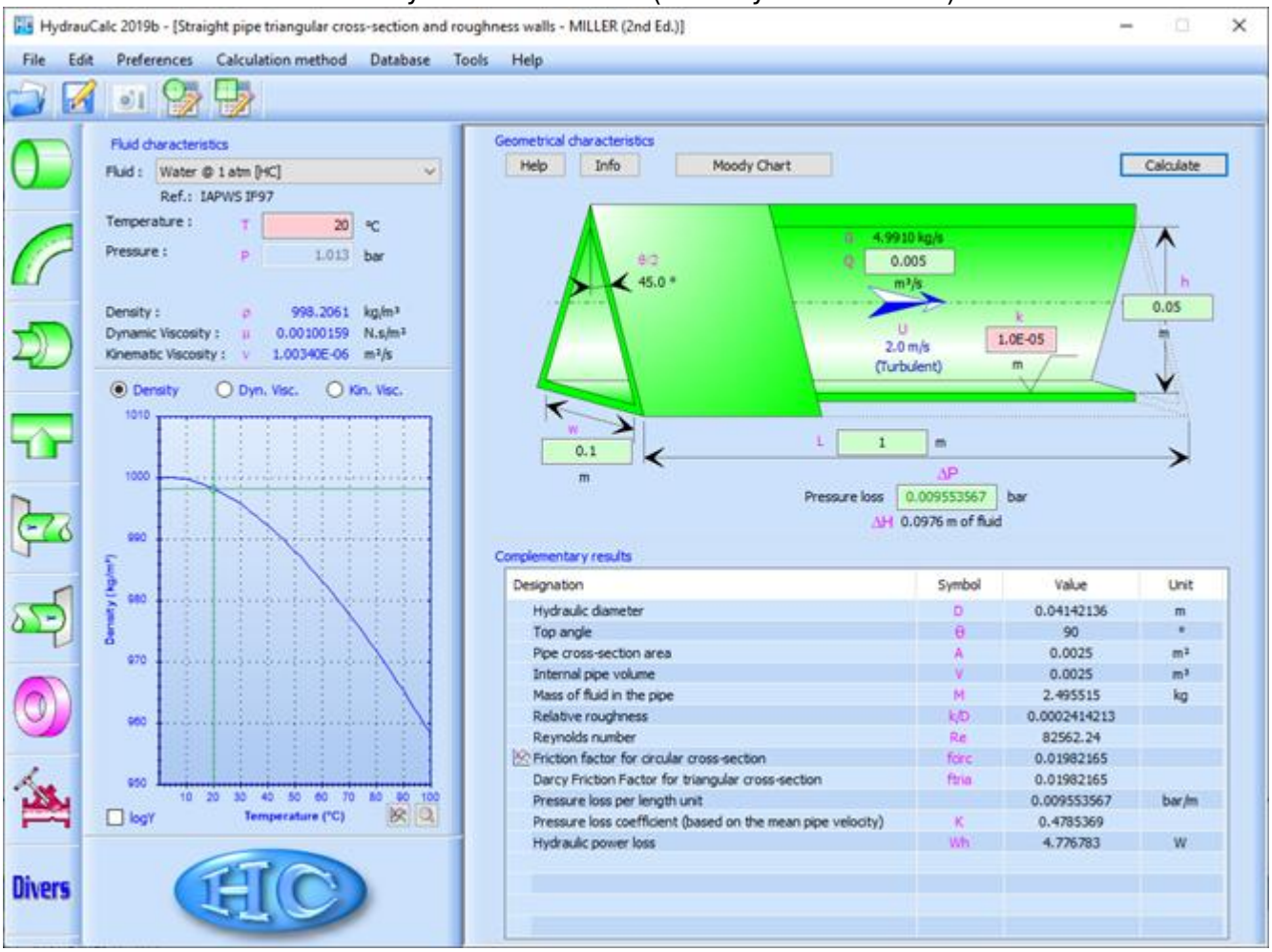
w	Cross-section base (m)
h	Cross-section height(m)
θ□□□□□□□□□□□□□□□	Top angle (°)
D	Hydraulic diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
m	Mass flow rate (kg/s)
L	Pipe length (m)

V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
Cf	Laminar flow coefficient ()
k	Absolute roughness of walls (m)
f_{circ}	Darcy friction factor for circular cross-section ()
Re''_{lim}	Reynolds number corresponding to the beginning of complete turbulence ()
f_{tria}	Darcy friction factor for triangular cross-section ()
K_f	Friction pressure loss coefficient ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
- relative roughness $k/D \leq 0.05$
- stabilized flow

Example of application:



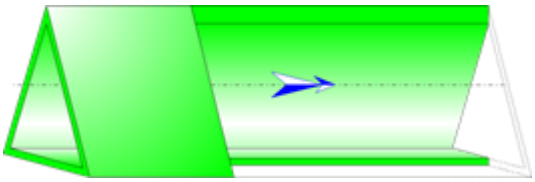
References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

[2] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

[3] Dunlop (1991)

2.1.3.6 MILLER (explicit Darcy friction factor)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of triangular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula.

In this model Darcy friction factor is filled explicitly.

Model formulation:

Top angle (°):

$$\theta = 2 \cdot \tan^{-1}\left(\frac{W}{2 \cdot h}\right)$$

Hydraulic diameter (m):

$$D = \frac{2 \cdot h}{1 + \sqrt{\frac{1}{\tan^2\left(\frac{\theta}{2}\right)} + 1}}$$

Cross-section area (m^2):

$$A = \frac{w}{2} \cdot h$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$m = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = A \cdot L$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

Darcy friction factor for triangular cross-section:

$$f_{tria} = f_{circ}$$

Friction pressure loss coefficient:

$$K_f = f_{tria} \cdot \frac{L}{D}$$ ([1] equation 8.3)

Total pressure loss coefficient (based on the mean pipe velocity):

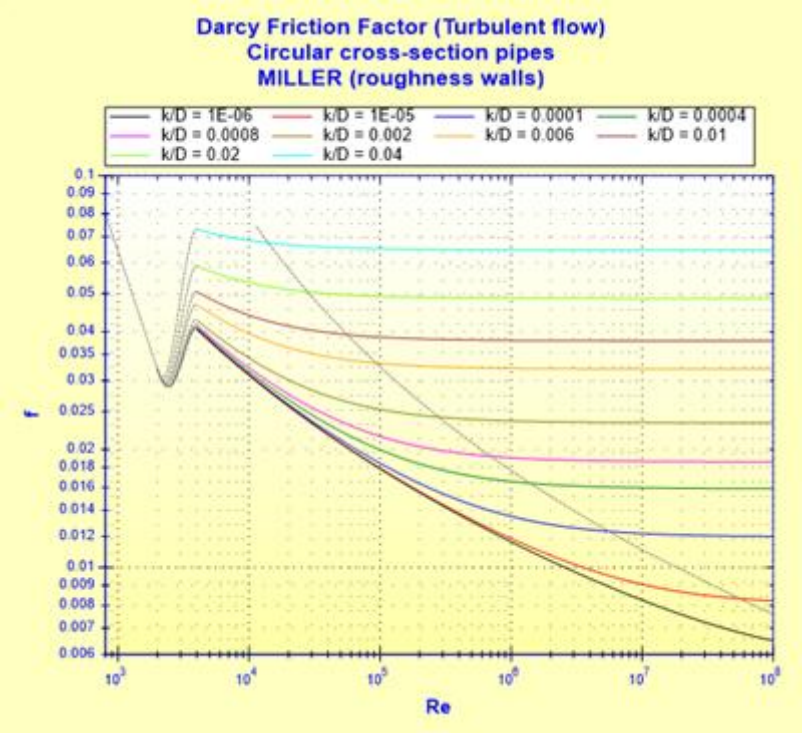
$$K = K_f$$

Equivalent absolute roughness for circular cross-section pipe (turbulent regime - Re ≥ 4000):

Swamee-Jain equation (Colebrook-White equation approximation)

$$f_{circ} = \frac{0.25}{\left[\log\left(\frac{k}{3.7 \cdot D} + \frac{5.74}{Re^{0.9}}\right)\right]^2}$$ ([1] equation 8.4)

where k is calculated by solving the equation.



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

θ□□□□□□□□□□□□□□□ Top angle (°)

w Cross-section base (m)

h Cross-section height(m)

D Hydraulic diameter (m)

A Cross-section area (m^2)

Q Volume flow rate (m^3/s)

m Mass flow rate (kg/s)

U Mean velocity (m/s)

L Pipe length (m)

V Fluid volume in the pipe (m^3)

M Fluid mass in the pipe (kg)

Re Reynolds number ()

f_{circ} Darcy friction factor for circular cross-section ()

f_{tria} Darcy friction factor for triangular cross-section ()

K_f Friction pressure loss coefficient ()

K Total pressure loss coefficient (based on the mean pipe velocity) ()

k Equivalent absolute roughness of walls (m)

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

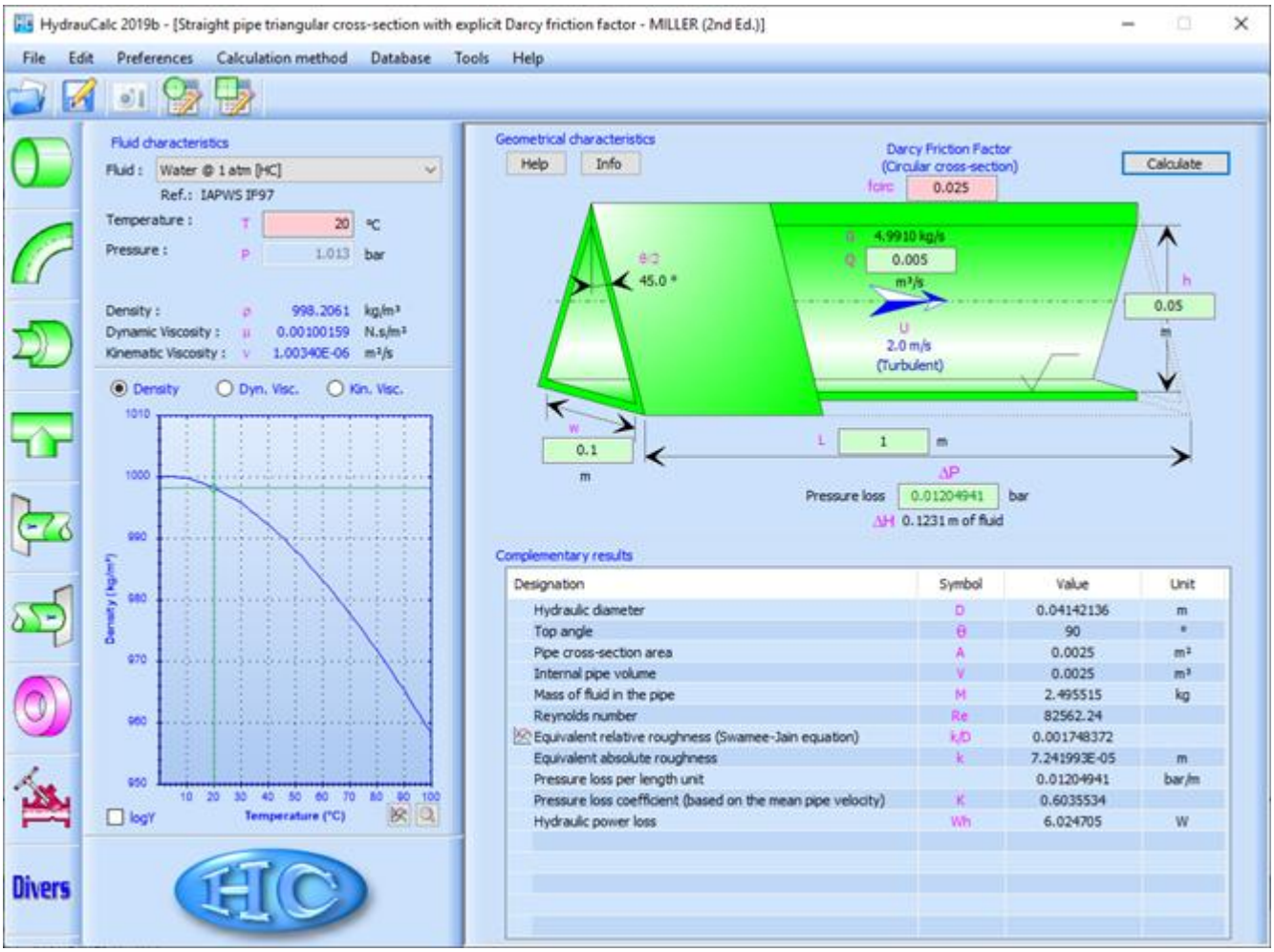
g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($4 \cdot 10^3 \leq Re \leq 10^8$)

- Darcy friction factor for circular cross-section $f_{circ} < 0.1$
- stabilized flow

Example of application:



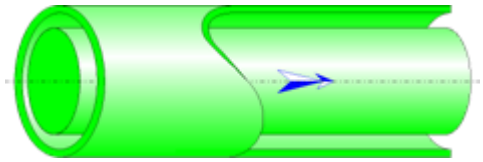
References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

2.1.4 Straight pipe - Annular cross-section

Straight Pipe

Annular Cross-section



To calculate the pressure losses by friction in straight pipes, Darcy Weisbach's equation is used.

For the calculation of the friction factor, the user can choose from one of the 4 available relationships, depending on the roughness of the inner walls:

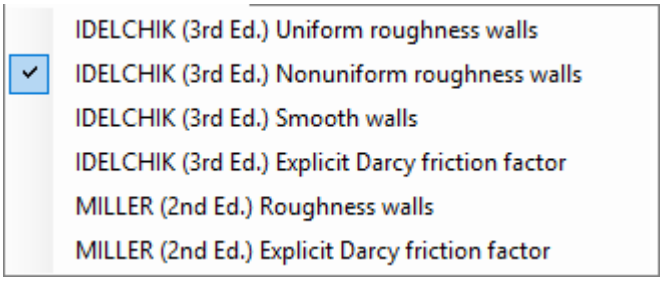
- Homogeneous roughness piping (uniform roughness - pipe used by Nikuradse for its experimental data) - Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Heterogeneous roughness piping (industrial type piping) - Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipes with smooth walls - Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipes with roughness walls - Internal Flow System, 2nd Edition, D.S. Miller

It is also possible to explicitly specify the value of the friction factor. This is available in case you are looking for results with another formulation of the friction factor (Haaland equation for example). The friction factor is available for the following references:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "Pipes with nonuniform roughness"

Calculation method

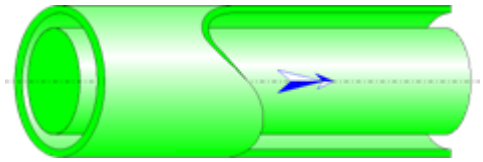


2.1.4.1 IDELCHIK (uniform roughness walls)

Straight Pipe

Annular Cross-Section and Uniform Roughness Walls

(IDELCHIK)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of annular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula. The roughness of the inner walls of the pipe is supposed uniform (pipe used by Nikuradse for its experimental data).

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille (independent of the value of relative roughness),
- for turbulent flow regime by the Nikuradse equation (dependent of the value of relative roughness),
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0 - d$$

Cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2 - d^2}{4}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\bar{\Delta} = \frac{\Delta}{D_h}$$

Relative eccentricity:

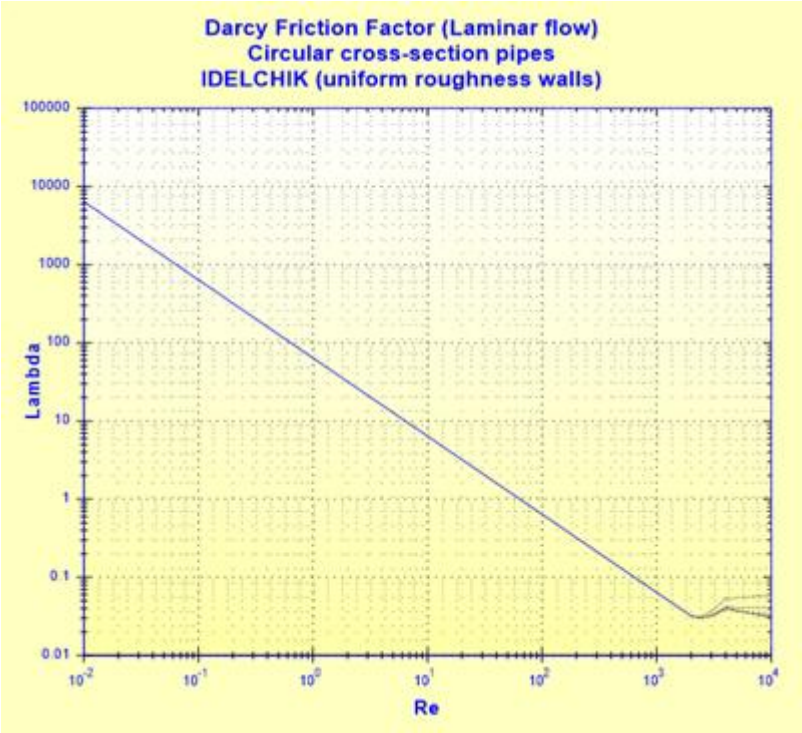
$$\bar{e} = \frac{2 \cdot e}{D_0 - d}$$

Darcy friction factor for circular cross-section:

- laminar flow regime (Re ≤ 2000):

  Hagen-Poiseuille law

  $$\lambda_{circ} = \frac{64}{Re}$$ ([1] diagram 2.1)



- turbulent flow regime – transition region and complete turbulence region (Re ≥ 4000):

  Nikuradse equation

  $$\lambda_{circ} = \frac{1}{\left[a_1 + b_1 \cdot \log(Re \cdot \sqrt{\lambda}) + c_1 \cdot \log(\overline{\Delta})\right]^2}$$ ([1] diagram 2.2)

  where the values of a_1, b_1 and c_1 are given below:

$\overline{\Delta} \cdot Re \cdot \sqrt{\lambda}$	a_1	b_1	c_1
3.6 - 10	-0.800	2.000	0.000
10 - 20	0.068	1.130	-0.870
20 - 40	1.538	0.000	-2.000
40 - 191.2	2.471	-0.588	-2.588
> 191.2	1.138	0.000	-2.000

Reynolds number at which pipe cease to be hydraulically smooth:

$$Re'_{lim} = \frac{26.9}{\overline{\Delta}^{1.143}}$$

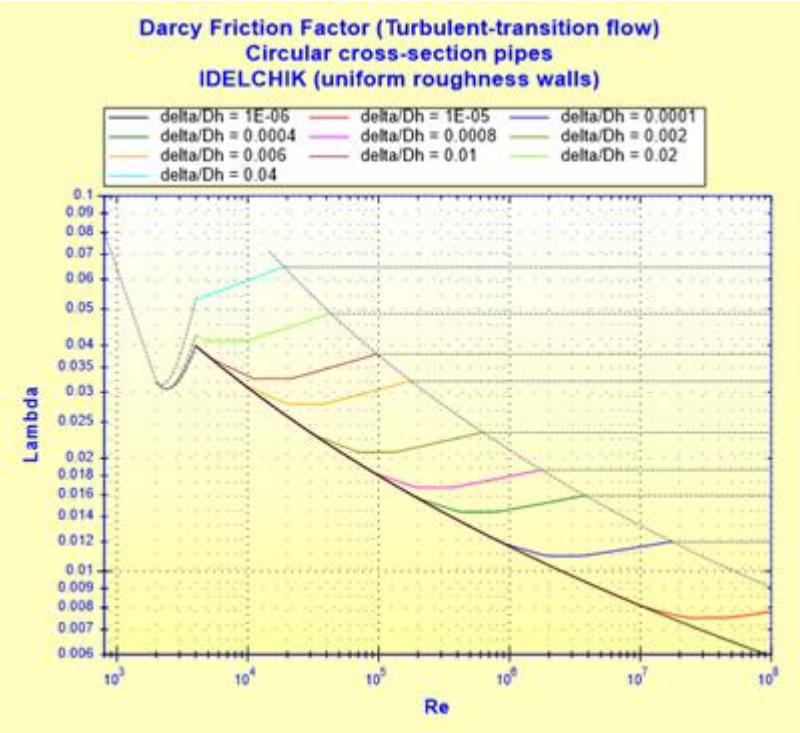
([1] §2.17)

Reynolds number corresponding to the beginning of complete turbulence:

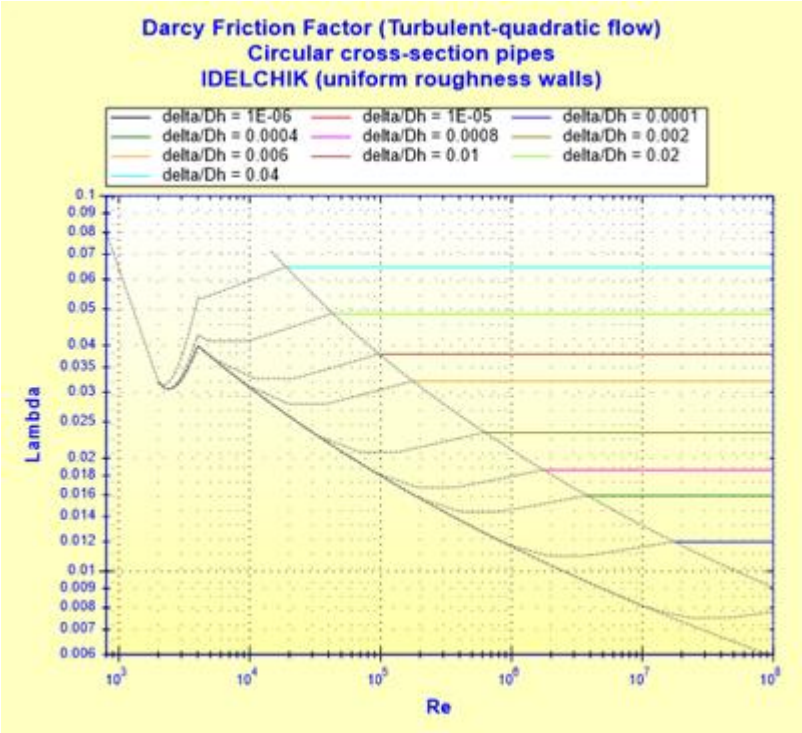
$$Re''_{lim} = \frac{217.6 - 382.4 \cdot \log(\overline{\Delta})}{\overline{\Delta}}$$

([1] diagram 2.2)

Transition region



Complete turbulence region



■ critical flow regime (2000 < Re < 4000):

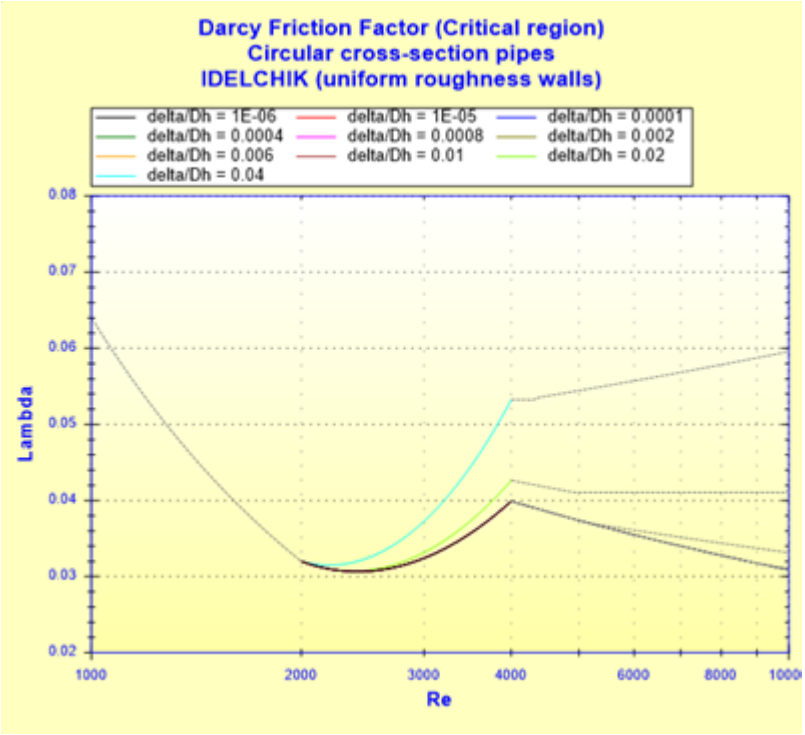
linear interpolation

$$\lambda_{circ} = \lambda_L \cdot \left(1 - \frac{Re - 2000}{2000}\right) + \lambda_T \cdot \left(\frac{Re - 2000}{2000}\right)$$

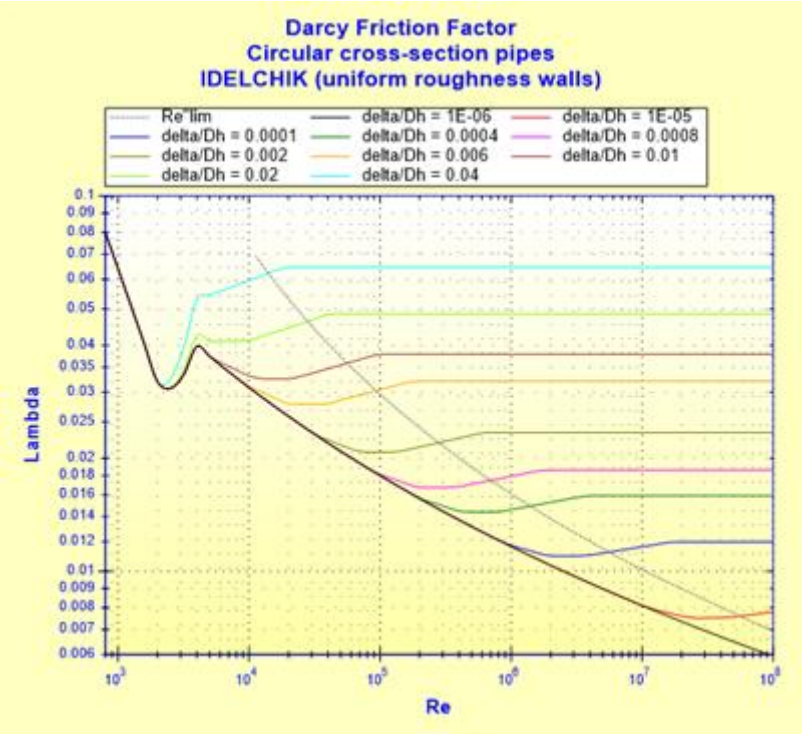
with:

λ_L = laminar friction coefficient obtained with Re = 2000

λ_T = turbulent friction coefficient obtained with Re = 4000



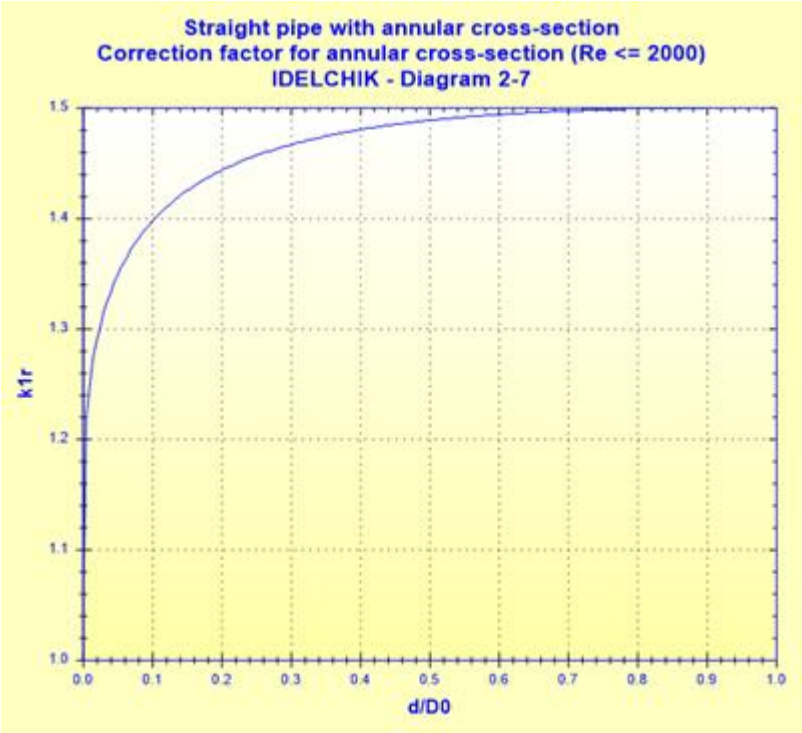
■ all flow regimes:



Correction for Darcy friction factor for annular cross-section:

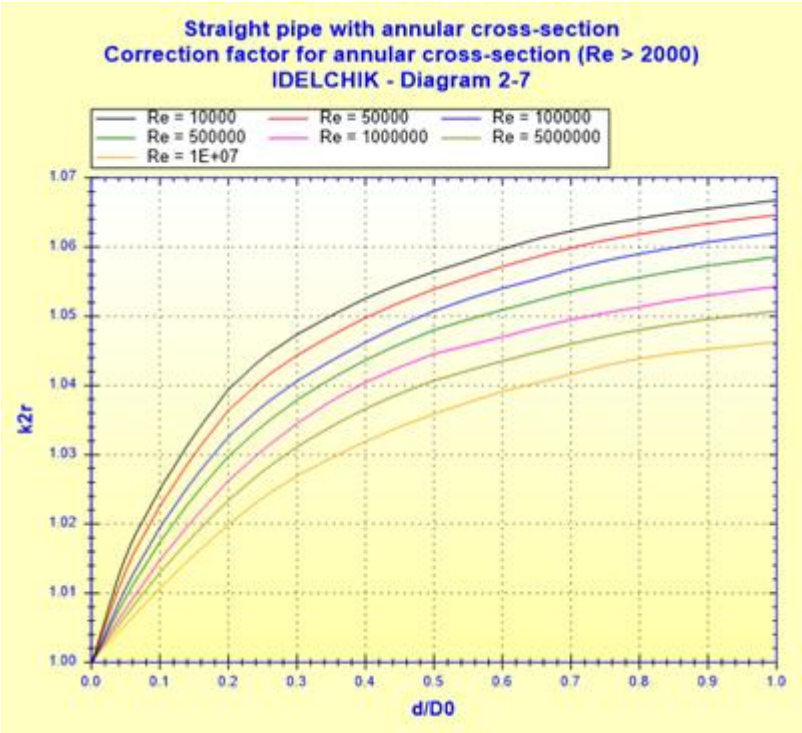
■ laminar flow (Re ≤ 2000):

$$k_{tr} = f(d/D_0)$$ ([1] diagram 2.7)



- turbulent flow (Re > 2000):

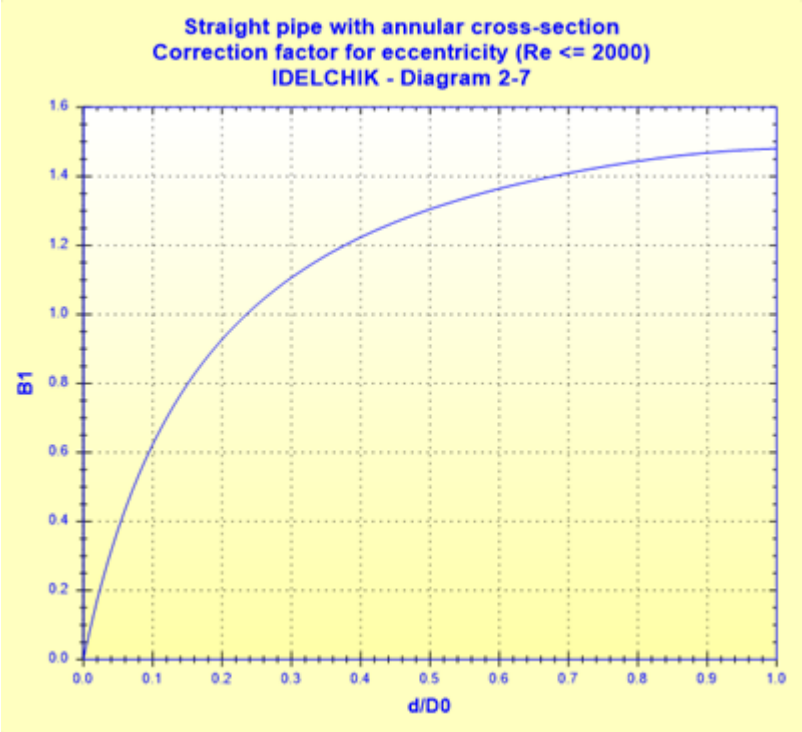
$$k_{2r} = f(d/D_0, \mathrm{Re})$$ ([1] diagram 2.7)



Correction for Darcy friction factor for axis eccentricity:

- laminar flow (Re ≤ 2000):

$B_1 = f(d/D_0)$ ([1] diagram 2.7)



■ turbulent flow (Re > 2000):

$k'_{ell} = f(\bar{e}, d/D_0)$ ([1] diagram 2.7)

Darcy friction factor for annular cross-section:

- laminar flow (Re ≤ 2000):

$$\lambda_{annu} = \lambda_{circ} \cdot k_{1r} \cdot B_1$$

- turbulent flow (Re > 2000):

$$\lambda_{annu} = \lambda_{circ} \cdot k_{2r} \cdot k'_{ell}$$

Total correction for Darcy friction factor for noncircular cross-section:

- laminar flow (Re ≤ 2000):

$$k_{non-c} = k_{1r} \cdot B_1$$

- turbulent flow (Re > 2000):

$$k_{non-c} = k_{2r} \cdot k'_{ell}$$

Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \lambda_{circ} \cdot k_{non-c} \cdot \frac{l}{D_h}$$ ([1] diagram 2.7)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$ ([1] diagram 2.7)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_0 Annulus outer diameter (m)

d	Annulus inner diameter (m)
D_h	Hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
l	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()
e	Pipes eccentricity (m)
$\bar{e}$	Relative eccentricity ()
λ_{circ}	Darcy friction factor for circular cross-section ()
Re'_{lim}	Limiting Reynolds number for hydraulically smooth law ()
Re''_{lim}	Limiting Reynolds number for quadratic law ()
K_{1r}	Correction for noncircular cross-section (laminar regime) ()
K_{2r}	Correction for noncircular cross-section (turbulent regime) ()
B_1	Correction for eccentricity (laminar regime) ()
K'_{ell}	Correction for eccentricity (turbulent regime) ()
λ_{annu}	Darcy friction factor for annular cross-section ()
k_{non-c}	Correction for Darcy friction factor for noncircular cross-section ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)

ρ Fluid density (kg/m³)

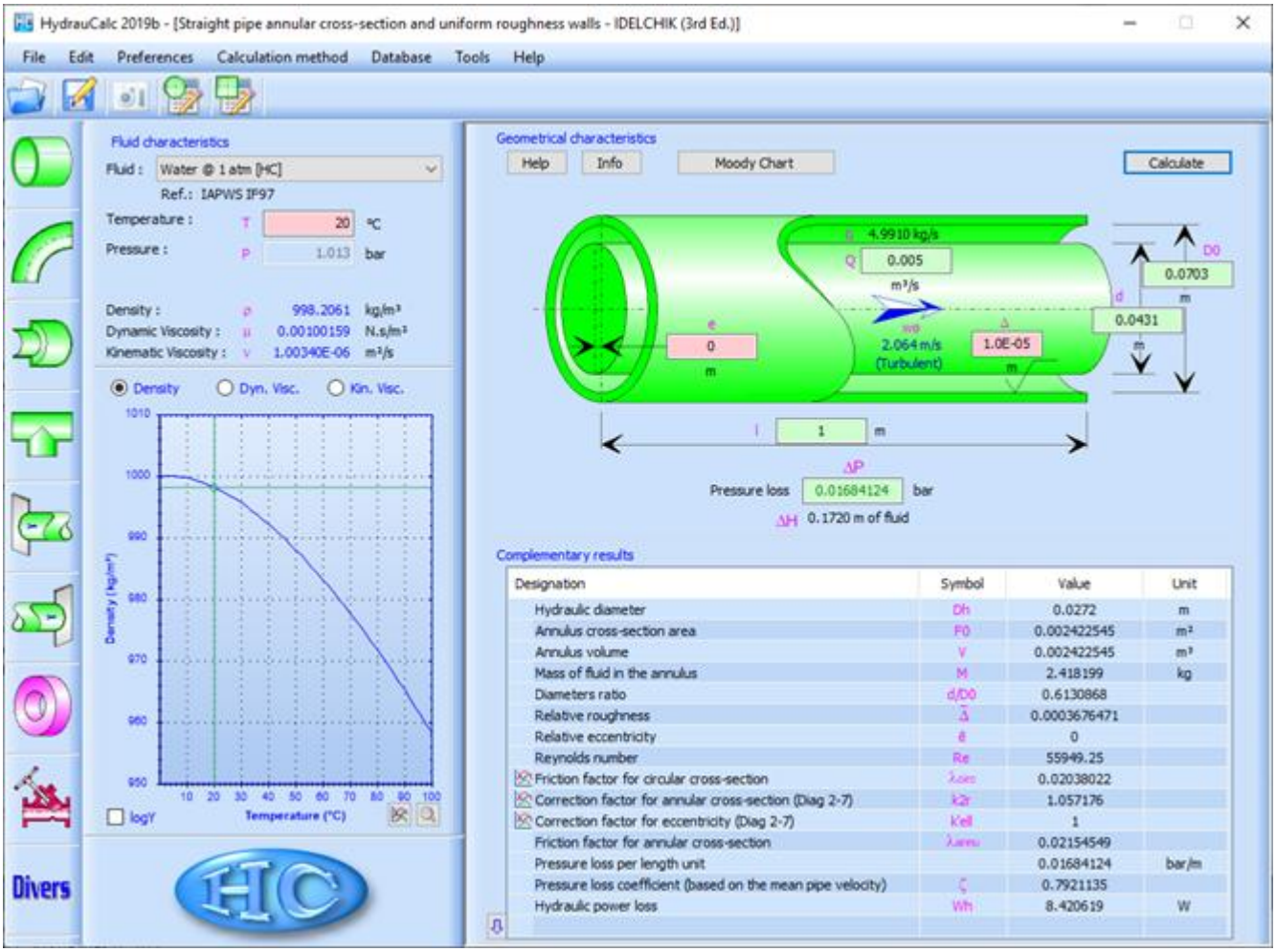
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
  note: for Reynolds number lower than 10^4 or greater than 10^7, the correction factor 'k2r' is extrapolated
- relative roughness $\overline{\Delta} \leq 0.05$
- stabilized flow

Example of input data and results:



References:

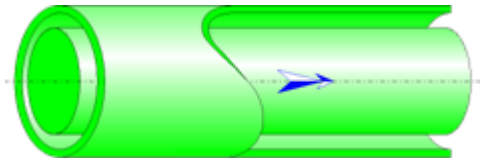
[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.4.2 IDELCHIK (nonuniform roughness walls)

Straight Pipe

Annular Cross-Section and Nonuniform Roughness Walls

(IDELCHIK)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of annular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula. The roughness of the inner walls of the pipe is supposed nonuniform (commercial pipe).

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille (independent of the value of relative roughness),
- for turbulent flow regime by the implicit Colebrook-White equation (dependent of the value of relative roughness),
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0 - d$$

Cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2 - d^2}{4}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\bar{\Delta} = \frac{\Delta}{D_h}$$

Relative eccentricity:

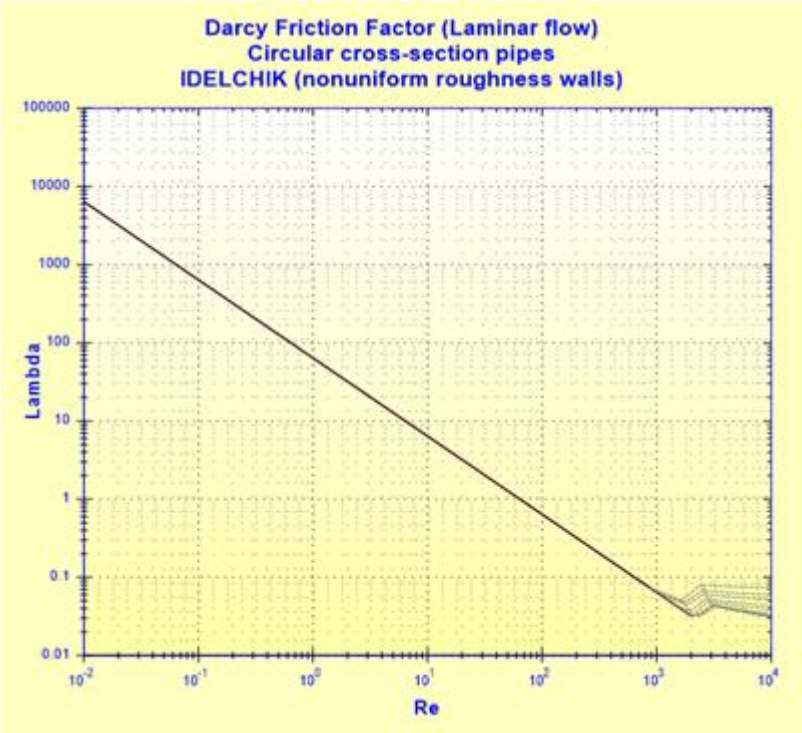
$$\bar{e} = \frac{2 \cdot e}{D_0 - d}$$

Darcy friction factor for circular cross-section:

- laminar flow regime ($Re \leq Re_0$):

  Hagen-Poiseuille law

  $$\lambda_{circ} = \frac{64}{Re}$$ ([1] diagram 2.1)



- turbulent flow regime – transition region and complete turbulence region ($Re \geq Re_2$):

  Colebrook-White equation

  $$\lambda_{circ} = \frac{1}{\left[2 \cdot \log\left(\frac{2.51}{Re \cdot \sqrt{\lambda}} + \frac{\overline{\Delta}}{3.7}\right)\right]^2}$$ ([1] diagram 2.4)

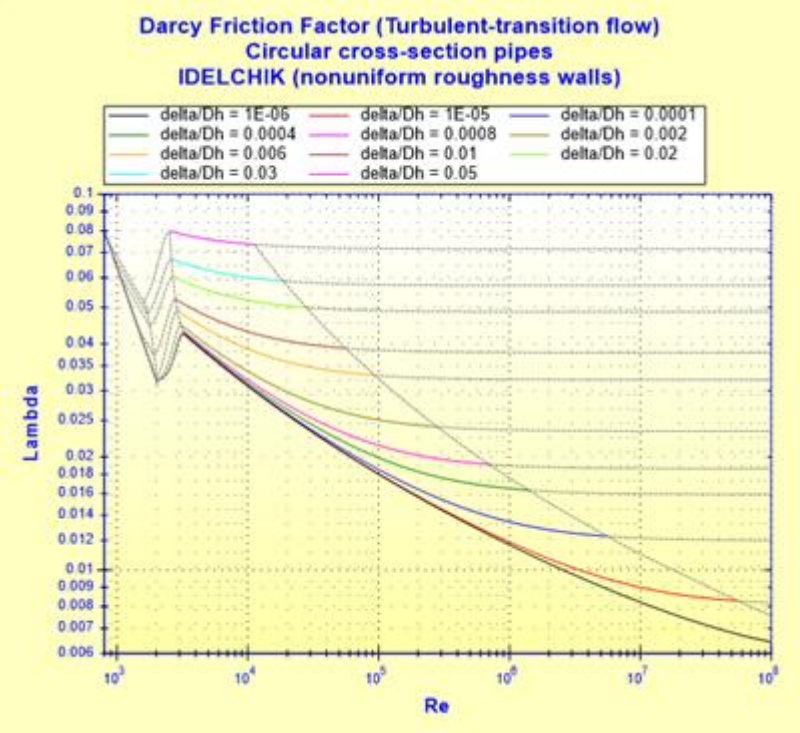
  Reynolds number at which pipe cease to be hydraulically smooth:

  $$Re'_{lim} = \frac{15}{\overline{\Delta}}$$ ([1] §2.23)

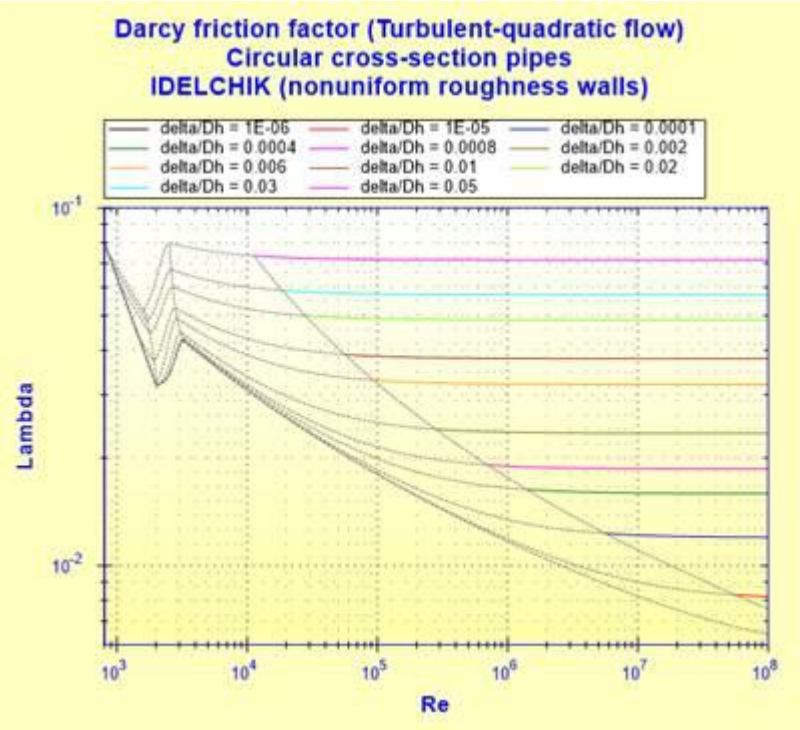
  Reynolds number corresponding to the beginning of complete turbulence:

  $$Re''_{lim} = \frac{560}{\overline{\Delta}}$$ ([1] diagram 2.4)

Transition region



Complete turbulence region



■ critical flow regime ($Re_0 < Re < Re_2$):

$$\lambda_{circ} = f(Re, \overline{\Delta})$$ ([1] diagram 2.3)

Reynolds number of start of critical zone:

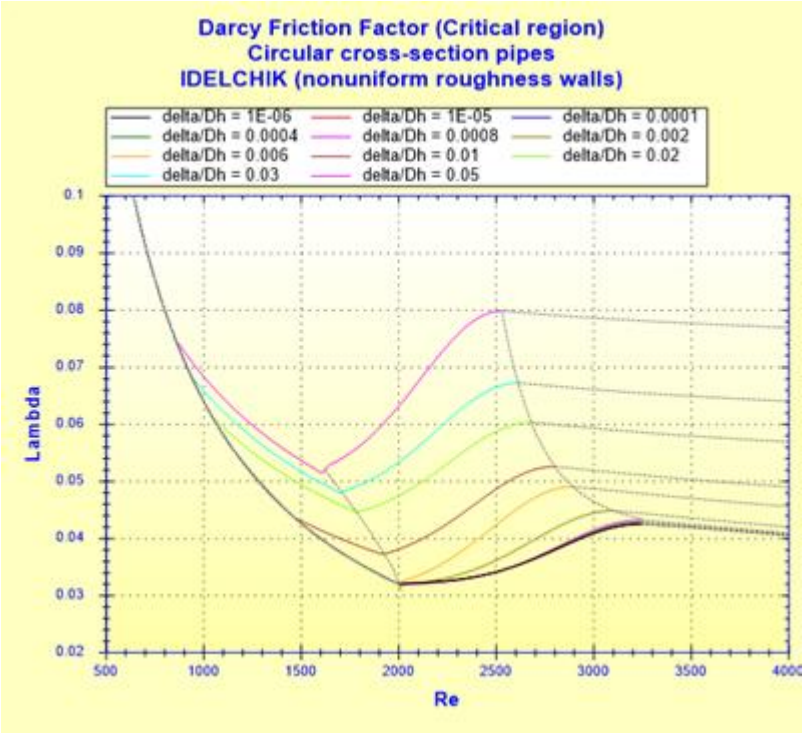
$$Re_0 = 754 \exp\left(\frac{0.0065}{\bar{\Delta}}\right)$$

([1] §2.21)

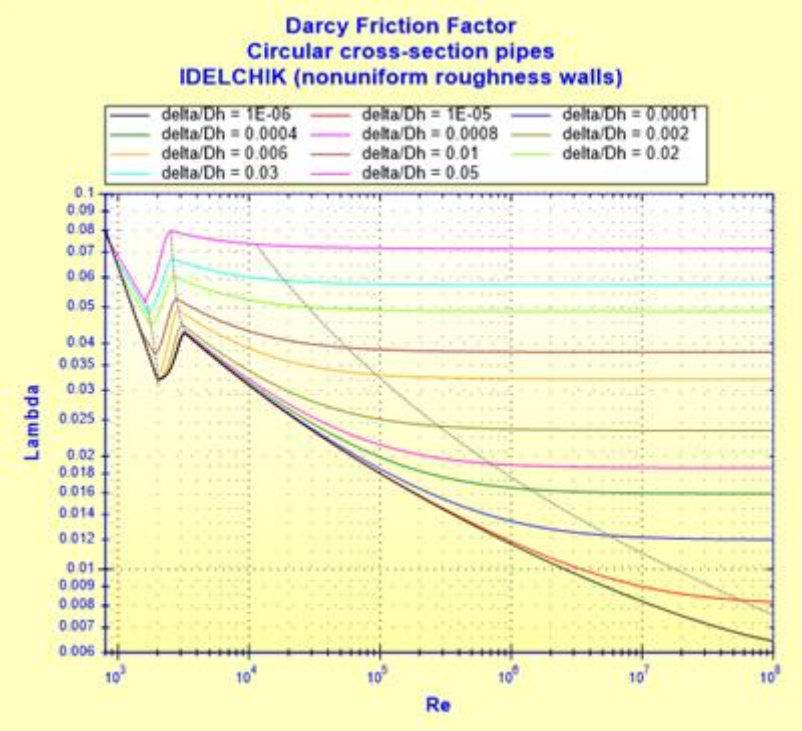
Reynolds number at end of critical zone:

$$Re_2 = 2090\left(\frac{1}{\bar{\Delta}}\right)^{0.0635}$$

([1] §2.22)



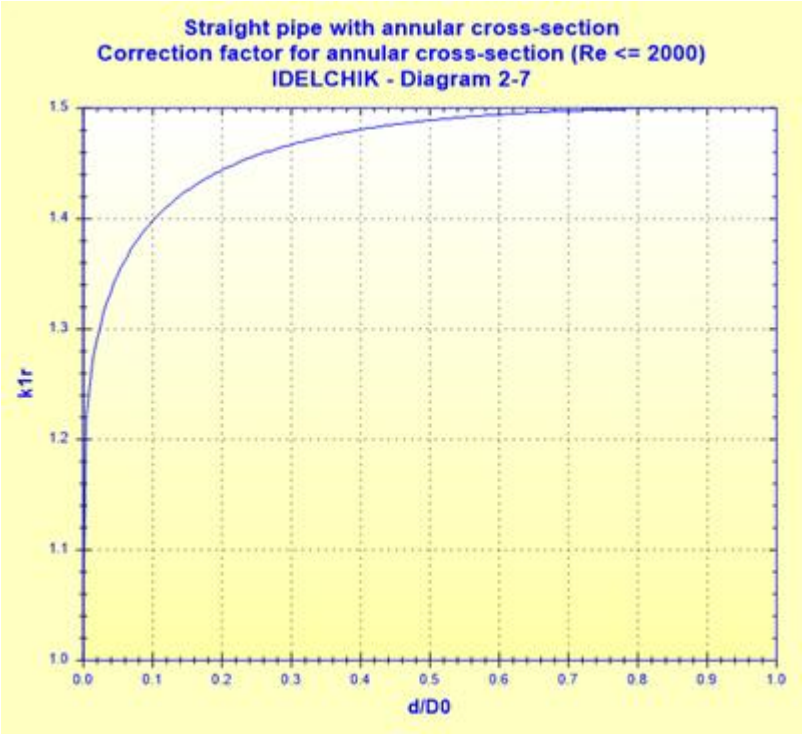
■ all flow regimes:



Correction for Darcy friction factor for annular cross-section:

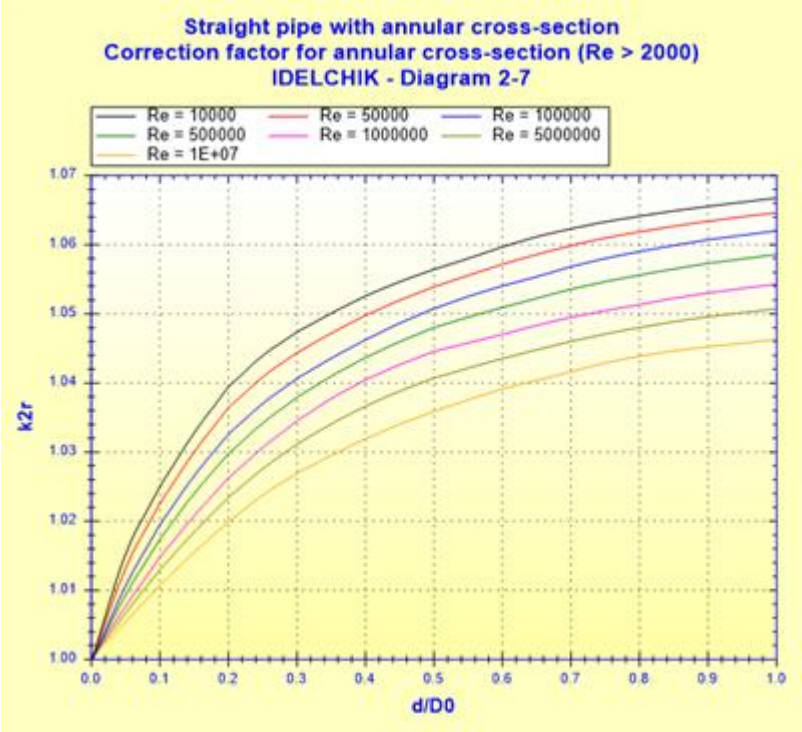
- laminar flow (Re ≤ 2000):

$$k_{1r} = f(d/D_0)$$ ([1] diagram 2.7)



- turbulent flow (Re > 2000):

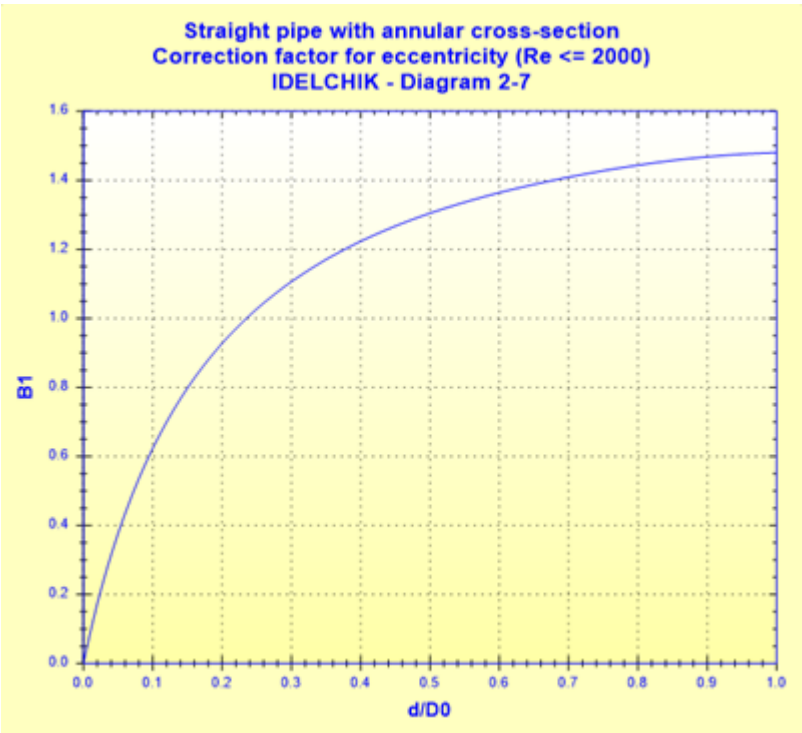
$k_{2r} = f(d/D_0, \mathrm{Re})$ ([1] diagram 2.7)



Correction for Darcy friction factor for axis eccentricity:

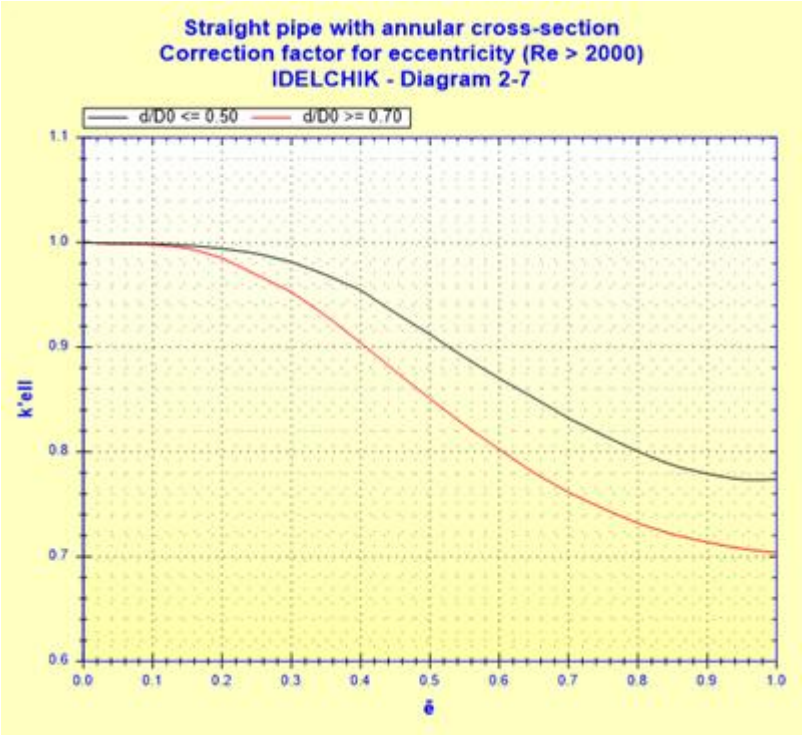
- laminar flow (Re ≤ 2000):

$B_1 = f(d/D_0)$ ([1] diagram 2.7)



- turbulent flow (Re > 2000):

$$k'_{ell} = f\left(\bar{e}, d/D_0\right)$$ ([1] diagram 2.7)



Darcy friction factor for annular cross-section:

- laminar flow (Re ≤ 2000):

$$\lambda_{annu} = \lambda_{circ} \cdot k_{1r} \cdot B_1$$

- turbulent flow (Re > 2000):

$$\lambda_{annu} = \lambda_{circ} \cdot k_{2r} \cdot k'_{ell}$$

Total correction for Darcy friction factor for noncircular cross-section:

- laminar flow (Re ≤ 2000):

$$k_{non-c} = k_{1r} \cdot B_1$$

- turbulent flow (Re > 2000):

$$k_{non-c} = k_{2r} \cdot k'_{ell}$$

Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \lambda_{circ} \cdot k_{non-c} \cdot \frac{l}{D_h}$$ ([1] diagram 2.7)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$ ([1] diagram 2.7)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

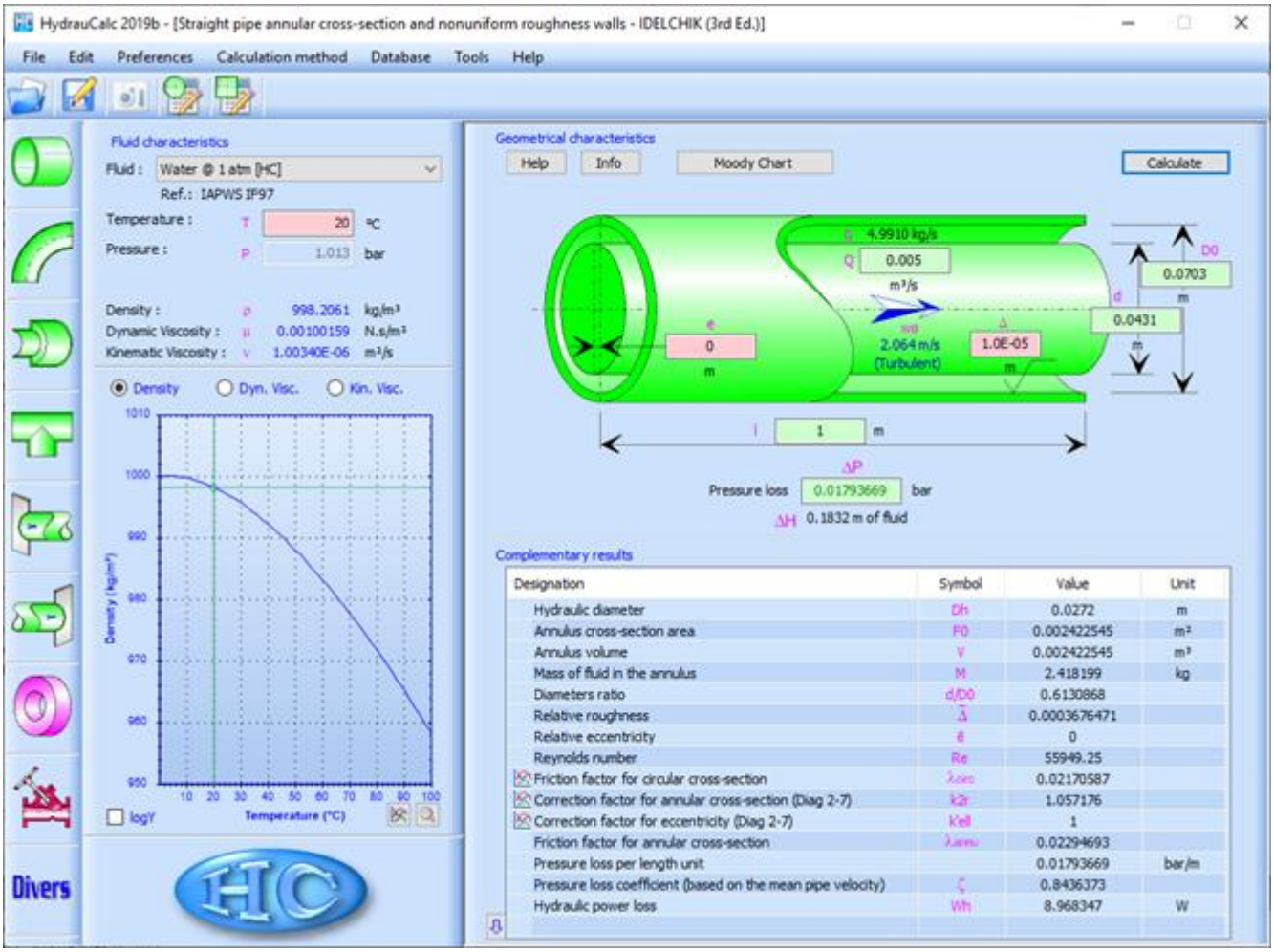
D_0	Annulus outer diameter (m)
d	Annulus inner diameter (m)
D_h	Hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
l	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()

e	Pipes eccentricity (m)
$\bar{e}$	Relative eccentricity ()
λ_{circ}	Darcy friction factor for circular cross-section ()
Re_0	Reynolds number of start of critical zone ()
Re_2	Reynolds number at end of critical zone ()
Re'_{lim}	Limiting Reynolds number for hydraulically smooth law ()
Re''_{lim}	Limiting Reynolds number for quadratic law ()
K_{1r}	Correction for noncircular cross-section (laminar regime) ()
K_{2r}	Correction for noncircular cross-section (turbulent regime) ()
B_1	Correction for eccentricity (laminar regime) ()
K'_{ell}	Correction for eccentricity (turbulent regime) ()
λ_{annu}	Darcy friction factor for annular cross-section ()
k_{non-c}	Correction for Darcy friction factor for noncircular cross-section ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
  note: for Reynolds number lower than 10^4 or greater than 10^7, the correction factor 'k2r' is extrapolated
- relative roughness $\bar{\Delta} \leq 0.05$
- stabilized flow

Example of input data and results:



References:

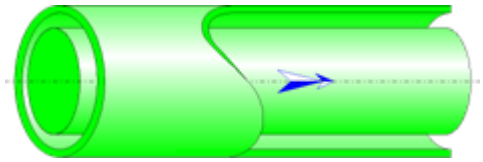
[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.4.3 IDELCHIK (smooth walls)

Straight Pipe

Annular Cross-Section and Smooth Walls

(IDELCHIK)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of annular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula. The inner wall of the piping is supposed to completely smooth (without roughness).

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille,
- for turbulent flow regime by the explicit Filonenko and Althsul equation,
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0 - d$$

Cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2 - d^2}{4}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\bar{\Delta} = \frac{\Delta}{D_h}$$

Relative eccentricity:

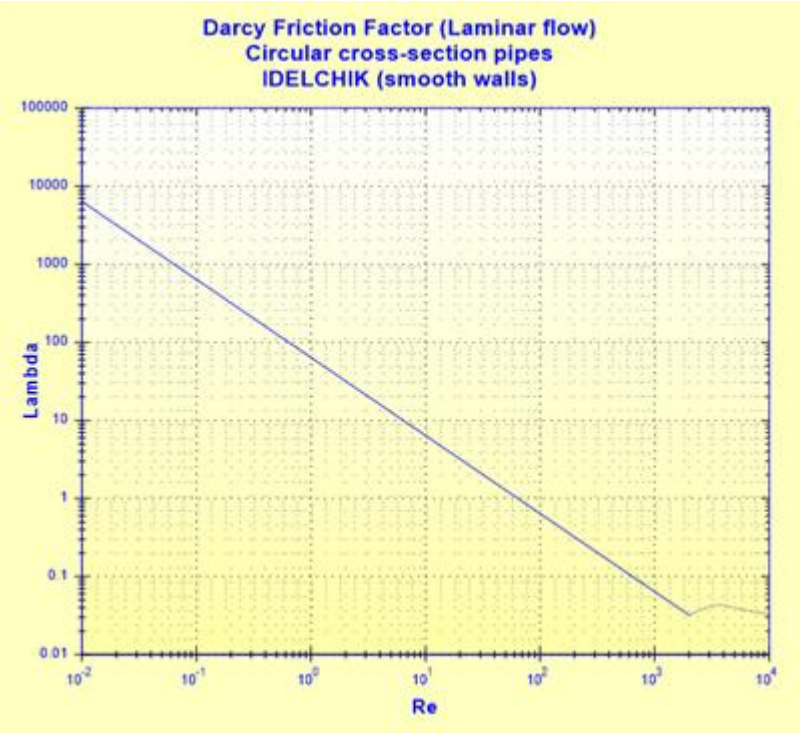
$$\bar{e} = \frac{2 \cdot e}{D_0 - d}$$

Darcy friction factor for circular cross-section:

- laminar flow regime (Re ≤ 2000):

  Hagen-Poiseuille law

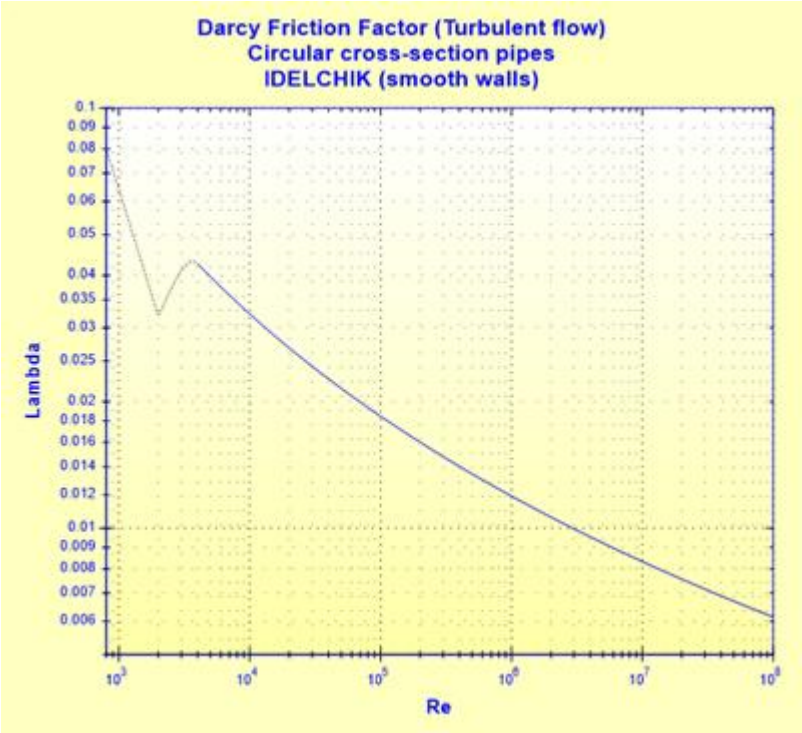
  $$\lambda_{circ} = \frac{64}{Re}$$ ([1] diagram 2.1)



- turbulent flow regime (Re ≥ 4000):

  Filonenko and Althsul Equation

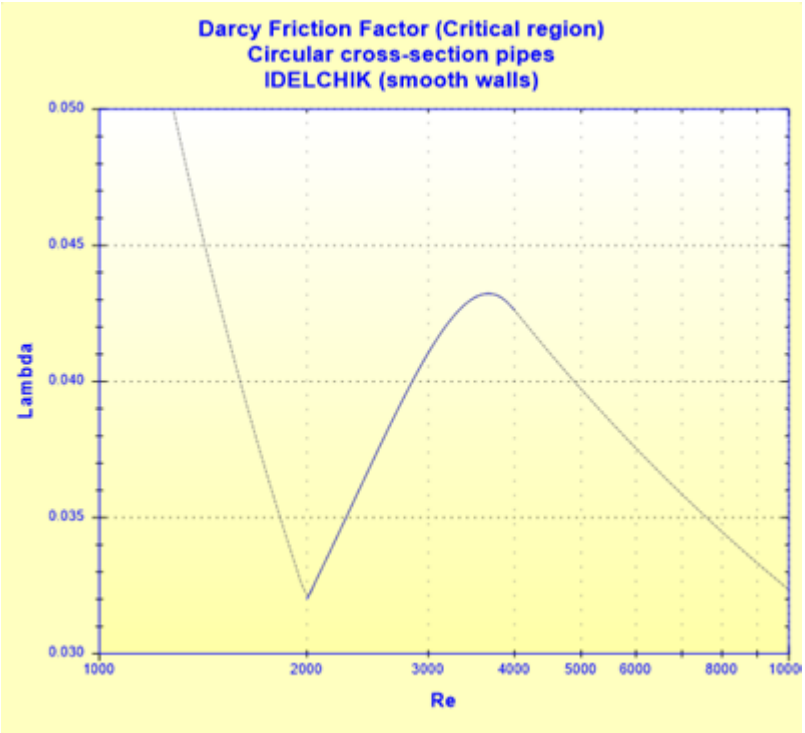
  $$\lambda_{circ} = \frac{1}{\left[1.8 \cdot \log(Re) - 1.64\right]^2}$$ ([1] diagramme 2.1)



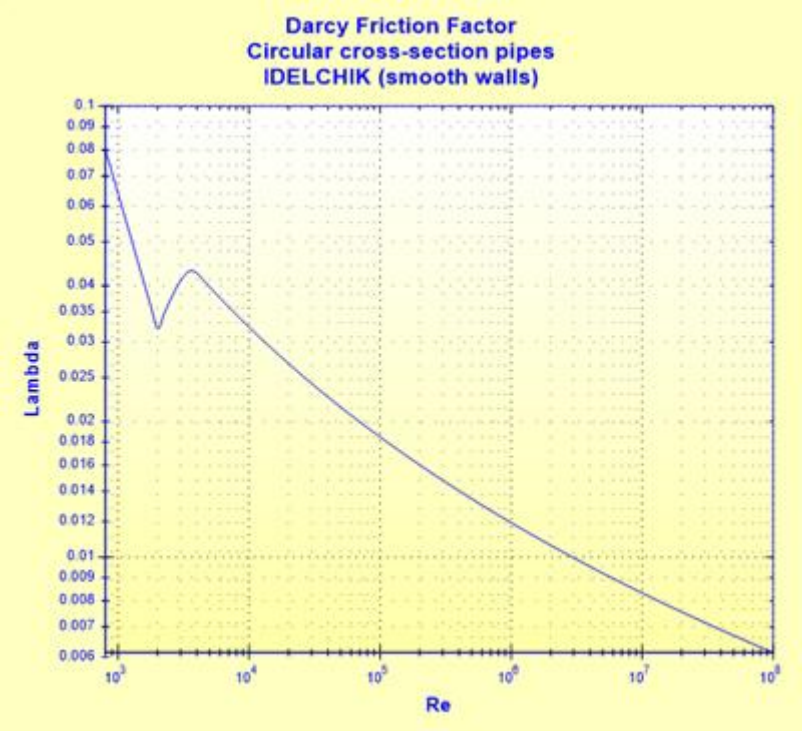
■ critical flow regime (2000 < Re < 4000):

interpolation between laminar and turbulent flows

$\lambda_{circ} = f(\mathrm{Re})$ ([1] diagram 2.1)



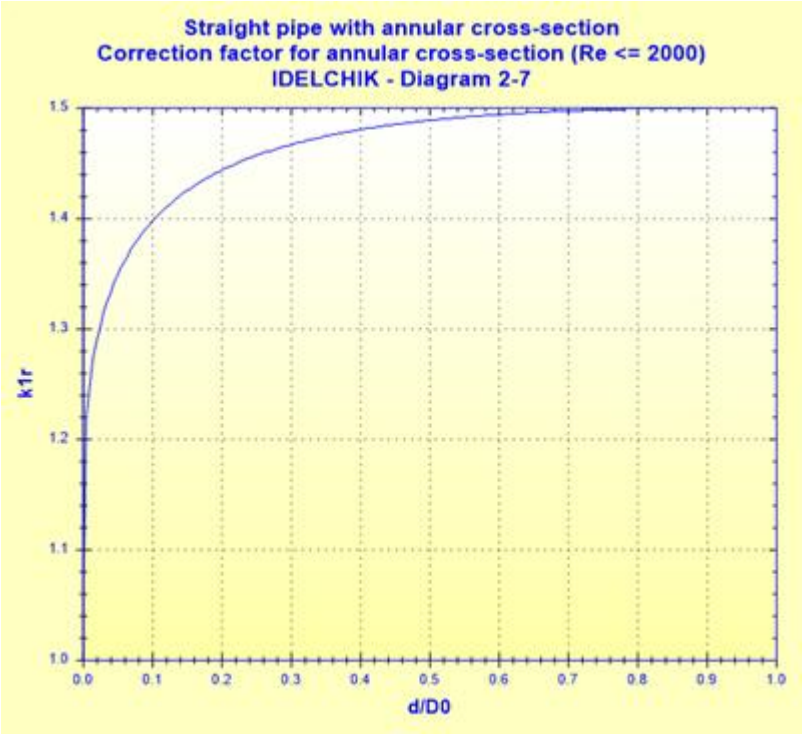
■ all flow regimes:



Correction for Darcy friction factor for annular cross-section:

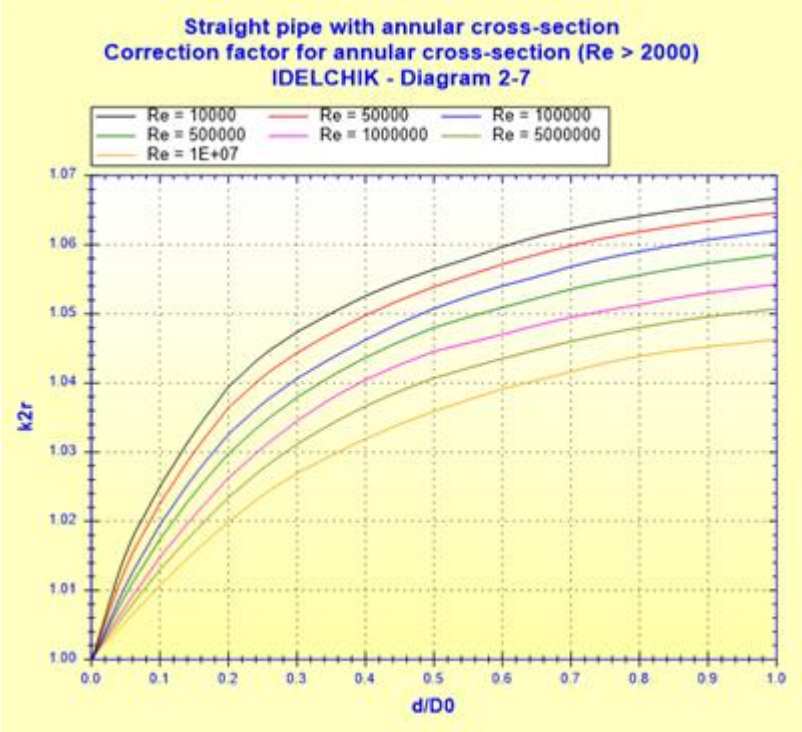
- laminar flow (Re ≤ 2000):

$$k_{1r} = f(d/D_0)$$ ([1] diagram 2.7)



- turbulent flow (Re > 2000):

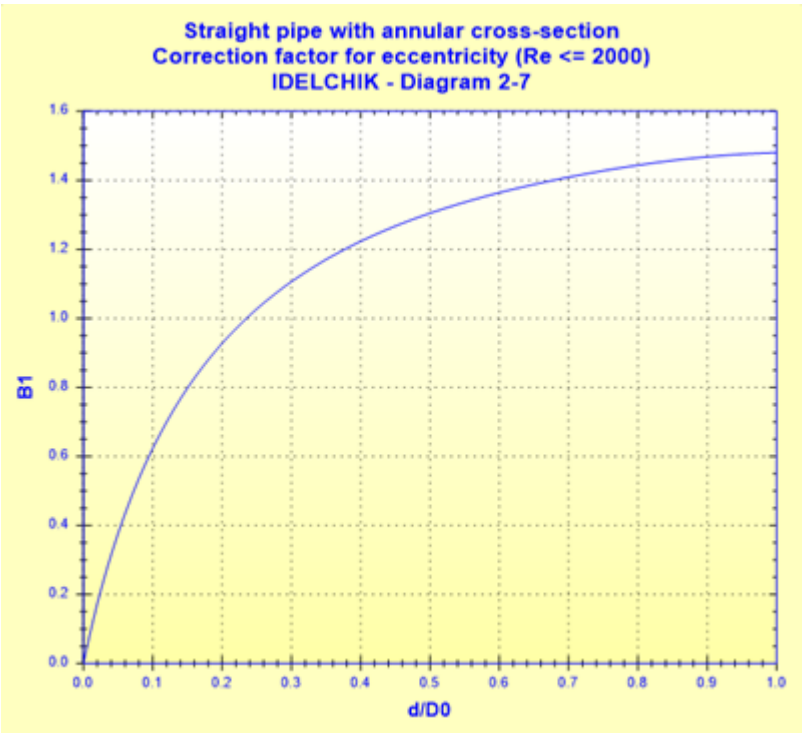
$k_{2r} = f(d/D_0, \mathrm{Re})$ ([1] diagram 2.7)



Correction for Darcy friction factor for axis eccentricity:

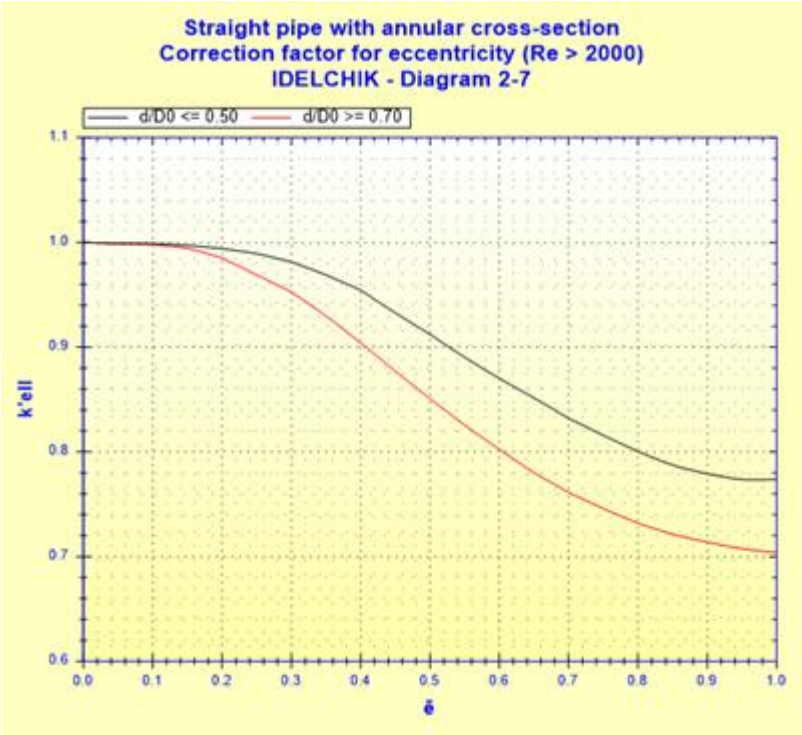
- laminar flow (Re ≤ 2000):

$B_1 = f(d/D_0)$ ([1] diagram 2.7)



- turbulent flow (Re > 2000):

$$k'_{ell} = f\left(\bar{e}, d/D_0\right)$$ ([1] diagram 2.7)



Darcy friction factor for annular cross-section:

- laminar flow (Re ≤ 2000):

$$\lambda_{annu} = \lambda_{circ} \cdot k_{1r} \cdot B_1$$

- turbulent flow (Re > 2000):

$$\lambda_{annu} = \lambda_{circ} \cdot k_{2r} \cdot k'_{ell}$$

Total correction for Darcy friction factor for noncircular cross-section:

- laminar flow (Re ≤ 2000):

$$k_{non-c} = k_{1r} \cdot B_1$$

- turbulent flow (Re > 2000):

$$k_{non-c} = k_{2r} \cdot k'_{ell}$$

Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \lambda_{circ} \cdot k_{non-c} \cdot \frac{l}{D_h}$$ ([1] diagram 2.7)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$ ([1] diagram 2.7)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_0	Annulus outer diameter (m)
d	Annulus inner diameter (m)
D_h	Hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
l	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
e	Pipes eccentricity (m)
$\bar{e}$	Relative eccentricity ()

λ_{circ} Darcy friction factor for circular cross-section ()

K_{1r} Correction for noncircular cross-section (laminar regime) ()

K_{2r} Correction for noncircular cross-section (turbulent regime) ()

B_1 Correction for eccentricity (laminar regime) ()

K'_{ell} Correction for eccentricity (turbulent regime) ()

λ_{annu} Darcy friction factor for annular cross-section ()

k_{non-c} Correction for Darcy friction factor for noncircular cross-section ()

ζ Pressure loss coefficient (based on the mean pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

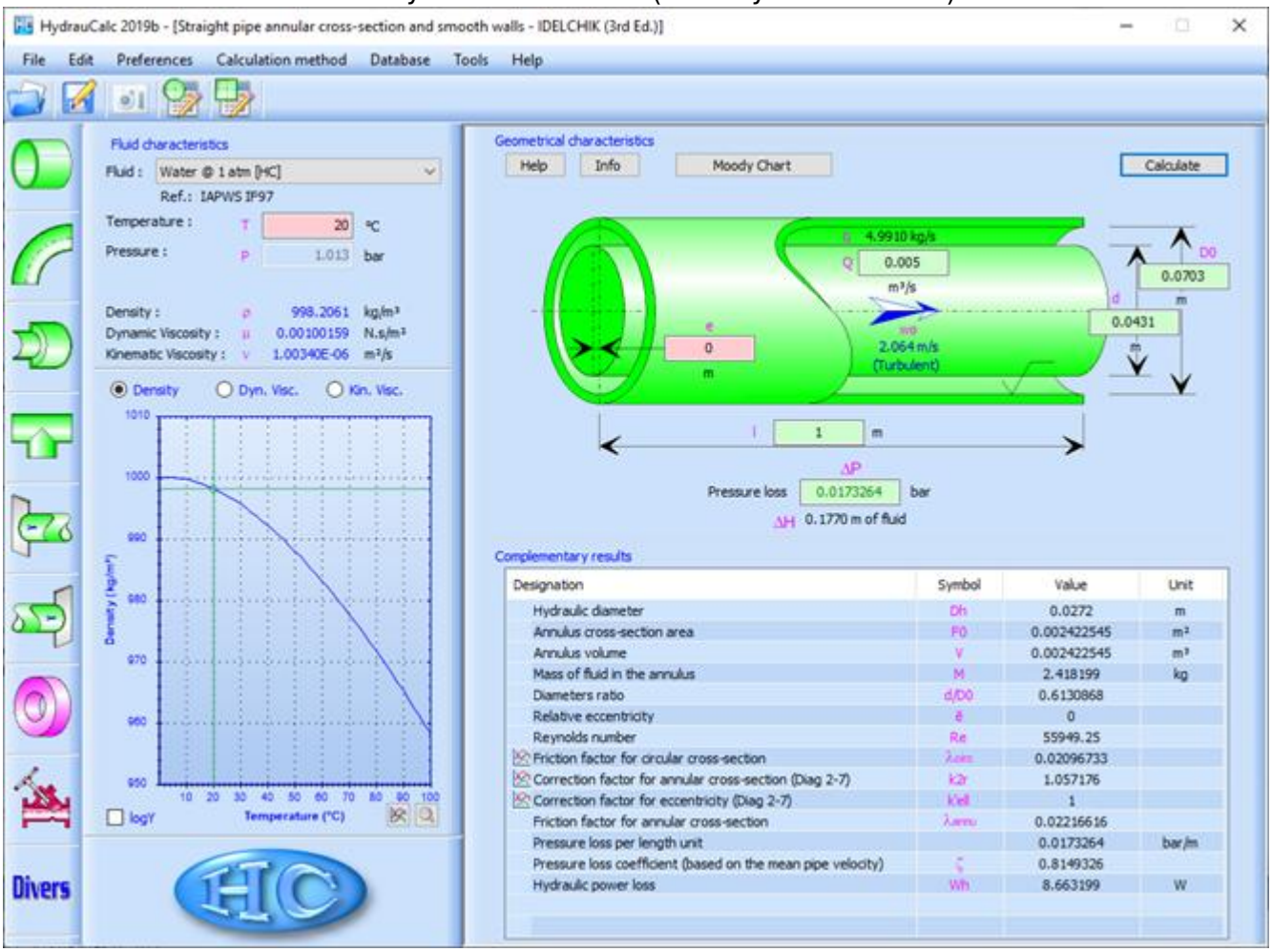
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
  note: for Reynolds number lower than 10^4 or greater than 10^7, the correction factor 'k2r' is extrapolated
- stabilized flow

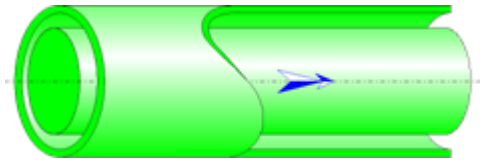
Example of input data and results:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.4.4 IDELCHIK (explicit Darcy friction factor)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of annular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula.

In this model Darcy friction factor is filled explicitly.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0 - d$$

Cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2 - d^2}{4}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

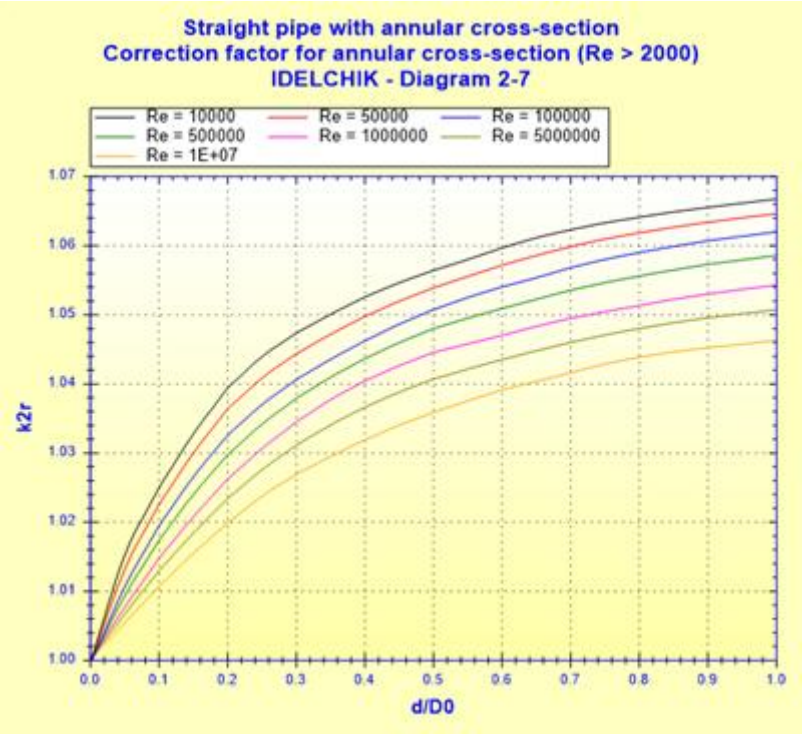
$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Correction for Darcy friction factor for annular cross-section:

$$k_{2r} = f(d/D_0, Re)$$ ([1] diagram 2.7)



Correction for Darcy friction factor for axis eccentricity:

$$k'_{ell} = f\left(\bar{e}, d/D_0\right)$$ ([1] diagram 2.7)

Darcy friction factor for annular cross-section:

$$\lambda_{annu} = \lambda_{circ} \cdot k_{2r} \cdot k'_{ell}$$

Total correction for Darcy friction factor for noncircular cross-section:

$$k_{non-c} = k_{2r} \cdot k'_{ell}$$

Pressure loss coefficient (based on the mean pipe velocity):

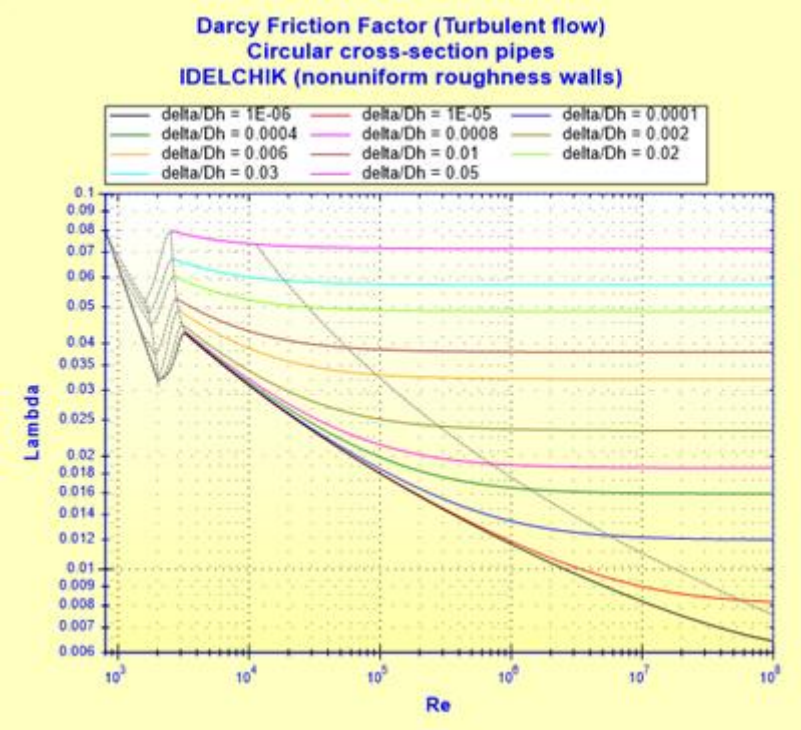
$$\zeta = \lambda_{circ} \cdot k_{non-c} \cdot \frac{l}{D_h}$$ ([1] diagram 2.7)

Equivalent relative roughness (turbulent regime - Re ≥ 4000):

Colebrook-White equation

$$\lambda_{circ} = \frac{1}{\left[2 \cdot \log\left(\frac{2.51}{Re \cdot \sqrt{\lambda_{circ}}} + \frac{\overline{\Delta}}{3.7}\right)\right]^2}$$ ([1] diagram 2.4)

where $\overline{\Delta}$ is calculated by solving the equation.



Equivalent absolute roughness (m):

$$\Delta = \overline{\Delta} \cdot D_h$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$ ([1] diagram 2.7)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_0	Annulus outer diameter (m)
d	Annulus inner diameter (m)
D_h	Hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
l	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
Δ	Equivalent absolute roughness of walls (m)
$\bar{\Delta}$	Equivalent relative roughness of walls ()
e	Pipes eccentricity (m)
$\bar{e}$	Relative eccentricity ()
λ_{circ}	Darcy friction factor for circular cross-section ()
K_{2r}	Correction for noncircular cross-section (turbulent regime) ()
K'_{ell}	Correction for eccentricity (turbulent regime) ()
λ_{annu}	Darcy friction factor for annular cross-section ()
k_{non-c}	Correction for Darcy friction factor for noncircular cross-section ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)

ρ Fluid density (kg/m³)

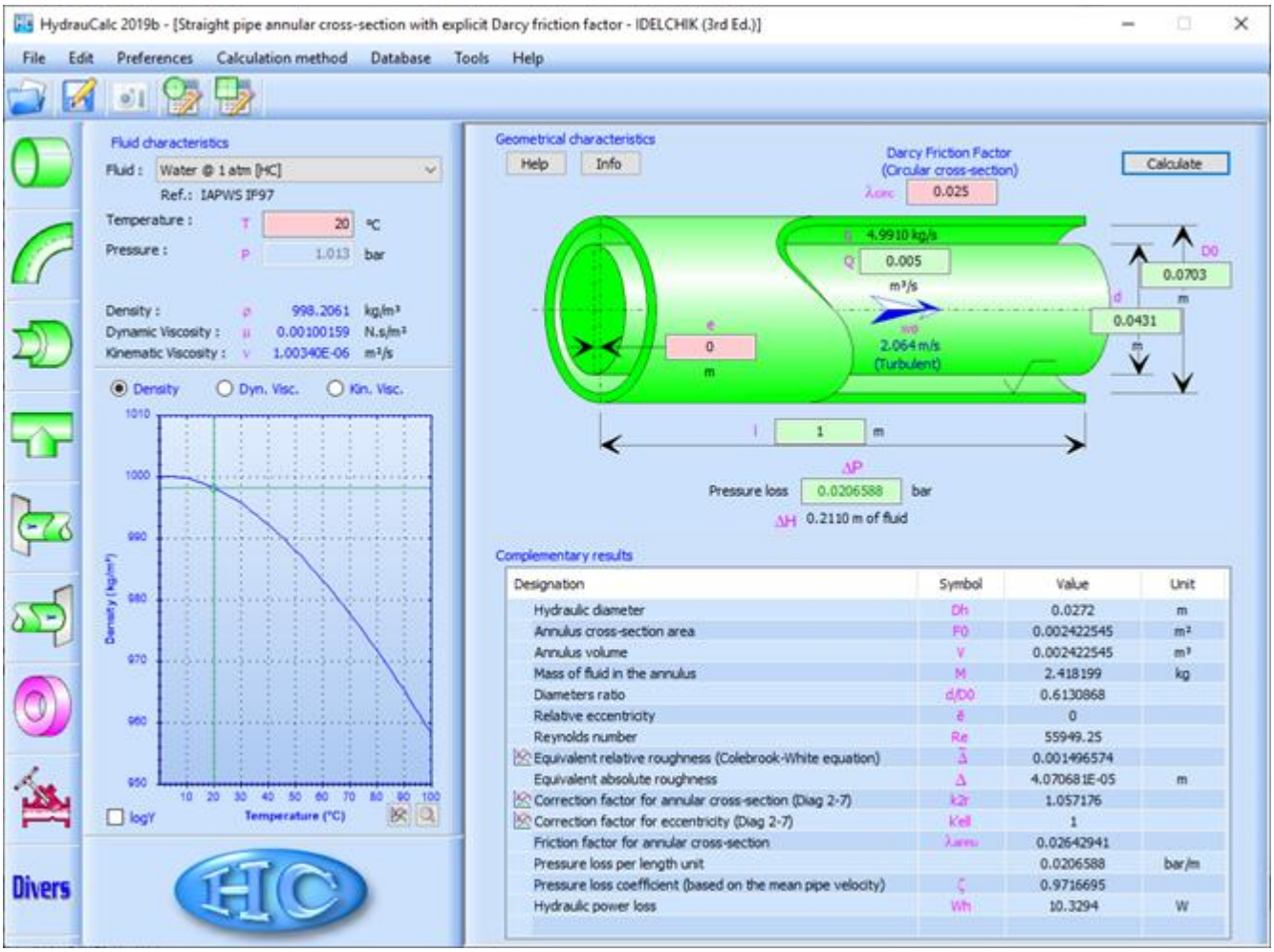
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($4 \cdot 10^3 \leq Re \leq 10^8$)
  note: for Reynolds number lower than 10^4 or greater than 10^7, the correction factor 'k2r' is extrapolated
- Darcy friction factor for circular cross-section $\lambda_{circ} < 0.1$
- stabilized flow

Example of input data and results:



References:

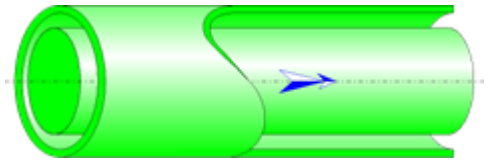
[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

2.1.4.5 MILLER (roughness walls)

Straight Pipe

Annular Cross-Section and Roughness Walls

(MILLER)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of annular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula.

Darcy friction factor is determined:

- for laminar flow regime by the law of Hagen-Poiseuille (independent of the value of relative roughness),
- for turbulent flow regime by the explicit Swamee-Jain equation (dependent of the value of relative roughness), the explicit Swamee-Jain equation is a Colebrook-White equation approximation,
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Hydraulic diameter (m):

$$D = d_0 - d_1$$

Cross-section area (m^2):

$$A = \pi \cdot \frac{d_0^2 - d_1^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$m = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = A \cdot L$$

Fluid mass in the pipe (kg):

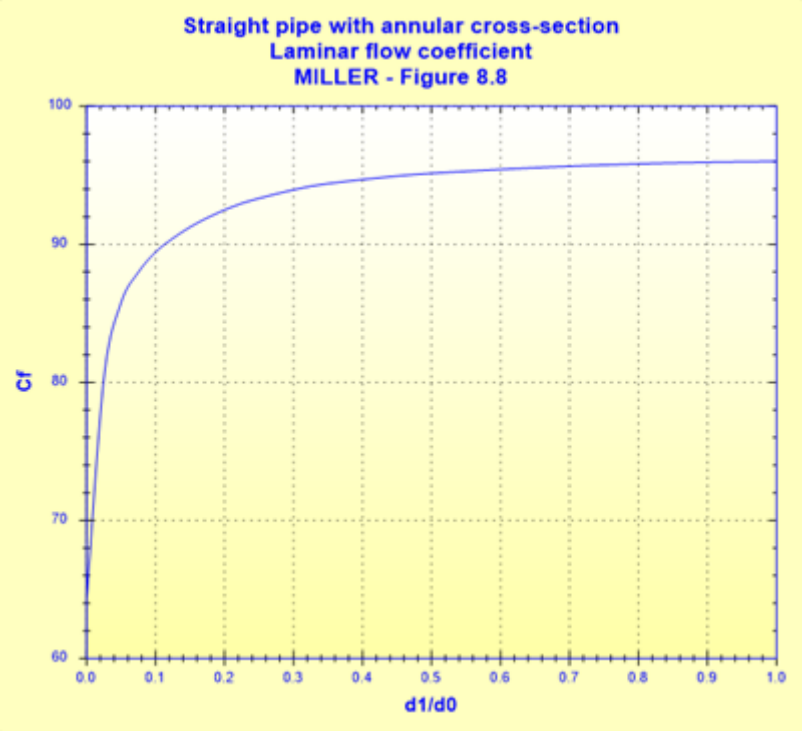
$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

Laminar flow coefficient:

$$Cf = f(d_1 / d_0)$$ ([1] figure 8.8)

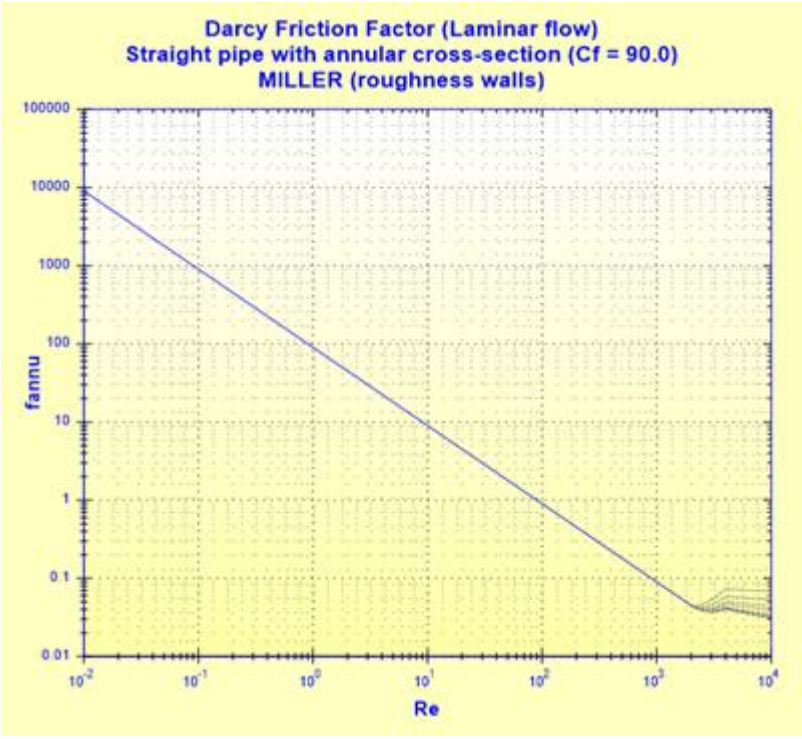


Darcy friction factor:

- laminar flow regime (Re ≤ 2000):

Darcy friction factor for annular cross-section:

$$f_{annu} = \frac{Cf}{Re}$$ ([1] equation 8.7)



([1] equation 8.7with Cf = 90)

■ turbulent flow regime – transition region and complete turbulence region (Re ≥ 4000):

Darcy friction factor for circular cross-section:

Swamee-Jain equation (Colebrook-White equation approximation)

$$f_{circ} = \frac{0.25}{\left[\log\left(\frac{k}{3.7 \cdot D} + \frac{5.74}{Re^{0.9}}\right)\right]^2}$$

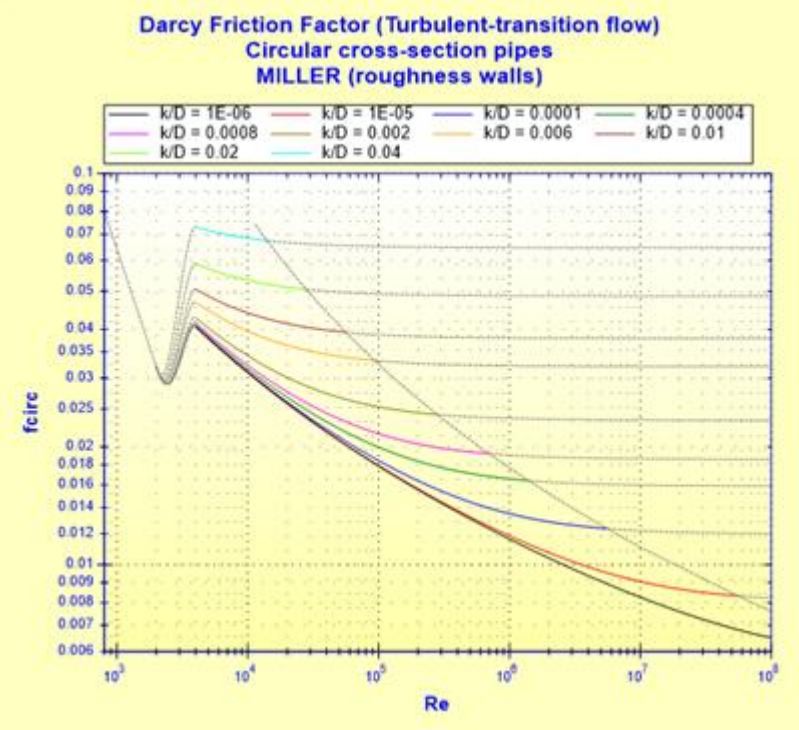
([1] equation 8.4)

Reynolds number corresponding to the beginning of complete turbulence:

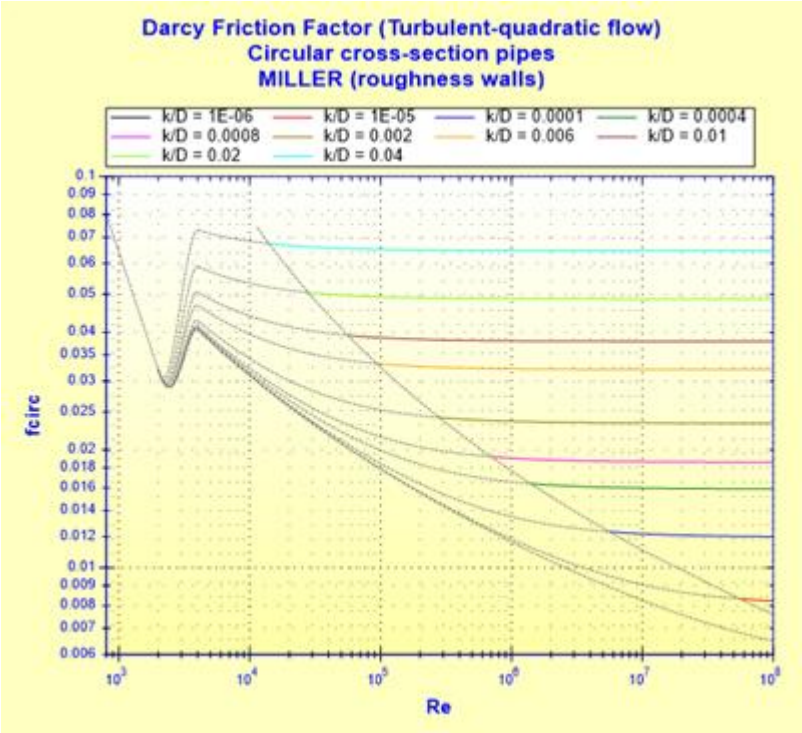
$$Re''_{lim} = \frac{560}{k/D}$$

([2] diagram 2.4)

Transition region



Complete turbulence region



Darcy friction factor for annular cross-section:

$$f_{annu} = 1.05 \cdot f_{circ}$$ ([1] equation 8.5)

■ critical flow regime (2000 < Re < 4000):

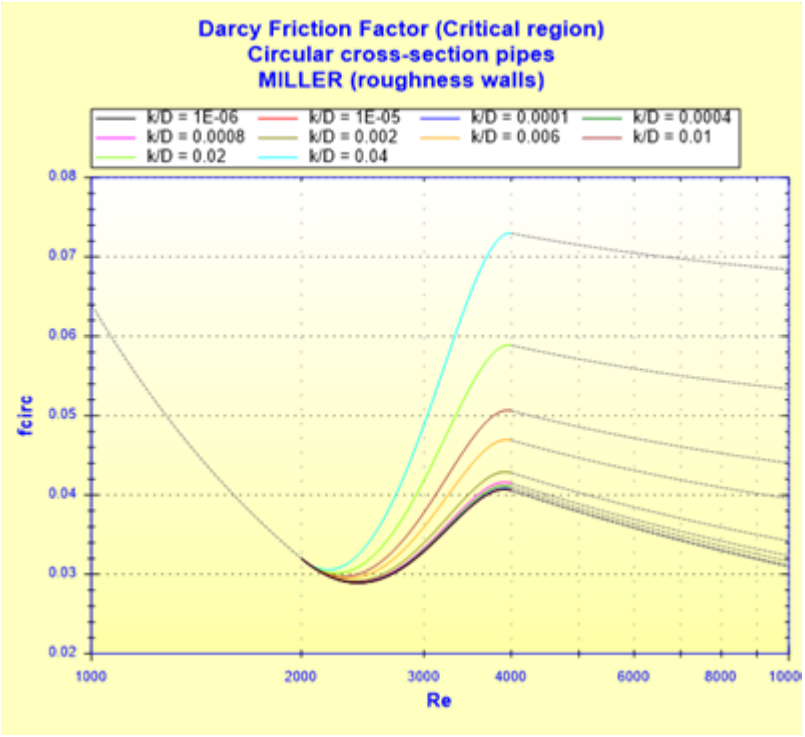
Darcy friction factor for circular cross-section:

cubic interpolation

$$f_{circ} = (X1 + R \cdot (X2 + R \cdot (X3 + X4)))$$ ([3])

with:

$$R = \frac{Re}{2000}$$
$$X1 = 7 \cdot FA - FB$$
$$X2 = 0.128 - 17 \cdot FA + 2.5 \cdot FB$$
$$X3 = -0.128 + 13 \cdot FA - 2 \cdot FB$$
$$X4 = R \cdot (0.032 - 3 \cdot FA + 0.5 \cdot FB)$$
$$FA = Y3^{-2}$$
$$FB = FA \cdot \left(2 - \frac{0.00514215}{Y2 \cdot Y3}\right)$$
$$Y2 = \frac{k}{3.7 \cdot D} + \frac{5.74}{Re^{0.9}}$$
$$Y3 = -0.86859 \cdot ln\left(\frac{k}{3.7 \cdot D} + \frac{5.74}{4000^{0.9}}\right)$$



Darcy friction factor for annular cross-section:

$$f_{annu} = 1.05 \cdot f_{circ}$$ ([1] equation 8.5)

Friction pressure loss coefficient:

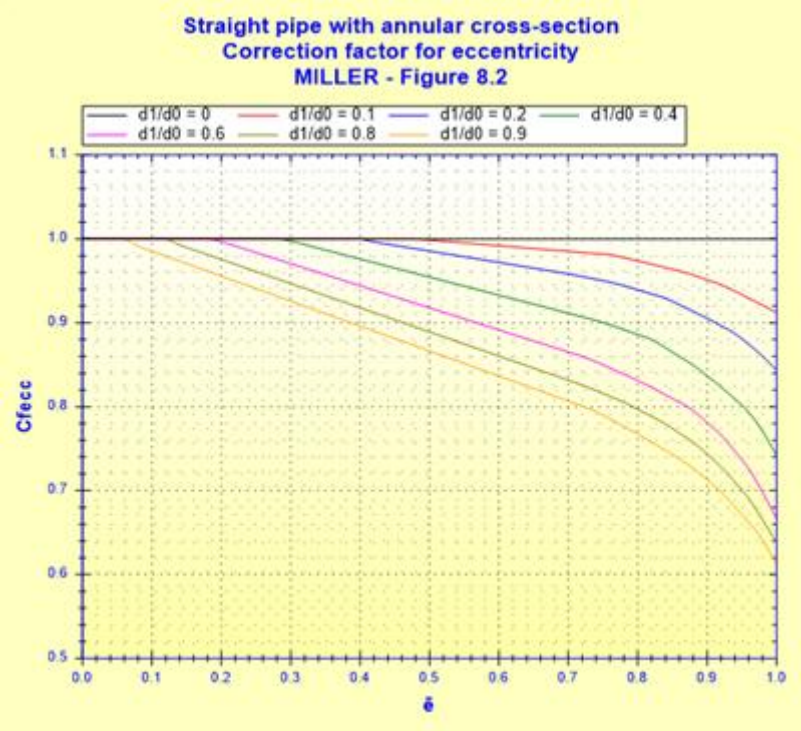
$$K_f = f_{annu} \cdot \frac{L}{D}$$ ([1] equation 8.3)

Relative eccentricity:

$$\bar{e} = \frac{2 \cdot e}{d_1 - d_0}$$

Correction for axis eccentricity:

$$Cf_{ecc} = f\left(\bar{e}, d_1/d_0\right)$$ ([1] figure 8.2)



Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_f \cdot Cf_{ecc}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_1	Annulus inner diameter (m)
d_0	Annulus outer diameter (m)
D	Hydraulic diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
m	Mass flow rate (kg/s)
L	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
Cf	Laminar flow coefficient ()
k	Absolute roughness of walls (m)
f_{circ}	Darcy friction factor for circular cross-section ()
Re''_{lim}	Reynolds number corresponding to the beginning of complete turbulence ()
f_{annu}	Darcy friction factor for annular cross-section ()
K_f	Friction pressure loss coefficient ()
e	Pipes eccentricity (m)
$\bar{e}$	Relative eccentricity ()
Cf_{ecc}	Correction for axis eccentricity ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

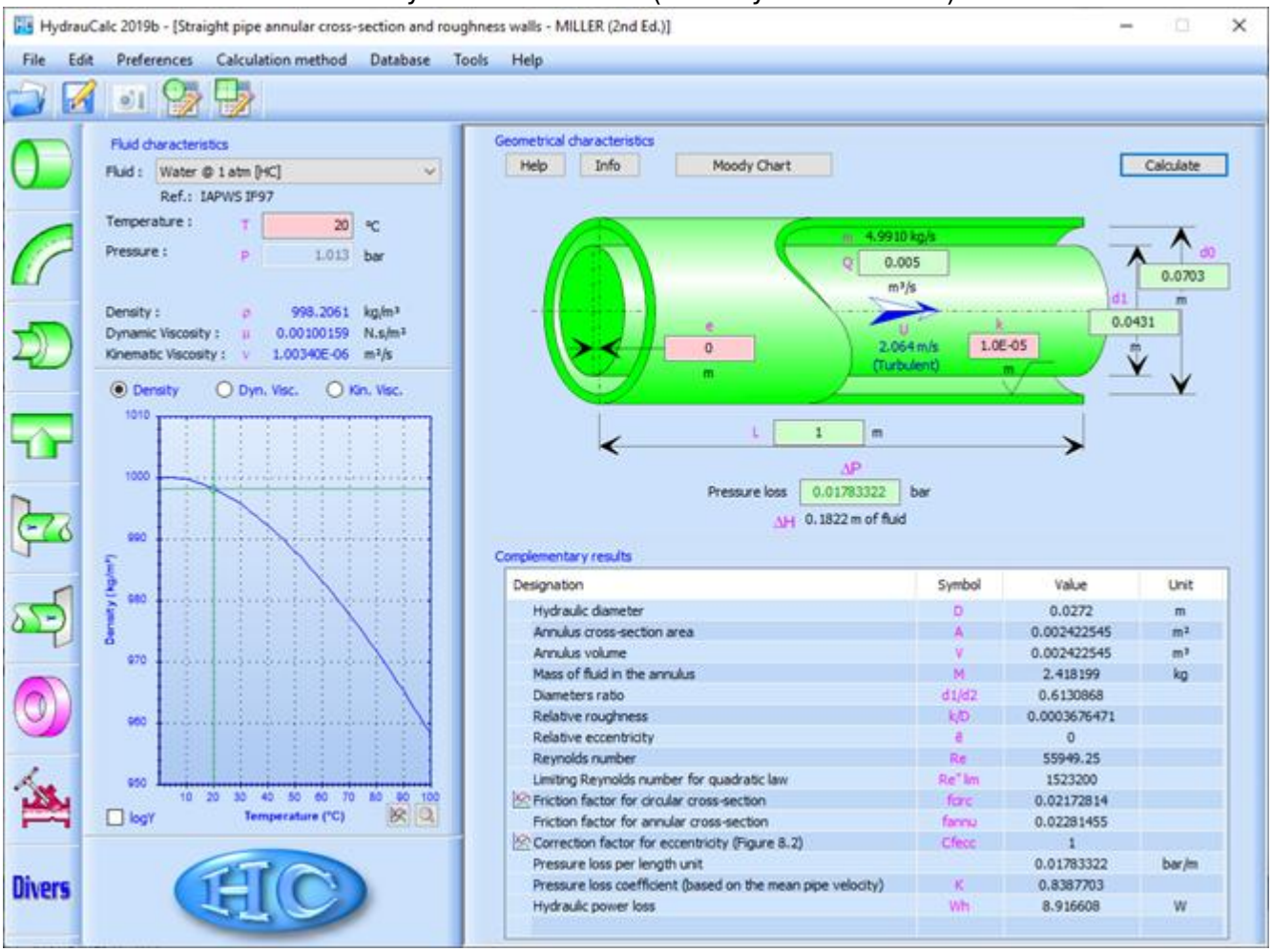
g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar, critical and turbulent ($Re \leq 10^8$)
- relative roughness $k/D \leq 0.05$
- stabilized flow
- relative eccentricity ≤ 0.9
  note: for relative eccentricity greater than 0.9, the correction factor for axis eccentricity 'Cfecc' is extrapolated

---

Example of application:



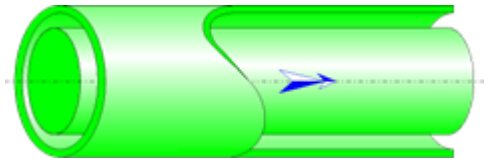
References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

[2] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik (2008)

[3] Dunlop (1991)

2.1.4.6 MILLER (explicit Darcy friction factor)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of annular and constant cross-section.

In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Darcy formula.

In this model Darcy friction factor is filled explicitly.

Model formulation:

Hydraulic diameter (m):

$$D = d_0 - d_1$$

Cross-section area (m^2):

$$A = \pi \cdot \frac{d_0^2 - d_1^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$m = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V = A \cdot L$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

Darcy friction factor for annular cross-section:

$$f_{annu} = 1.05 \cdot f_{circ}$$ ([1] equation 8.5)

Friction pressure loss coefficient:

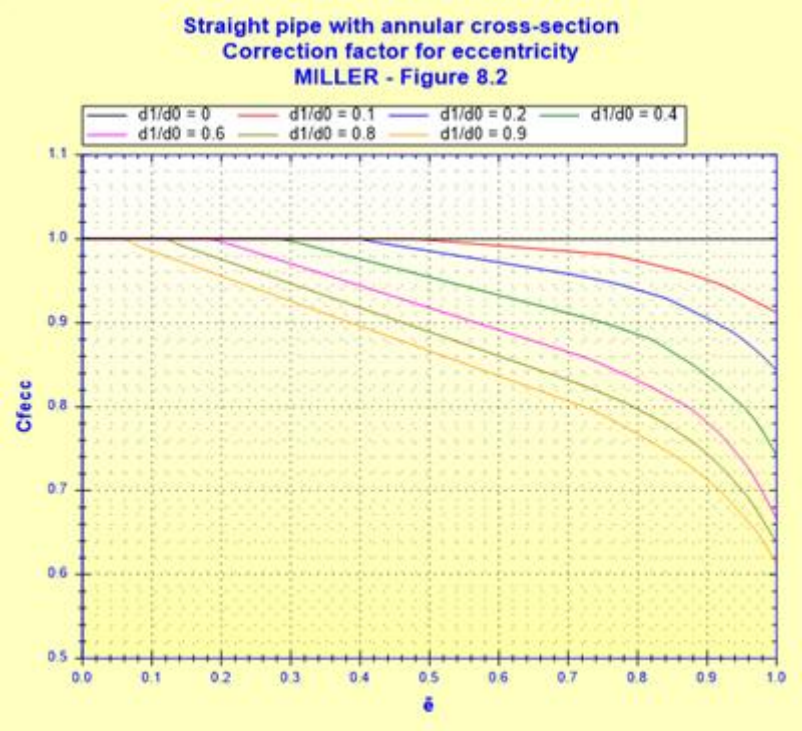
$$K_f = f_{annu} \cdot \frac{L}{D}$$ ([1] equation 8.3)

Relative eccentricity:

$$\bar{e} = \frac{2 \cdot e}{d_1 - d_0}$$

Correction for axis eccentricity:

$$Cf_{ecc} = f\left(\bar{e}, d_1/d_0\right)$$ ([1] figure 8.2)



Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_f \cdot Cf_{ecc}$$

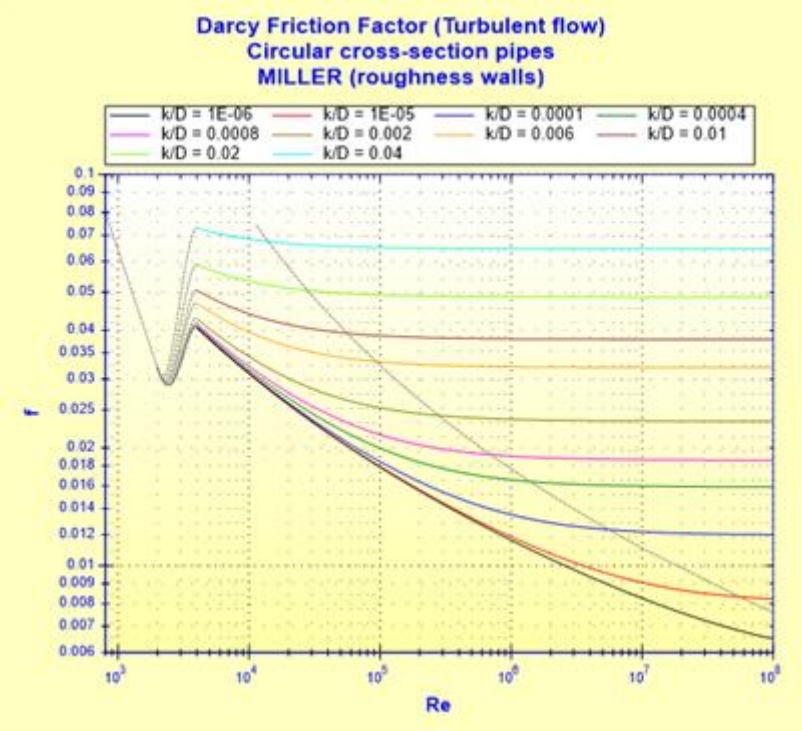
Equivalent absolute roughness for annular cross-section pipe (turbulent regime - Re ≥ 4000):

Swamee-Jain equation (Colebrook-White equation approximation)

$$f_{circ} = \frac{0.25}{\left[\log\left(\frac{k}{3.7 \cdot D} + \frac{5.74}{\mathrm{Re}^{0.9}}\right)\right]^2}$$

([1] equation 8.4)

where k is calculated by solving the equation.



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_1	Annulus inner diameter (m)
d_0	Annulus outer diameter (m)
D	Hydraulic diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)

U	Mean velocity (m/s)
m	Mass flow rate (kg/s)
L	Pipe length (m)
V	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
f_{circ}	Darcy friction factor for circular cross-section ()
f_{annu}	Darcy friction factor for annular cross-section ()
K_f	Friction pressure loss coefficient ()
e	Pipes eccentricity (m)
$\bar{e}$	Relative eccentricity ()
Cf_{ecc}	Correction for axis eccentricity ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
k	Equivalent absolute roughness of walls (m)
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

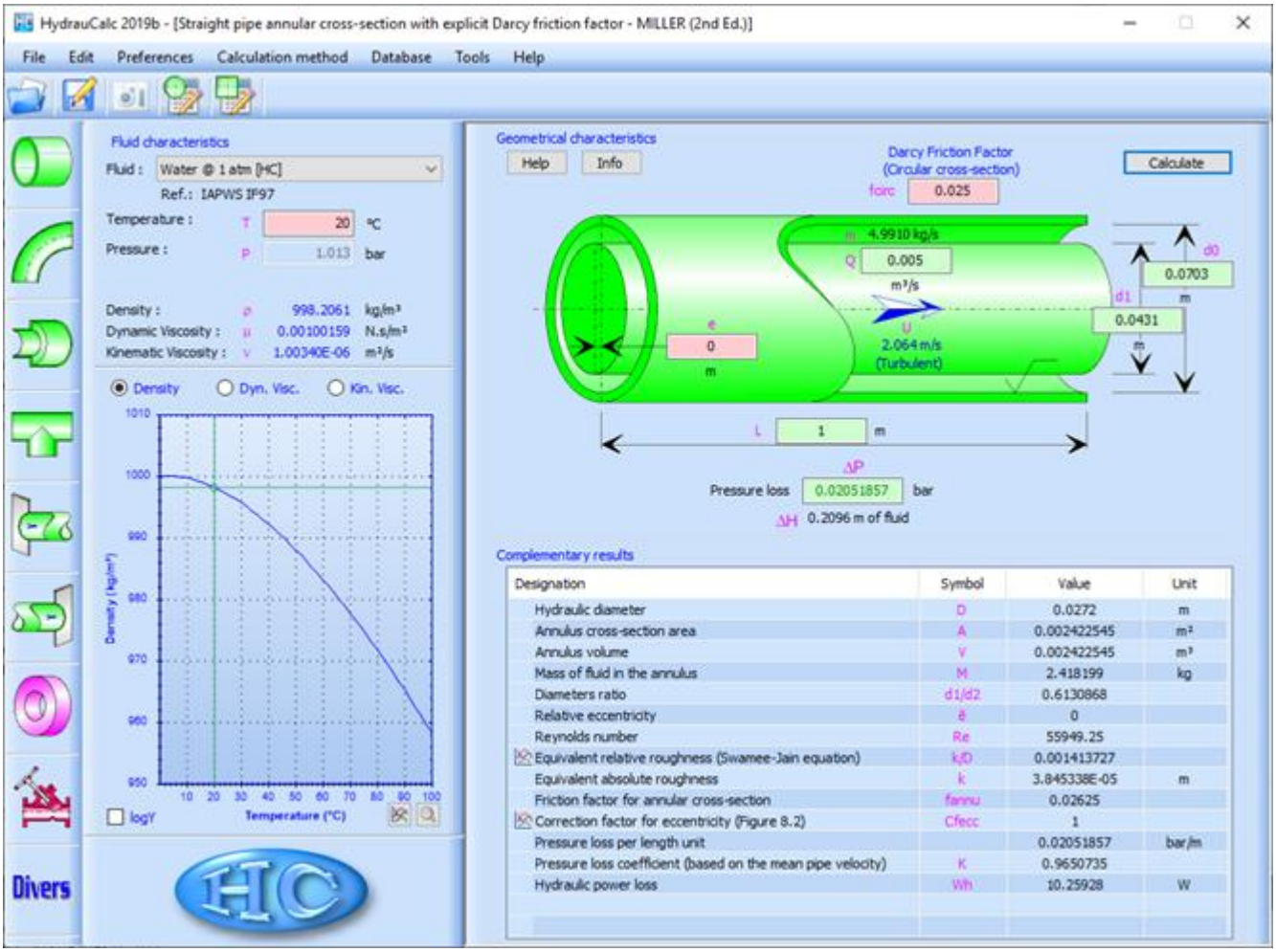
Validity range:

- turbulent flow regime ($4\ 10^3 \leq Re \leq 10^8$)
- stabilized flow
- Darcy friction factor for circular cross-section $f_{circ} < 0.1$

- relative eccentricity ≤ 0.9
  note: for relative eccentricity greater than 0.9, the correction factor for axis eccentricity 'Cfecc' is extrapolated

---

Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

2.2 Bends

This subsection regroups the set of bends elements that can be modeled and calculated. The types of bend available are:

- Smooth Bend - Circular Cross-Section

- Smooth Bend - Rectangular Cross-Section

- Miter Bend - Circular Cross-Section

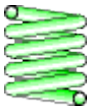
- Miter Bend - Rectangular Cross-Section

- Composite Bend 90° (2 x 45°) - Circular Cross-Section

- Composite Bend 90° (3 x 30°) - Circular-Cross-Section

- Composite Bend 90° (4 x 22.5°) - Circular Cross-Section

- Helical Tube - Circular Cross-Section



- S-shaped Bends - Circular Cross-Section (flow in one plane)

- S-shaped Bends - Rectangular Cross-Section (flow in one plane)

- S-shaped Bends - Circular Cross-Section (flow in two perpendicular planes)

- S-shaped Bends - Rectangular Cross-Section (flow in two perpendicular planes)

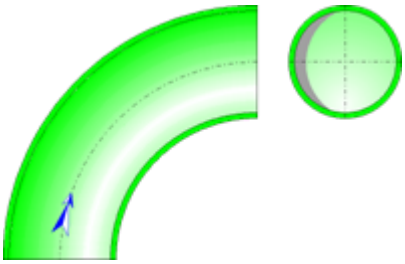
- U-shaped Bends - Circular Cross-Section (flow in one plane)

- U-shaped Bends - Rectangular Cross-Section (flow in one plane)

2.2.1 Smooth Bend - Circular cross-section

Smooth Bend

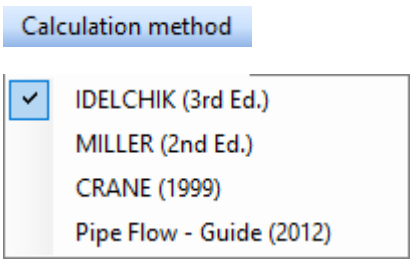
Circular Cross-Section



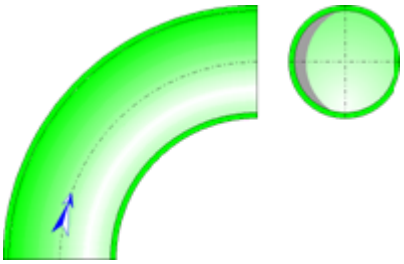
For the calculation of the pressure loss coefficient of smooth bends with circular cross-section, the user can choose from one of the methods described in the following four reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.2.1.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) of a bend smoothly curved whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized at the entrance bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Length measured along the axis (m):

$$l = 2 \cdot \pi \cdot R_0 \cdot \frac{\delta}{360}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = F_0 \cdot l$$

Fluid mass (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

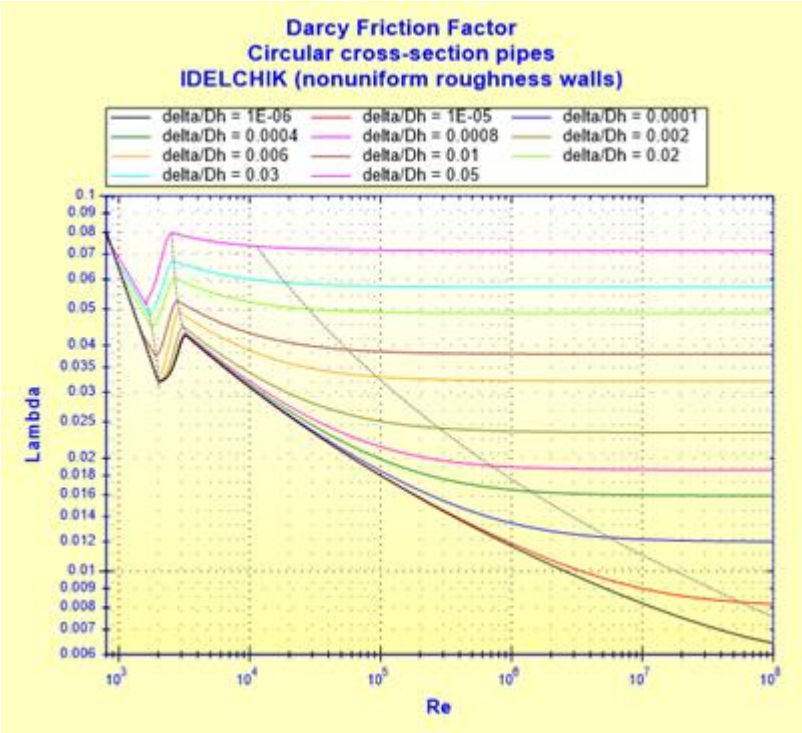
$$\bar{\Delta} = \frac{\Delta}{D_0}$$

Darcy friction factor:

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)

- Darcy friction factor for circular cross-section

$$\lambda = f\left(Re, \frac{\Delta}{D_h}\right)$$



■ Case of relative radius of curvature lower than 3 ($R_0/D_0 < 3$) ([1] diagram 6.1)

Coefficient of effect of the roughness:

$$k_\Delta = f\left(\frac{R_0}{D_0}, \mathrm{Re}, \overline{\Delta}\right)$$ ([1] diagram 6.1)

- $0.50 \le R_0/D_0 \le 0.55$

$\overline{\Delta}$	Re	
	$3 \cdot 10^3$ - $4 \cdot 10^4$	$> 4 \cdot 10^4$
0	1.0	1.0
0 - 0.001	1.0	$1 + 0.5 \cdot 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	1.5

- $R_0/D_0 > 0.55$

$\overline{\Delta}$	Re		
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$ - $2 \cdot 10^5$	> $2 \cdot 10^5$
0	1.0	1.0	1.0
0 - 0.001	1.0	$\lambda_\Delta / \lambda_{sm}$	$1 + 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	2.0	2.0

with:

λ_{sm} : Darcy friction factor for hydraulically smooth pipe ($\overline{\Delta} = 0$) at Re

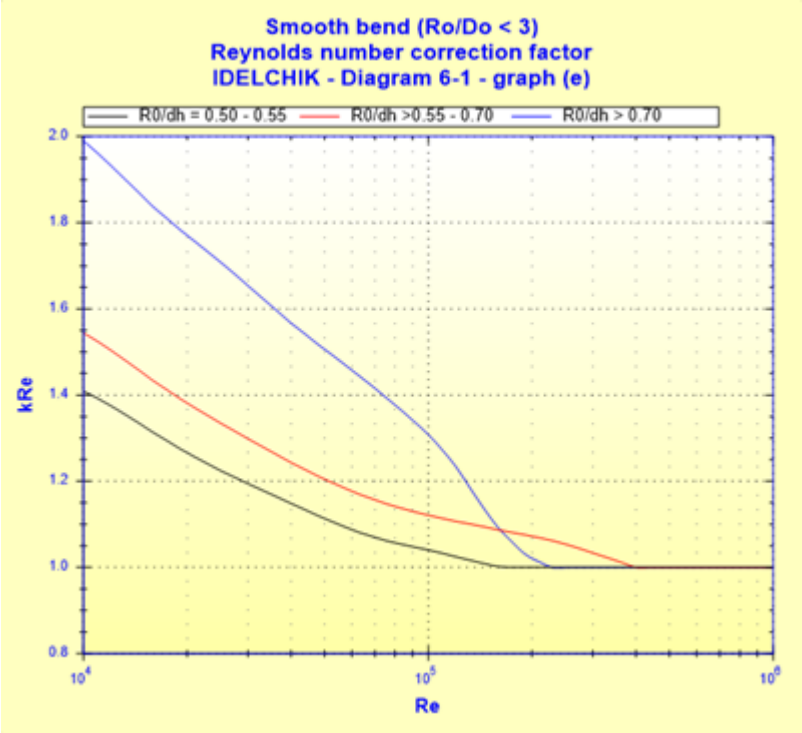
λ_Δ : Darcy friction factor for rough pipe ($\overline{\Delta} = \Delta/D_h$) at Re

---

Coefficient of effect of the Reynolds number (Re ≥ 10^4):

$$k_{Re} = f\left(\mathrm{Re}, \frac{R_0}{D_h}\right)$$

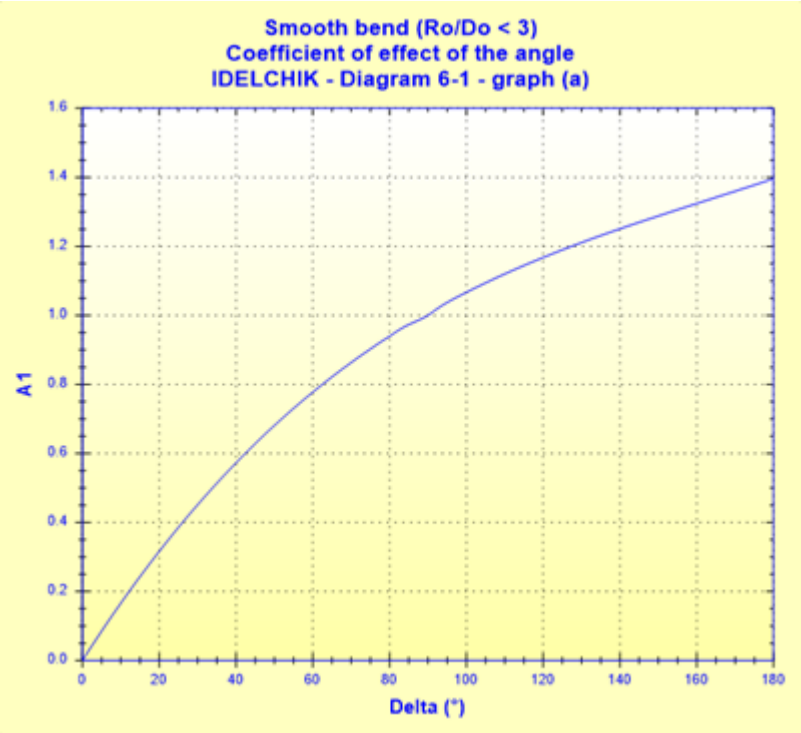
([1] diagram 6.1)



Coefficient of effect of the angle:

$$A1 = f(\delta)$$

([1] diagram 6.1)

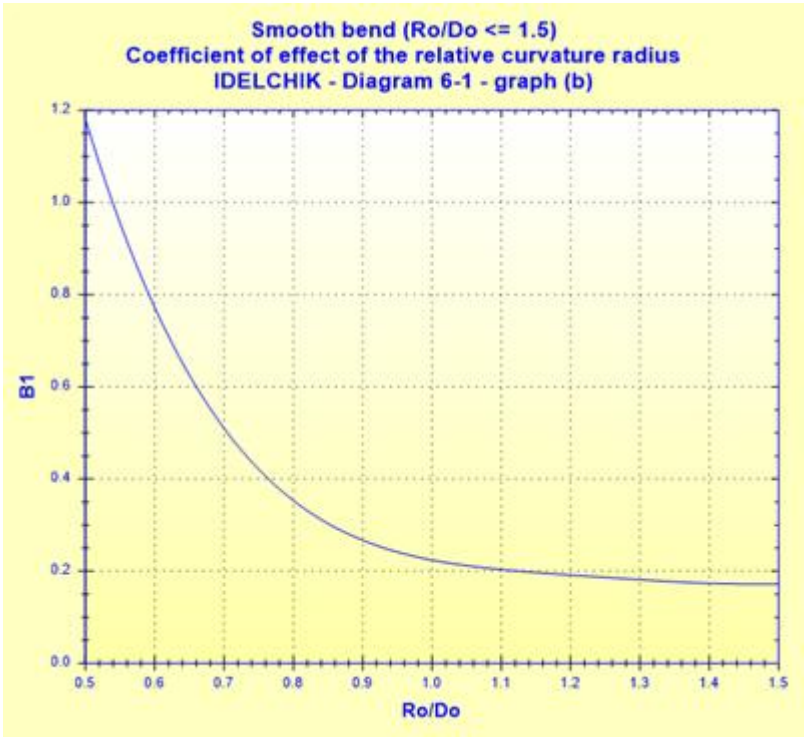


Coefficient of effect of the relative curvature radius:

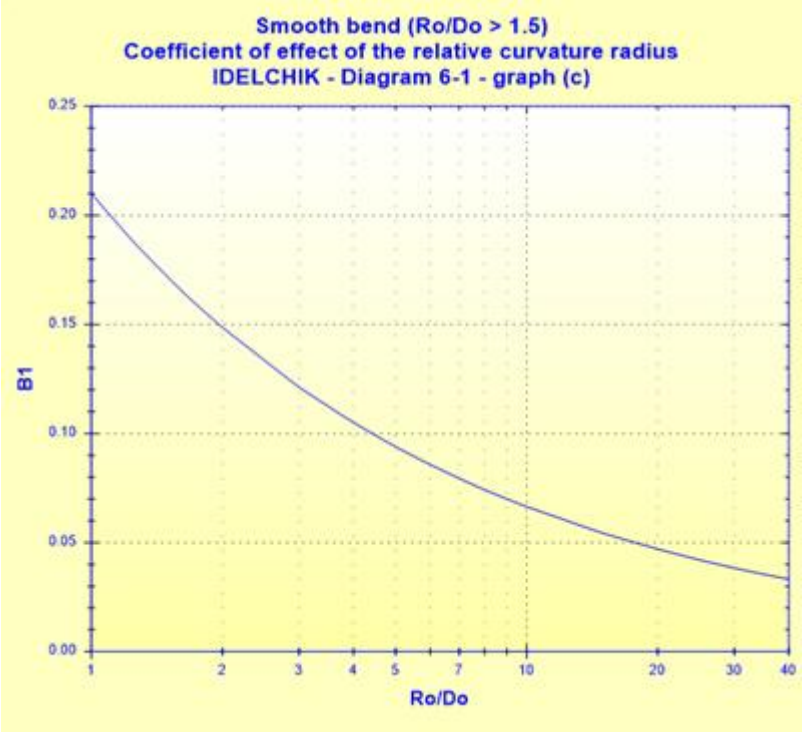
$$B1 = f\left(\frac{R_0}{D_h}\right)$$

([1] diagram 6.1)

- $0.5 \leq R_0/D_0 \leq 1.5$



- $R_0/D_0 > 1.5$



Coefficient of effect of the relative elongation of the cross section:

$$C1 = 1$$ ([1] diagram 6.1)

Coefficient of local resistance:

$$\zeta_{loc} = A1 \cdot B1 \cdot C1$$ ([1] diagram 6.1)

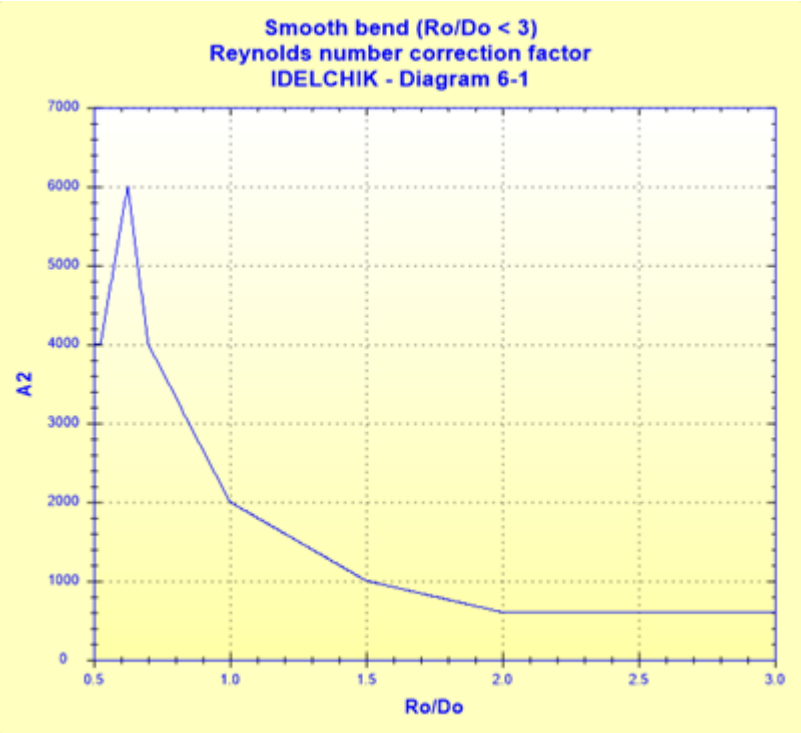
Pressure loss friction factor:

$$\zeta_{fr} = 0.0175 \cdot \delta \cdot \lambda \cdot \frac{R_0}{D_h}$$ ([1] diagram 6.1)

Reynolds number correction factor that depends on the relative curvature radius:

$$A2 = f\left(\frac{R_0}{D_0}\right)$$ ([1] diagram 6.1)

R_0/D_0	0.50 - 0.55	>0.55 - 0.70	>0.70 - 1.0	>1.0 - 2.0	>2.0
$A2 \times 10^{-3}$	4.0	6.0	4.0 - 2.0	1.0	0.6



Total pressure loss coefficient:

- $Re \geq 10^4$

$$\zeta = k_{\Delta} \cdot k_{Re} \cdot \zeta_{loc} + \zeta_{fr}$$ ([1] diagram 6.1)

- $3 \cdot 10^3 < Re < 10^4$

$$\zeta = \frac{A2}{Re} + \zeta_{loc} + \zeta_{fr}$$ ([1] diagram 6.1)

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_0}{\lambda}$$

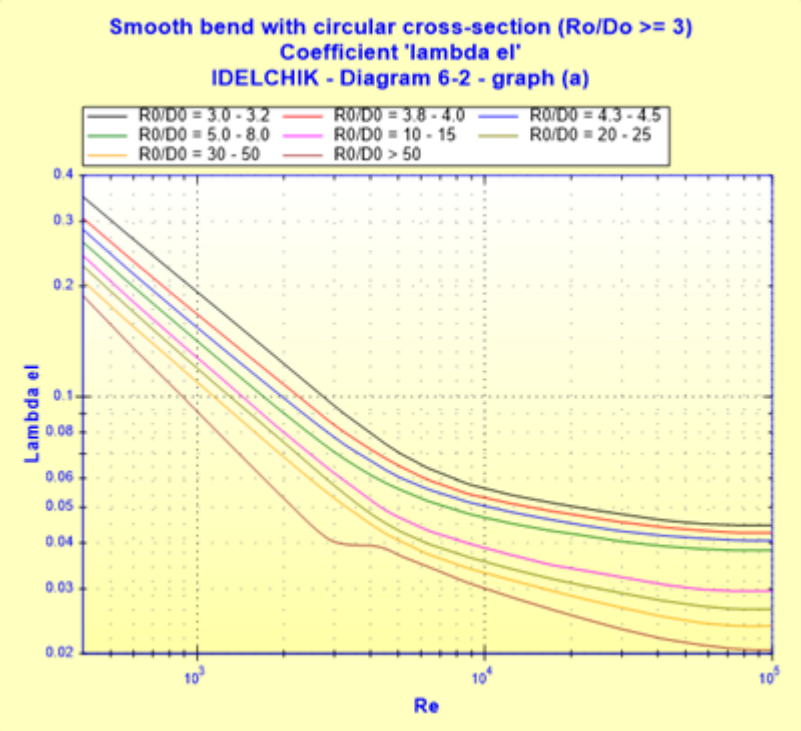
■ Case of relative radius of curvature greater than or equal to 3 ($R_0/D_0 \geq 3$) ([1] diagram 6.2)

Friction factor smooth wall:

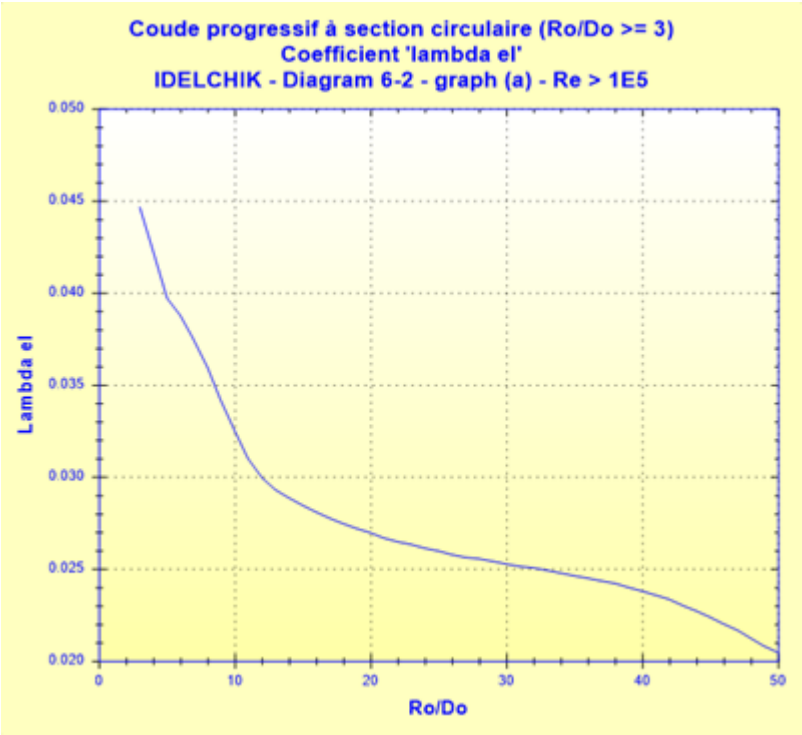
$$\lambda_{el} = f\left(\mathrm{Re}, \frac{R_0}{D_0}\right)$$

([1] diagram 6.2)

- Re < 10^5



- Re ≥ 10^5



Roughness correction factor:

$$C_f = \frac{\lambda_r}{\lambda_s}$$ ([2] equation 9.3)

with:

λ_r : Darcy friction factor for rough pipe ($\bar{\Delta} = \Delta/D_h$) at Re

λ_s : Darcy friction factor for hydraulically smooth pipe ($\bar{\Delta} = 0$) at Re

---

Pressure loss coefficient:

$$\zeta = 0.0175 \cdot \delta \cdot \lambda_{el} \cdot C_f \cdot \frac{R_0}{D_h}$$ ([1] diagram 6.2 & [2] equation 9.3)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$ ([1] diagram 6.1 – 6.2)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_0}{\lambda}$$

Symbols, Definitions, SI Units:

D_h Bend hydraulic diameter (m)

D_0 Bend internal diameter (m)

F_0	Cross-sectional area (m^2)
l	Length measured along the axis (m)
R_0	Radius of curvature (m)
δ	Curvature angle (°)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)
$\overline{\Delta}$	Relative roughness of walls ()
k_Δ	Coefficient that allows for the effect of the roughness ()
k_{Re}	Coefficient that allows for the effect of the Reynolds number ()
A1	Coefficient that allows for the effect of the angle ()
B1	Coefficient that allows for the effect of the relative curvature radius ()
C1	Coefficient that allows for the effect of the relative elongation of the cross section ()
ζ_{loc}	Coefficient of local resistance ()
λ	Darcy friction coefficient ()
ζ_{fr}	Pressure loss friction factor ()
ζ	Total pressure loss coefficient (based on the mean velocity in the bend) ()
L_{eq}	Straight length of equivalent pressure loss (m)
λ_{el}	Friction coefficient ()
C_f	Roughness correction factor ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- stabilized flow upstream bend
- length of the straight section downstream: $\geq 10\ D_0$
- curvature angle: 0 to 180°

■ case of relative radius of curvature lower than 3 ($R_0/D_0 < 3$)

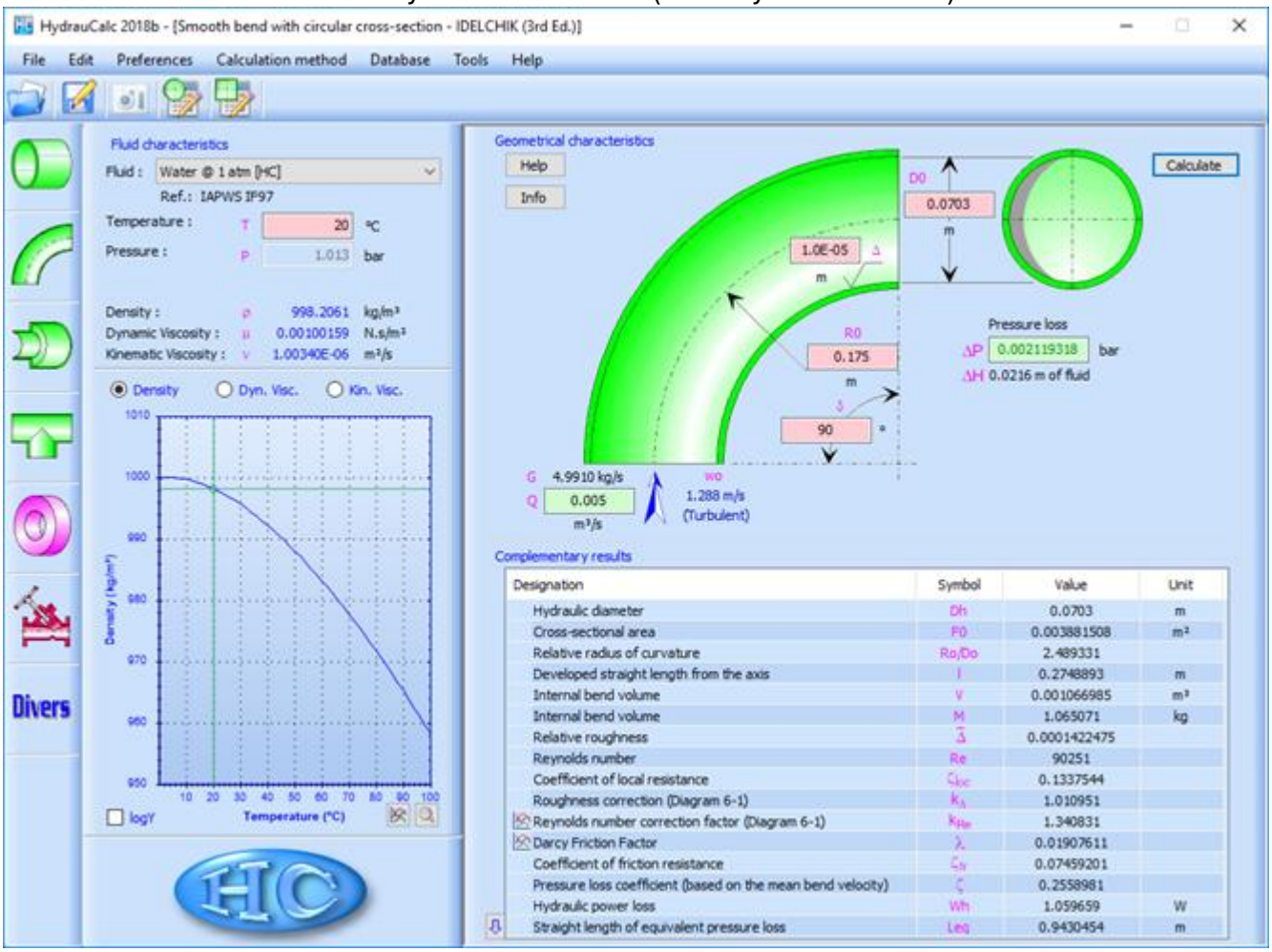
- flow regime: $Re \geq 3 \cdot 10^3$

■ case of relative radius of curvature greater than or equal to 3 ($R_0/D_0 \geq 3$)

- flow regime: $400 \leq Re \leq 10^5$

  for Reynolds number 'Re' lower than 400 the coefficient 'λ_{el}' is linearly extrapolated.

Example of application:

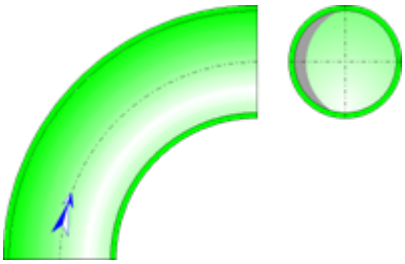


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

[2] Internal Flow System, Second Edition, D.S. Miller

2.2.1.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) of a bend smoothly curved whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

An option allows to take into account the effect of the straight length at the exit of the bend.

Model formulation:

Hydraulic diameter (m):

$$D = d$$

Cross-section area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Length measured along the axis (m):

$$L = 2 \cdot \pi \cdot r \cdot \frac{\theta_b}{360}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

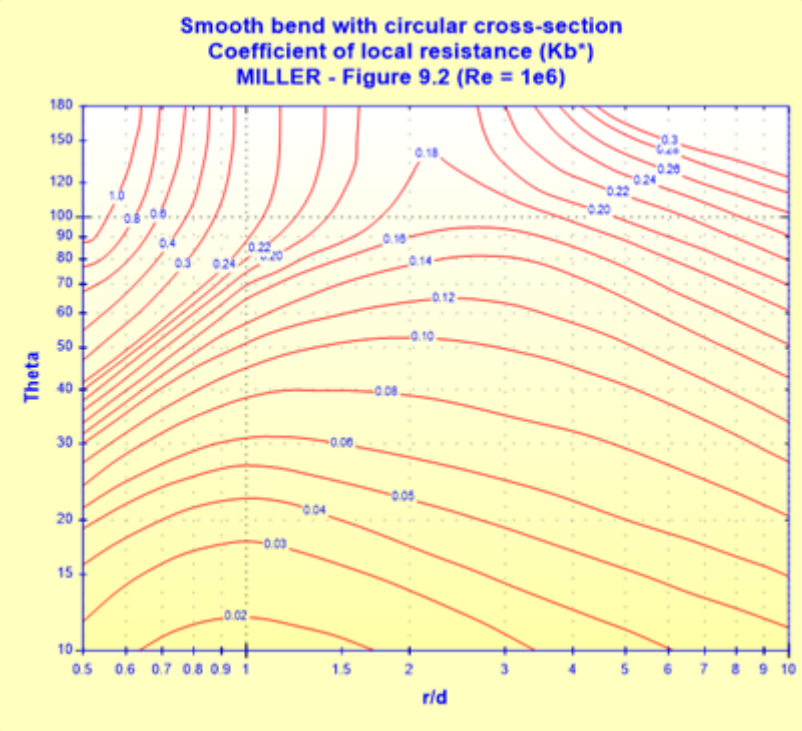
$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

Basic resistance coefficient:

$$K_b^* = f\left(\frac{r}{d}, \theta_b\right)$$ ([1] figure 9.2)



Reynolds number correction factor:

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$

([1] figure 9.3)

■ r/d ≥ 1

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3)

■ r/d < 1

● r/d > 0.7 or K_b^* < 0.4

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3 with r/d=1)

● otherwise (r/d ≤ 0.7 and K_b^* ≥ 0.4)

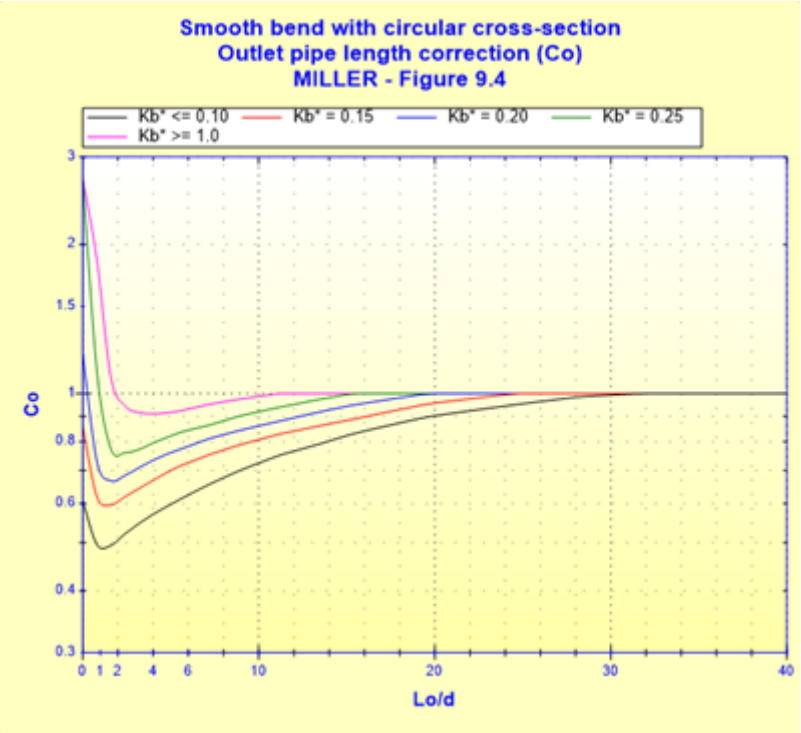
$$C_{Re} = \frac{K_b^*}{K_b^* - 0.2C'_{Re} + 0.2}$$ ([1] equation 9.2)

with:

$$C'_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3 with r/d=1)

Outlet pipe length correction factor (optional):

$$C_o = f\left(\frac{L_o}{d}, K_b^*\right)$$ ([1] figure 9.4)



■ r/d < 3 et θ_b < 100°

$$C_o = f\left(\frac{L_o}{d}, K_b^*\right)$$ ([1] figure 9.4)

- otherwise (r/d > 3 and/or $\theta_b > 100°$)

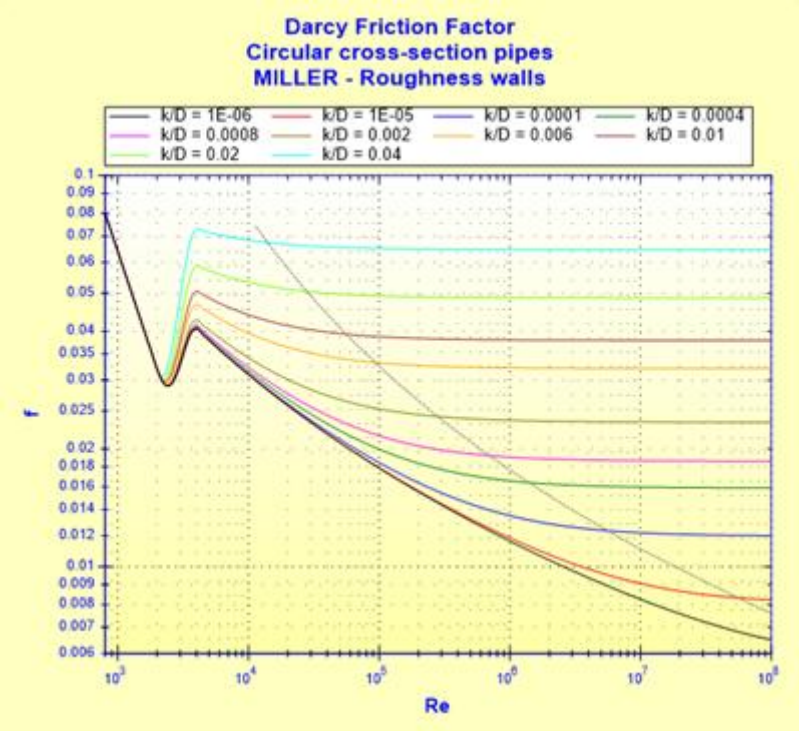
$$C_o = 1$$ (negligible effect)

If this option is not activated, the factor C_o is equal to unity.

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{D}\right)$$

See Straight Pipe - Circular Cross-Section and Roughness Walls (MILLER)



Roughness correction factor:

$$C_f = \frac{f_{rough}}{f_{smooth}}$$ ([1] equation 9.3)

with:

f_{rough}: Darcy friction factor for rough pipe at Re

f_{smooth}: Darcy friction factor for smooth pipe (k = 0) at Re

For Re > 10^6, C_f is calculated from equation (9.3) for Re = 10^6

Corrected loss coefficient:

$$K_b = K_b^* \cdot C_{Re} \cdot C_o \cdot C_f$$ ([1] equation 9.4)

Total pressure loss coefficient (based on the mean velocity in the bend)

$$K = K_b$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{d}{f_{rough}}$$

Symbols, Definitions, SI Units:

D	Bend hydraulic diameter (m)
d	Bend internal diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)

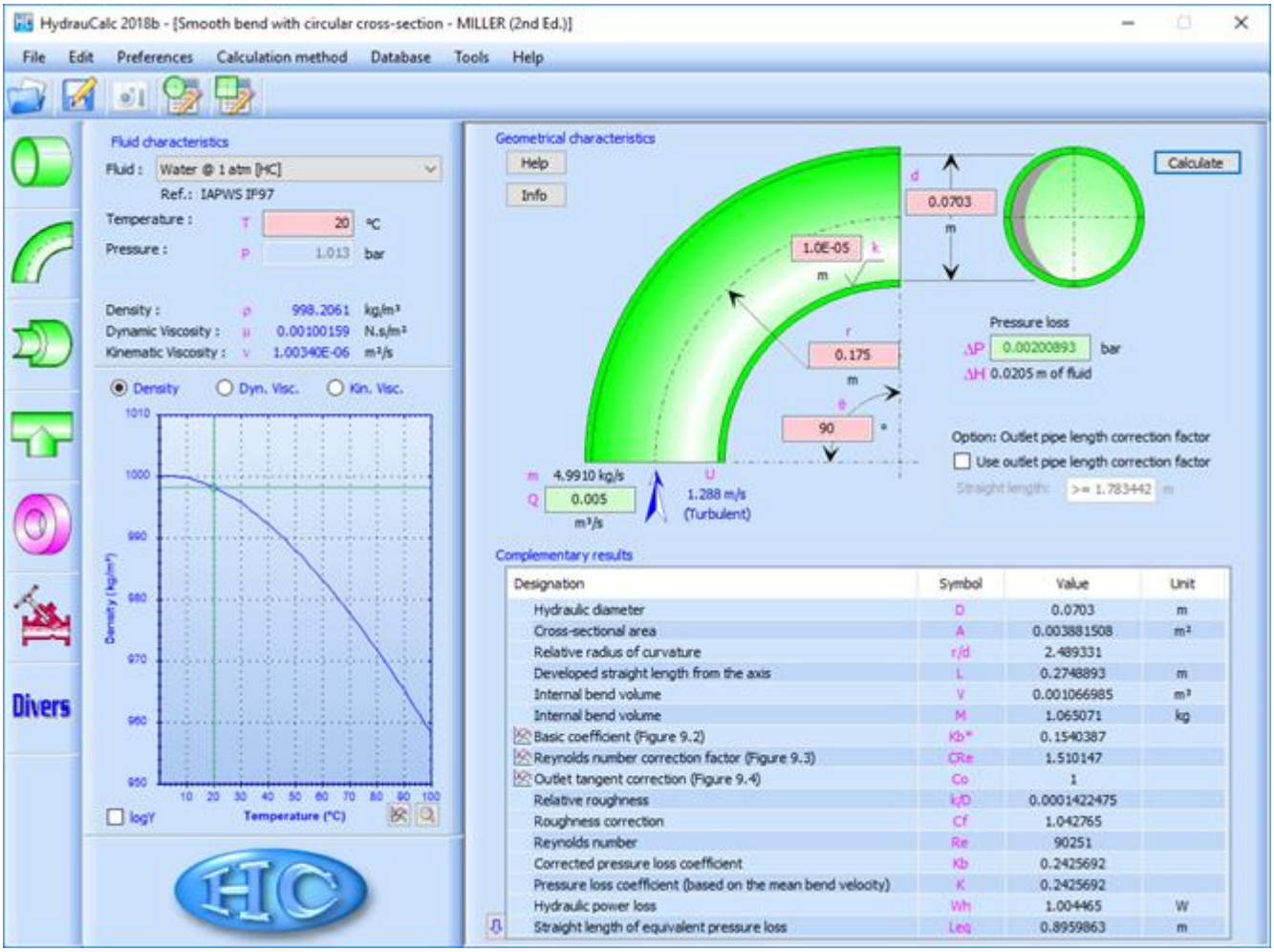
L	Length measured along the axis (m)
r	Radius of curvature (m)
θ_b	Curvature angle (°)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
K_b^*	Basic loss coefficient ()
C_{Re}	Reynolds number correction factor ()
C_o	Outlet pipe length correction factor ()
L_0	Length of the straight section downstream of the bend (m)
f	Darcy friction factor ()
k	Absolute roughness of walls (m)
C_f	Roughness correction factor ()
K_b	Corrected loss coefficient ()
K	Total pressure loss coefficient (based on the mean velocity in the bend) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
L_{eq}	Straight length of equivalent pressure loss (m)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)

- stabilized flow upstream bend
- curvature angle: 10 - 180°
- relative radius of curvature 'r/d': lower than 10

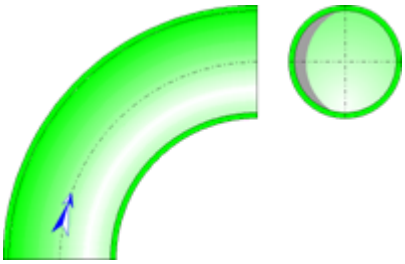
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.2.1.3 CRANE



Model description:

This model of component calculates the head loss (pressure drop) of a bend smoothly curved whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

Model formulation:

Cross-section area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity (m/s):

$$v = \frac{q}{A}$$

Length measured along the axis (m):

$$L = 2 \cdot \pi \cdot r \cdot \frac{\alpha}{360}$$

Mass flow rate (kg/s):

$$w = q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

$$M = Vol \cdot \rho_m$$

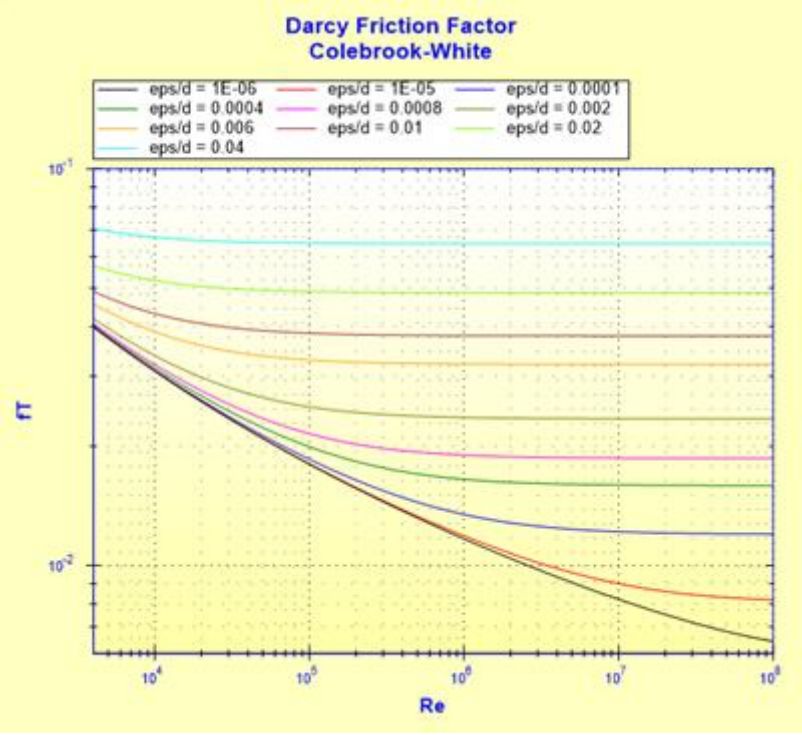
Reynolds number:

$$Re = \frac{v \cdot d}{\nu}$$

Darcy friction factor:

$$f_T = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d} + \frac{2.51}{Re \cdot \sqrt{f_T}}\right)\right]^2}$$

Colebrook-White equation

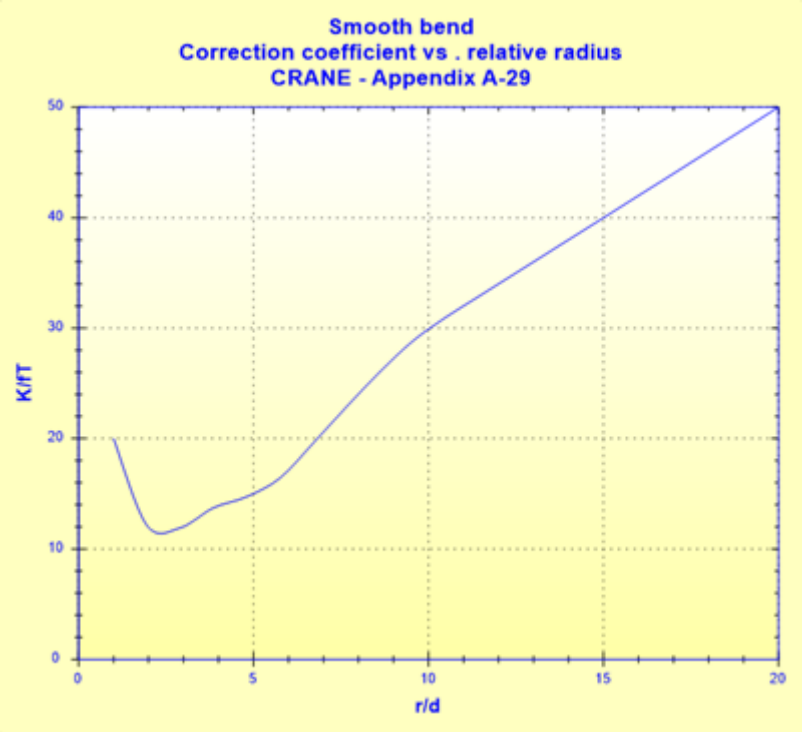


Resistance coefficient for one 90° smooth bend:

$$K = f\left(\frac{r}{d}, f_T\right)$$

([1] Appendix A-29)

r/d	K	K/f_T
1	20 f_T	20
1.5	14 f_T	14
2	12 f_T	12
3	12 f_T	12
4	14 f_T	14
6	17 f_T	17
8	24 f_T	24
10	30 f_T	30
12	34 f_T	34
14	38 f_T	38
16	42 f_T	42
20	50 f_T	50



Correction coefficient for angle lower than 90°:

$$K_{corr} = \alpha \cdot \left(0.0142 - 3.703 \cdot 10^{-5} \cdot \alpha\right)$$ ([2])

Total pressure loss coefficient (based on mean velocity in bend):

- $\alpha \geq 90°$

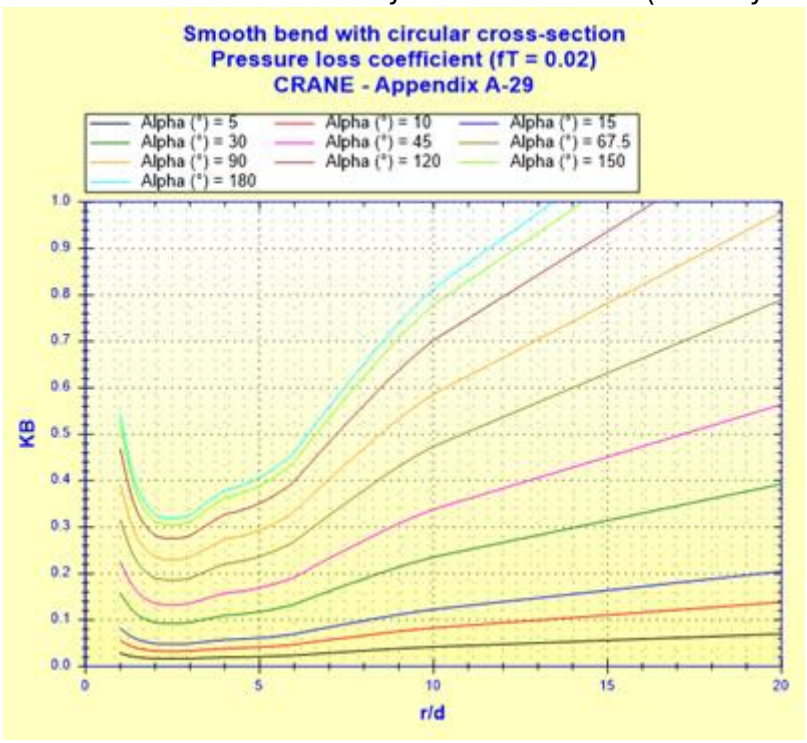
$$K_B = \left(\frac{\alpha}{90} - 1\right)\left(0.25 \cdot \pi \cdot f_T \cdot \frac{r}{d} + 0.5 \cdot K\right) + K$$

([1] Appendix A-29)

- $\alpha < 90°$

$$K_B = K \cdot K_{corr}$$

([[1] Appendix A-29 & [2])



(with $f_T = 0.02$)

(with $f_T = 0.02$)

Total pressure loss (Pa):

$$\Delta P = K_B \cdot \frac{\rho \cdot v^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K_B \cdot \frac{v^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K_B \cdot \frac{d}{f_T}$$

Symbols, Definitions, SI Units:

d	Pipe internal diameter (m)
A	Cross-section area (m^2)
q	Volume flow rate (m^3/s)
v	Mean velocity (m/s)
L	Length measured along the axis (m)
r	Radius of curvature (m)
α	Curvature angle (°)
w	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
f_T	Darcy friction factor ()
ε	Absolute roughness of walls (m)
K	Resistance coefficient for one 90° smooth bend ()
K_{corr}	Correction coefficient for angle lower than 90° ()
K_B	Total pressure loss coefficient (based on mean velocity in bend) ()
ΔP	Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

L_{eq} Straight length of equivalent pressure loss (m)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

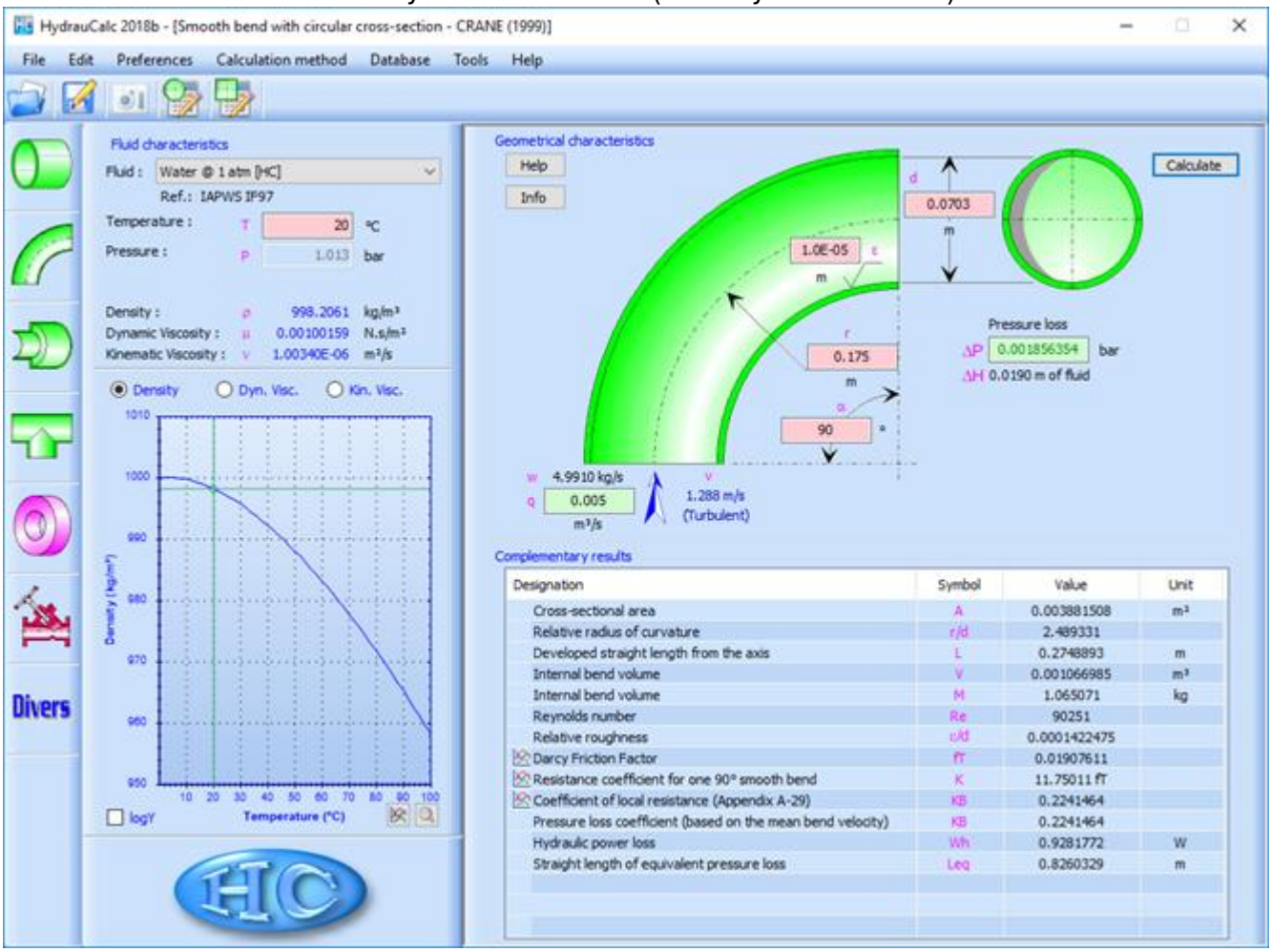
g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream of the bend
- curvature angle between 0° and 180°
- relative radius of curvature (r/d) range between 1 and 20

  for relative radii 'r/d' between 0.5 and 1 or those greater than 20, the coefficient 'K' is linearly extrapolated.

Example of application:

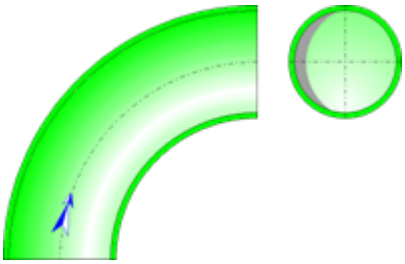


References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999

[2] George R. Keller, Hydraulic System Analysis, Published by the Editors of Hydraulics & Pneumatics Magazine, 1970

2.2.1.4 Pipe Flow - Guide



Model description:

This model of component calculates the head loss (pressure drop) of a bend smoothly curved whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

Model formulation:

Cross-section area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity (m/s):

$$V = \frac{Q}{A}$$

Length measured along the axis (m):

$$L = 2 \cdot \pi \cdot r \cdot \frac{\alpha}{360}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Fluid volume (m^3):

$$Vol = A \cdot L$$

Fluid mass (kg):

$$Mas = Vol \cdot \rho_m$$

Reynolds number:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

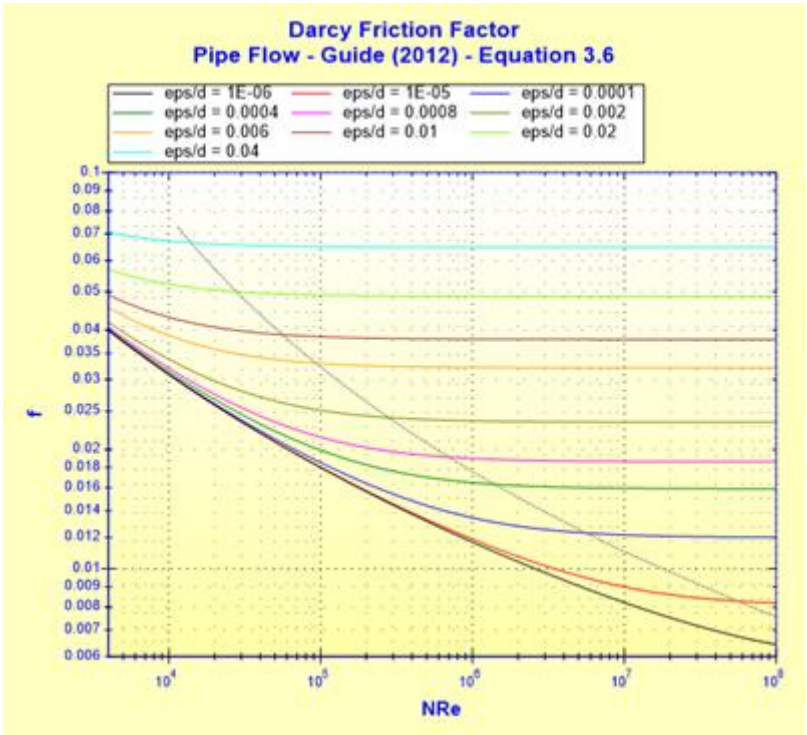
Relative roughness:

$$R_r = \frac{\varepsilon}{d}$$

Darcy friction factor:

$$f = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d} + \frac{2.51}{N_{Re} \cdot \sqrt{f}}\right)\right]^2}$$

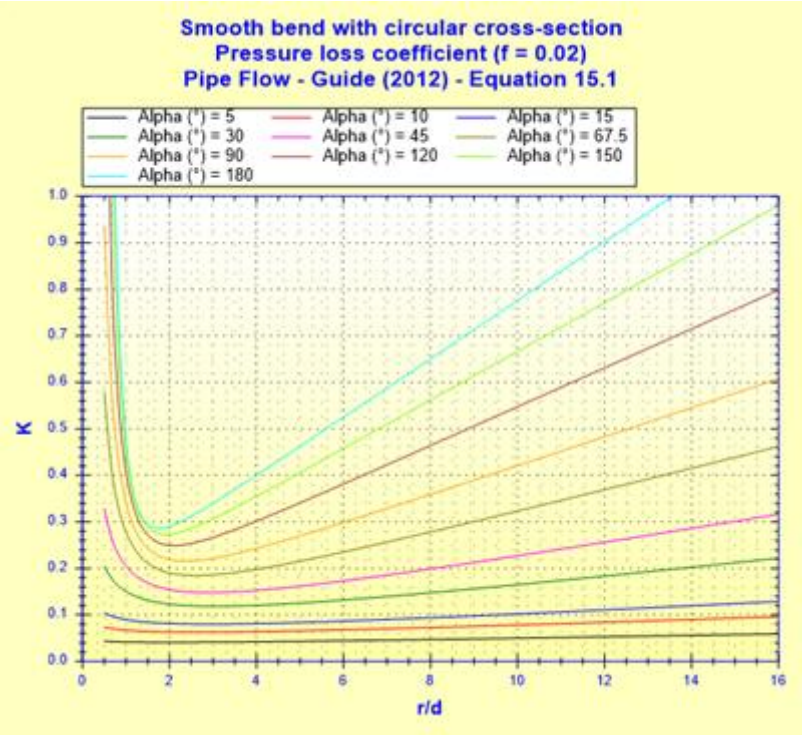
Colebrook-White equation ([1] equation 3.6)



Total pressure loss coefficient (based on mean velocity in bend):

$$K = f \cdot \alpha \cdot \frac{r}{d} + (0.10 + 2.4 \cdot f) \cdot \sin(\alpha/2) + \frac{6.6 \cdot f \cdot \left(\sqrt{\sin(\alpha/2)} + \sin(\alpha/2)\right)}{\left(\frac{r}{d}\right)^{\frac{4 \cdot \alpha}{\pi}}}$$

([1] equation 15.1)



([1] equation 15.1 with f = 0.02)

([1] equation 15.1 with f = 0.02)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{d}{f}$$

Symbols, Definitions, SI Units:

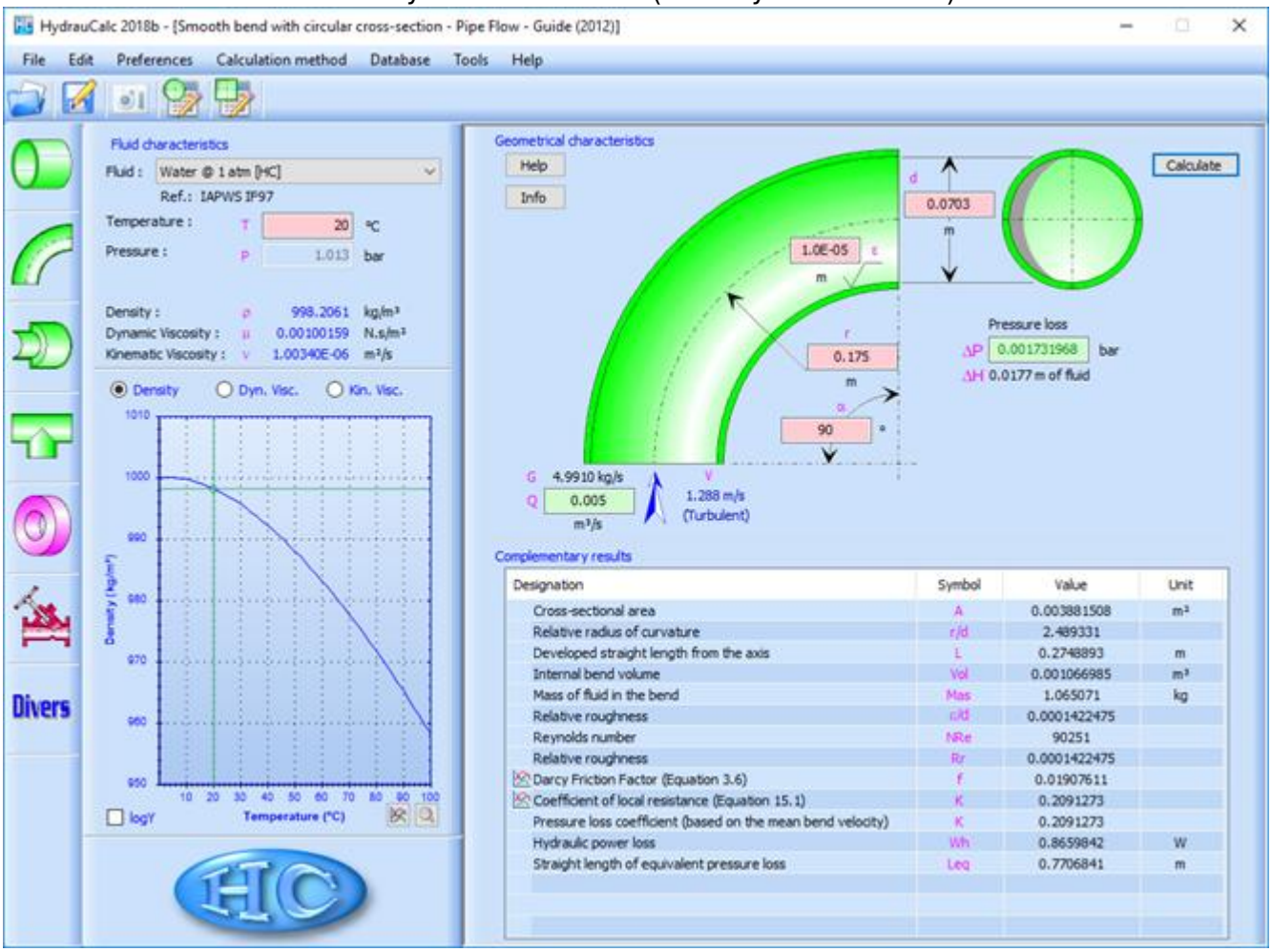
d	Bend internal diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
V	Mean velocity (m/s)
L	Length measured along the axis (m)
r	Radius of curvature (m)
α	Curvature angle (°)
G	Mass flow rate (kg/s)
Vol	Fluid volume (m^3)
Mas	Fluid mass (kg)
N_{Re}	Reynolds number ()
R_r	Relative roughness ()
ε	Absolute roughness of walls (m)

f	Darcy friction factor ()
K	Total pressure loss coefficient (based on mean velocity in bend) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
L_{eq}	Straight length of equivalent pressure loss (m)
ρ_m	Fluid density (kg/m³)
ν	Fluid kinematic viscosity (m²/s)
g	Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($N_{Re} \geq 10^4$)
- stabilized flow upstream of the bend
- curvature angle between 0° and 180°

Example of application:



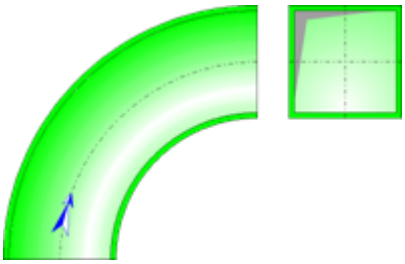
References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.2.2 Smooth Bend - Rectangular cross-section

Smooth Bend

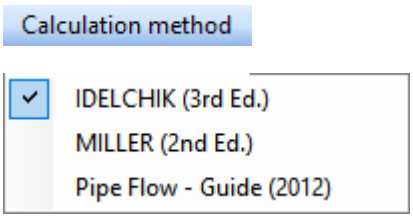
Rectangular Cross-Section



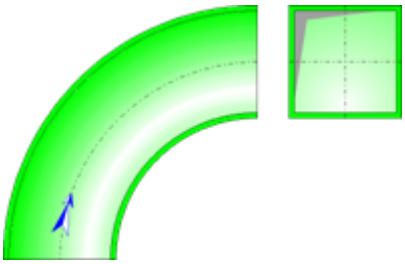
For the calculation of the pressure loss coefficient of smooth bends with rectangular cross-section, the user can choose from one of the methods described in the following three reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.2.2.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) of a bend smoothly curved whose cross-section is rectangular and constant. In addition, the flow is assumed fully developed and stabilized à the entrance bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = \frac{2 \cdot a_0 \cdot b_0}{a_0 + b_0}$$ ([1] diagram 6-1)

Cross-section area (m^2):

$$F_0 = a_0 \cdot b_0$$

Length measured along the axis (m):

$$l = 2 \cdot \pi \cdot R_0 \cdot \frac{\delta}{360}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = F_0 \cdot l$$

Fluid mass (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

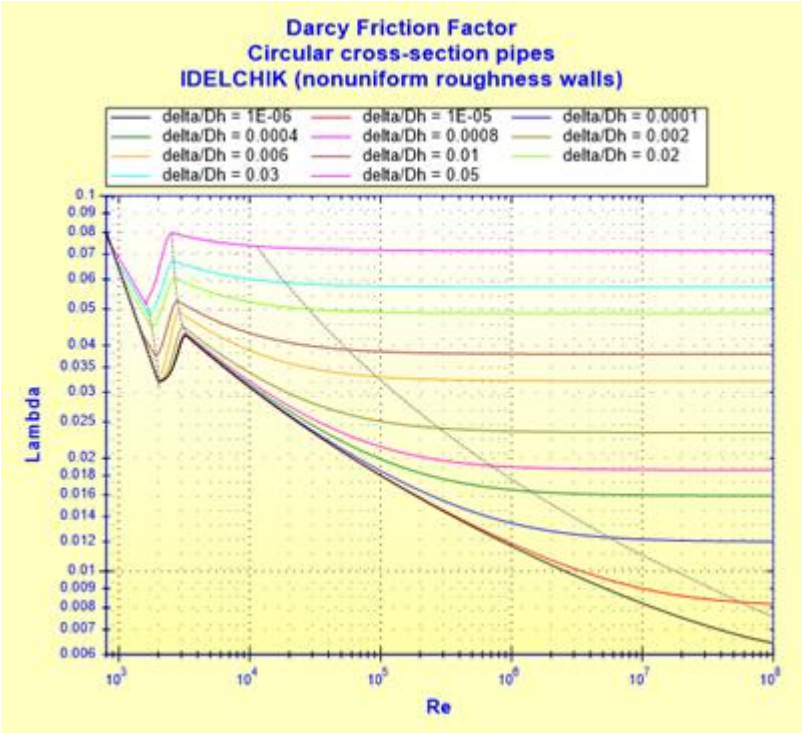
$$\bar{\Delta} = \frac{\Delta}{D_h}$$

Darcy friction factor:

See Straight Pipe - Rectangular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)

- Darcy friction factor for circular cross-section

$$\lambda_{circ} = f\left(Re, \frac{\Delta}{D_h}\right)$$



■ Correction for Darcy friction factor for noncircular cross-section

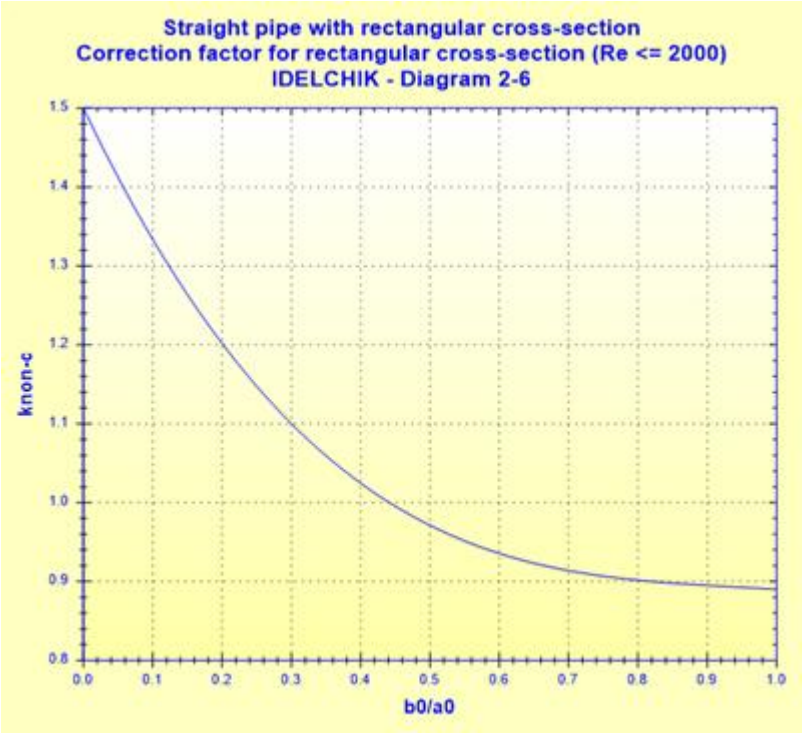
♦ $a_0 \geq b_0$

$$k_{non-c} = f(b_0/a_0)$$ ([1] diagram 2.6)

♦ $a_0 < b_0$

$$k_{non-c} = f(a_0/b_0)$$ ([1] diagram 2.6)

● laminar flow (Re ≤ 2000):



- turbulent flow (Re > 2000):

■ Darcy friction factor for rectangular cross-section

$$\lambda_{rect} = \lambda_{circ} \cdot K_{non-c}$$ ([1] diagram 2.6)

■ Case of relative radius of curvature lower than 3 ($R_0/b_0 < 3$) ([1] diagram 6-1)

Coefficient of effect of the roughness:

$$k_\Delta = f\left(\frac{R_0}{b_0}, \mathrm{Re}, \overline{\Delta}\right)$$ ([1] diagram 6-1)

- $0.50 \le R_0/b_0 \le 0.55$

$\overline{\Delta}$	Re	
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$
0	1.0	1.0
0 - 0.001	1.0	$1 + 0.5 \cdot 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	1.5

- $R_0/b_0 > 0.55$

$\overline{\Delta}$	Re		
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$ - $2 \cdot 10^5$	> $2 \cdot 10^5$
0	1.0	1.0	1.0
0 - 0.001	1.0	$\lambda_\Delta / \lambda_{sm}$	$1 + 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	2.0	2.0

with:

λ_{sm} : Darcy friction factor for hydraulically smooth pipe ($\overline{\Delta} = 0$) at Re

λ_Δ : Darcy friction factor for rough pipe ($\overline{\Delta} = \Delta/D_h$) at Re

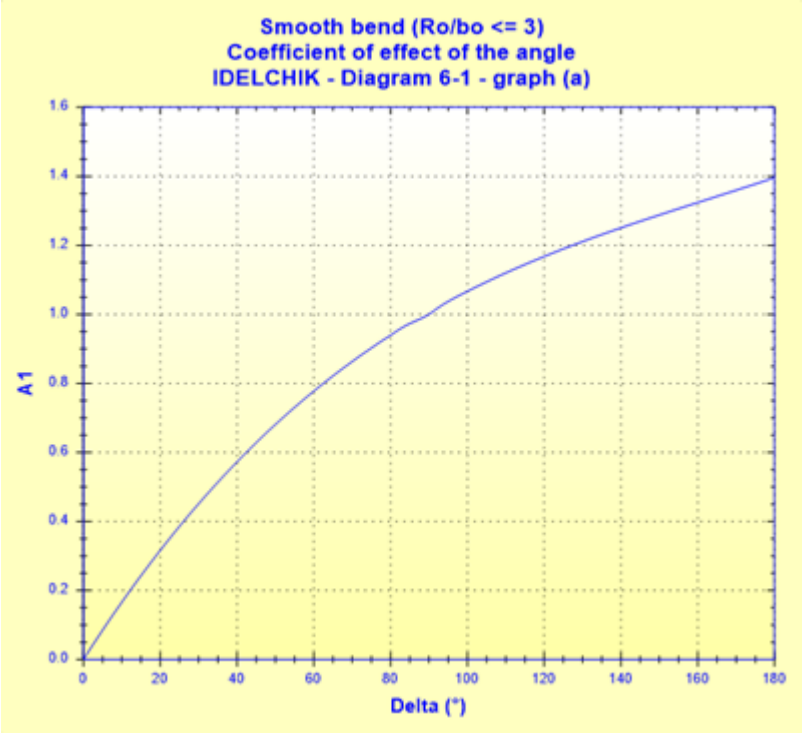
---

Coefficient of effect of the Reynolds number ($Re \ge 10^4$):

$$k_{Re} = f\left(\mathrm{Re}, \frac{R_0}{b_0}\right)$$ ([1] diagram 6-1)

Coefficient of effect of the angle:

$A1 = f(\delta)$ ([1] diagram 6-1)



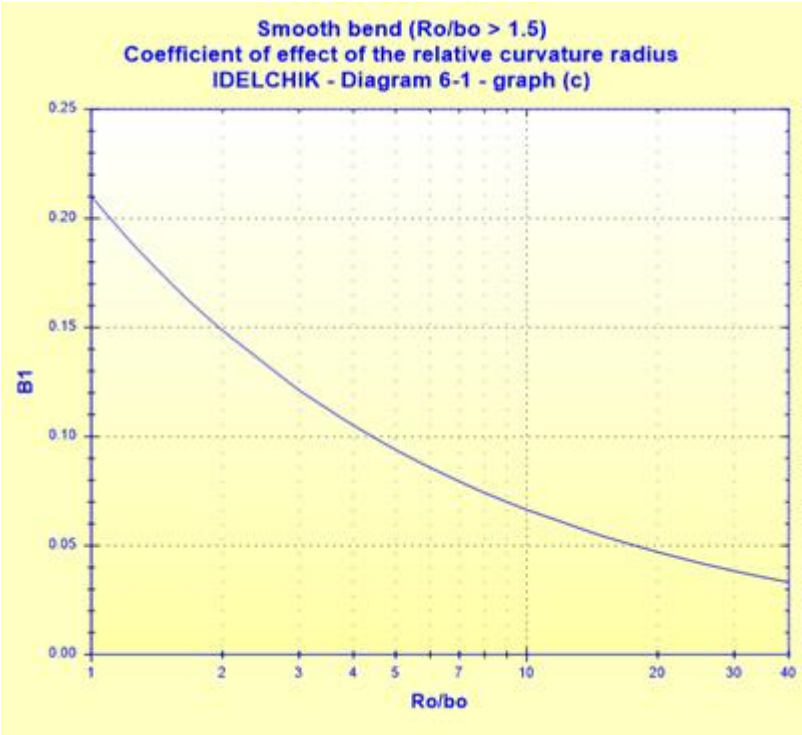
Coefficient of effect of the relative curvature radius:

$$B1 = f\left(\frac{R_0}{b_0}\right)$$

([1] diagram 6-1)

- $0.5 \le R_0/b_0 \le 1.5$

- $R_0/b_0 > 1.5$



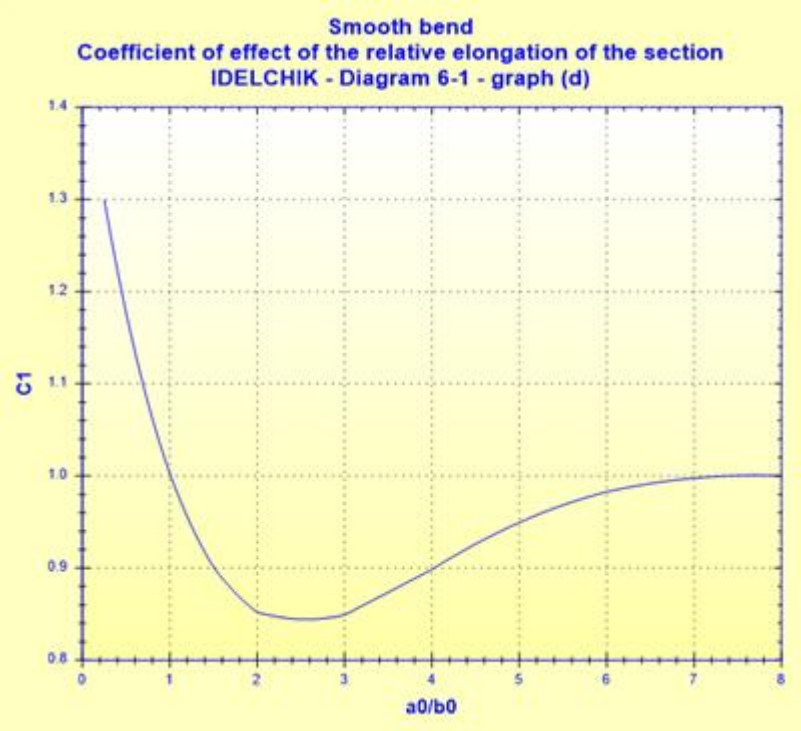
Coefficient of effect of the relative elongation of the cross section:

- $a_0 \geq b_0$

$$C1 = f\left(\frac{a_0}{b_0}\right)$$ ([1] diagram 6.1)

- $a_0 < b_0$

$$C1 = f\left(\frac{b_0}{a_0}\right)$$ ([1] diagram 6.1)



Coefficient of local resistance:

$$\zeta_{loc} = A1 \cdot B1 \cdot C1$$ ([1] diagram 6-1)

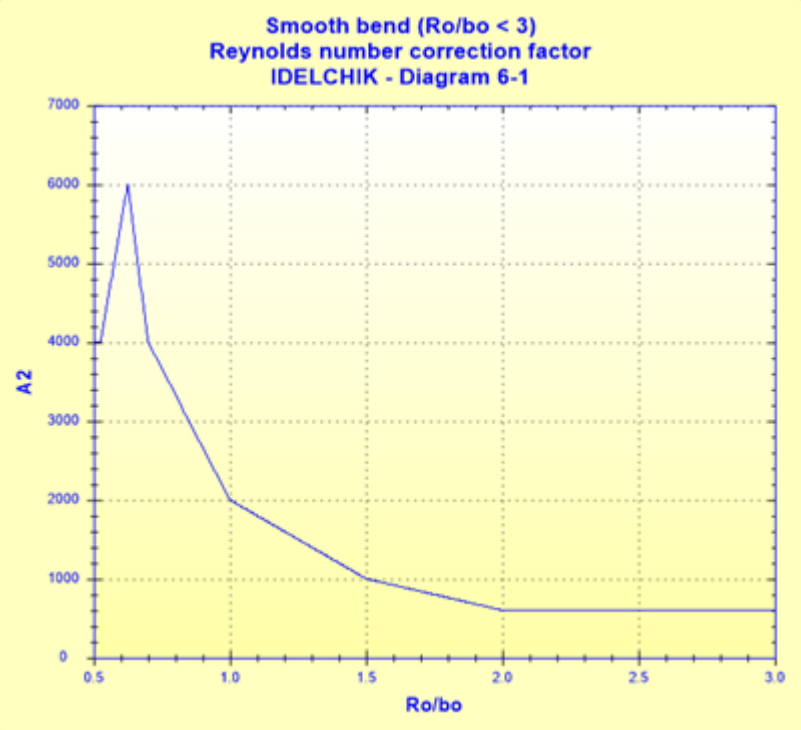
Pressure loss friction factor:

$$\zeta_{fr} = 0.0175 \cdot \delta \cdot \lambda_{rect} \cdot \frac{R_0}{D_h}$$ ([1] diagram 6-1)

Reynolds number correction factor that depends on the relative curvature radius:

$$A2 = f\left(\frac{R_0}{b_0}\right)$$ ([1] diagram 6.1)

R_0/b_0	0.50 - 0.55	>0.55 - 0.70	>0.70 - 1.0	>1.0 - 2.0	>2.0
$A2 \times 10^{-3}$	4.0	6.0	4.0 - 2.0	1.0	0.6



Total pressure loss coefficient:

- $Re \geq 10^4$

$$\zeta = k_{\Delta} \cdot k_{Re} \cdot \zeta_{loc} + \zeta_{fr}$$ ([1] diagram 6-1)

- $3 \cdot 10^3 < Re < 10^4$

$$\zeta = \frac{A2}{Re} + \zeta_{loc} + \zeta_{fr}$$ ([1] diagram 6-1)

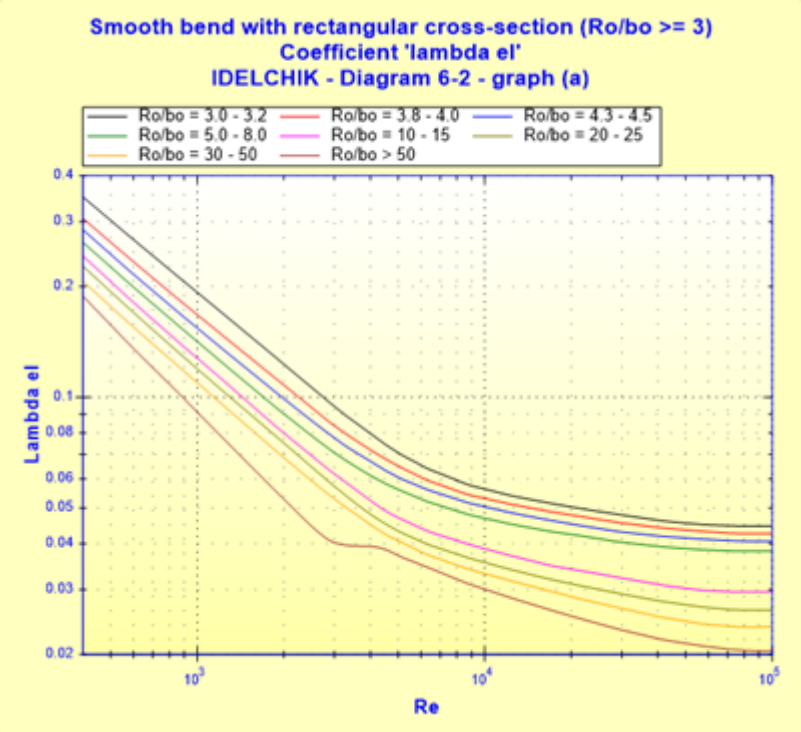
■ Case of relative radius of curvature greater than or equal to 3 ($R_0/b_0 \geq 3$) ([1] diagram 6-2)

Friction factor smooth wall:

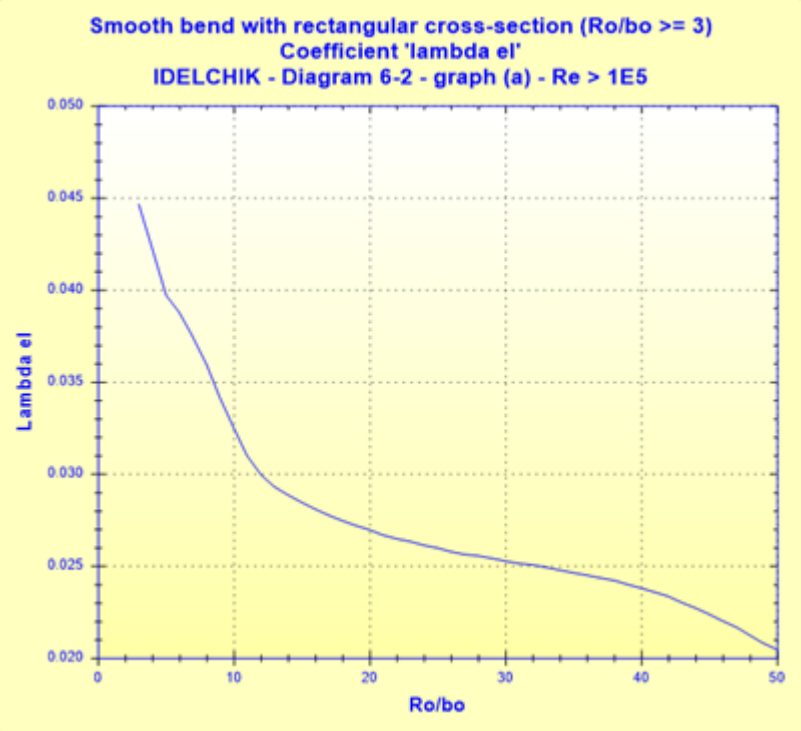
$$\lambda_{el} = f\left(\mathrm{Re}, \frac{R_0}{b_0}\right)$$

([1] diagram 6.2)

- Re < 10^5



- Re ≥ 10^5



Roughness correction factor:

$$C_f = \frac{\lambda_r}{\lambda_s}$$ ([2] equation 9-3)

with:

λ_r : Darcy friction factor for rough pipe ($\overline{\Delta} = \Delta/D_h$) at Re

λ_s : Darcy friction factor for hydraulically smooth pipe ($\overline{\Delta} = 0$) at Re

---

Pressure loss coefficient (based on the mean velocity in the bend):

$$\zeta = 0.0175 \cdot \delta \cdot \lambda_{el} \cdot C_f \cdot \frac{R_0}{D_h}$$ ([1] diagram 6-2 & [2] equation 9.3)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$ ([1] diagram 6-1 – 6-2)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_h}{\lambda_{rect}}$$

Symbols, Definitions, SI Units:

a_0	Rectangular cross-section width (m)
b_0	Rectangular cross-section height (m)
D_h	Bend hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
l	Length measured along the axis (m)
R_0	Radius of curvature (m)
δ	Curvature angle (°)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)
$\overline{\Delta}$	Relative roughness of walls ()
λ_{circ}	Darcy friction coefficient for circular cross-section ()
λ_{rect}	Darcy friction coefficient for rectangular cross-section ()

k_{non-c} Correction for Darcy friction factor for noncircular cross-section ()

k_{Δ} Coefficient that allows for the effect of the roughness ()

k_{Re} Coefficient that allows for the effect of the Reynolds number ()

A1 Coefficient that allows for the effect of the angle ()

B1 Coefficient that allows for the effect of the relative curvature radius ()

C1 Coefficient that allows for the effect of the relative elongation of the cross section ()

ζ_{loc} Coefficient of local resistance ()

ζ_{fr} Pressure loss friction factor ()

A2 Reynolds number correction factor that depends on the relative curvature radius ()

ζ Total pressure loss coefficient (based on the mean velocity in the bend) ()

L_{eq} Straight length of equivalent pressure loss (m)

λ_{el} Friction coefficient ()

A_{lam} Laminar coefficient ()

A_{tur} Turbulent coefficient ()

C_f Roughness correction factor ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- stabilized flow upstream bend
- length of the straight section downstream: $\geq 10\ D_h$

- curvature angle: 0 to 180°

■ case of relative radius of curvature lower than 3 ($R_0/b_0 < 3$)

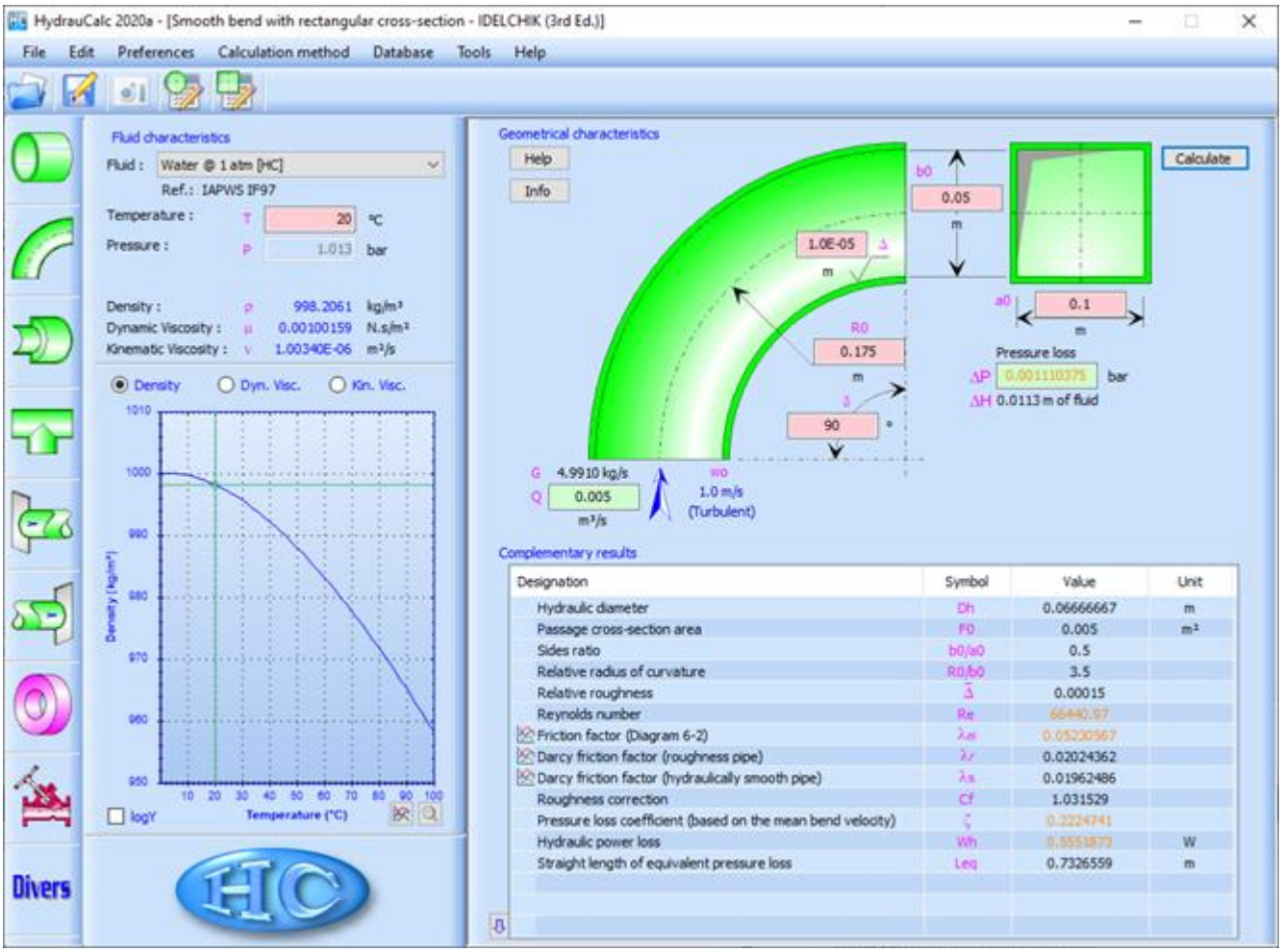
- flow regime: $Re \geq 3 \cdot 10^3$

■ case of relative radius of curvature greater than or equal to 3 ($R_0/b_0 \geq 3$)

- flow regime: $500 \leq Re \leq 38 \cdot 10^3$

  for Reynolds number 'Re' lower than 400 the coefficient 'λ_{el}' is linearly extrapolated.

Example of application:

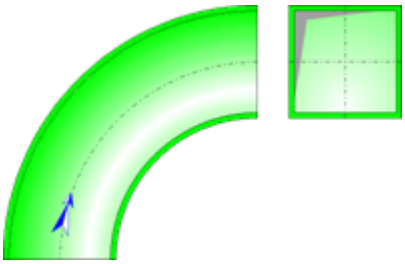


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

[2] Internal Flow System, Second Edition, D.S. Miller

2.2.2.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) of a bend smoothly curved whose cross-section is rectangular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

An option allows to take into account the effect of the straight length at the exit of the bend.

Model formulation:

Hydraulic diameter (m):

$$D = \frac{2 \cdot b \cdot W}{b + W}$$ ([1] equation 9.5)

Cross-section area (m^2):

$$A = b \cdot W$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Length measured along the axis (m):

$$L = 2 \cdot \pi \cdot r \cdot \frac{\theta_b}{360}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

$$M = V \cdot \rho$$

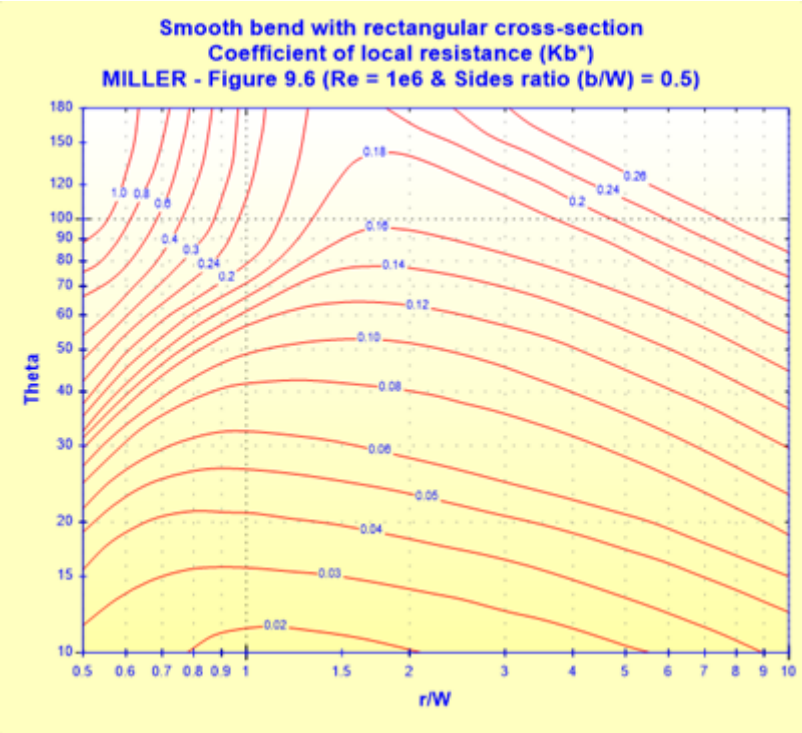
Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$ ([1] equation 9.6)

Basic resistance coefficient:

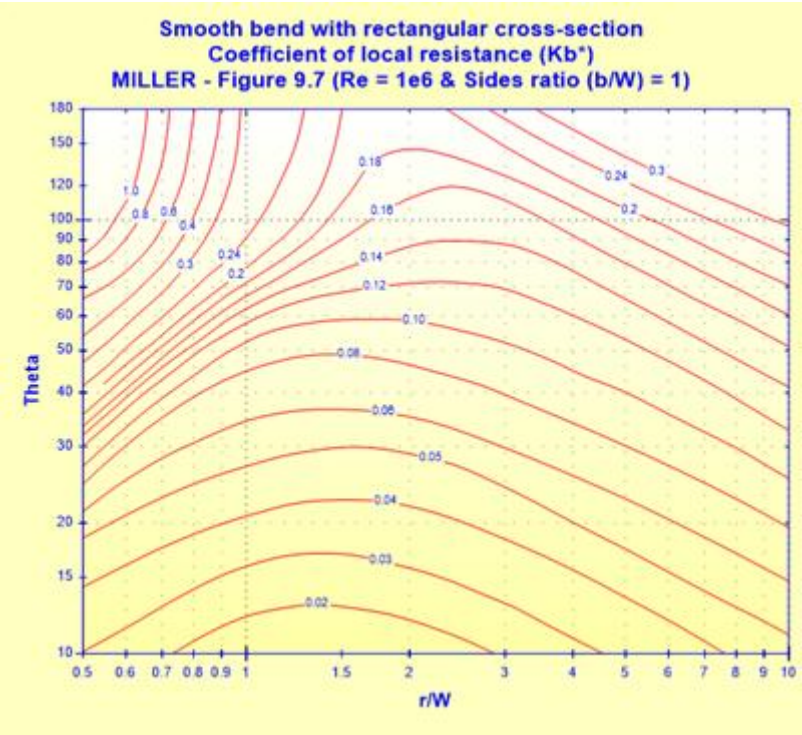
$$K_b^* = f\left(\frac{r}{W}, \theta_b\right)$$ ([1] figures 9.6 – 9.7 – 9.8)

- Sides ratio b/W = 0.5



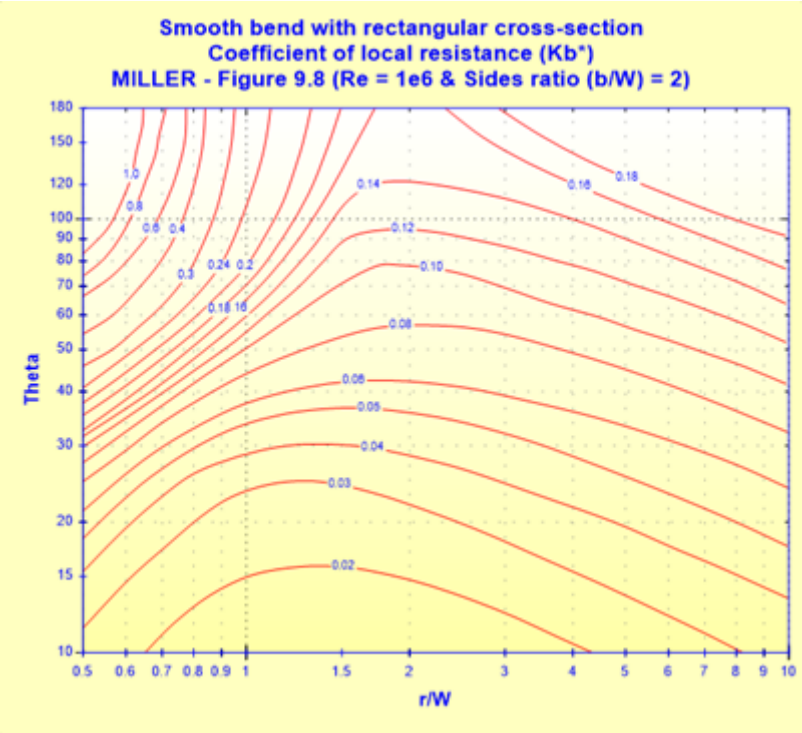
([1] figure 9.6)

■ Sides ratio b/W = 1



([1] figure 9.7)

■ Sides ratio b/W = 2



([1] figure 9.8)

For any sides ratio 'b/W' between 0.5 and 2, the coefficient K_b^* is obtained by curvilinear interpolation between the values of K_b^* calculated for aspect ratios of 0.5, 1 and 2.

Reynolds number correction factor:

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{W}\right)$$

([1] figure 9.3)

- $r/W \geq 1$

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{D}\right)$$ ([1] figure 9.3)

- $r/W < 1$
  - $r/W > 0.7$ or $K_b^* < 0.4$

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{D}\right)$$ ([1] figure 9.3 with r/W=1)

  - otherwise ($r/W \leq 0.7$ and $K_b^* \geq 0.4$)

$$C_{Re} = \frac{K_b^*}{K_b^* - 0.2C'_{Re} + 0.2}$$ ([1] equation 9.2)

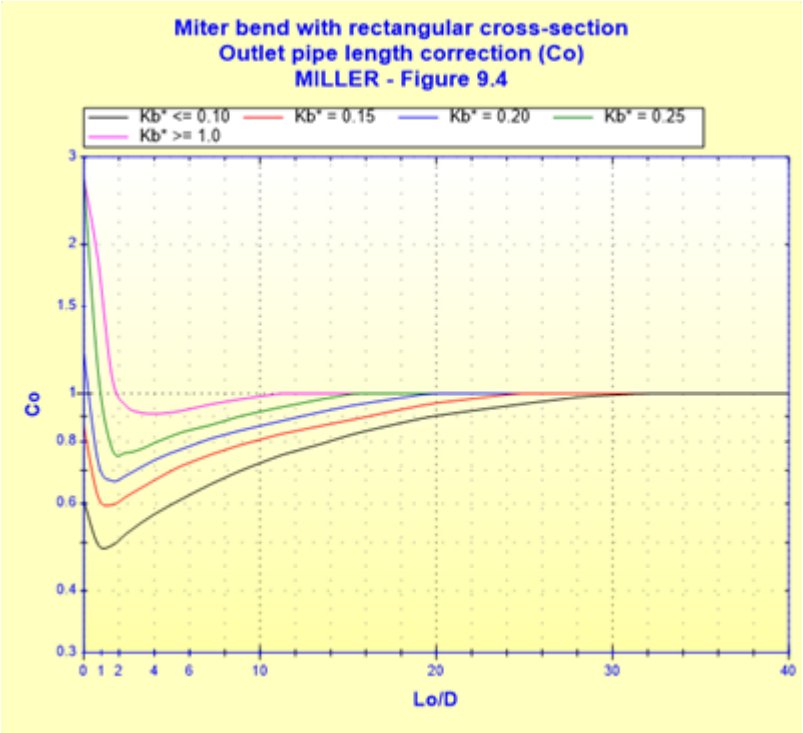
with:

$$C'_{Re} = f\left(\mathrm{Re}, \frac{r}{D}\right)$$ ([1] figure 9.3 with r/W=1)

Outlet pipe length correction factor (optional):

- correction factor for circular cross-section
  - $\theta_b < 100°$

$$C_o = f\left(\frac{L_o}{D}, K_b^*\right)$$ ([1] figure 9.4)



- $\theta_b \geq 100°$

$$C_o = 1$$ (negligible effect)

■ correction factor for rectangular cross-section

- b/W < 0.7 and Lo/D > 1

$$C_{or} = 1 - \frac{1 - C_o}{2}$$

- b/W > 1 and Lo/D < 1
  - ♦ 1.5 < r/W < 3

$$C_{or} = 2$$

  - ♦ r/W ≤ 1.5 or r/W ≥ 3

$$C_{or} = C_o$$

- otherwise

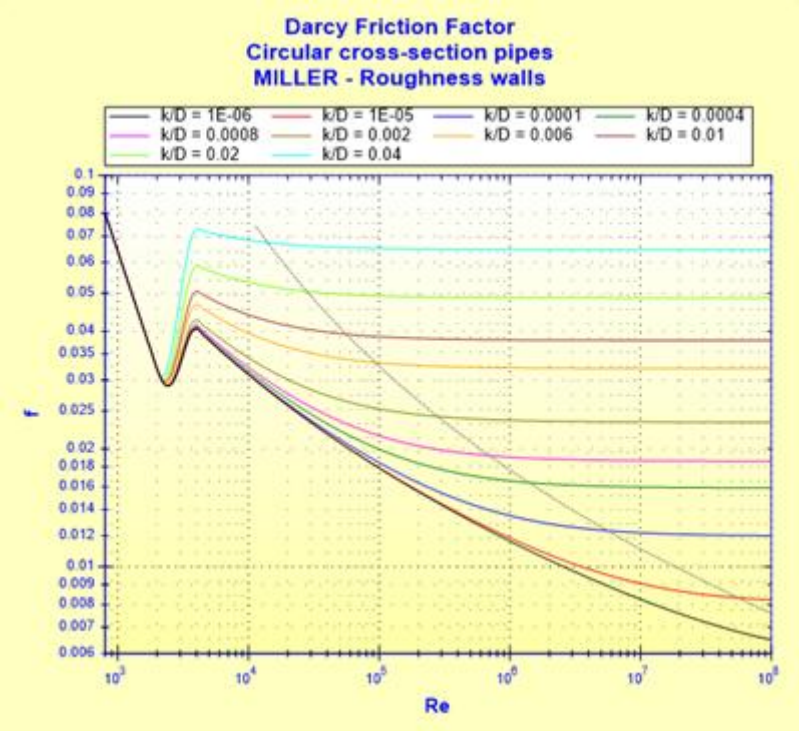
$$C_{or} = C_o$$

If this option is not activated, the factors C_o and C_{or} are equal to unity.

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{D}\right)$$

See Straight Pipe - Rectangular Cross-Section and Roughness Walls (MILLER)



Roughness correction factor:

$$C_f = \frac{f_{rough}}{f_{smooth}}$$ ([1] equation 9.3)

with:

f_{rough}: Darcy friction factor for rough pipe at Re

f_{smooth}: Darcy friction factor for smooth pipe (k = 0) at Re

For Re > 10^6, C_f is calculated from equation (9.3) for Re = 10^6

Corrected loss coefficient:

$$K_b = K_b^* \cdot C_{Re} \cdot C_{or} \cdot C_f$$ ([1] equation 9.4)

Total pressure loss coefficient (based on the mean velocity in the bend)

$$K = K_b$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{D}{f_{rough}}$$

Symbols, Definitions, SI Units:

W	Cross-section height (m)
b	Cross-section width (m)
D	Bend hydraulic diameter (m)
d	Bend internal diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
L	Length measured along the axis (m)
r	Radius of curvature (m)
θ_b	Curvature angle (°)

G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
K_b^*	Basic loss coefficient ()
C_{Re}	Reynolds number correction factor ()
C_o	Outlet pipe length correction factor for circular cross-section ()
C_{or}	Outlet pipe length correction factor for rectangular cross-section ()
L_0	Length of the straight section downstream of the bend (m)
f	Darcy friction factor ()
k	Absolute roughness of walls (m)
C_f	Roughness correction factor ()
K_b	Corrected loss coefficient ()
K	Total pressure loss coefficient (based on the mean velocity in the bend) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
L_{eq}	Straight length of equivalent pressure loss (m)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

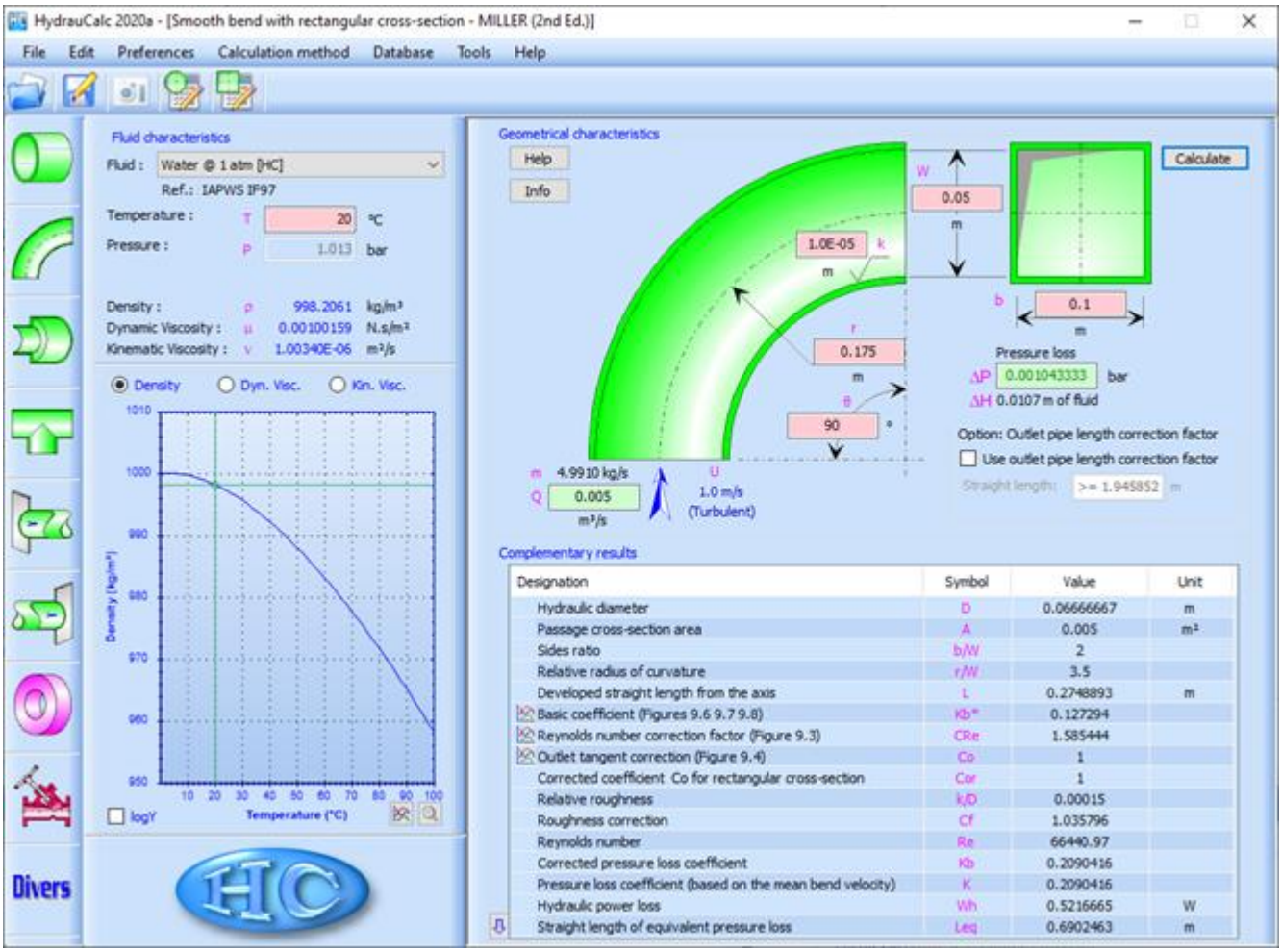
- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream bend
- curvature angle: between 10° and 180°
- relative radius of curvature 'r/W': between 0.5 and 10

- sides ratio 'b/W': between 0.5 and 2

  note: for any sides ratio 'b/W' less than 0.5, the resistance coefficients K_b^* are obtained by linear extrapolation from the values of K_b^* calculated for sides ratios of 0.5 and 1.

  for any sides ratio 'b/W' greater than 0.5 and 2, the resistance coefficients K_b^* are obtained by linear extrapolation from the values of K_b^* calculated for sides ratios of 0.5 and 1.

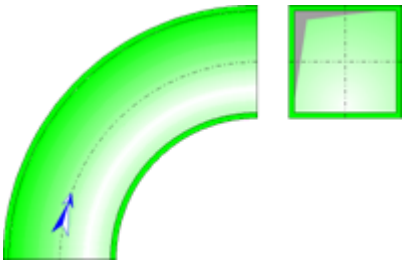
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.2.2.3 Pipe Flow - Guide



Model description:

This model of component calculates the head loss (pressure drop) of a smoothly curved bend whose cross-section is rectangular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

Model formulation:

Hydraulic diameter (m):

$$d_h = \frac{2 \cdot w \cdot h}{w + h}$$

Cross-section area (m^2):

$$A = w \cdot h$$

Mean velocity (m/s):

$$V = \frac{Q}{A}$$

Length measured along the axis (m):

$$L = 2 \cdot \pi \cdot r \cdot \frac{\alpha}{360}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Fluid volume (m^3):

$$Vol = A \cdot L$$

Fluid mass (kg):

$$Mas = Vol \cdot \rho_m$$

Reynolds number:

$$N_{Re} = \frac{V \cdot d_h}{\nu}$$

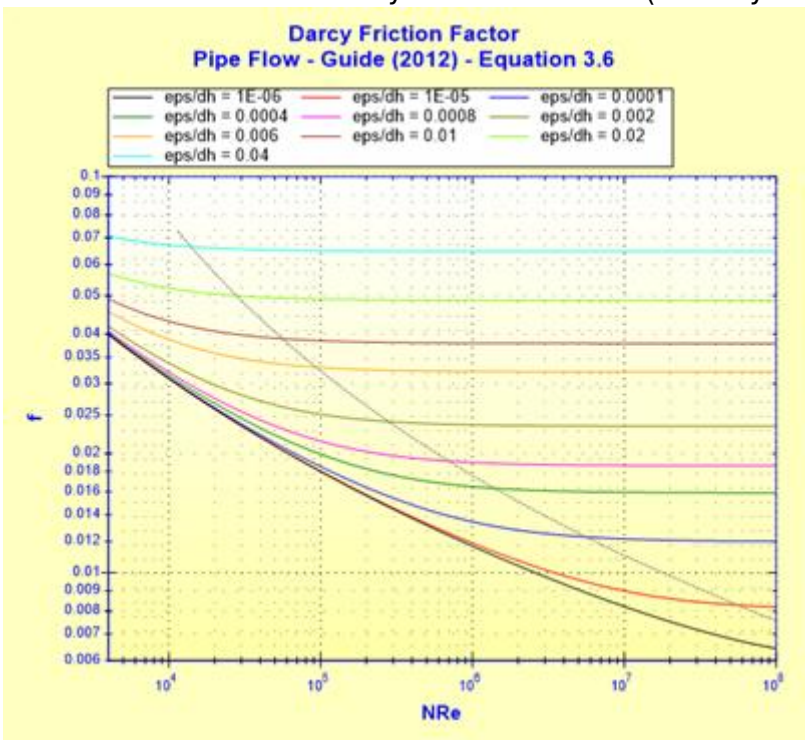
Relative roughness:

$$R_r = \frac{\varepsilon}{d_h}$$

Darcy friction factor:

$$f = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d_h} + \frac{2.51}{N_{Re} \cdot \sqrt{f}}\right)\right]^2}$$

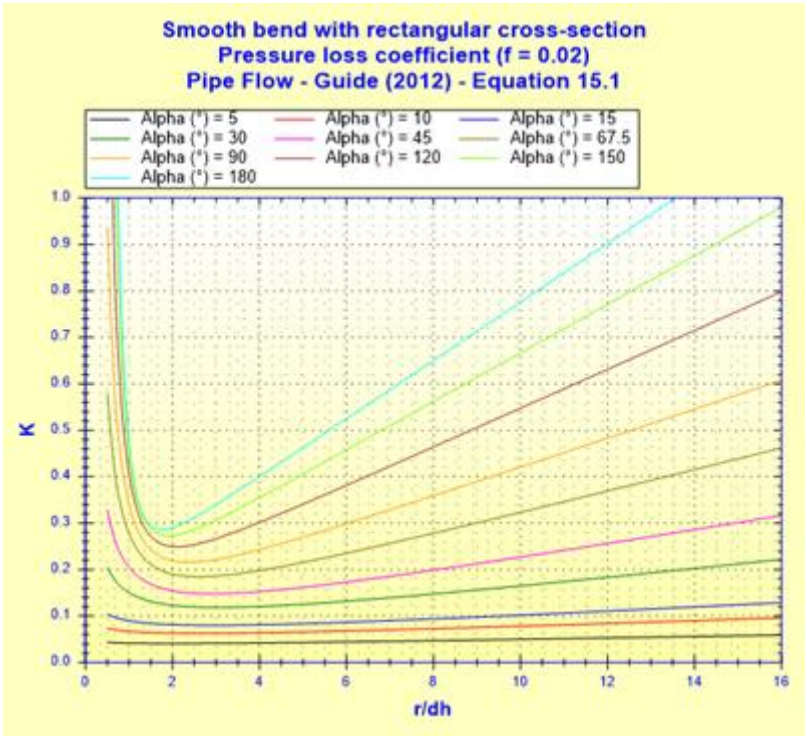
Colebrook-White equation ([1] equation 3.6)



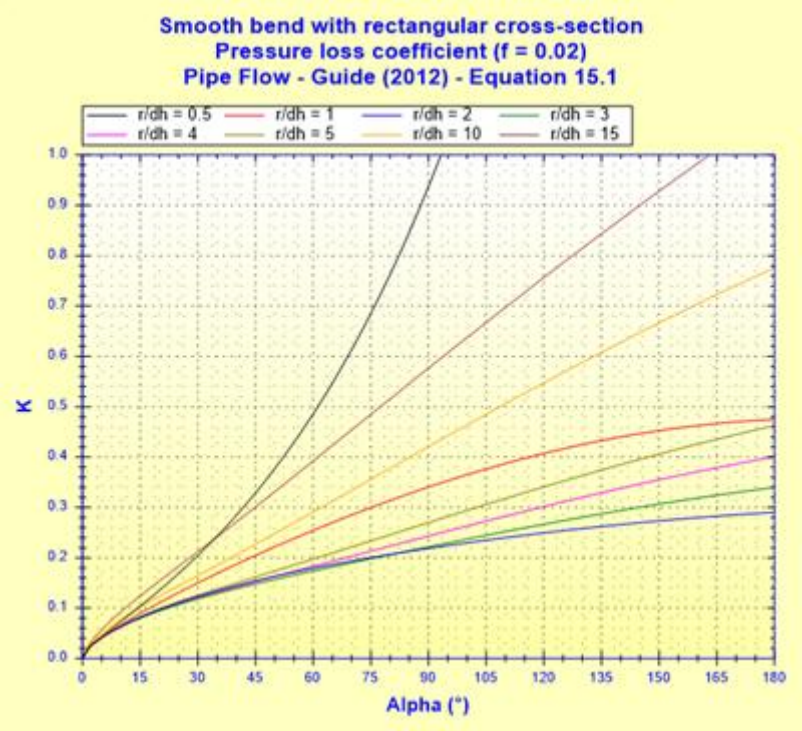
Total pressure loss coefficient (based on mean velocity in bend):

$$K = f \cdot \alpha \cdot \frac{r}{d_h} + (0.10 + 2.4 \cdot f) \cdot \sin(\alpha/2) + \frac{6.6 \cdot f \cdot \left(\sqrt{\sin(\alpha/2)} + \sin(\alpha/2)\right)}{\left(\frac{r}{d_h}\right)^{\frac{4 \cdot \alpha}{\pi}}}$$

([1] equation 15.1)



([1] equation 15.1 with f = 0.02)



([1] equation 15.1 with f = 0.02)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{d_h}{f}$$

Symbols, Definitions, SI Units:

w	Rectangular cross-section width (m)
h	Rectangular cross-section height (m)

d_h	Bend hydraulic diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
V	Mean velocity (m/s)
L	Length measured along the axis (m)
r	Radius of curvature (m)
α	Curvature angle (°)
G	Mass flow rate (kg/s)
Vol	Fluid volume (m^3)
Mas	Fluid mass (kg)
N_{Re}	Reynolds number ()
R_r	Relative roughness ()
ε	Absolute roughness of walls (m)
f	Darcy friction factor ()
K	Total pressure loss coefficient (based on mean velocity in bend) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
L_{eq}	Straight length of equivalent pressure loss (m)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($N_{Re} \geq 10^4$)
- stabilized flow upstream of the bend
- curvature angle between 0° and 180°

- this formulation is for circular passages, but can be reasonably applied to square ducts or to rectangular ducts of low aspect ratio

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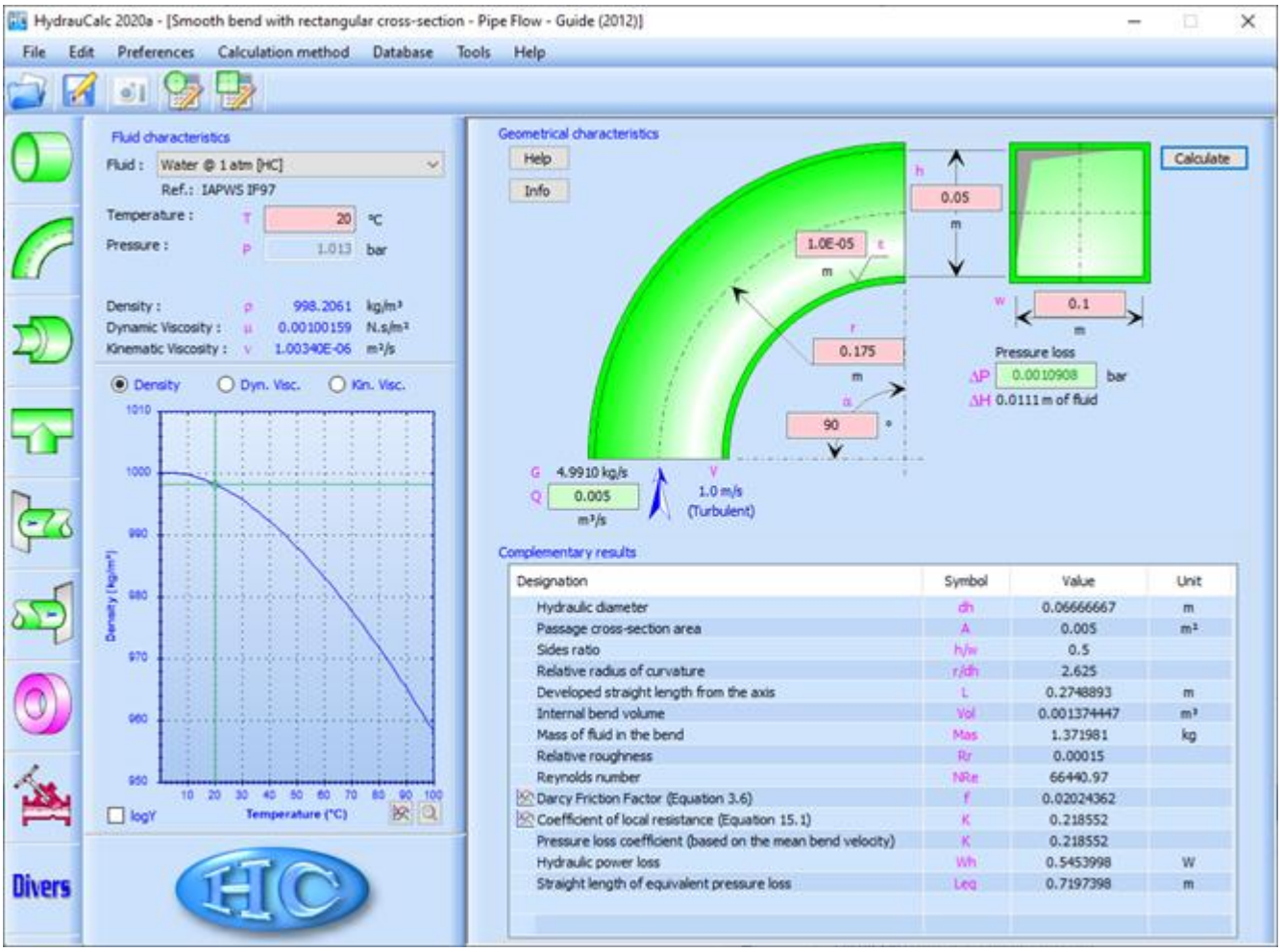
Example of application:



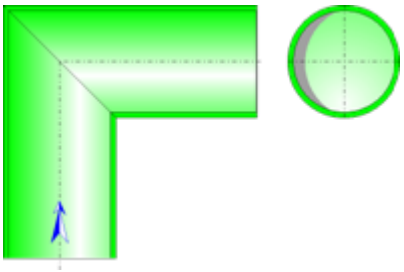
References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.2.3 Miter Bend - Circular cross-section

Miter Bend

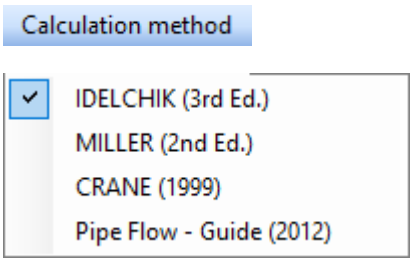
Circular Cross-Section



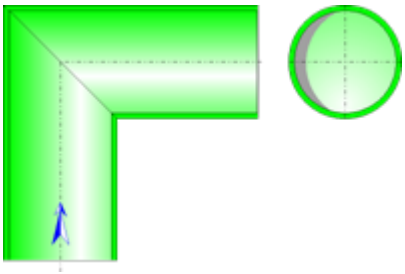
For the calculation of the pressure loss coefficient of miter bends with circular cross-section, the user can choose from one of the methods described in the following four reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.2.3.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) of a miter bend whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized at the entrance bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\bar{\Delta} = \frac{\Delta}{D_h}$$

Coefficient of effect of the roughness:

$$k_\Delta = f\left(\mathrm{Re}, \bar{\Delta}\right)$$ ([1] diagram 6.6)

$\bar{\Delta}$	Re	
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$
0	1.0	1.0
0 - 0.001	1.0	$1 + 0.5 \cdot 10^3 \cdot \bar{\Delta}$
> 0.001	1.0	1.5

Coefficient of effect of the Reynolds number (Re ≥ 10^4):

$$k_{Re} = f\left(\mathrm{Re}\right)$$ ([1] diagram 6.6)

Coefficient of effect of the angle:

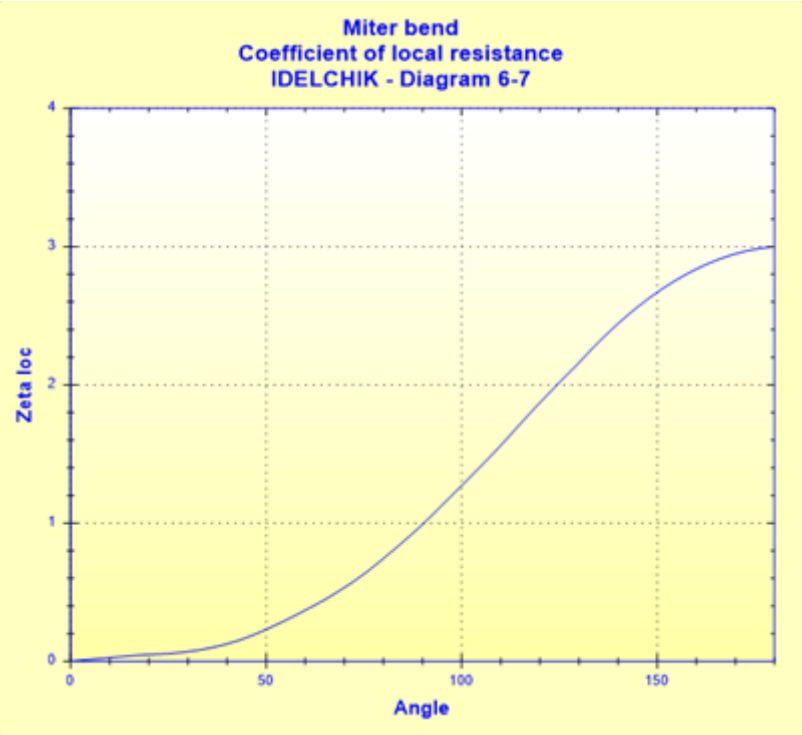
$A = f(\delta)$ ([1] diagram 6.7)

Coefficient of effect of the relative elongation of the cross section:

$C_1 = 1$ ([1] diagram 6.7)

Coefficient of local resistance:

$\zeta_{loc} = f(\delta)$ ([1] diagram 6.7)



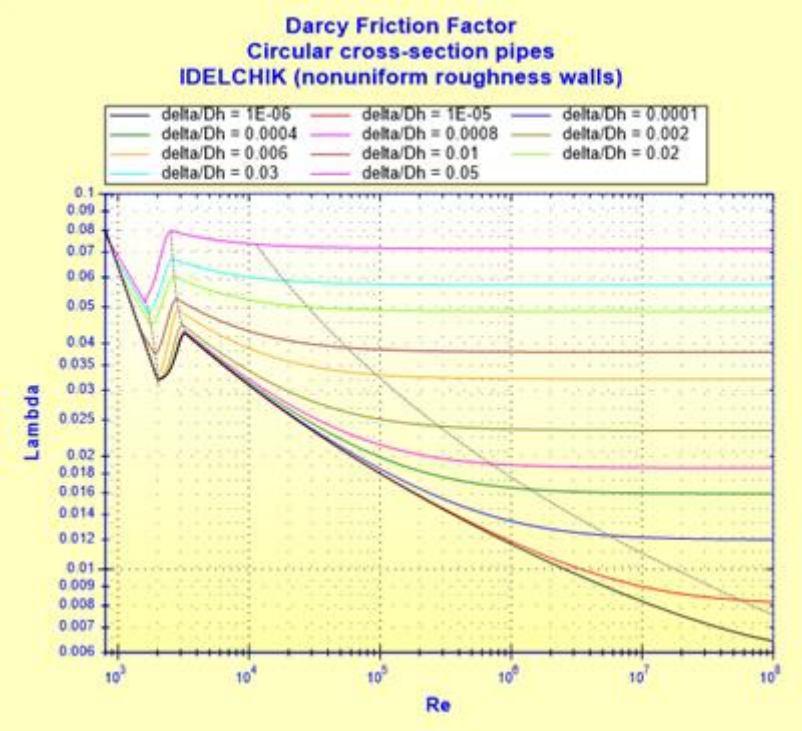
Total pressure loss coefficient (based on the mean velocity in the bend):

$\zeta = k_{\Delta} \cdot k_{Re} \cdot C_1 \cdot A \cdot \zeta_{loc}$ ([1] diagram 6.7)

Darcy friction factor:

$\lambda = f\left(\mathrm{Re}, \frac{\Delta}{D_h}\right)$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_0}{\lambda}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

([1] diagram 6.7)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

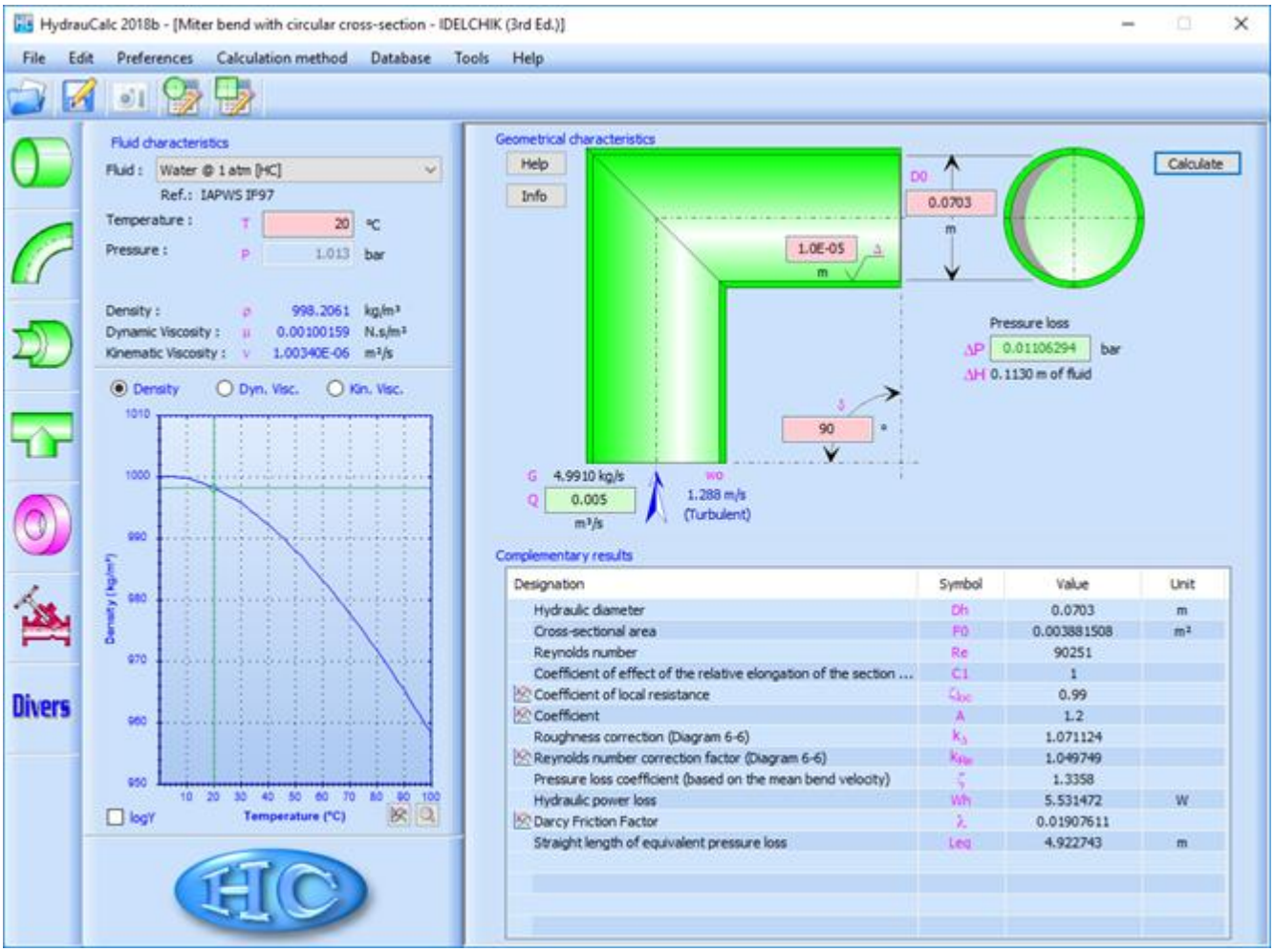
D_h	Bend hydraulic diameter (m)

D_0	Bend internal diameter (m)
F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()
k_Δ	Coefficient that allows for the effect of the roughness ()
k_{Re}	Coefficient that allows for the effect of the Reynolds number ()
δ	Angle of the bend (°)
A	Coefficient that allows for the effect of the angle ()
C_1	Coefficient that allows for the effect of the relative elongation of the cross section ()
ζ_{loc}	Coefficient of local resistance ()
ζ	Total pressure loss coefficient (based on the mean velocity in the bend) ()
λ	Darcy friction coefficient ()
L_{eq}	Straight length of equivalent pressure loss (m)
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- stabilized flow upstream bend
- length of the straight section downstream: ≥ 10 D_0
- curvature angle: 0 to 180°
- flow regime: Re ≥ 10^4

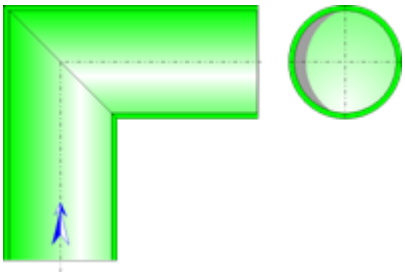
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.2.3.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) of a miter bend whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

An option allows to take into account the effect of the straight length at the exit of the bend.

Model formulation:

Hydraulic diameter (m):

$$D = d$$

Cross-section area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$m = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Basic resistance coefficient:

$$K_b^* = f(\theta_b)$$

([1] figure 9.9)

Reynolds number correction factor:

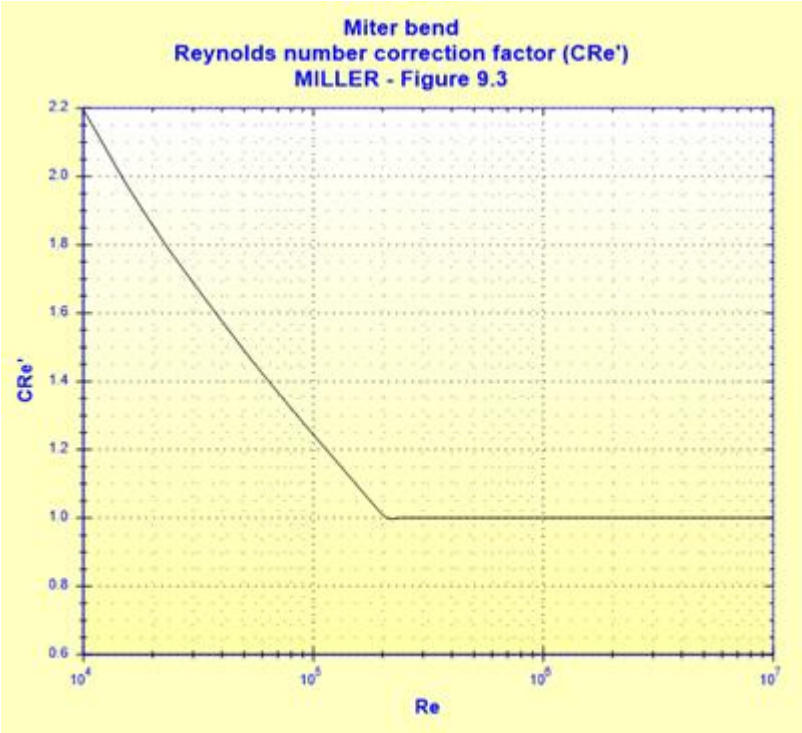
$$C_{\mathrm{Re}} = \frac{K_b^*}{K_b^* - 0.2C'_{\mathrm{Re}} + 0.2}$$

([1] equation 9.2)

with:

$$C'_{\mathrm{Re}} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$

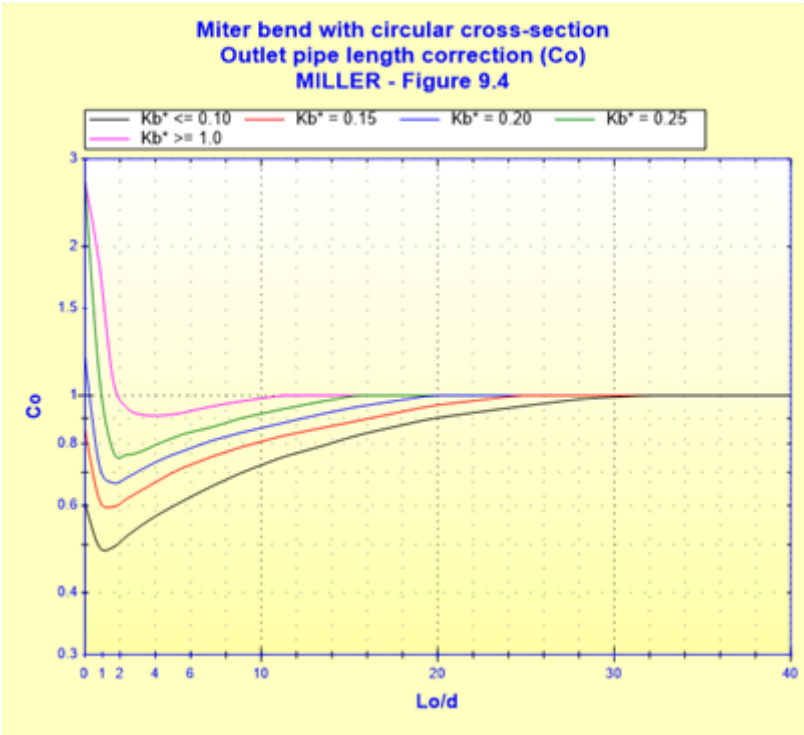
([1] figure 9.3 with r/d=1)



Outlet pipe length correction factor (optional):

$$C_o = f\left(\frac{L_o}{d}, K_b^*\right)$$

([1] figure 9.4)

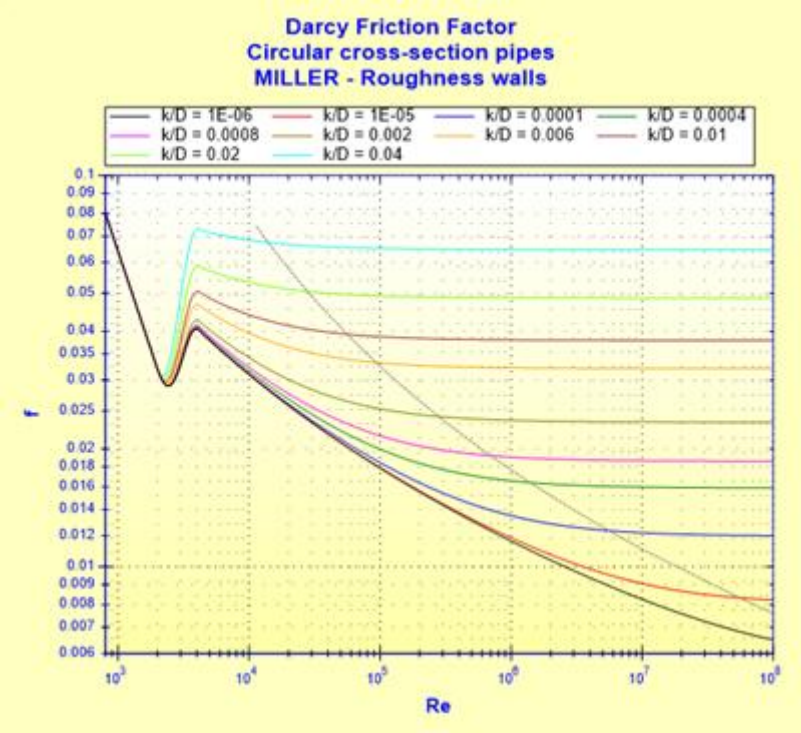


If this option is not activated, the factor Co is equal to unity.

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{D}\right)$$

See Straight Pipe - Circular Cross-Section and Roughness Walls (MILLER)



Roughness correction factor:

- $\theta_b \leq 45$:

$$C_f = \frac{f_{rough}}{f_{smooth}}$$ ([1] equation 9.3)

with:

f_{rough}: Darcy friction factor for rough pipe at Re

f_{smooth}: Darcy friction factor for smooth pipe (k = 0) at Re

- $\theta_b > 45$:

$$C_f = 1$$

Corrected loss coefficient:

$$K_b = K_b^{\circ} \cdot C_{Re} \cdot C_o \cdot C_f$$

Total pressure loss coefficient (based on the mean velocity in the bend):

$$K = K_b$$

Total pressure loss (Pa):

$$\Delta P = K_b \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K_b \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K_b \cdot \frac{d}{f_{rough}}$$

Symbols, Definitions, SI Units:

D	Bend hydraulic diameter (m)
d	Bend internal diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
m	Mass flow rate (kg/s)
Re	Reynolds number ()
θ_b	Angle of the bend (°)

K_b^* Basic loss coefficient ()

C_{Re} Reynolds number correction factor ()

L_0 Length of the straight section downstream of the bend (m)

C_o Outlet pipe length correction factor ()

k Absolute roughness of walls (m)

f Darcy friction factor for ()

C_f Roughness correction factor ()

K_b Corrected loss coefficient ()

K Total pressure loss coefficient (based on the mean velocity in the bend) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

L_{eq} Straight length of equivalent pressure loss (m)

ρ Fluid density (kg/m^3)

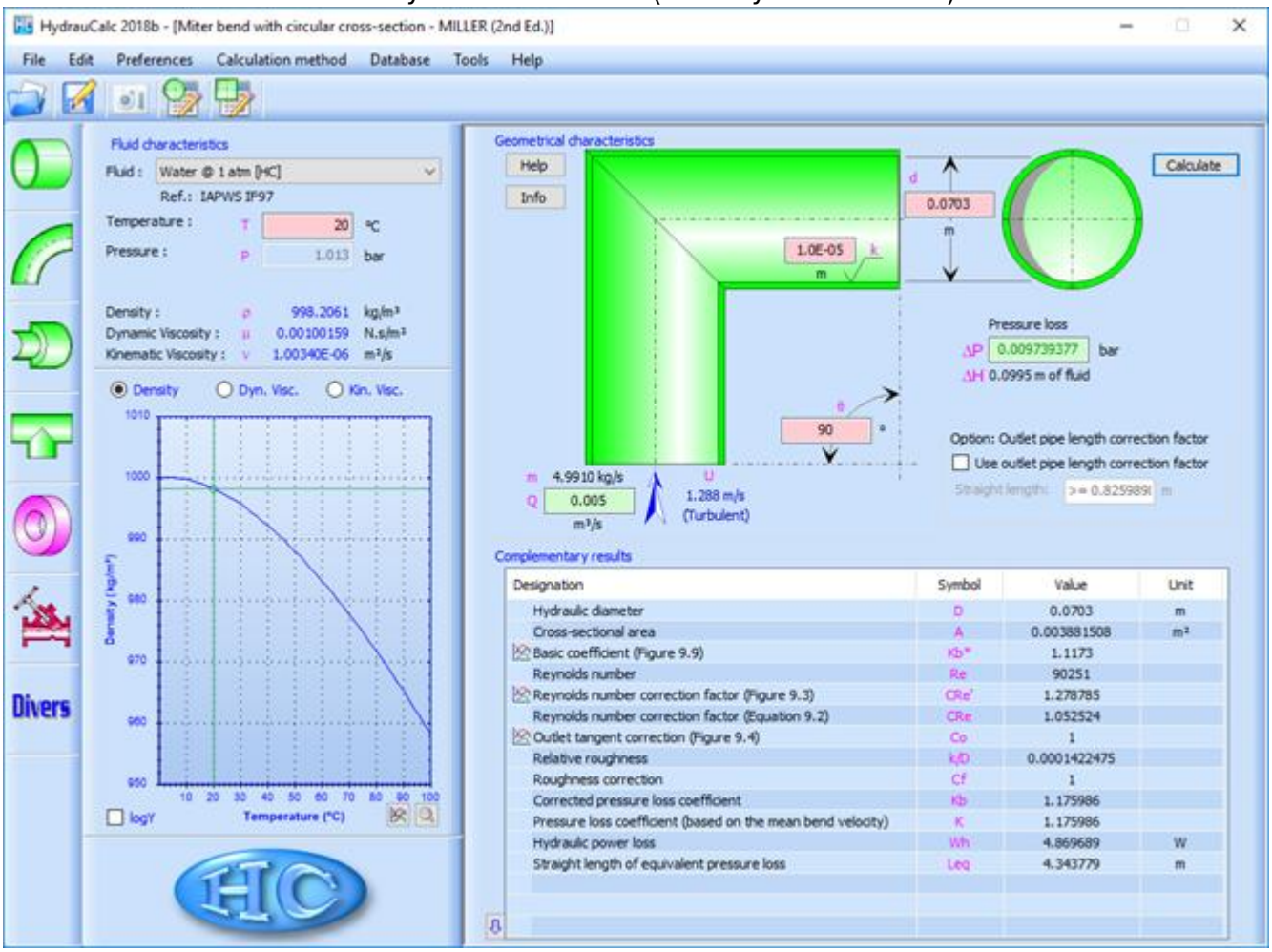
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream bend
- curvature angle: 0 - 120°

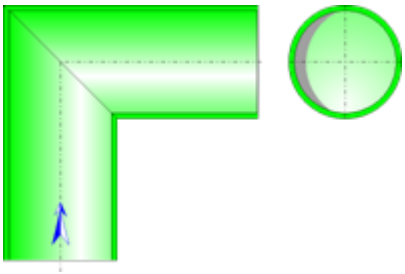
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.2.3.3 CRANE



Model description:

This model of component calculates the head loss (pressure drop) of a miter bend whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

Model formulation:

Cross-section area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity (m/s):

$$v = \frac{q}{A}$$

Mass flow rate (kg/s):

$$w = q \cdot \rho$$

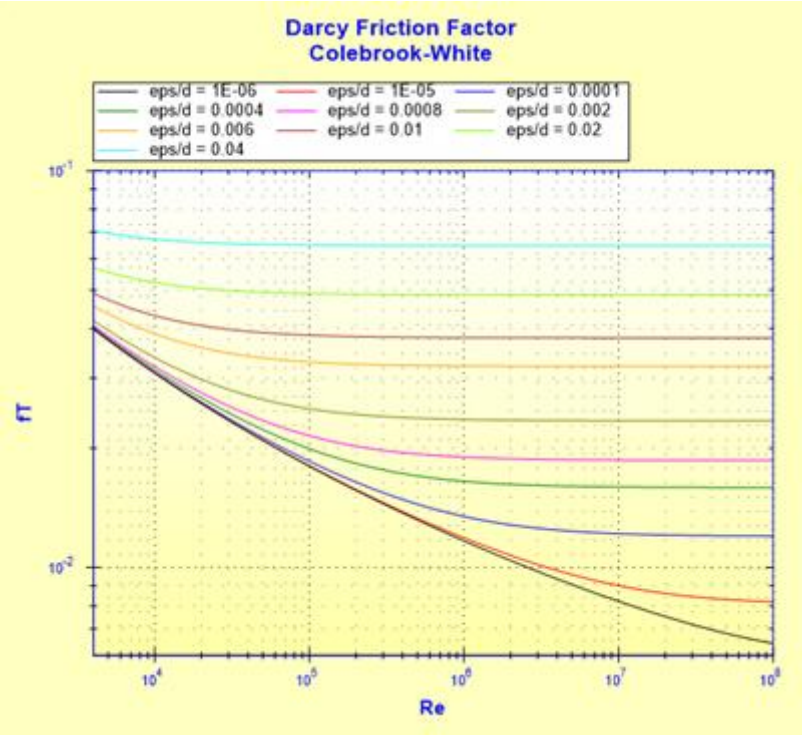
Reynolds number:

$$Re = \frac{v \cdot d}{\nu}$$

Darcy friction factor:

$$f_T = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d} + \frac{2.51}{Re \cdot \sqrt{f_T}}\right)\right]^2}$$

Colebrook-White equation

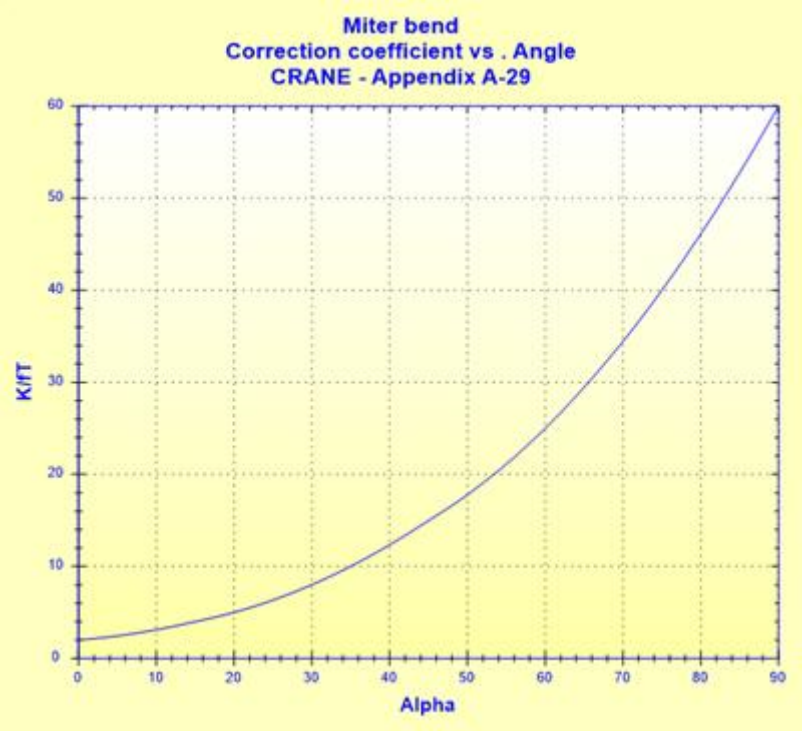


Resistance coefficient for a miter bend:

$$K = f(\alpha, f_T)$$

([1] Appendix A-29)

α	K	K/f_T
0	$2\ f_T$	2
15	$4\ f_T$	4
30	$8\ f_T$	8
45	$15\ f_T$	15
60	$25\ f_T$	25
75	$40\ f_T$	40
90	$60\ f_T$	60



Total pressure loss coefficient (based on mean velocity in bend):

$$K_B = K$$

Total pressure loss (Pa):

$$\Delta P = K_B \cdot \frac{\rho \cdot v^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K_B \cdot \frac{v^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K_B \cdot \frac{d}{f_T}$$

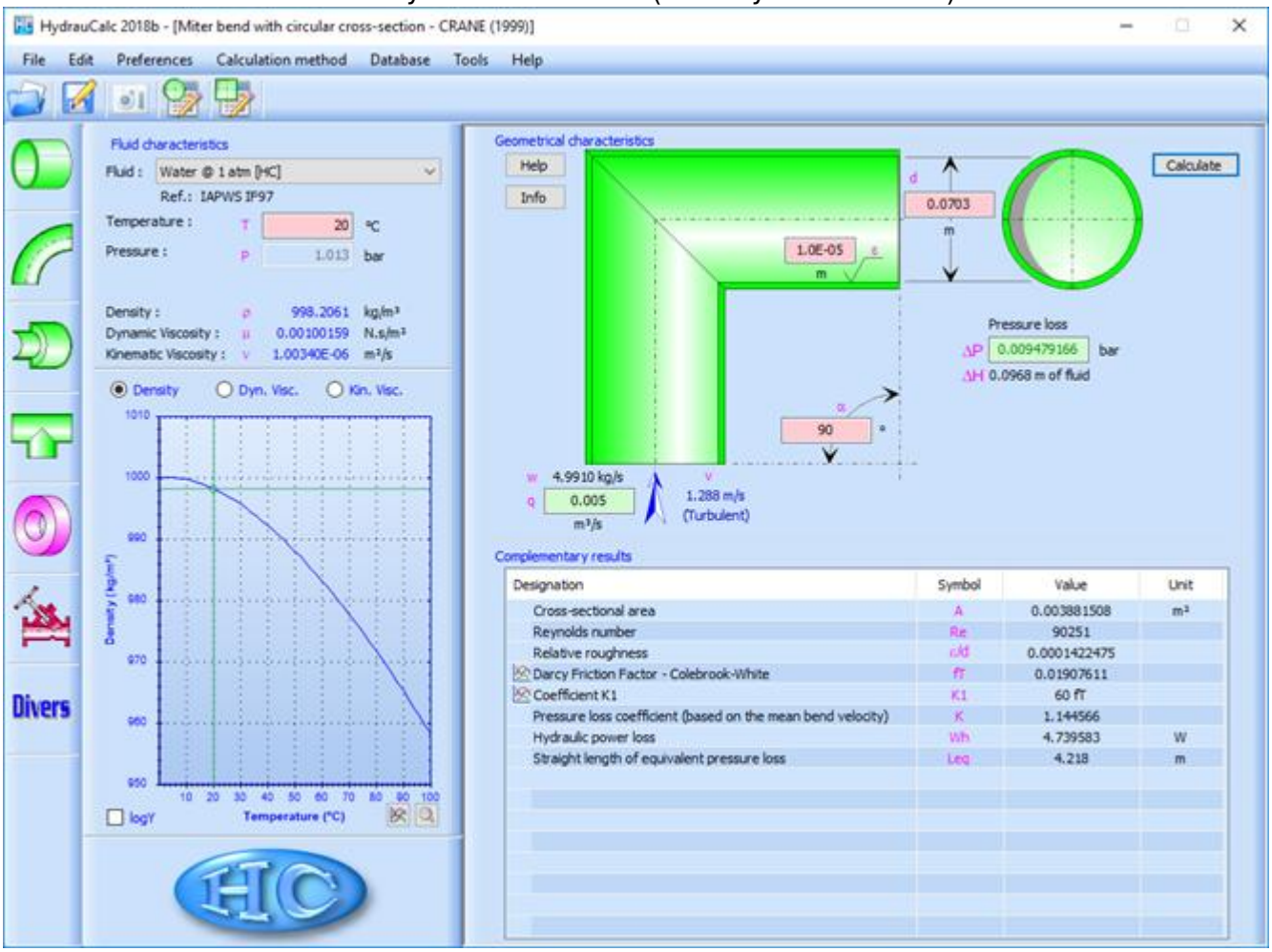
Symbols, Definitions, SI Units:

d	Pipe internal diameter (m)
A	Cross-section area (m^2)
q	Volume flow rate (m^3/s)
v	Mean velocity (m/s)
w	Mass flow rate (kg/s)
Re	Reynolds number ()
ε	Absolute roughness of walls (m)
f_T	Darcy friction factor ()
α	Angle of bend (°)
K	Resistance coefficient for a miter bend ()
K_B	Total pressure loss coefficient (based on mean velocity in bend) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
L_{eq}	Straight length of equivalent pressure loss (m)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream of the bend
- angle between 0° and 90°

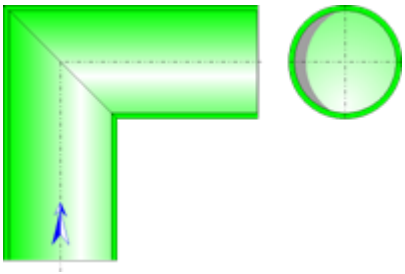
Example of application:



References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999

2.2.3.4 Pipe Flow - Guide



Model description:

This model of component calculates the head loss (pressure drop) of a miter bend whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

Model formulation:

Cross-section area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity (m/s):

$$V = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

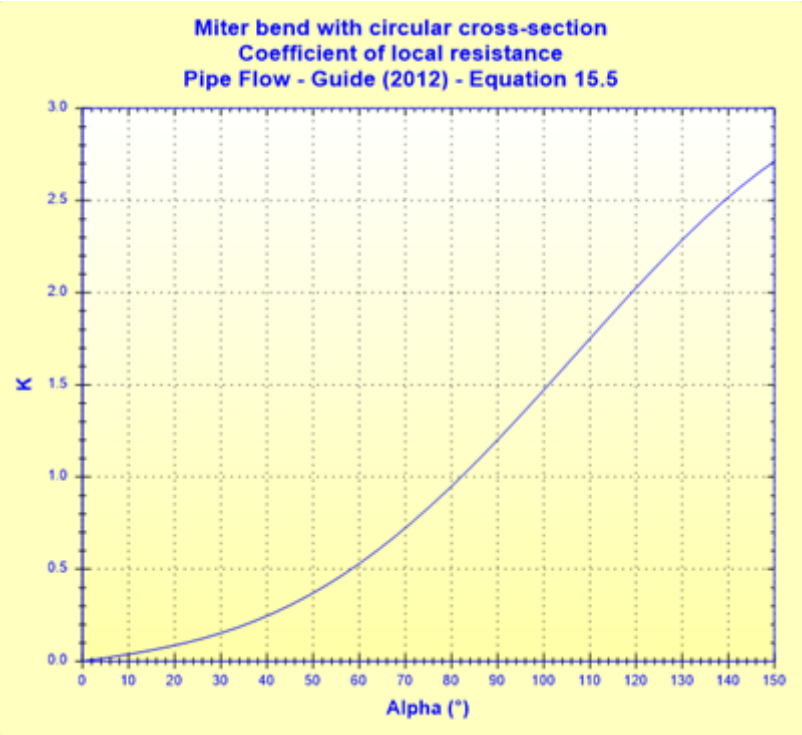
Reynolds number:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

Total pressure loss coefficient (based on mean velocity in bend):

$$K = 0.42 \cdot \sin(\alpha/2) + 2.56 \cdot (\sin(\alpha/2))^3$$

([1] equation 15.5)



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

([1] equation 3.7)

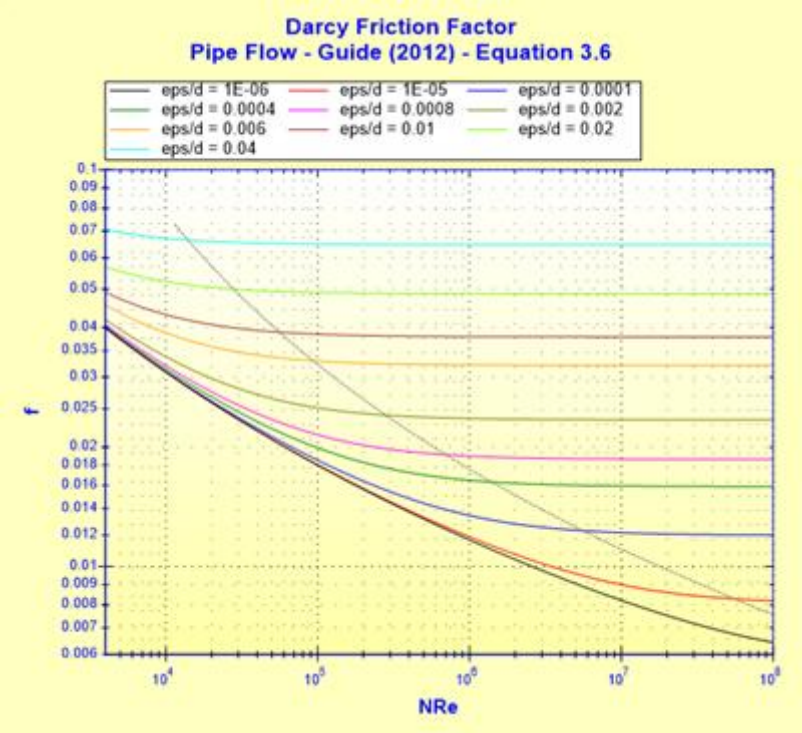
Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Darcy friction factor:

$$f = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d} + \frac{2.51}{N_{Re} \cdot \sqrt{f}}\right)\right]^2}$$

Colebrook-White equation ([1] equation 3.6)



Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{d}{f}$$

Symbols, Definitions, SI Units:

d	Bend internal diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
V	Mean velocity (m/s)
α	Angle (°)
G	Mass flow rate (kg/s)
N_{Re}	Reynolds number ()
K	Total pressure loss coefficient (based on mean velocity in bend) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)

f Darcy friction coefficient ()

L_{eq} Straight length of equivalent pressure loss (m)

ρ_m Fluid density (kg/m³)

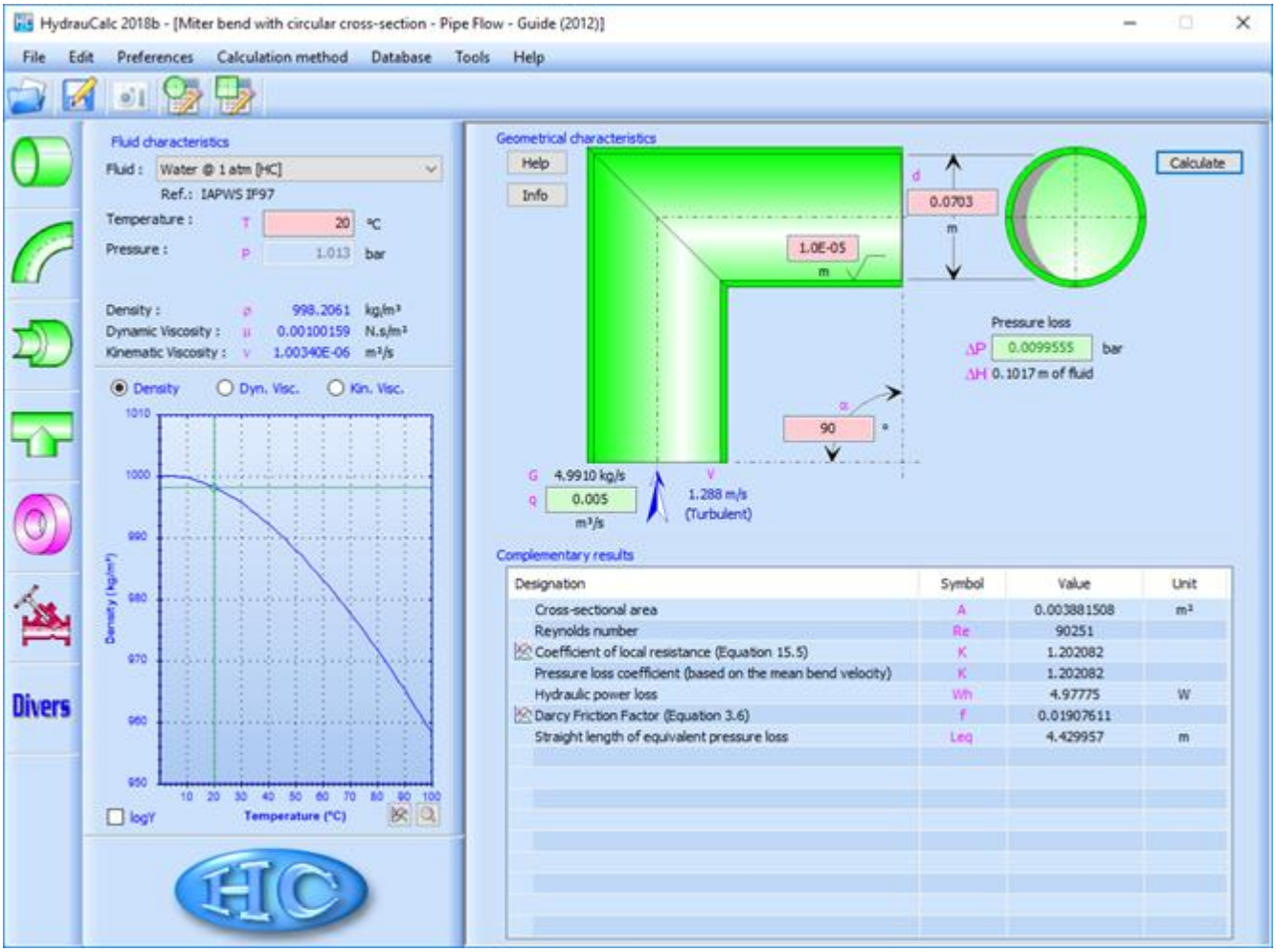
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($N_{Re} \geq 10^4$)
- stabilized flow upstream of the bend
- angle between 0° and 150°

Example of application:



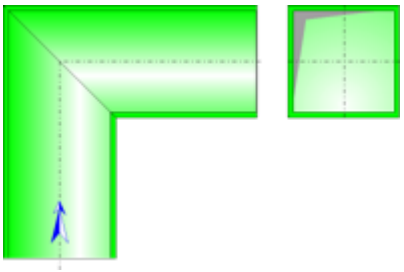
References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.2.4 Miter Bend - Rectangular cross-section

Miter Bend

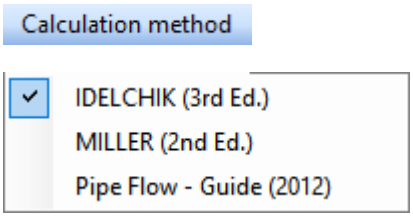
Rectangular Cross-Section



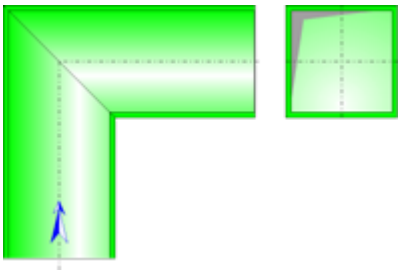
For the calculation of the pressure loss coefficient of miter bends with rectangular cross-section, the user can choose from one of the methods described in the following three reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.2.4.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) of a miter bend whose cross-section is rectangular and constant. In addition, the flow is assumed fully developed and stabilized à the entrance bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = \frac{2 \cdot a_0 \cdot b_0}{a_0 + b_0}$$ ([1] diagram 6-7)

Cross-section area (m^2):

$$F_0 = a_0 \cdot b_0$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\overline{\Delta} = \frac{\Delta}{D_h}$$

Coefficient of effect of the roughness:

$$k_\Delta = f\left(\mathrm{Re}, \overline{\Delta}\right)$$ ([1] diagram 6-6)

$\overline{\Delta}$	Re	
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$
0	1.0	1.0
0 - 0.001	1.0	$1 + 0.5 \cdot 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	1.5

Coefficient of effect of the Reynolds number (Re ≥ 10^4):

$$k_{Re} = f\left(\mathrm{Re}\right)$$ ([1] diagram 6-6)

Coefficient of effect of the angle:

$A = f(\delta)$ ([1] diagram 6-7)

Coefficient of effect of the relative elongation of the cross section:

- $a_0 \geq b_0$

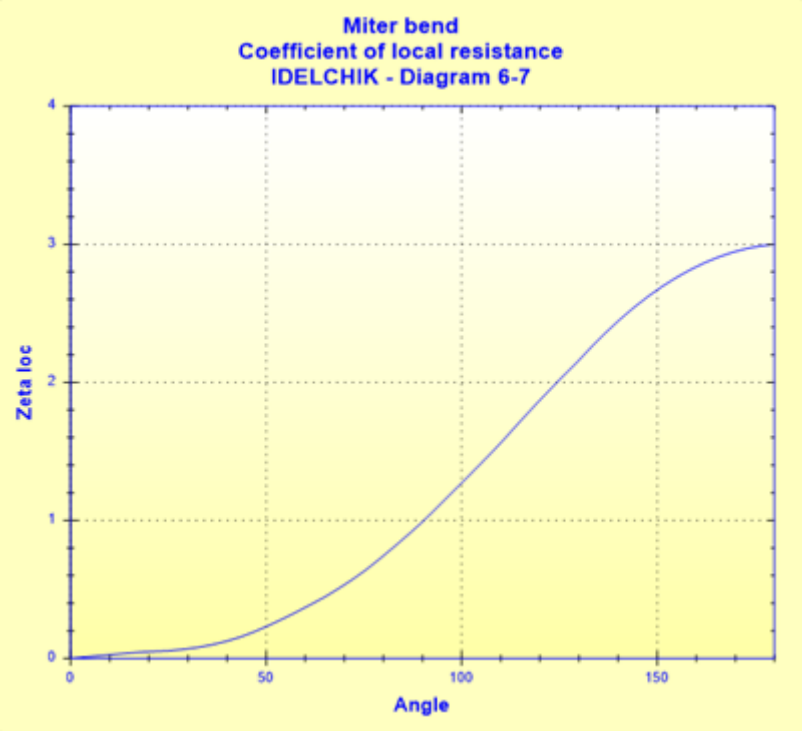
$$C1 = f\left(\frac{a_0}{b_0}\right)$$ ([1] diagram 6.7)

♦ $a_0 < b_0$

$$C1 = f\left(\frac{b_0}{a_0}\right)$$ ([1] diagram 6.7)

Coefficient of local resistance:

$$\zeta_{loc} = f(\delta)$$ ([1] diagram 6-7)



Total pressure loss coefficient (based on the mean velocity in the bend):

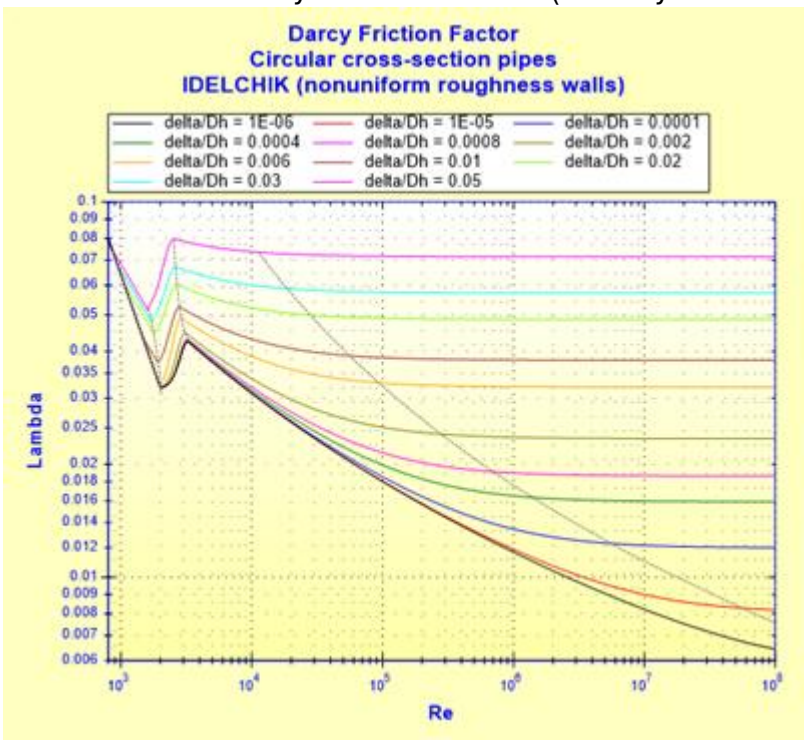
$$\zeta = k_{\Delta} \cdot k_{Re} \cdot C_1 \cdot A \cdot \zeta_{loc}$$ ([1] diagram 6-7)

Darcy friction factor:

See Straight Pipe - Rectangular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)

- Darcy friction factor for circular cross-section

$$\lambda_{circ} = f\left(\mathrm{Re}, \frac{\Delta}{D_h}\right)$$



■ Correction for Darcy friction factor for noncircular cross-section

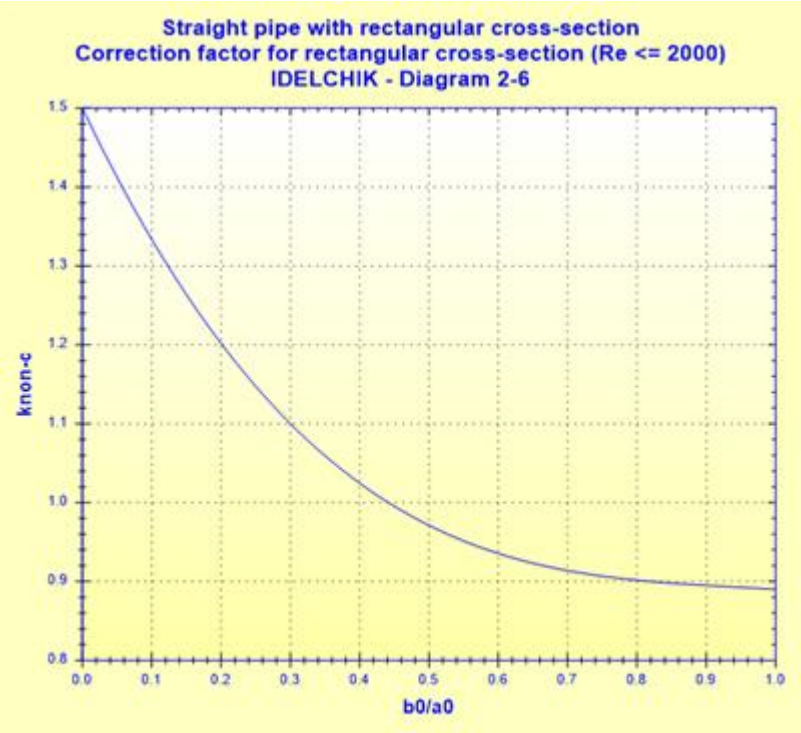
♦ $a_0 \geq b_0$

$$k_{non-c} = f(b_0/a_0)$$ ([1] diagramme 2.6)

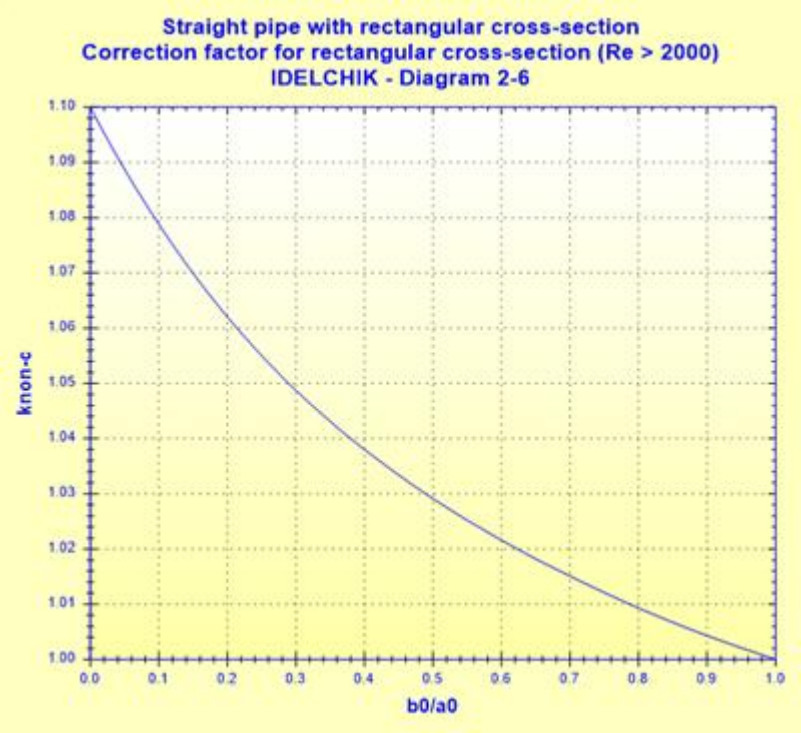
♦ $a_0 < b_0$

$$k_{non-c} = f(a_0/b_0)$$ ([1] diagramme 2.6)

● laminar flow ($Re \leq 2000$):



- turbulent flow (Re > 2000):



■ Darcy friction factor for rectangular cross-section

$$\lambda_{rect} = \lambda_{circ} \cdot k_{non-c}$$ ([1] diagram 2.6)

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_h}{\lambda_{rect}}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

([1] diagram 6-7)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

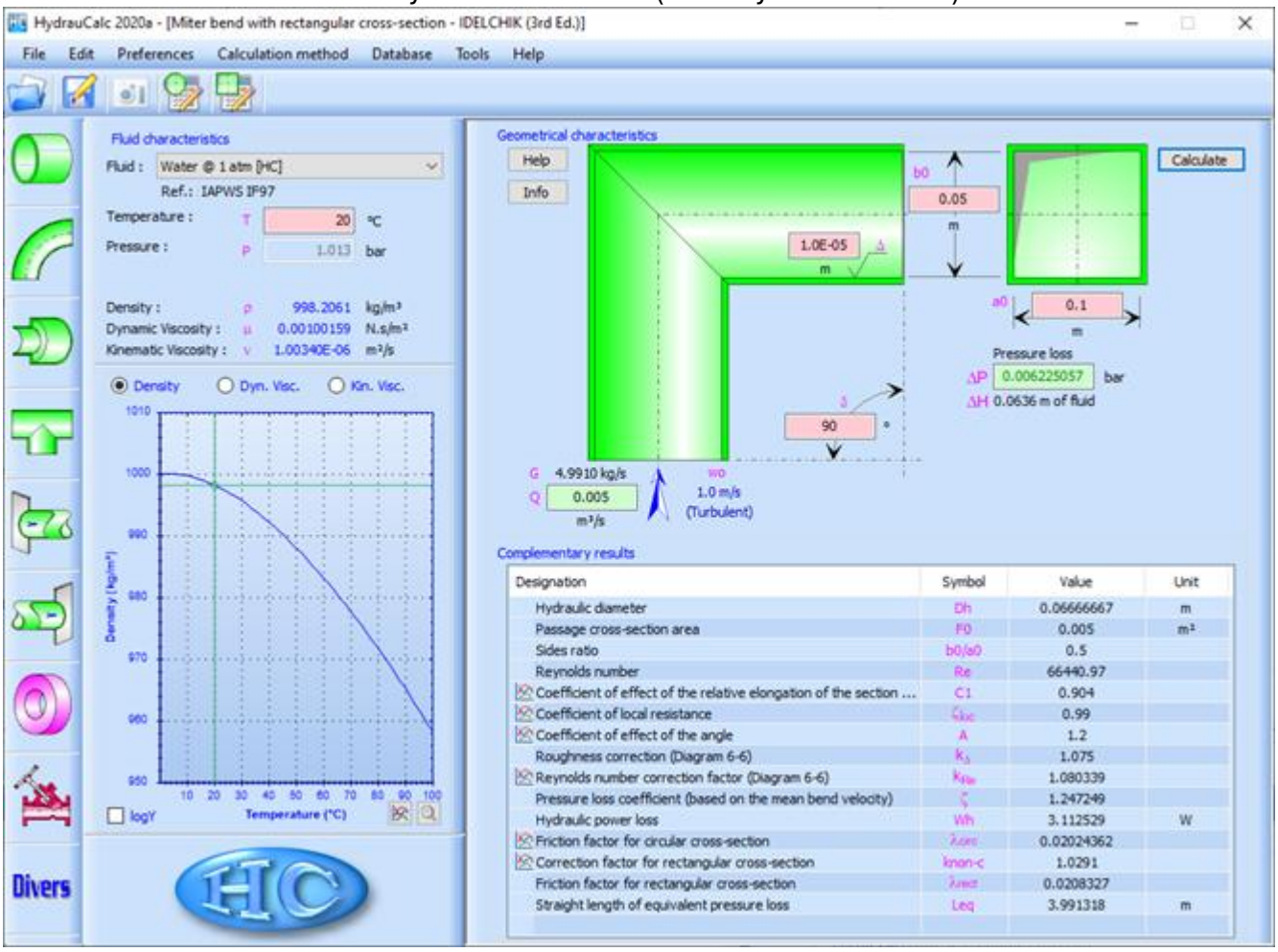
a_0	Rectangular cross-section width (m)
b_0	Rectangular cross-section height (m)
D_h	Bend hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()
k_Δ	Coefficient that allows for the effect of the roughness ()
k_{Re}	Coefficient that allows for the effect of the Reynolds number ()
δ	Angle of the bend (°)

A	Coefficient that allows for the effect of the angle ()
C_1	Coefficient that allows for the effect of the relative elongation of the cross section ()
ζ_{loc}	Coefficient of local resistance ()
ζ	Total pressure loss coefficient (based on the mean velocity in the bend) ()
λ_{circ}	Darcy friction coefficient for circular cross-section ()
λ_{rect}	Darcy friction coefficient for rectangular cross-section ()
k_{non-c}	Correction for Darcy friction factor for noncircular cross-section ()
L_{eq}	Straight length of equivalent pressure loss (m)
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m³)
ν	Fluid kinematic viscosity (m²/s)
g	Gravitational acceleration (m/s²)

Validity range:

- stabilized flow upstream bend
- length of the straight section downstream: $\geq 10\ D_h$
- curvature angle: 0 to 180°
- flow regime: $Re \geq 10^4$

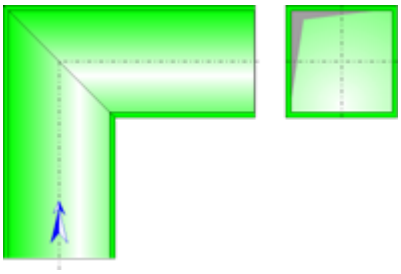
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.2.4.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) of a miter bend whose cross-section is rectangular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

An option allows to take into account the effect of the straight length at the exit of the bend.

Model formulation:

Hydraulic diameter (m):

$$D = \frac{2 \cdot b \cdot W}{b + W}$$

Cross-section area (m^2):

$$A = b \cdot W$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

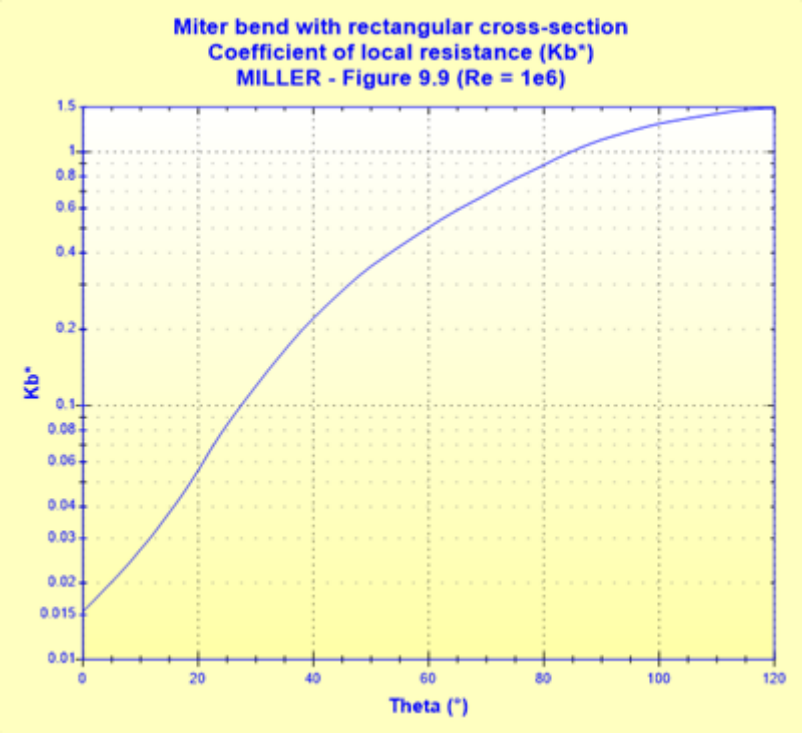
$$m = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Basic resistance coefficient:

$$K_b^* = f(\theta_b)$$ ([1] figure 9.9)

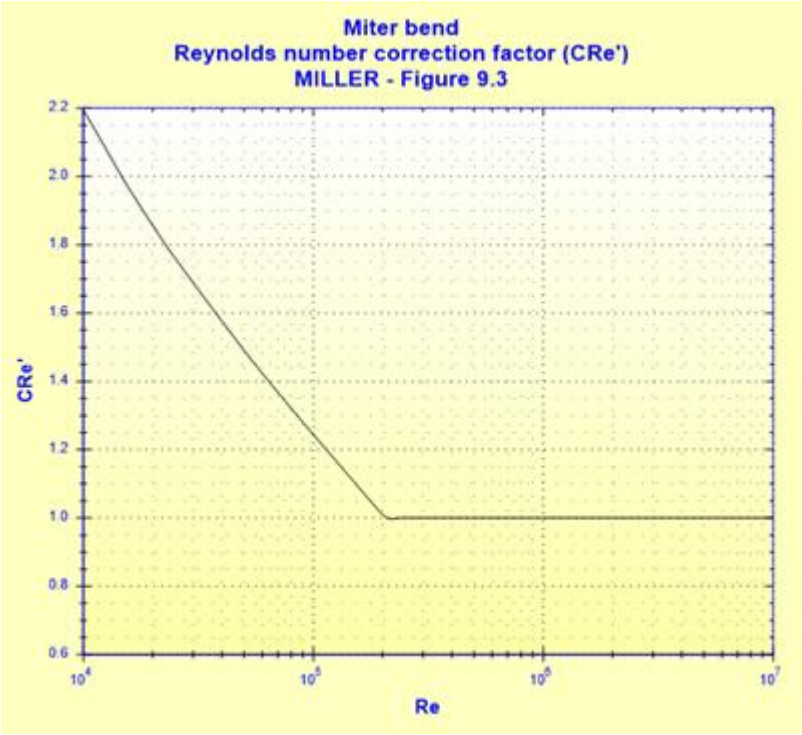


Reynolds number correction factor:

$$C_{Re} = \frac{K_b^*}{K_b^* - 0.2C'_{Re} + 0.2}$$ ([1] equation 9.2)

with:

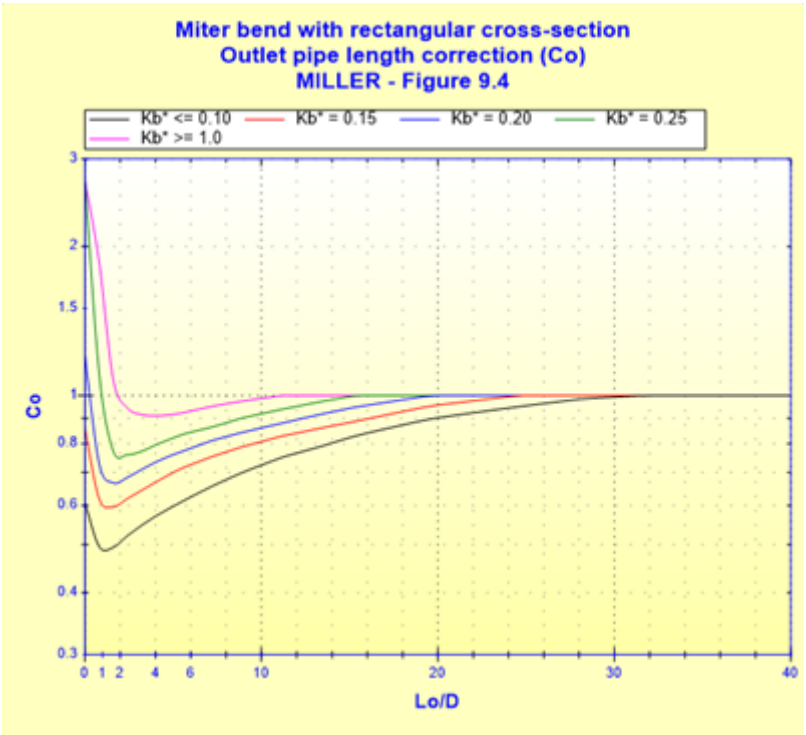
$$C'_{Re} = f(\mathrm{Re})$$ ([1] figure 9.3 with r/d=1)



Outlet pipe length correction factor (optional):

$$C_o = f\left(\frac{L_o}{D}, K_b^*\right)$$

([1] figure 9.4)

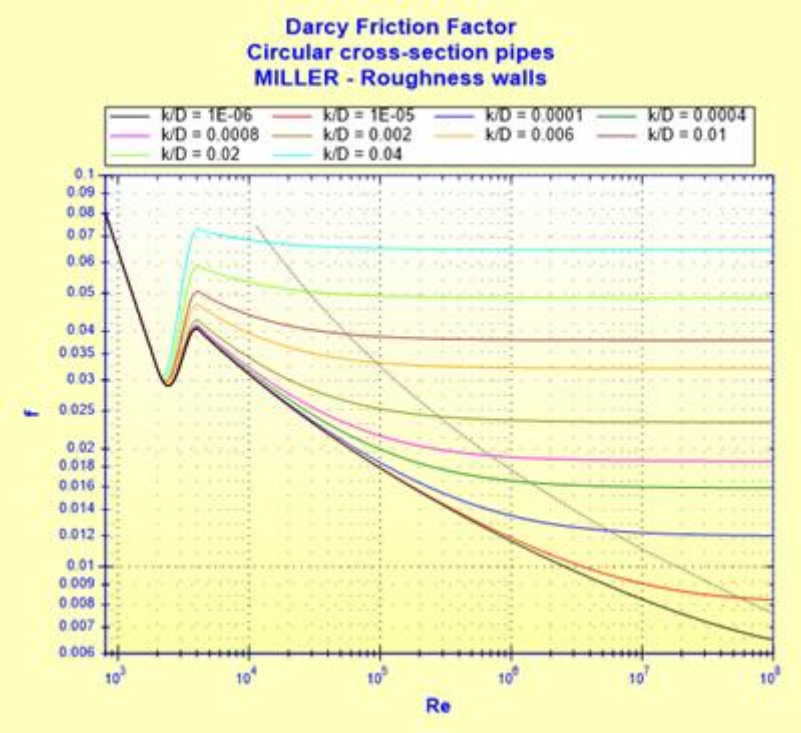


If this option is not activated, the factor Co is equal to unity.

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{D}\right)$$

See Straight Pipe - Rectangular Cross-Section and Roughness Walls (MILLER)



Roughness correction factor:

- $\theta_b \leq 45$:

$$C_f = \frac{f_{rough}}{f_{smooth}}$$ ([1] equation 9.3)

with:

f_{rough}: Darcy friction factor for rough pipe at Re

f_{smooth}: Darcy friction factor for smooth pipe (k = 0) at Re

- $\theta_b > 45$:

$$C_f = 1$$

Corrected loss coefficient:

$$K_b = K_b^{\circ} \cdot C_{Re} \cdot C_o \cdot C_f$$ ([1] equation 9.4)

Total pressure loss coefficient (based on the mean velocity in the bend):

$$K = K_b$$

Total pressure loss (Pa):

$$\Delta P = K_b \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K_b \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K_b \cdot \frac{D}{f_{rough}}$$

with:

f_{rough}: Darcy friction factor for rough pipe at Re

Symbols, Definitions, SI Units:

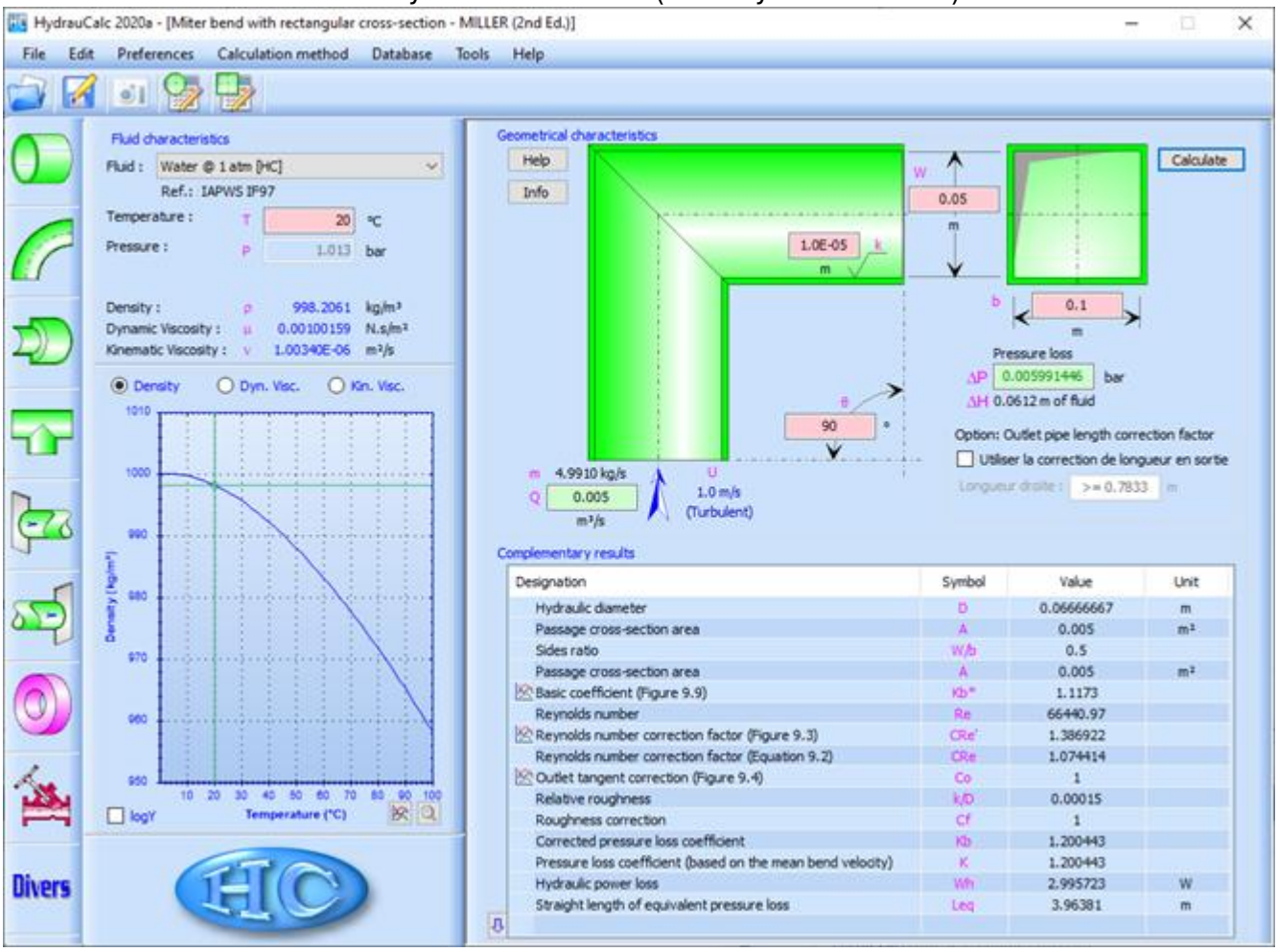
W	Cross-section height (m)
b	Cross-section width (m)
D	Hydraulic diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)

m	Mass flow rate (kg/s)
Re	Reynolds number ()
θ_b	Angle of the bend (°)
K_b^*	Basic loss coefficient ()
C_{Re}	Reynolds number correction factor ()
L_0	Length of the straight section downstream of the bend (m)
C_o	Outlet pipe length correction factor ()
k	Absolute roughness of walls (m)
f	Darcy friction factor for ()
C_f	Roughness correction factor ()
K_b	Corrected loss coefficient ()
K	Total pressure loss coefficient (based on the mean velocity in the bend) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
L_{eq}	Straight length of equivalent pressure loss (m)
ρ	Fluid density (kg/m³)
ν	Fluid kinematic viscosity (m²/s)
g	Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream bend
- curvature angle: 0 - 120°

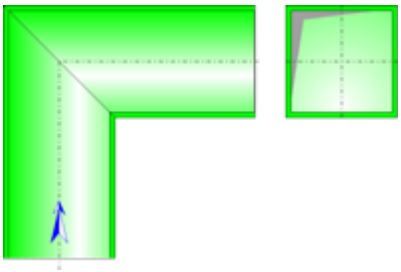
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.2.4.3 Pipe Flow - Guide



Model description:

This model of component calculates the head loss (pressure drop) of a miter bend whose cross-section is rectangular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

Model formulation:

Hydraulic diameter (m):

$$d_h = \frac{2 \cdot w \cdot h}{w + h}$$

Cross-section area (m^2):

$$A = w \cdot h$$

Mean velocity (m/s):

$$V = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

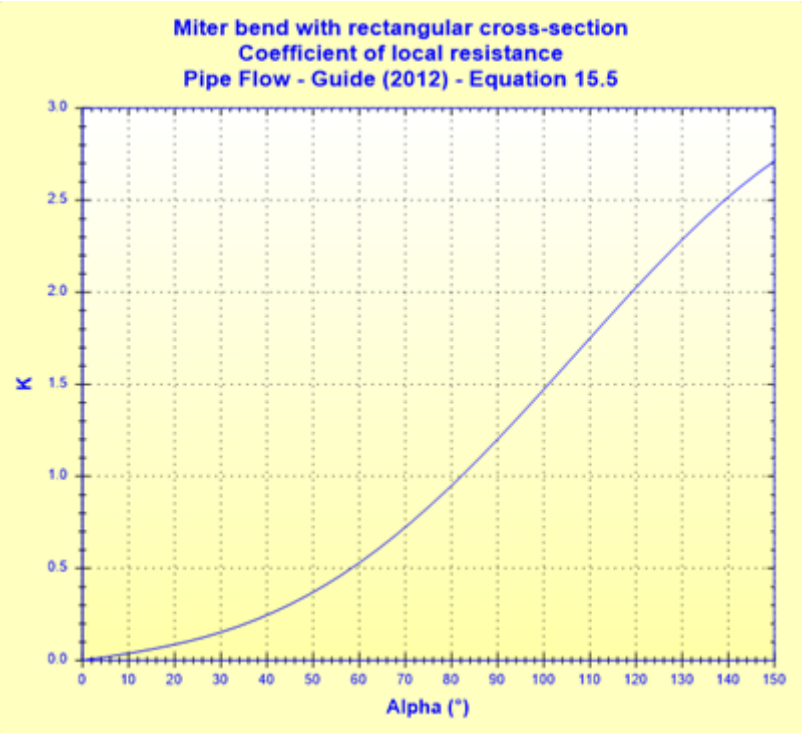
Reynolds number:

$$N_{Re} = \frac{V \cdot d_h}{\nu}$$

Total pressure loss coefficient (based on mean velocity in bend):

$$K = 0.42 \cdot \sin(\alpha/2) + 2.56 \cdot \left(\sin^3(\alpha/2)\right)$$

([1] equation 15.5)



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

([1] equation 3.7)

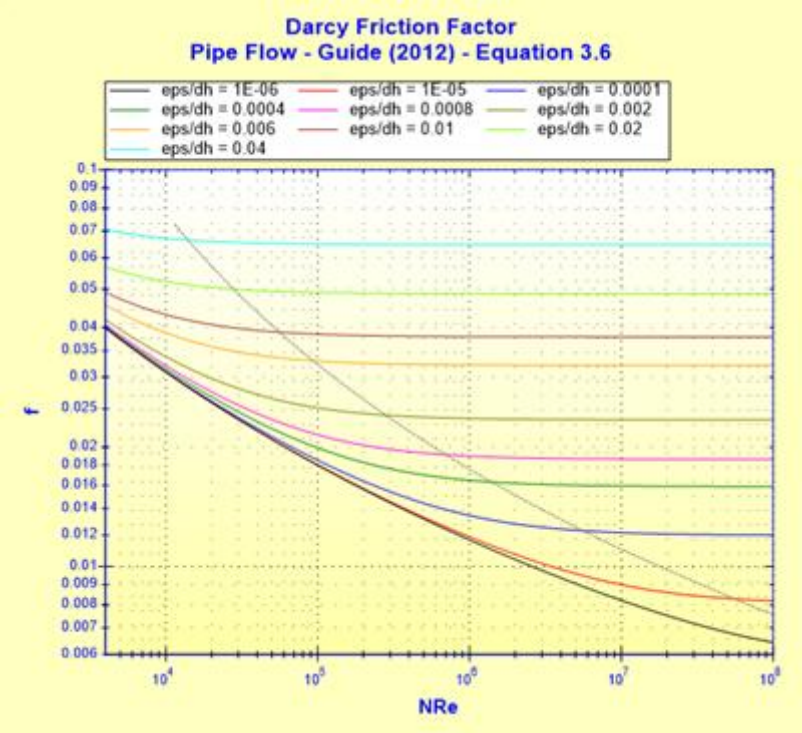
Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Darcy friction factor:

$$f = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d_h} + \frac{2.51}{N_{Re} \cdot \sqrt{f}}\right)\right]^2}$$

Colebrook-White equation ([1] equation 3.6)



Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{d_h}{f}$$

Symbols, Definitions, SI Units:

w	Rectangular cross-section width (m)
h	Rectangular cross-section height (m)
d_h	Bend hydraulic diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
V	Mean velocity (m/s)
α	Angle (°)

G	Mass flow rate (kg/s)
N_{Re}	Reynolds number ()
K	Total pressure loss coefficient (based on mean velocity in bend) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
f	Darcy friction coefficient ()
L_{eq}	Straight length of equivalent pressure loss (m)
ρ_m	Fluid density (kg/m³)
ν	Fluid kinematic viscosity (m²/s)
g	Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($N_{Re} \geq 10^4$)
- stabilized flow upstream of the bend
- angle between 0° and 150°
- this formulation is for circular passages, but can be reasonably applied to square ducts or to rectangular ducts of low aspect ratio

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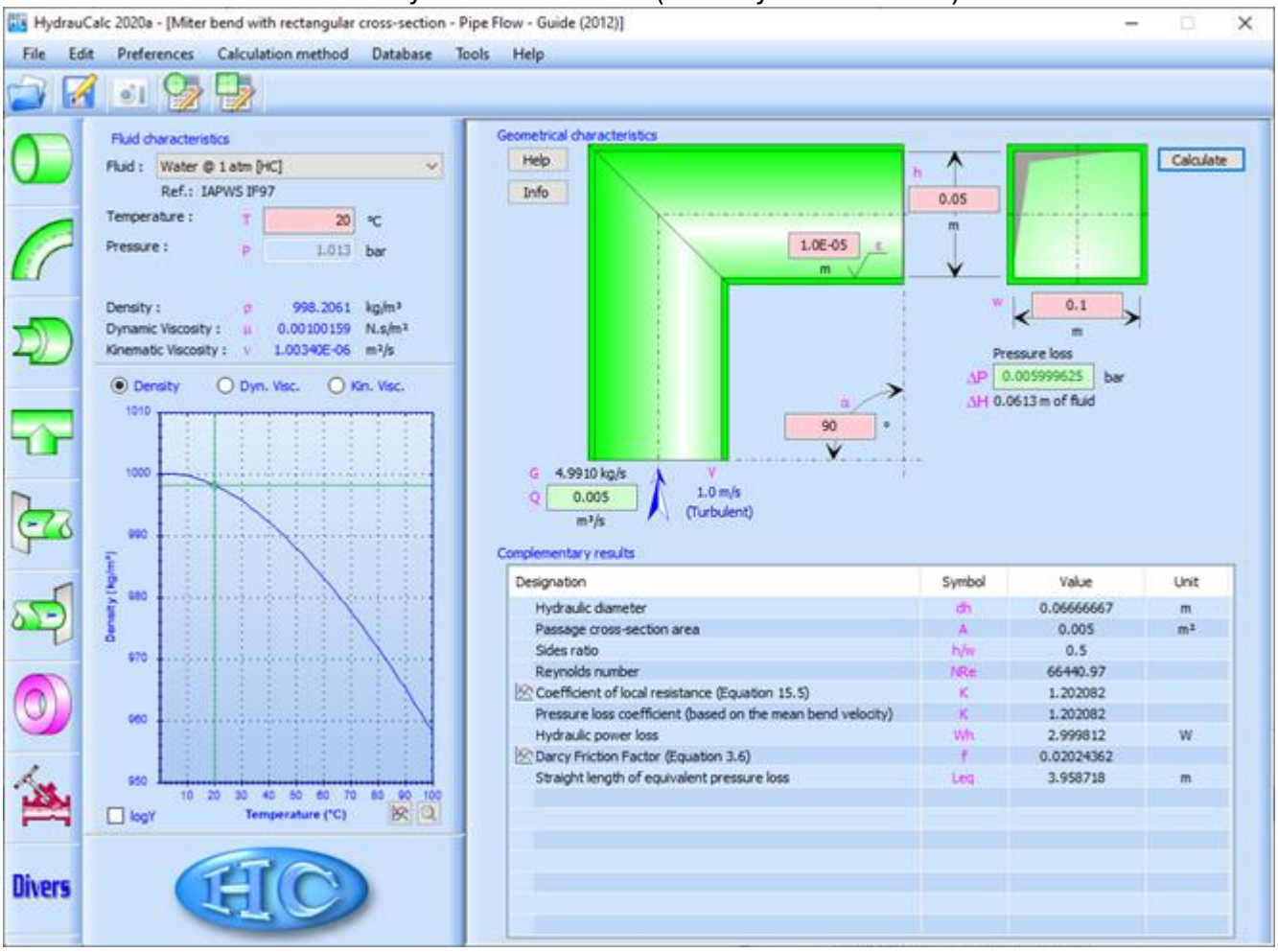
Example of application:



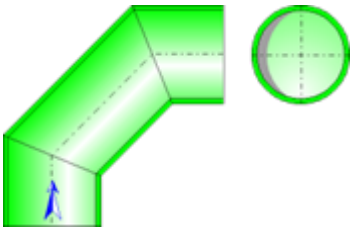
References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.2.5 Composite Bend 90° (2 x 45°) - Circular cross-section

Composite Bend 90° (2 x 45°)

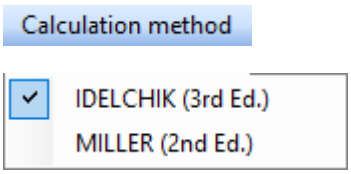
Circular Cross-Section



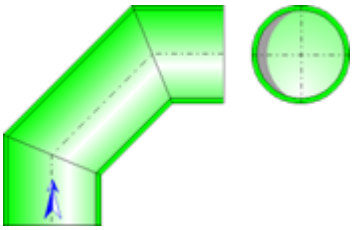
For the calculation of the pressure loss coefficient of composite bends 90° (2 x 45°) with circular cross-section, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.2.5.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) of a composite bend 90° (2 x 45°) whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized at the entrance bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Length measured along the axis (m):

$$l = 4 \cdot R_0 \cdot tg\left(\frac{90°}{4}\right)$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = F_0 \cdot l$$

Fluid mass (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\bar{\Delta} = \frac{\Delta}{D_0}$$

Coefficient of effect of the roughness:

$$k_\Delta = f\left(\frac{R_0}{D_0}, Re, \bar{\Delta}\right)$$

([1] diagram 6.1)

- $0.50 \le R_0/D_0 \le 0.55$

$\bar{\Delta}$	Re	
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$
0	1.0	1.0
0 - 0.001	1.0	$1 + 0.5 \cdot 10^3 \cdot \bar{\Delta}$
> 0.001	1.0	1.5

- $R_0/D_0 > 0.55$

$\overline{\Delta}$	Re		
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$ - $2 \cdot 10^5$	> $2 \cdot 10^5$
0	1.0	1.0	1.0
0 - 0.001	1.0	$\lambda_\Delta / \lambda_{sm}$	$1 + 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	2.0	2.0

with:

λ_{sm} : Darcy friction factor for hydraulically smooth pipe ($\overline{\Delta} = 0$) at Re

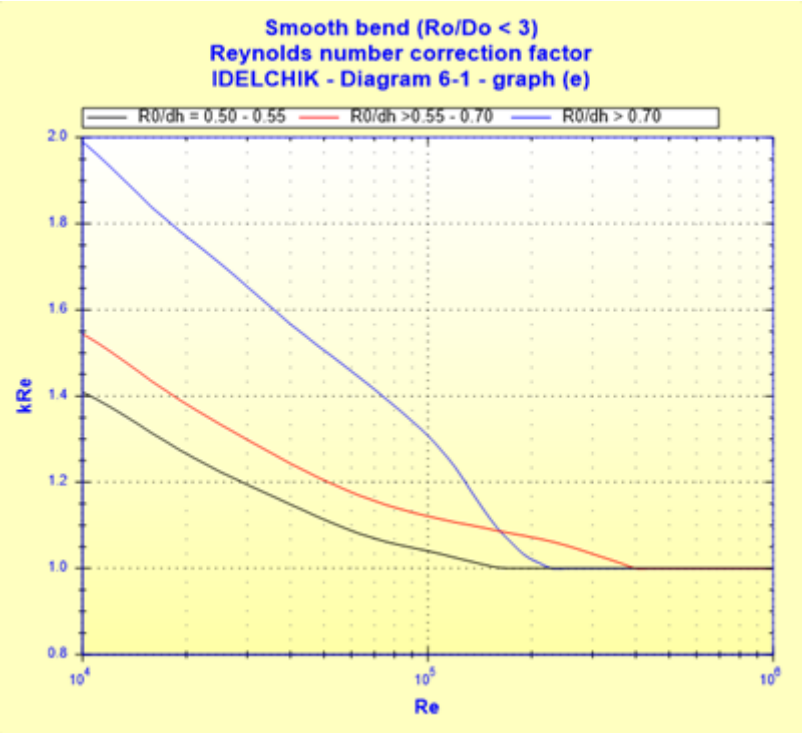
λ_Δ : Darcy friction factor for rough pipe ($\overline{\Delta} = \Delta/D_h$) at Re

---

Coefficient of effect of the Reynolds number (Re ≥ 10^4):

$$k_{Re} = f\left(\mathrm{Re}, \frac{R_0}{D_h}\right)$$

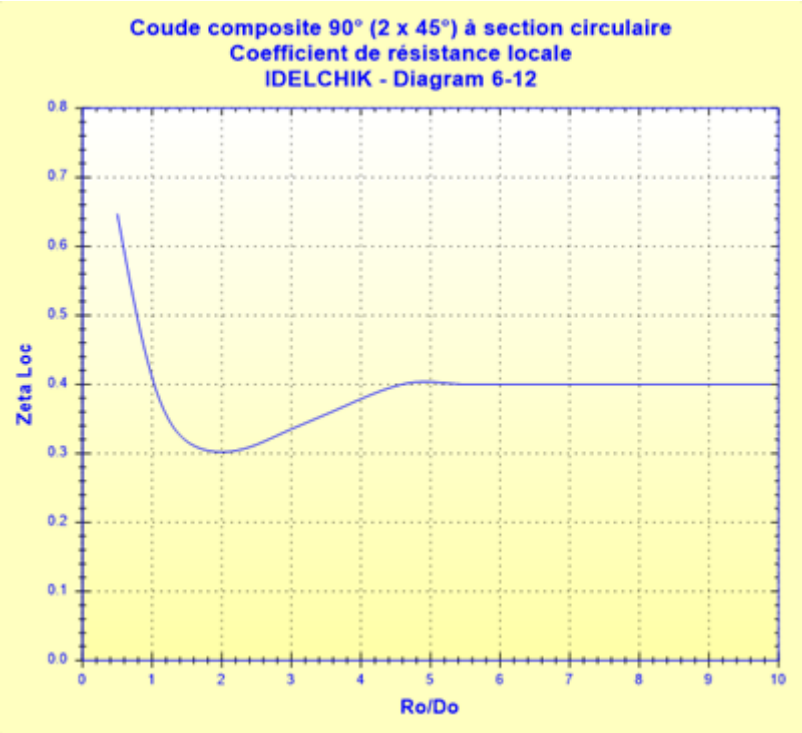
([1] diagram 6.1)



Coefficient of local resistance:

$$\zeta_{loc} = f\left(\frac{R_0}{D_0}\right)$$

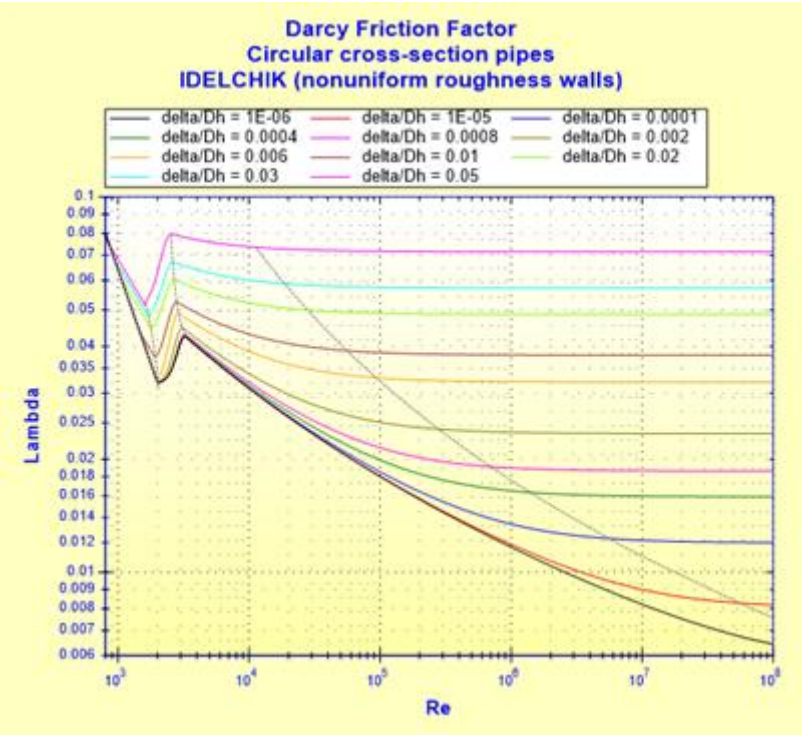
([1] diagram 6.12)



Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}, \frac{\Delta}{D_h}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



Pressure loss friction factor:

$$\zeta_{fr} = \lambda \cdot \frac{l}{D_0}$$ ([1] diagram 6.12)

Corrected pressure loss coefficient:

- Re ≥ 10^4 (turbulent flow)

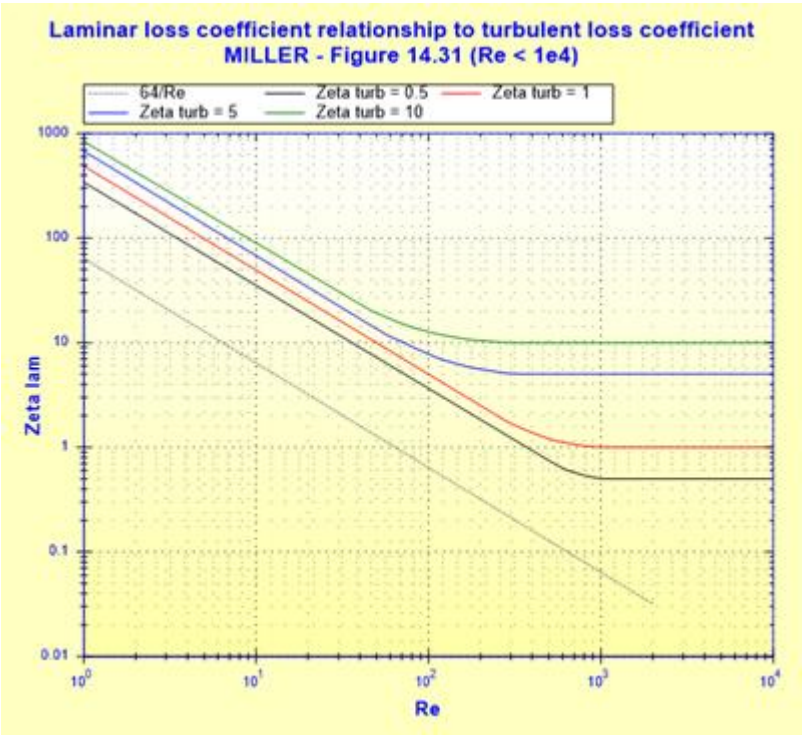
  $$\zeta_{turb} = k_{\Delta} \cdot k_{Re} \cdot \zeta_{loc}$$ ([1] diagram 6.12)

- Re < 10^4 (laminar flow)

  $$\zeta_{lam} = f(\zeta_{turb}, Re)$$ ([2] figure 14.31)

  where:

  ζ_{turb} is the resistance coefficient in turbulent regime for Re = 10^4



Total pressure loss coefficient (based on the mean velocity in the bend):

- Re ≥ 10^4 (turbulent flow)

  $$\zeta = \zeta_{turb} + \zeta_{fr}$$ ([1] diagram 6.12)

- Re < 10^4 (laminar flow)

  $$\zeta = \zeta_{lam} + \zeta_{fr}$$ ([1] diagram 6.12)

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_0}{\lambda}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$

([1] diagram 6.1 – 6.2)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Bend hydraulic diameter (m)
D_0	Bend internal diameter (m)
F_0	Cross-sectional area (m^2)
l	Length measured along the axis (m)
R_0	Radius of curvature (m)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)

$\bar{\Delta}$ Relative roughness of walls ()

k_{Δ} Coefficient that allows for the effect of the roughness ()

k_{Re} Coefficient that allows for the effect of the Reynolds number ()

ζ_{loc} Coefficient of local resistance ()

λ Darcy friction coefficient ()

ζ_{fr} Pressure loss friction factor ()

ζ_{turb} Corrected pressure loss coefficient for $Re \geq 10^4$ ()

ζ_{lam} Corrected pressure loss coefficient for $Re < 10^4$ ()

ζ Total pressure loss coefficient (based on the mean velocity in the bend) ()

L_{eq} Straight length of equivalent pressure loss (m)

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

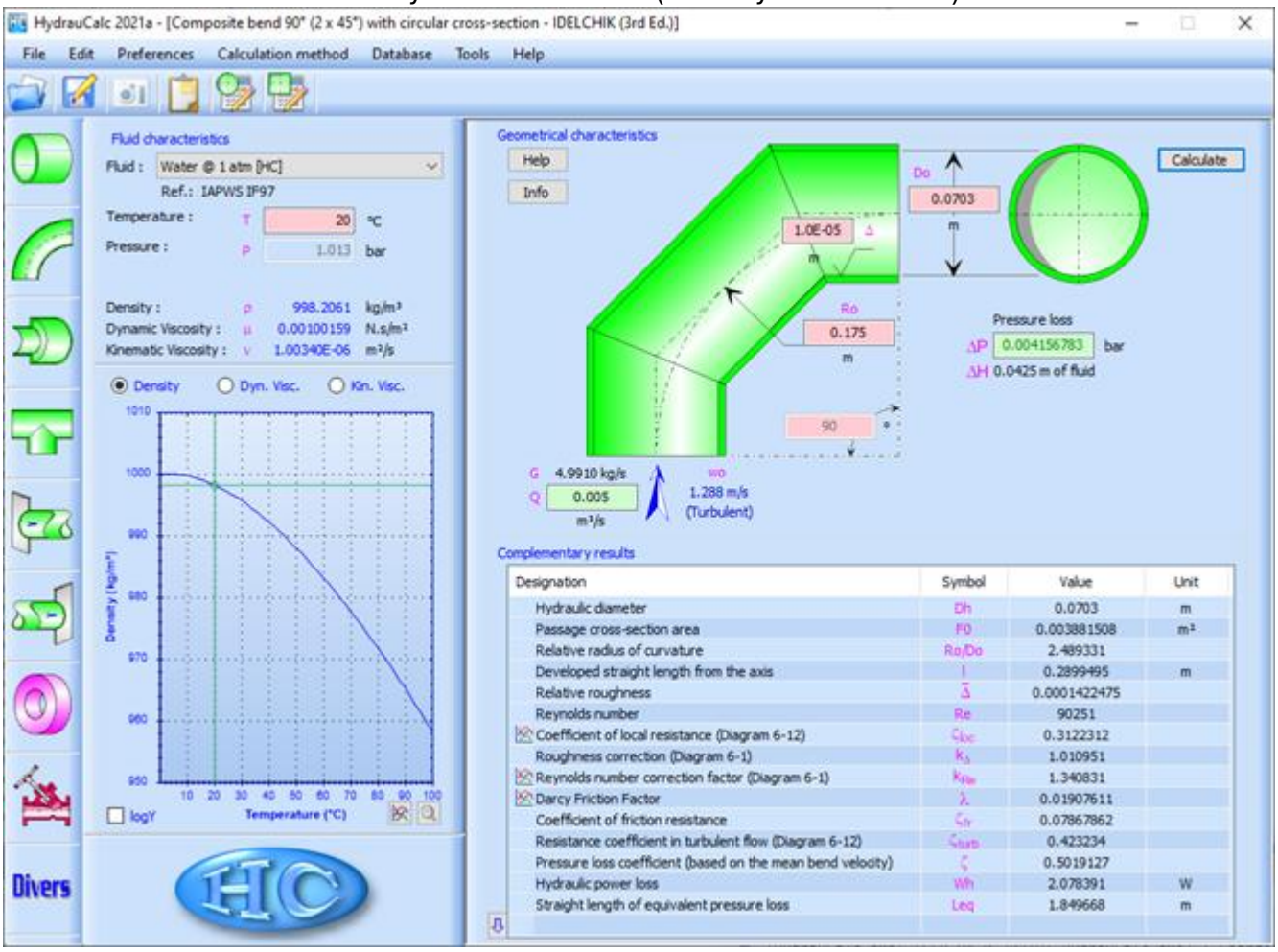
Validity range:

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "ζ_{lam}" is estimated

- stabilized flow upstream bend
- length of the straight section downstream: $\geq 10\ D_0$

Example of application:

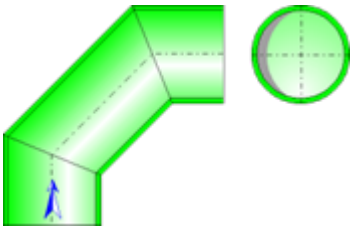


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

[2] Internal Flow System, Second Edition, D.S. Miller

2.2.5.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) of a composite bend 90° (2 x 45°) whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

An option allows to take into account the effect of the straight length at the exit of the bend.

Model formulation:

Hydraulic diameter (m):

$$D = d$$

Cross-section area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Length measured along the axis (m):

$$L = 4 \cdot r \cdot tg\left(\frac{90°}{4}\right)$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

$$M = V \cdot \rho$$

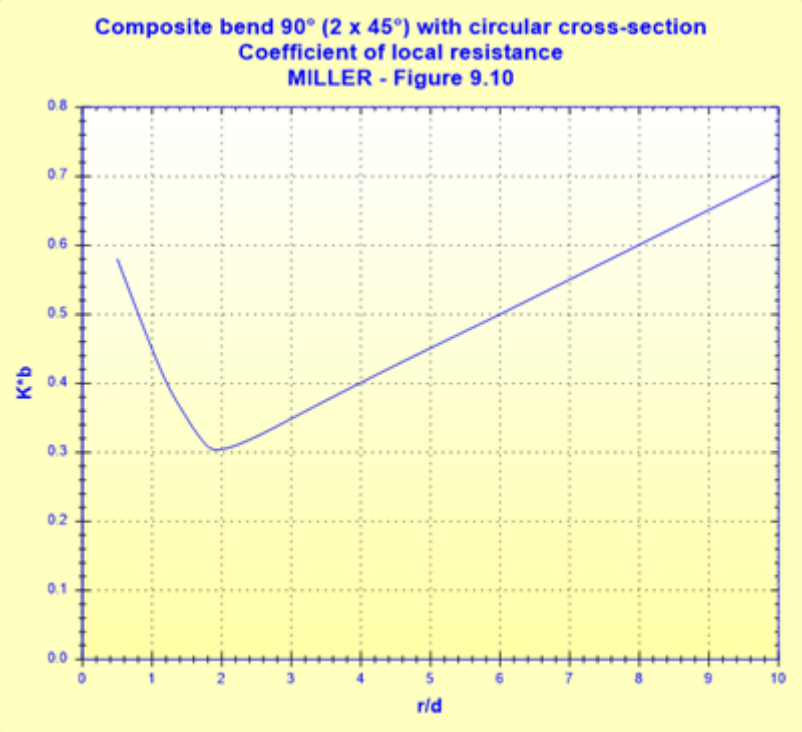
Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

Basic resistance coefficient:

$$K_b^* = f\left(\frac{r}{d}\right)$$

([1] figure 9.10)



Reynolds number correction factor:

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3)

- r/d ≥ 1

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3)

- r/d < 1
  - r/d > 0.7 or K_b^* < 0.4

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3 with r/d=1)

  - otherwise (r/d ≤ 0.7 and K_b^* ≥ 0.4)

$$C_{Re} = \frac{K_b^*}{K_b^* - 0.2C'_{Re} + 0.2}$$ ([1] equation 9.2)

with:

$$C'_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$

([1] figure 9.3 with r/d=1)

Local resistance coefficient:

- Re ≥ 10^4 (turbulent flow)

$$K_{turb} = K_b^* \cdot C_{Re}$$

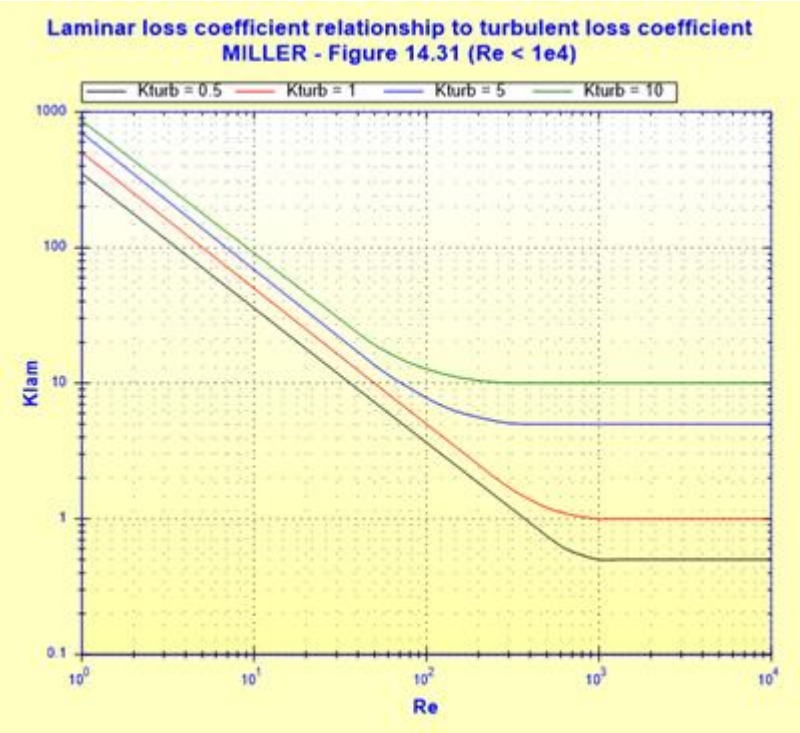
- Re < 10^4 (laminar flow)

$$K_{lam} = f(K_{turb}, \mathrm{Re})$$

([1] figure 14.31)

where:

K_{turb} is the resistance coefficient in turbulent regime for Re = 10^4

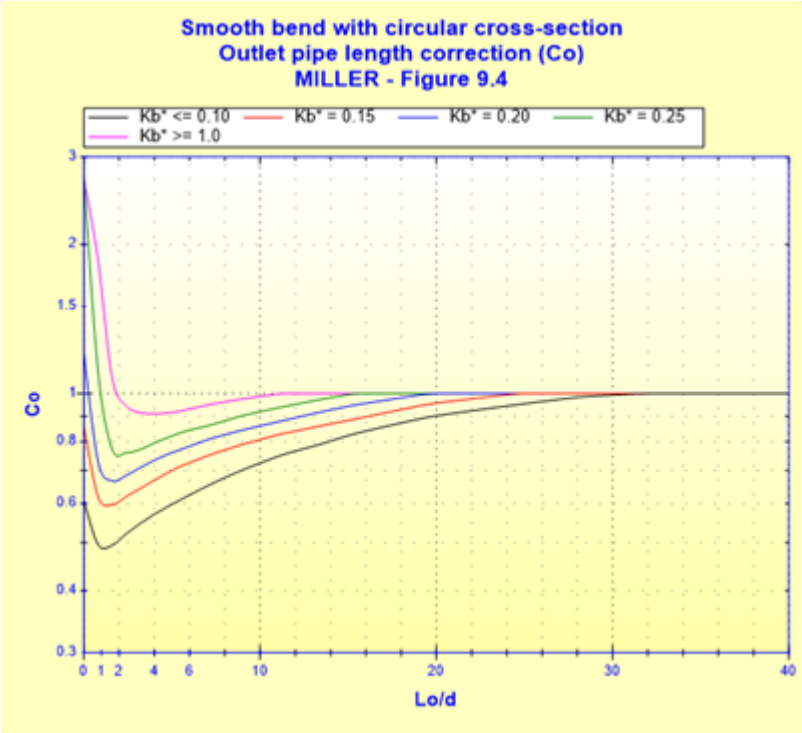


Outlet pipe length correction factor (optional):

- r/d < 3

$$C_o = f\left(\frac{L_o}{d}, K_b^*\right)$$

([1] figure 9.4)



- otherwise ($r/d \leq 3$)

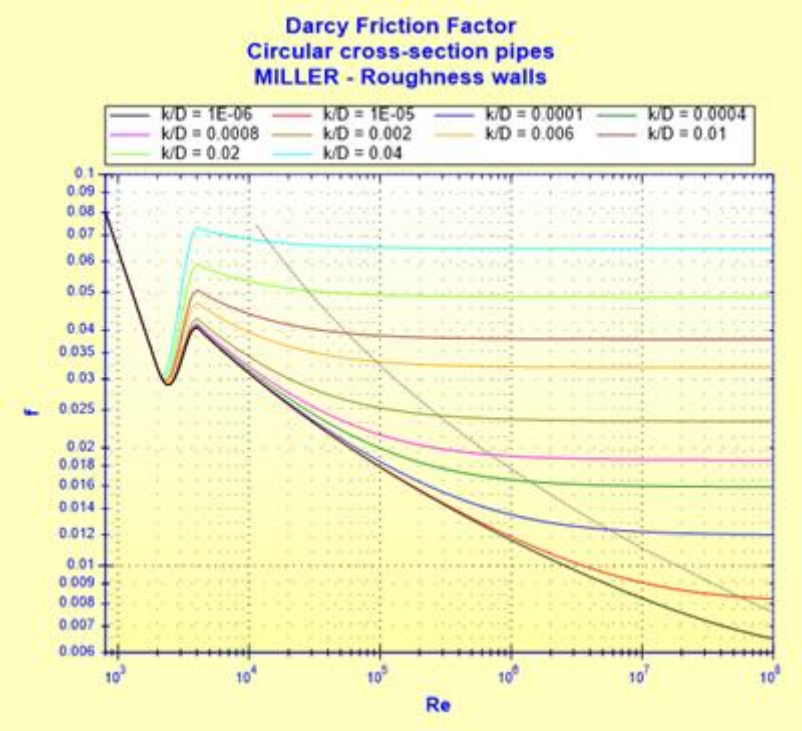
$$C_o = 1$$ (negligible effect)

If this option is not activated, the factor C_o is equal to unity.

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{D}\right)$$

See Straight Pipe - Circular Cross-Section and Roughness Walls (MILLER)



Roughness correction factor:

$$C_f = \frac{f_{rough}}{f_{smooth}}$$ ([1] equation 9.3)

with:

f_{rough}: Darcy friction factor for rough pipe at Re

f_{smooth}: Darcy friction factor for smooth pipe (k = 0) at Re

For Re > 10^6, C_f is calculated from equation (9.3) for Re = 10^6

Corrected loss coefficient:

- turbulent flow (Re ≥ 10^4):

$$K_b = K_{turb} \cdot C_o \cdot C_f$$

- laminar flow (Re < 10^4):

$$K_b = K_{lam} \cdot C_o \cdot C_f$$

Total pressure loss coefficient (based on the mean velocity in the bend)

$$K = K_b$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{d}{f_{rough}}$$

Symbols, Definitions, SI Units:

D	Bend hydraulic diameter (m)
d	Bend internal diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
L	Length measured along the axis (m)
r	Radius of curvature (m)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()

K_b^*	Basic loss coefficient ()
C_{Re}	Reynolds number correction factor ()
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_o	Outlet pipe length correction factor ()
L_0	Length of the straight section downstream of the bend (m)
f	Darcy friction factor ()
k	Absolute roughness of walls (m)
C_f	Roughness correction factor ()
K_b	Corrected loss coefficient ()
K	Total pressure loss coefficient (based on the mean velocity in the bend) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
L_{eq}	Straight length of equivalent pressure loss (m)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

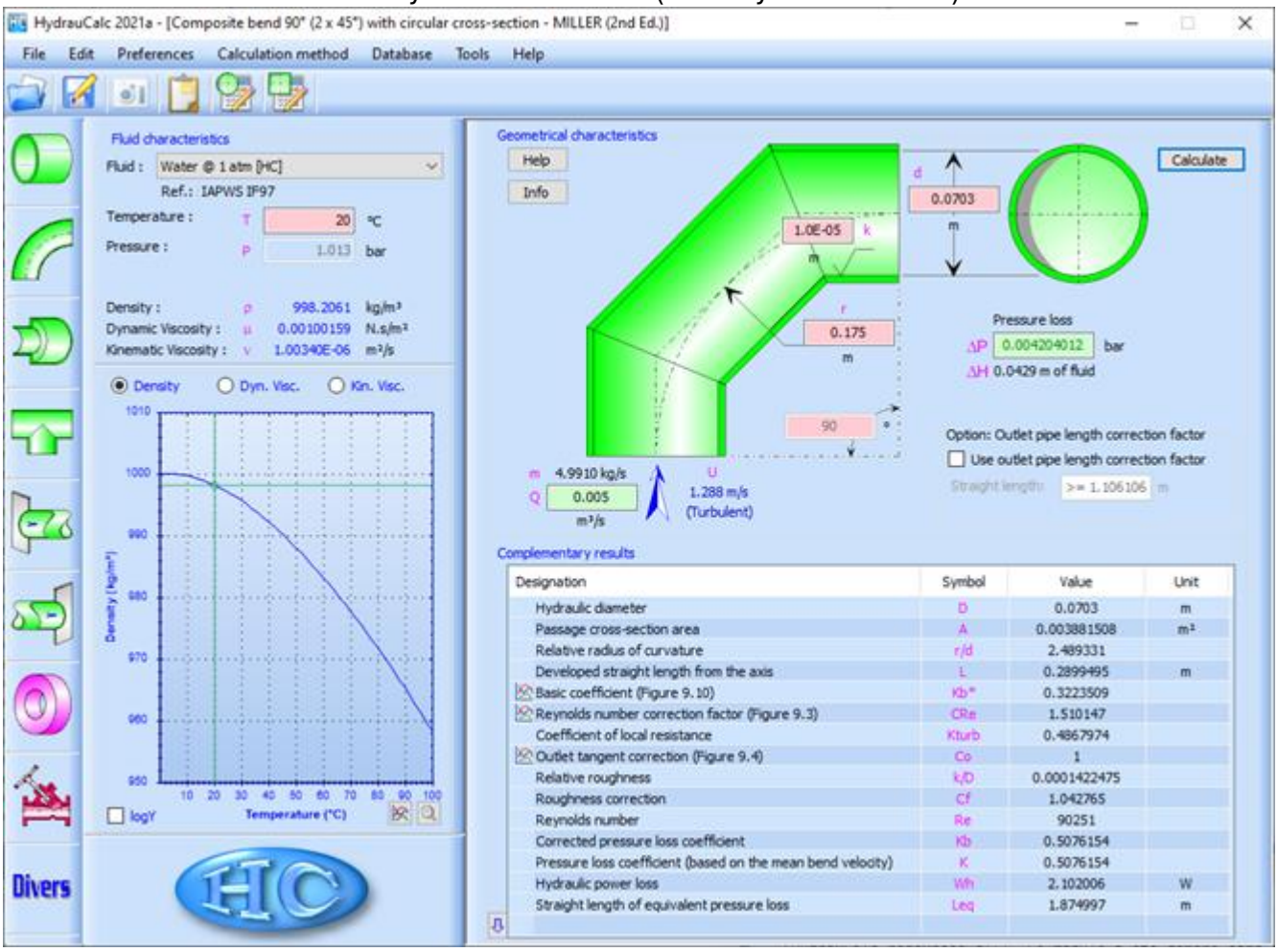
Validity range:

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

- stabilized flow upstream bend

Example of application:



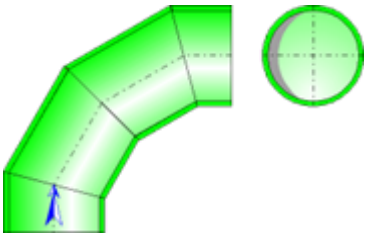
References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.2.6 Composite Bend 90° (3 x 30°) - Circular cross-section

Composite Bend 90° (3 x 30°)

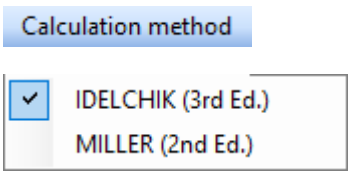
Circular Cross-Section



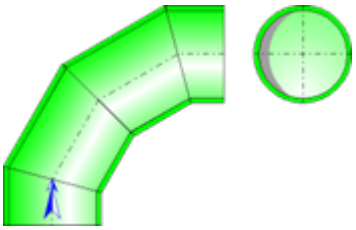
For the calculation of the pressure loss coefficient of composite bends 90° (3 x 30°) with circular cross-section, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.2.6.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) of a composite bend 90° (3 x 30°) whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized at the entrance bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Length measured along the axis (m):

$$l = 6 \cdot R_0 \cdot tg\left(\frac{90°}{6}\right)$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = F_0 \cdot l$$

Fluid mass (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\bar{\Delta} = \frac{\Delta}{D_0}$$

Coefficient of effect of the roughness:

$$k_\Delta = f\left(\frac{R_0}{D_0}, Re, \bar{\Delta}\right)$$ ([1] diagram 6.1)

- $0.50 \le R_0/D_0 \le 0.55$

$\bar{\Delta}$	Re	
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$
0	1.0	1.0
0 - 0.001	1.0	$1 + 0.5 \cdot 10^3 \cdot \bar{\Delta}$
> 0.001	1.0	1.5

- $R_0/D_0 > 0.55$

$\overline{\Delta}$	Re		
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$ - $2 \cdot 10^5$	> $2 \cdot 10^5$
0	1.0	1.0	1.0
0 - 0.001	1.0	$\lambda_\Delta / \lambda_{sm}$	$1 + 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	2.0	2.0

with:

λ_{sm} : Darcy friction factor for hydraulically smooth pipe ($\overline{\Delta} = 0$) at Re

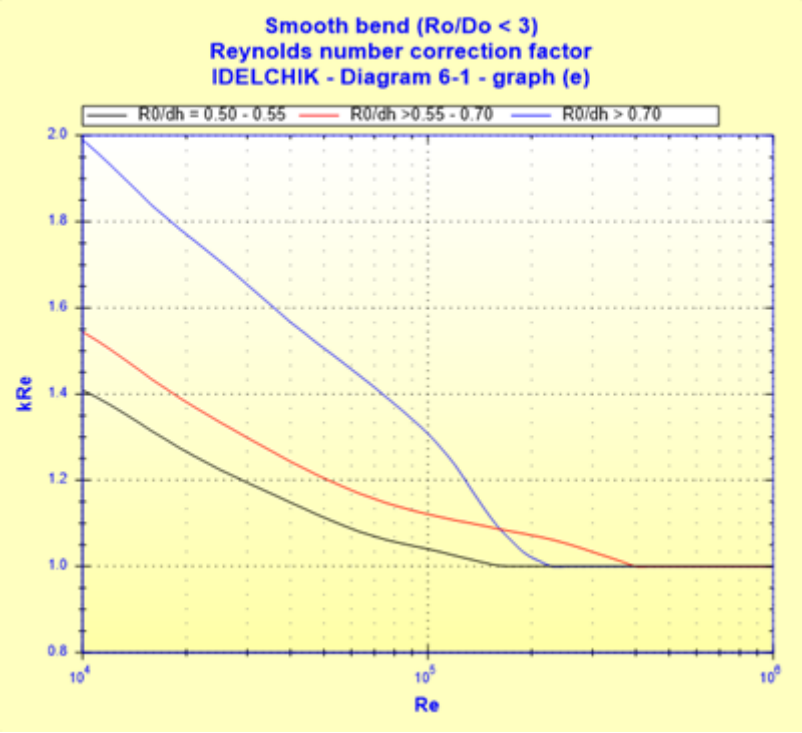
λ_Δ : Darcy friction factor for rough pipe ($\overline{\Delta} = \Delta/D_h$) at Re

---

Coefficient of effect of the Reynolds number (Re ≥ 10^4):

$$k_{Re} = f\left(\mathrm{Re}, \frac{R_0}{D_h}\right)$$

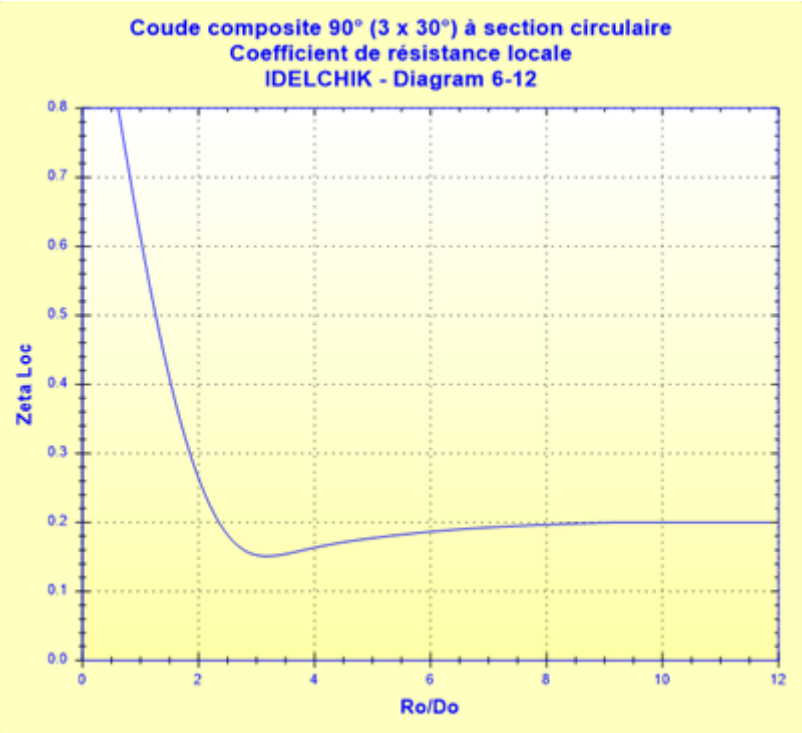
([1] diagram 6.1)



Coefficient of local resistance:

$$\zeta_{loc} = f\left(\frac{R_0}{D_0}\right)$$

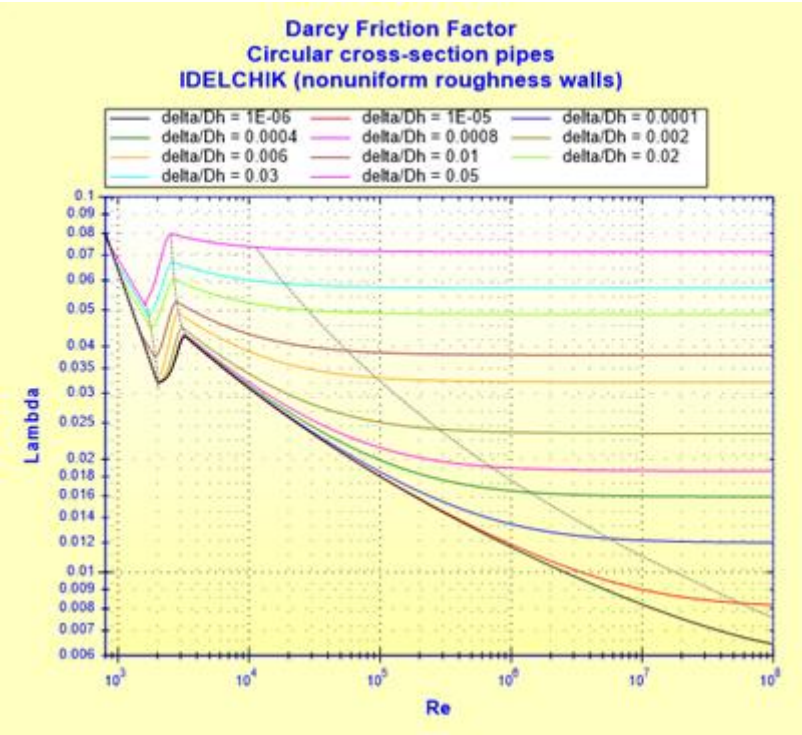
([1] diagram 6.12)



Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}, \frac{\Delta}{D_h}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



Pressure loss friction factor:

$$\zeta_{fr} = \lambda \cdot \frac{l}{D_0}$$ ([1] diagram 6.12)

Corrected pressure loss coefficient:

- Re ≥ 10^4 (turbulent flow)

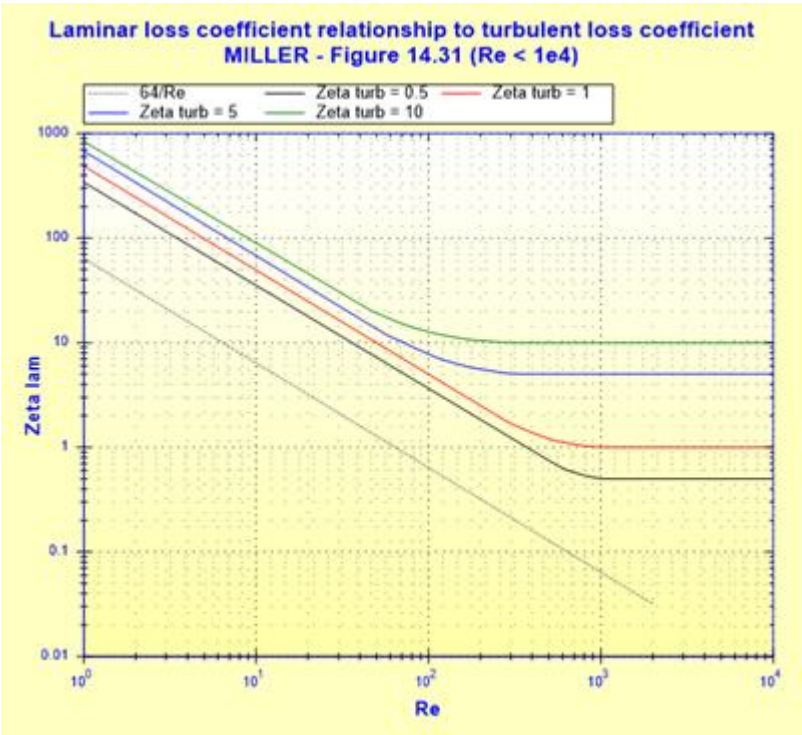
  $$\zeta_{turb} = k_{\Delta} \cdot k_{Re} \cdot \zeta_{loc}$$ ([1] diagram 6.12)

- Re < 10^4 (laminar flow)

  $$\zeta_{lam} = f(\zeta_{turb}, Re)$$ ([2] figure 14.31)

  where:

  ζ_{turb} is the resistance coefficient in turbulent regime for Re = 10^4



Total pressure loss coefficient (based on the mean velocity in the bend):

- Re ≥ 10^4 (turbulent flow)

  $$\zeta = \zeta_{turb} + \zeta_{fr}$$ ([1] diagram 6.12)

- Re < 10^4 (laminar flow)

  $$\zeta = \zeta_{lam} + \zeta_{fr}$$ ([1] diagram 6.12)

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_0}{\lambda}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$

([1] diagram 6.1 – 6.2)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Bend hydraulic diameter (m)
D_0	Bend internal diameter (m)
F_0	Cross-sectional area (m^2)
l	Length measured along the axis (m)
R_0	Radius of curvature (m)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)

$\bar{\Delta}$ Relative roughness of walls ()

k_{Δ} Coefficient that allows for the effect of the roughness ()

k_{Re} Coefficient that allows for the effect of the Reynolds number ()

ζ_{loc} Coefficient of local resistance ()

λ Darcy friction coefficient ()

ζ_{fr} Pressure loss friction factor ()

ζ_{turb} Corrected pressure loss coefficient for $Re \geq 10^4$ ()

ζ_{lam} Corrected pressure loss coefficient for $Re < 10^4$ ()

ζ Total pressure loss coefficient (based on the mean velocity in the bend) ()

L_{eq} Straight length of equivalent pressure loss (m)

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

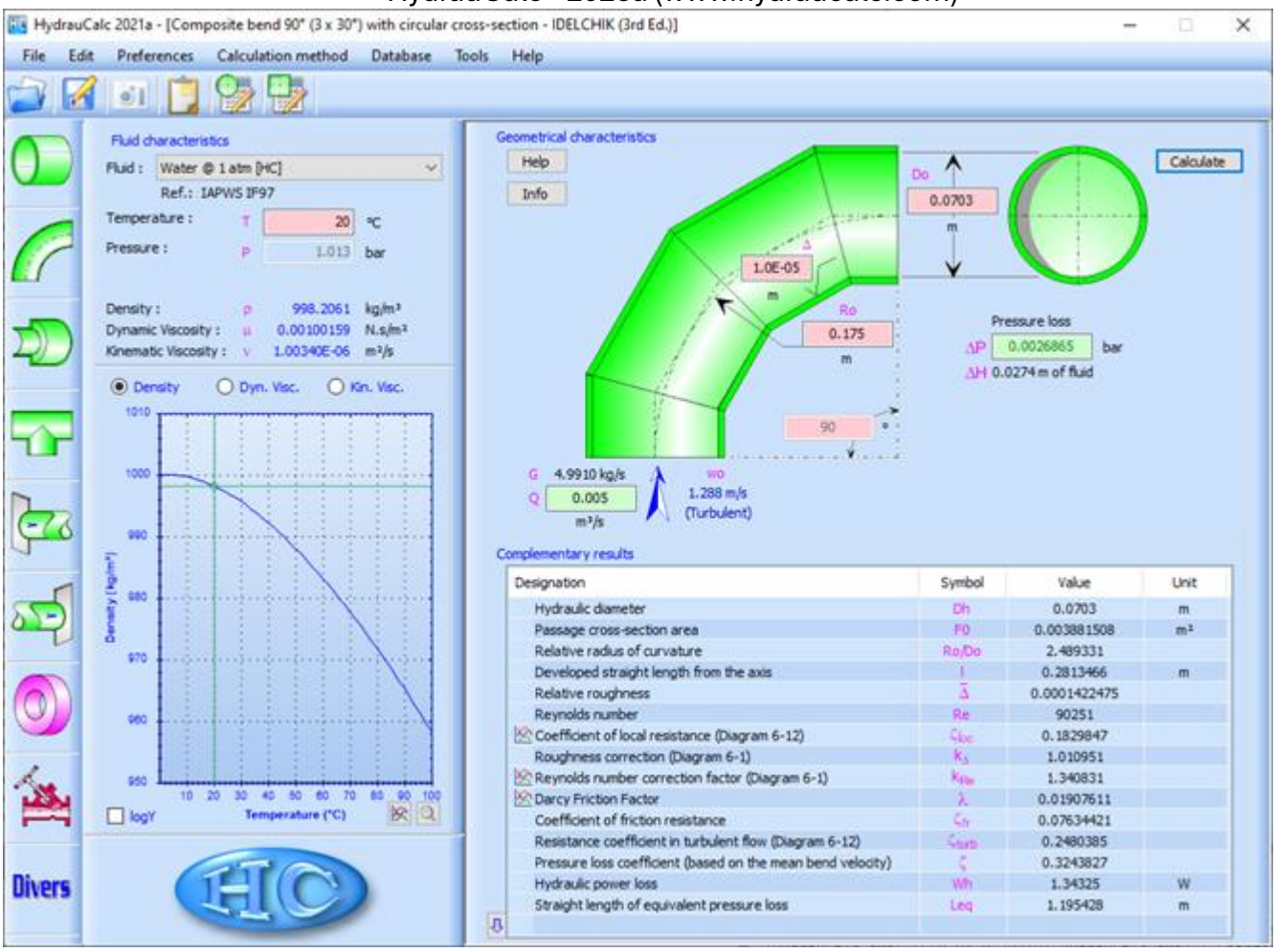
Validity range:

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "ζ_{lam}" is estimated

- stabilized flow upstream bend
- length of the straight section downstream: $\geq 10\ D_0$

Example of application:

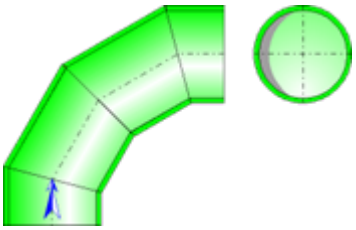


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

[2] Internal Flow System, Second Edition, D.S. Miller

2.2.6.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) of a composite bend 90° (3 x 30°) whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

An option allows to take into account the effect of the straight length at the exit of the bend.

Model formulation:

Hydraulic diameter (m):

$$D = d$$

Cross-section area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Length measured along the axis (m):

$$L = 6 \cdot r \cdot tg\left(\frac{90°}{6}\right)$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

$$M = V \cdot \rho$$

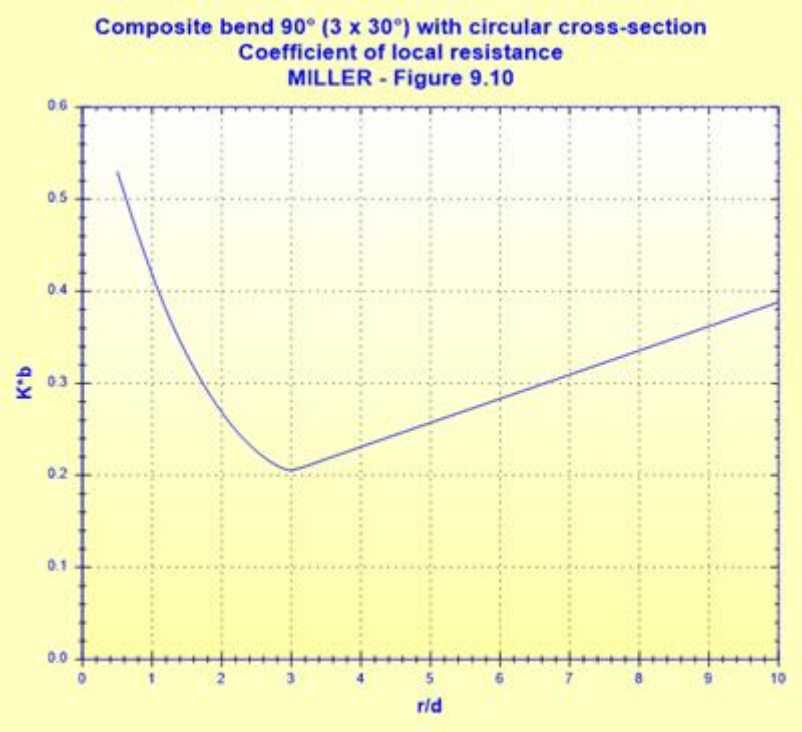
Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

Basic resistance coefficient:

$$K_b^* = f\left(\frac{r}{d}\right)$$

([1] figure 9.10)



Reynolds number correction factor:

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3)

- r/d ≥ 1

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3)

- r/d < 1
  - r/d > 0.7 or K_b^* < 0.4

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3 with r/d=1)

  - otherwise (r/d ≤ 0.7 and K_b^* ≥ 0.4)

$$C_{Re} = \frac{K_b^*}{K_b^* - 0.2C'_{Re} + 0.2}$$ ([1] equation 9.2)

with:

$$C'_{Re} = f\left(Re, \frac{r}{d}\right)$$

([1] figure 9.3 with r/d=1)

Local resistance coefficient:

- Re ≥ 10^4 (turbulent flow)

$$K_{turb} = K_b^* \cdot C_{Re}$$

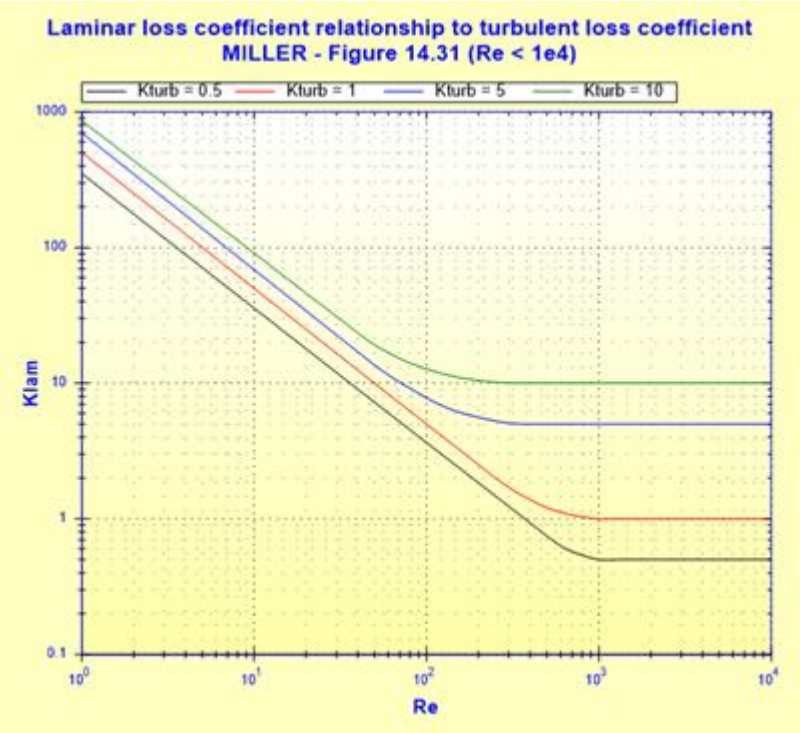
- Re < 10^4 (laminar flow)

$$K_{lam} = f(K_{turb}, Re)$$

([1] figure 14.31)

where:

K_{turb} is the resistance coefficient in turbulent regime for Re = 10^4

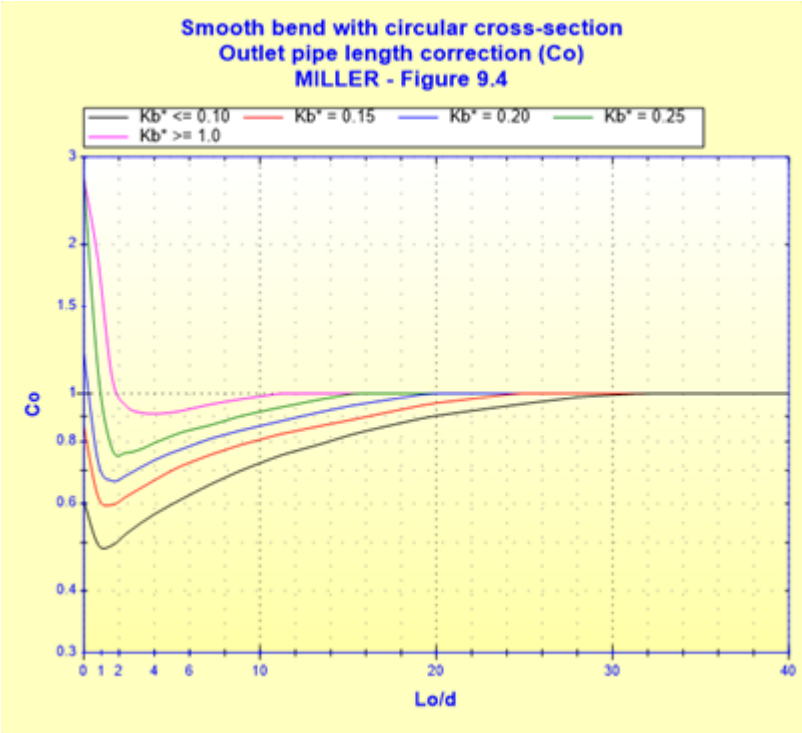


Outlet pipe length correction factor (optional):

- r/d < 3

$$C_o = f\left(\frac{L_o}{d}, K_b^*\right)$$

([1] figure 9.4)



- otherwise ($r/d \leq 3$)

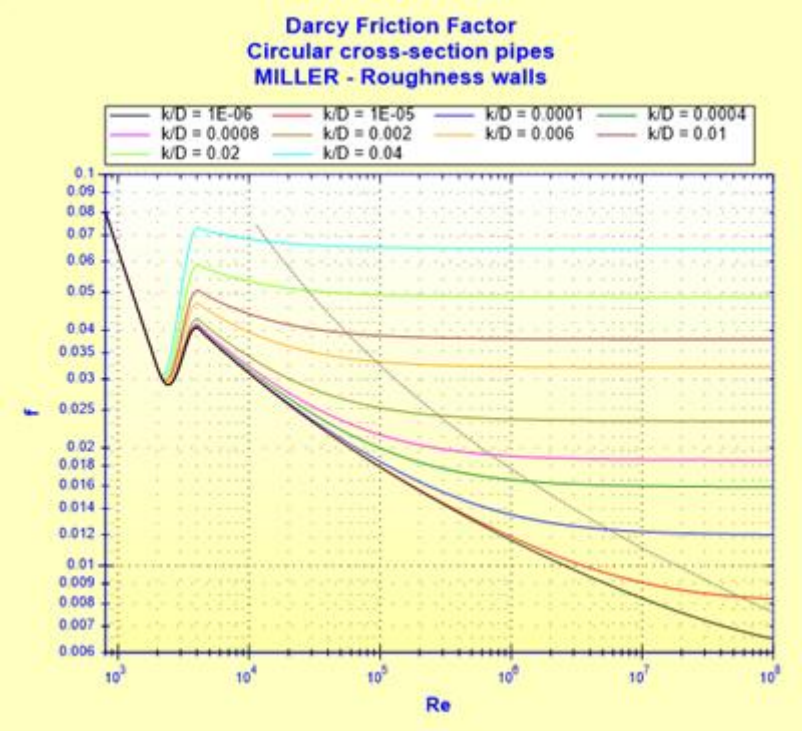
$$C_o = 1$$ (negligible effect)

If this option is not activated, the factor C_o is equal to unity.

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{D}\right)$$

See Straight Pipe - Circular Cross-Section and Roughness Walls (MILLER)



Roughness correction factor:

$$C_f = \frac{f_{rough}}{f_{smooth}}$$ ([1] equation 9.3)

with:

f_{rough}: Darcy friction factor for rough pipe at Re

f_{smooth}: Darcy friction factor for smooth pipe (k = 0) at Re

For $Re > 10^6$, C_f is calculated from equation (9.3) for $Re = 10^6$

Corrected loss coefficient:

- turbulent flow ($Re \geq 10^4$):

$$K_b = K_{turb} \cdot C_o \cdot C_f$$

- laminar flow ($Re < 10^4$):

$$K_b = K_{lam} \cdot C_o \cdot C_f$$

Total pressure loss coefficient (based on the mean velocity in the bend)

$$K = K_b$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{d}{f_{rough}}$$

Symbols, Definitions, SI Units:

D	Bend hydraulic diameter (m)
d	Bend internal diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
L	Length measured along the axis (m)
r	Radius of curvature (m)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()

K_b^* Basic loss coefficient ()

C_{Re} Reynolds number correction factor ()

K_{turb} Local resistance coefficient for $Re \geq 10^4$ ()

K_{lam} Local resistance coefficient for $Re < 10^4$ ()

C_o Outlet pipe length correction factor ()

L_0 Length of the straight section downstream of the bend (m)

f Darcy friction factor ()

k Absolute roughness of walls (m)

C_f Roughness correction factor ()

K_b Corrected loss coefficient ()

K Total pressure loss coefficient (based on the mean velocity in the bend) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

L_{eq} Straight length of equivalent pressure loss (m)

ρ Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

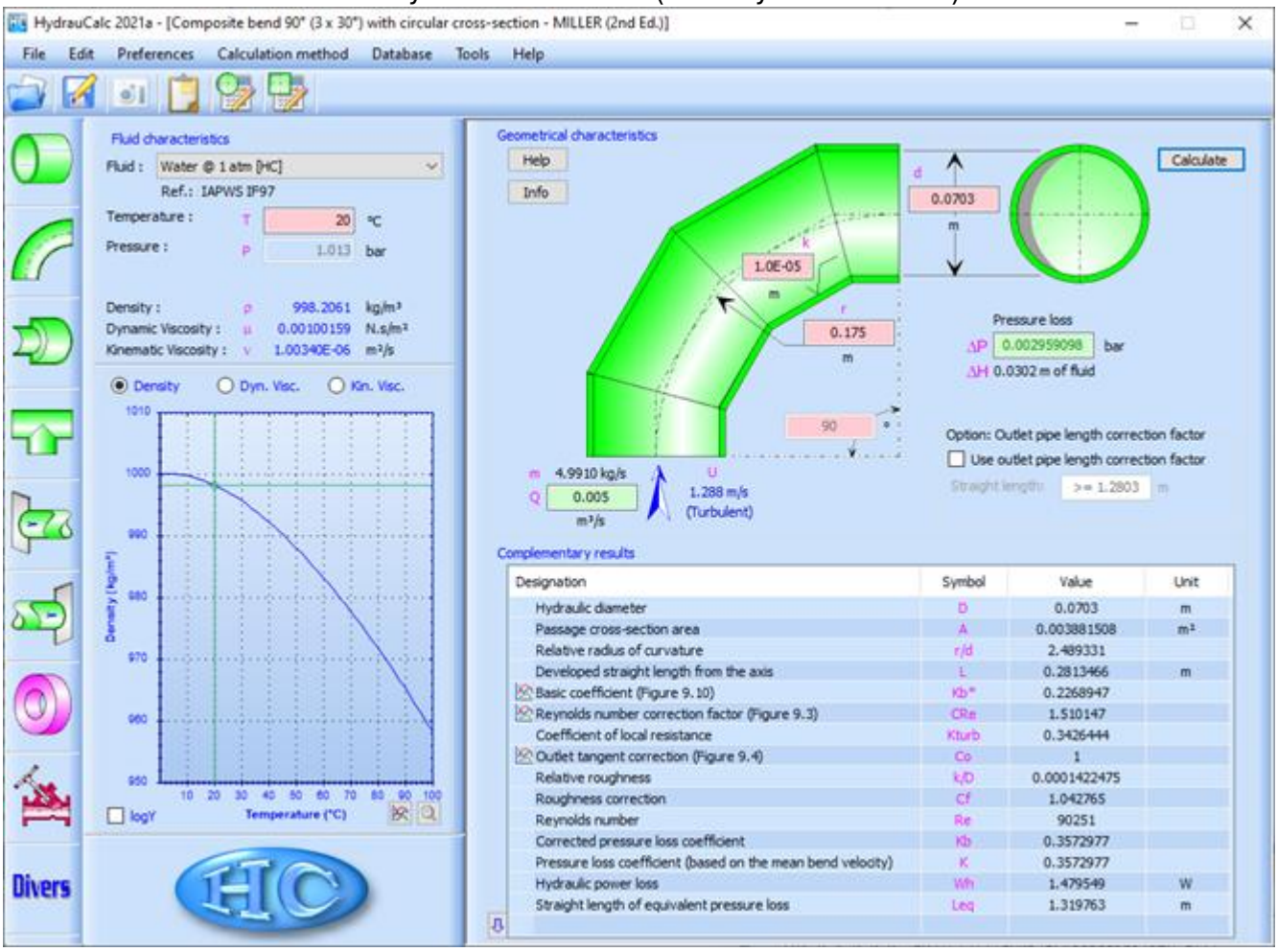
Validity range:

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

- stabilized flow upstream bend

Example of application:



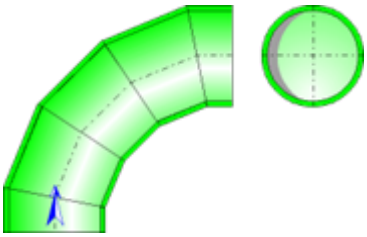
References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.2.7 Composite Bend 90° (4 x 22.5°) - Circular cross-section

Composite Bend 90° (4 x 22.5°)

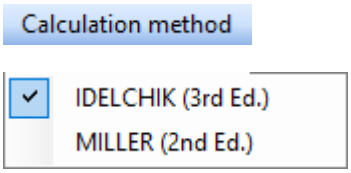
Circular Cross-Section



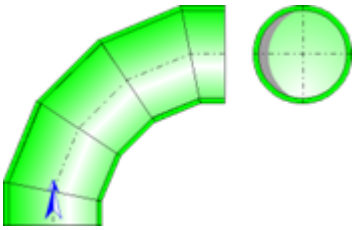
For the calculation of the pressure loss coefficient of composite bends 90° (4 x 22.5°) with circular cross-section, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.2.7.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) of a composite bend 90° (4 x 22.5°) whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized at the entrance bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Length measured along the axis (m):

$$l = 8 \cdot R_0 \cdot tg\left(\frac{90°}{8}\right)$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = F_0 \cdot l$$

Fluid mass (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\bar{\Delta} = \frac{\Delta}{D_0}$$

Coefficient of effect of the roughness:

$$k_\Delta = f\left(\frac{R_0}{D_0}, Re, \bar{\Delta}\right)$$

([1] diagram 6.1)

- $0.50 \le R_0/D_0 \le 0.55$

$\bar{\Delta}$	Re	
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$
0	1.0	1.0
0 - 0.001	1.0	$1 + 0.5 \cdot 10^3 \cdot \bar{\Delta}$
> 0.001	1.0	1.5

- $R_0/D_0 > 0.55$

$\overline{\Delta}$	Re		
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$ - $2 \cdot 10^5$	> $2 \cdot 10^5$
0	1.0	1.0	1.0
0 - 0.001	1.0	$\lambda_\Delta / \lambda_{sm}$	$1 + 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	2.0	2.0

with:

λ_{sm} : Darcy friction factor for hydraulically smooth pipe ($\overline{\Delta} = 0$) at Re

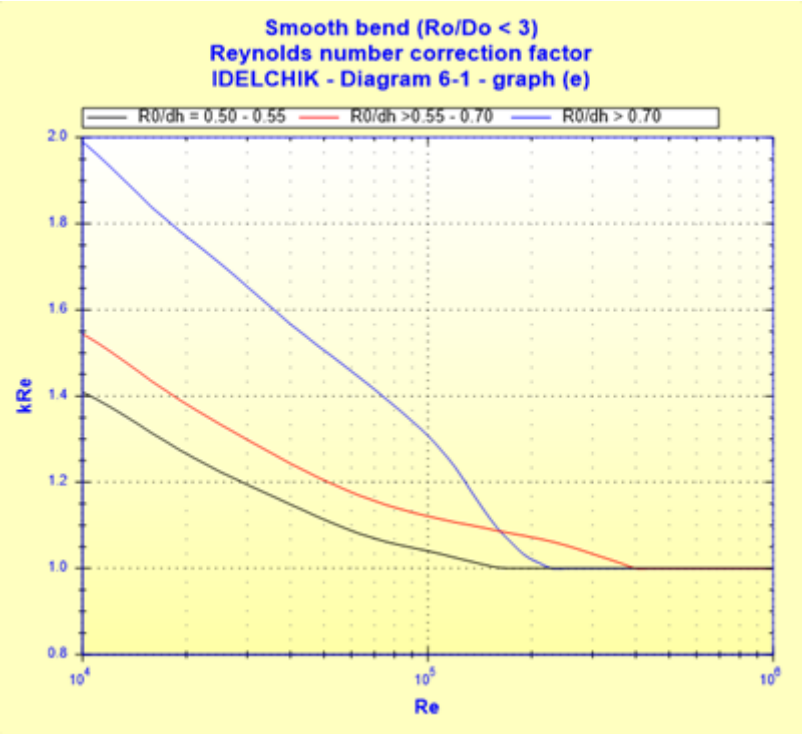
λ_Δ : Darcy friction factor for rough pipe ($\overline{\Delta} = \Delta / D_h$) at Re

---

Coefficient of effect of the Reynolds number (Re ≥ 10^4):

$$k_{Re} = f\left(\mathrm{Re}, \frac{R_0}{D_h}\right)$$

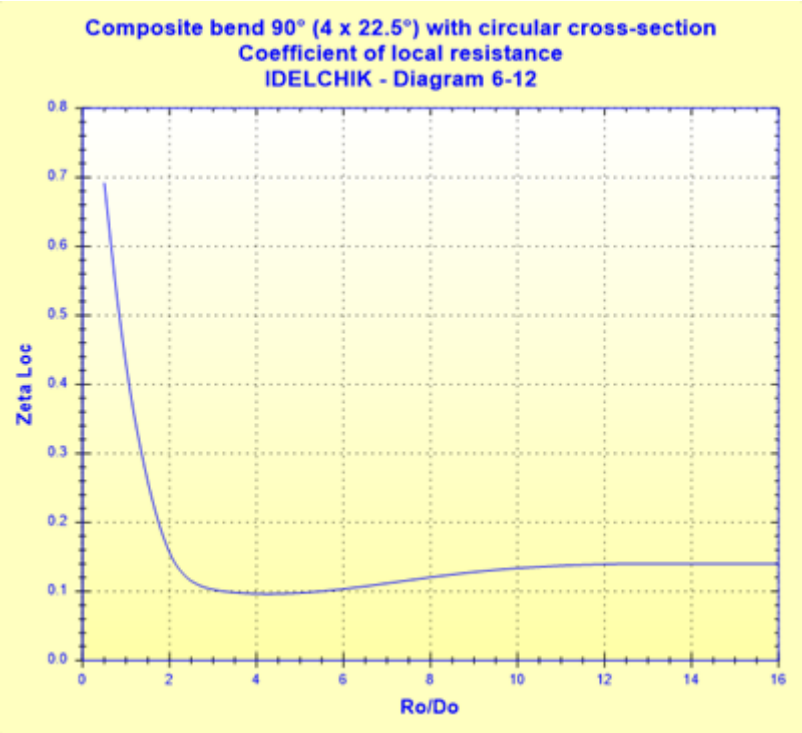
([1] diagram 6.1)



Coefficient of local resistance:

$$\zeta_{loc} = f\left(\frac{R_0}{D_0}\right)$$

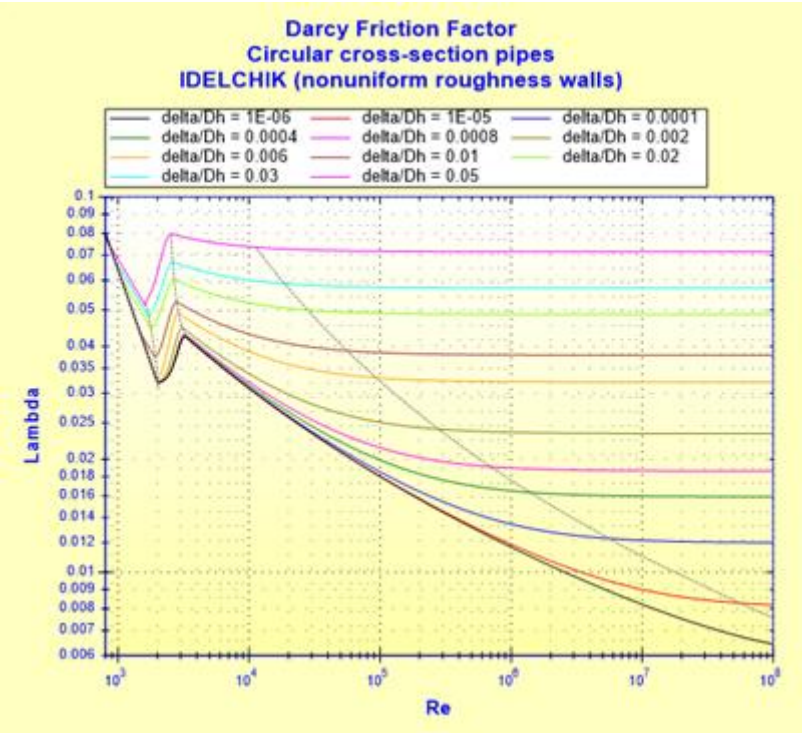
([1] diagram 6.12)



Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}, \frac{\Delta}{D_h}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



Pressure loss friction factor:

$$\zeta_{fr} = \lambda \cdot \frac{l}{D_0}$$ ([1] diagram 6.12)

Corrected pressure loss coefficient:

- Re ≥ 10^4 (turbulent flow)

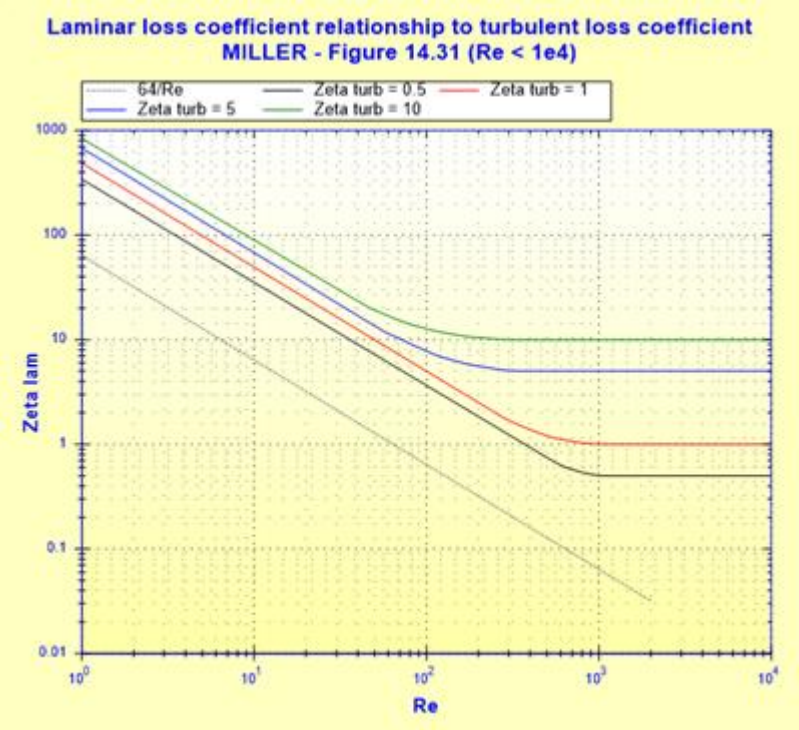
  $$\zeta_{turb} = k_{\Delta} \cdot k_{Re} \cdot \zeta_{loc}$$ ([1] diagram 6.12)

- Re < 10^4 (laminar flow)

  $$\zeta_{lam} = f(\zeta_{turb}, Re)$$ ([2] figure 14.31)

  where:

  ζ_{turb} is the resistance coefficient in turbulent regime for Re = 10^4



Total pressure loss coefficient (based on the mean velocity in the bend):

- Re ≥ 10^4 (turbulent flow)

  $$\zeta = \zeta_{turb} + \zeta_{fr}$$ ([1] diagram 6.12)

- Re < 10^4 (laminar flow)

  $$\zeta = \zeta_{lam} + \zeta_{fr}$$ ([1] diagram 6.12)

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_0}{\lambda}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$

([1] diagram 6.1 – 6.2)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Bend hydraulic diameter (m)
D_0	Bend internal diameter (m)
F_0	Cross-sectional area (m^2)
l	Length measured along the axis (m)
R_0	Radius of curvature (m)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)

$\bar{\Delta}$ Relative roughness of walls ()

k_{Δ} Coefficient that allows for the effect of the roughness ()

k_{Re} Coefficient that allows for the effect of the Reynolds number ()

ζ_{loc} Coefficient of local resistance ()

λ Darcy friction coefficient ()

ζ_{fr} Pressure loss friction factor ()

ζ_{turb} Corrected pressure loss coefficient for $Re \geq 10^4$ ()

ζ_{lam} Corrected pressure loss coefficient for $Re < 10^4$ ()

ζ Total pressure loss coefficient (based on the mean velocity in the bend) ()

L_{eq} Straight length of equivalent pressure loss (m)

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

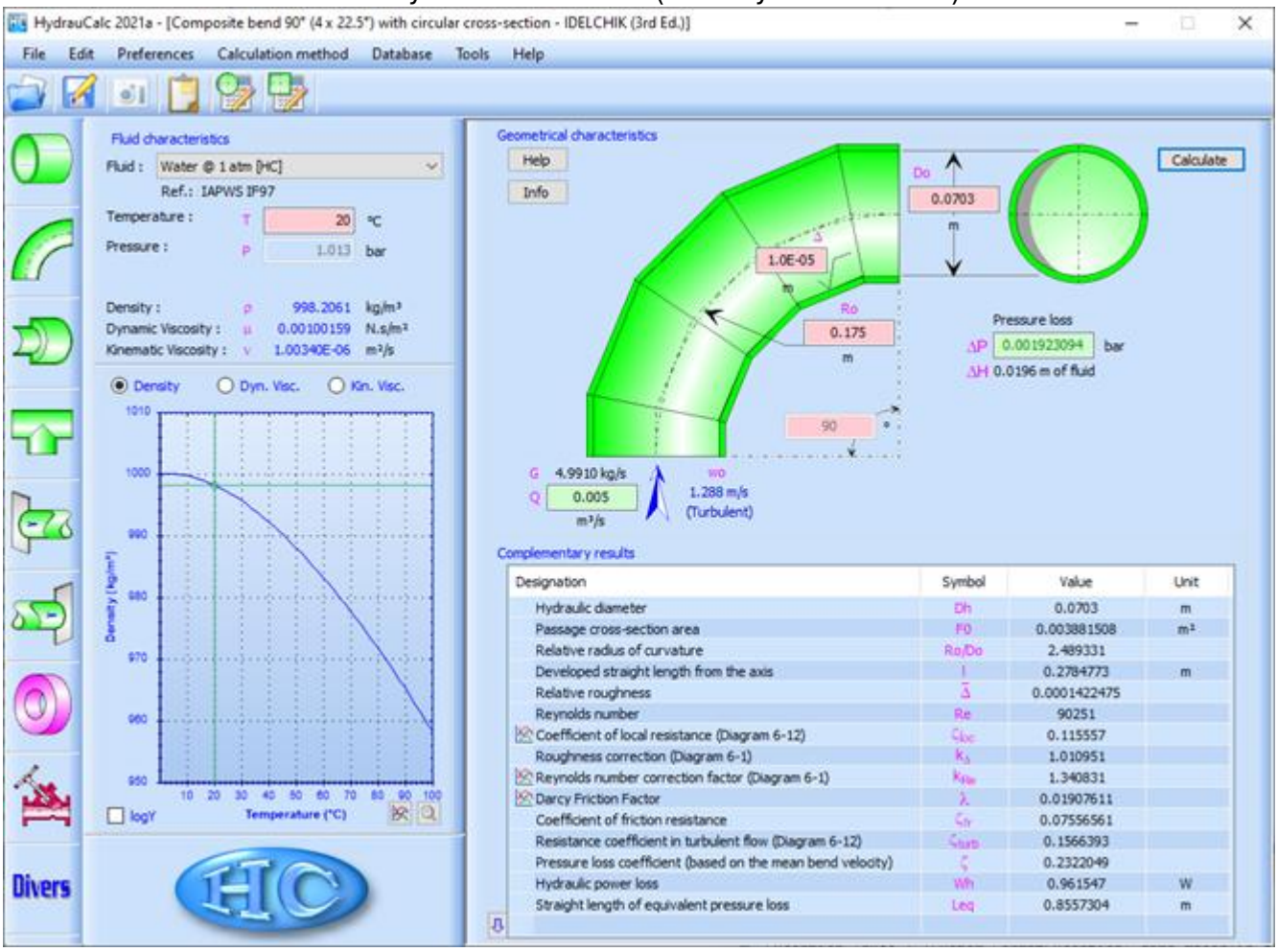
Validity range:

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "ζ_{lam}" is estimated

- stabilized flow upstream bend
- length of the straight section downstream: $\geq 10\ D_0$

Example of application:

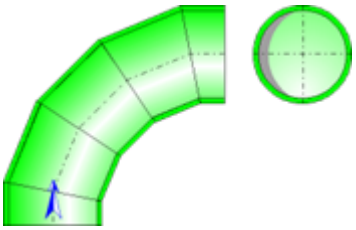


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

[2] Internal Flow System, Second Edition, D.S. Miller

2.2.7.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) of a composite bend 90° (4 x 22.5°) whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

An option allows to take into account the effect of the straight length at the exit of the bend.

Model formulation:

Hydraulic diameter (m):

$$D = d$$

Cross-section area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Length measured along the axis (m):

$$L = 8 \cdot r \cdot tg\left(\frac{90°}{8}\right)$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

$$M = V \cdot \rho$$

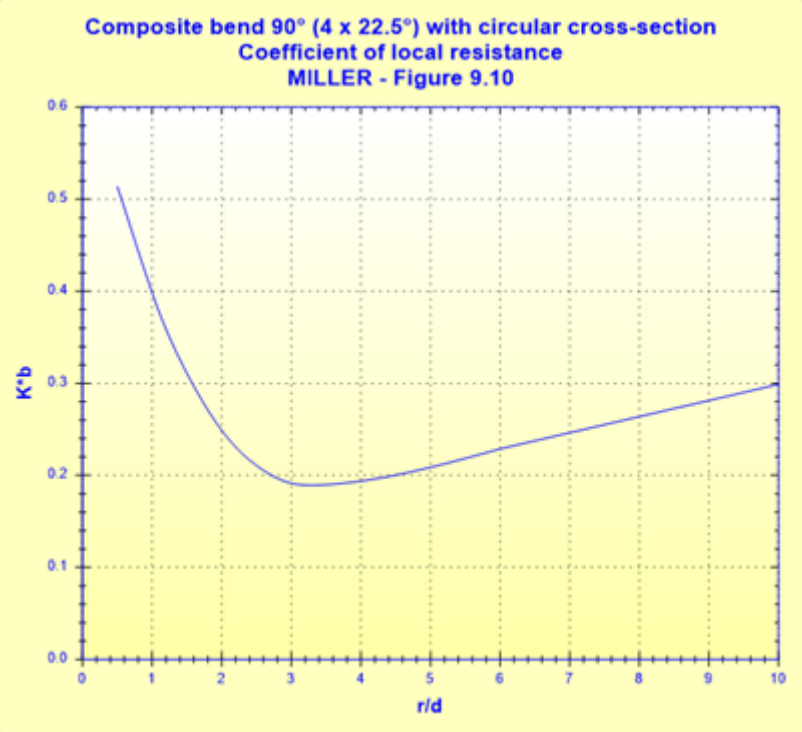
Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

Basic resistance coefficient:

$$K_b^* = f\left(\frac{r}{d}\right)$$

([1] figure 9.10)



Reynolds number correction factor:

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3)

■ r/d ≥ 1

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3)

■ r/d < 1

● r/d > 0.7 or K_b^* < 0.4

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3 with r/d=1)

● otherwise (r/d ≤ 0.7 and K_b^* ≥ 0.4)

$$C_{Re} = \frac{K_b^*}{K_b^* - 0.2C'_{Re} + 0.2}$$ ([1] equation 9.2)

with:

$$C'_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$

([1] figure 9.3 with r/d=1)

Local resistance coefficient:

- Re ≥ 10^4 (turbulent flow)

$$K_{turb} = K_b^* \cdot C_{Re}$$

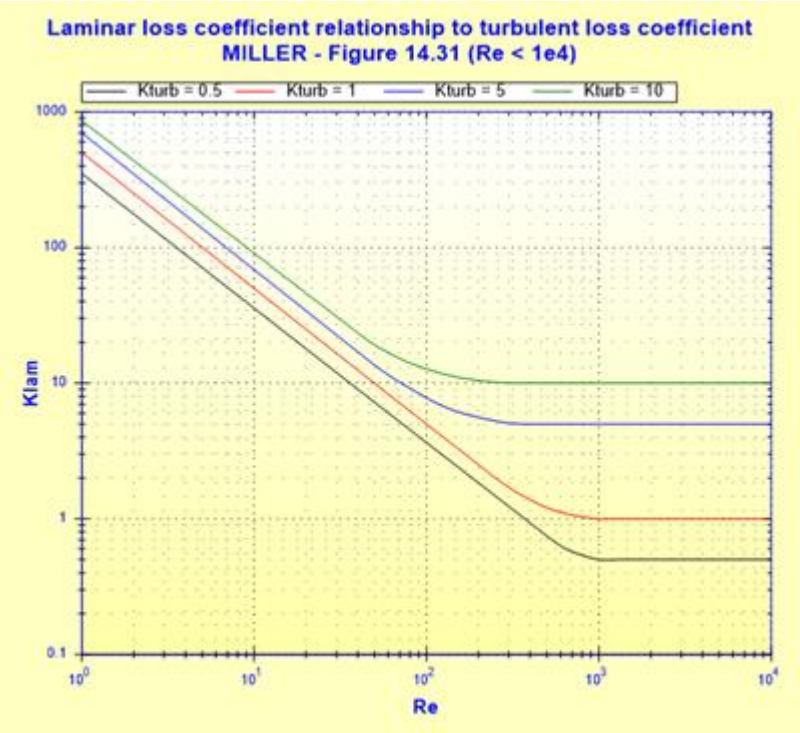
- Re < 10^4 (laminar flow)

$$K_{lam} = f(K_{turb}, \mathrm{Re})$$

([1] figure 14.31)

where:

K_{turb} is the resistance coefficient in turbulent regime for Re = 10^4

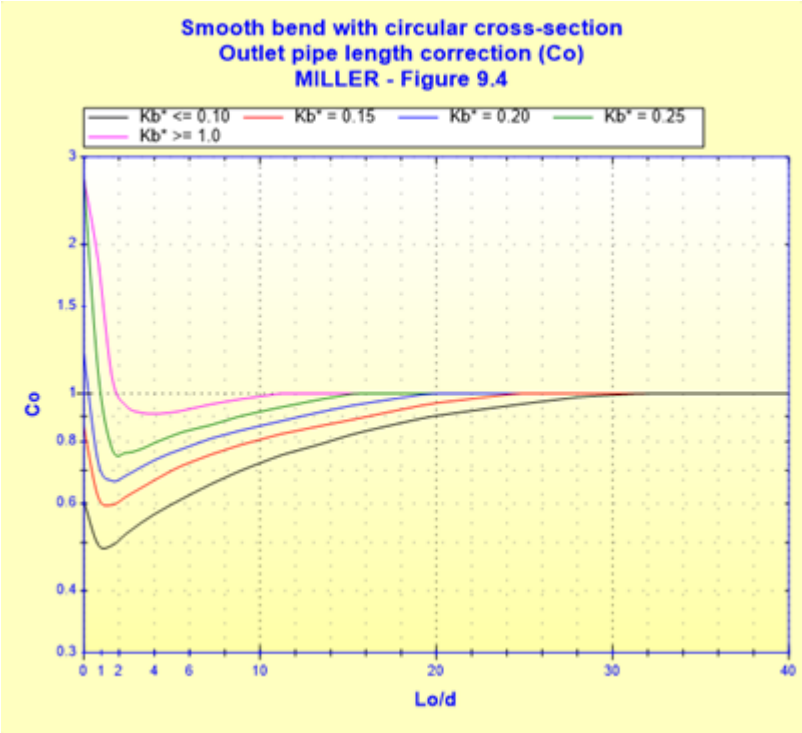


Outlet pipe length correction factor (optional):

- r/d < 3

$$C_o = f\left(\frac{L_o}{d}, K_b^*\right)$$

([1] figure 9.4)



- otherwise ($r/d \leq 3$)

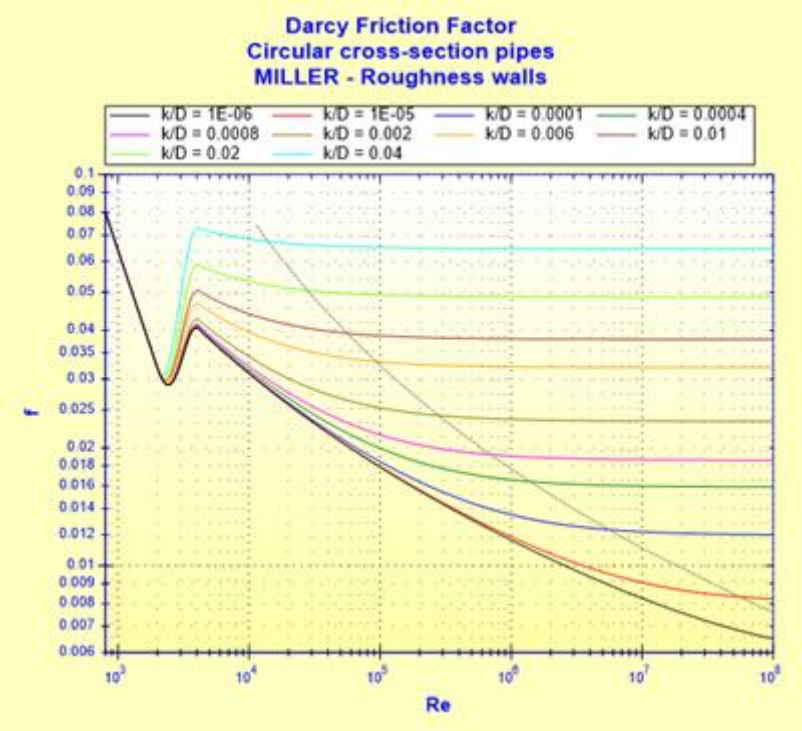
$$C_o = 1$$ (negligible effect)

If this option is not activated, the factor C_o is equal to unity.

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{D}\right)$$

See Straight Pipe - Circular Cross-Section and Roughness Walls (MILLER)



Roughness correction factor:

$$C_f = \frac{f_{rough}}{f_{smooth}}$$ ([1] equation 9.3)

with:

f_{rough}: Darcy friction factor for rough pipe at Re

f_{smooth}: Darcy friction factor for smooth pipe (k = 0) at Re

For $Re > 10^6$, C_f is calculated from equation (9.3) for $Re = 10^6$

Corrected loss coefficient:

- turbulent flow ($Re \geq 10^4$):

$$K_b = K_{turb} \cdot C_o \cdot C_f$$

- laminar flow ($Re < 10^4$):

$$K_b = K_{lam} \cdot C_o \cdot C_f$$

Total pressure loss coefficient (based on the mean velocity in the bend)

$$K = K_b$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{d}{f_{rough}}$$

Symbols, Definitions, SI Units:

D	Bend hydraulic diameter (m)
d	Bend internal diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
L	Length measured along the axis (m)
r	Radius of curvature (m)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()

K_b^* Basic loss coefficient ()

C_{Re} Reynolds number correction factor ()

K_{turb} Local resistance coefficient for $Re \geq 10^4$ ()

K_{lam} Local resistance coefficient for $Re < 10^4$ ()

C_o Outlet pipe length correction factor ()

L_0 Length of the straight section downstream of the bend (m)

f Darcy friction factor ()

k Absolute roughness of walls (m)

C_f Roughness correction factor ()

K_b Corrected loss coefficient ()

K Total pressure loss coefficient (based on the mean velocity in the bend) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

L_{eq} Straight length of equivalent pressure loss (m)

ρ Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

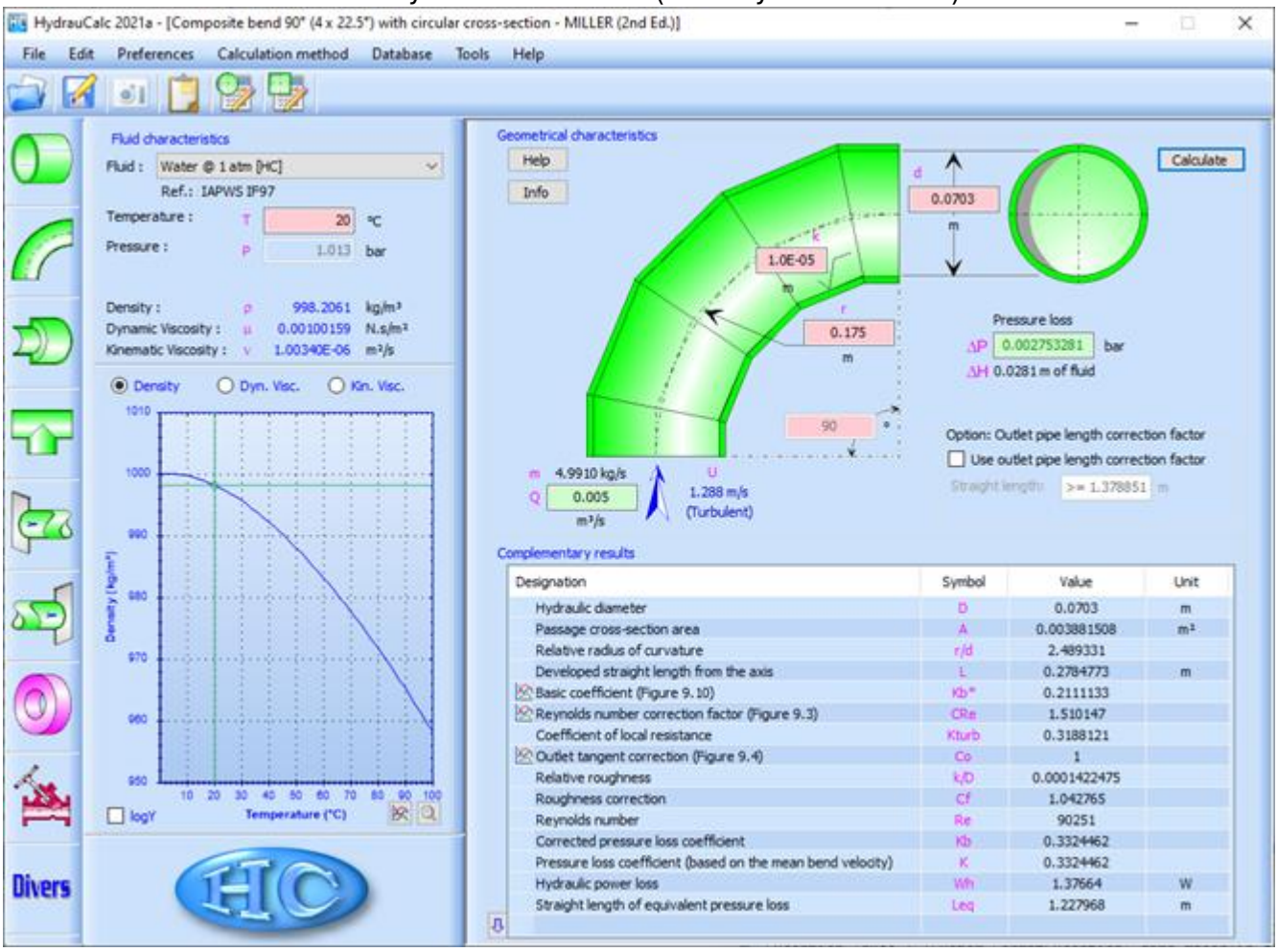
Validity range:

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

- stabilized flow upstream bend

Example of application:



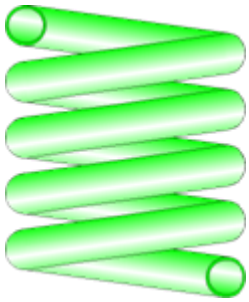
References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.2.8 Helical Tube - Circular cross-section

Helical Tube (Coil)

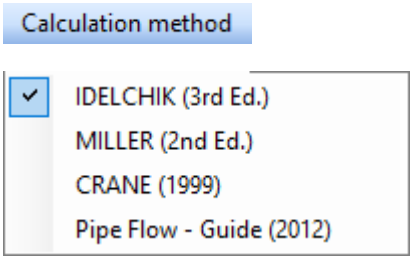
Circular Cross-Section



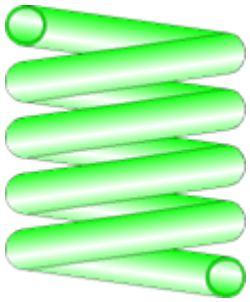
For the calculation of the pressure loss coefficient of helical tubes with circular cross-section, the user can choose from one of the methods described in the following four reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.2.8.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) of a helical tube whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized at the entrance bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Length measured along the axis (m):

$$l = N \cdot 2 \cdot \pi \cdot R_0$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = F_0 \cdot l$$

Fluid mass (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

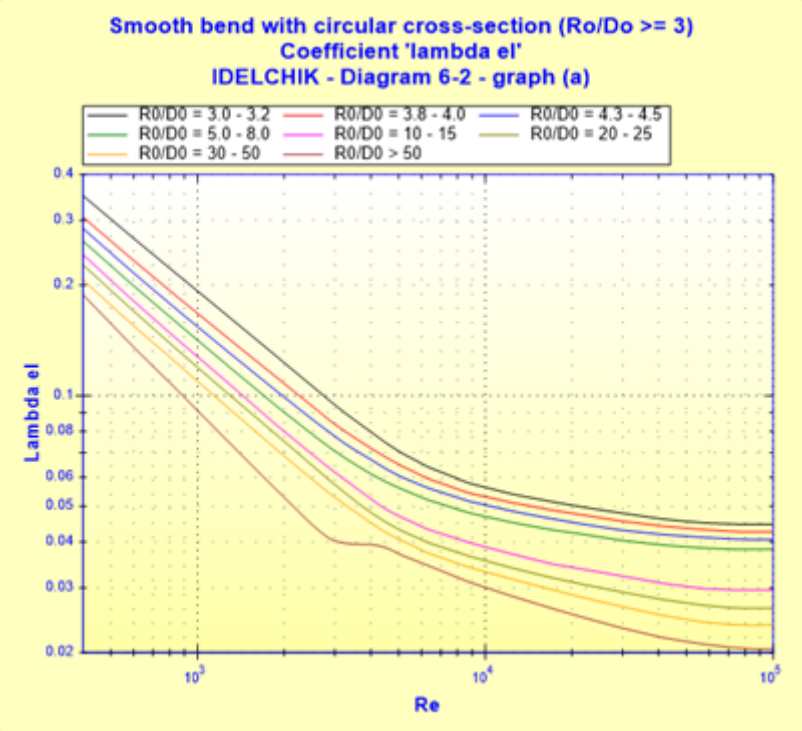
Relative roughness:

$$\bar{\Delta} = \frac{\Delta}{D_0}$$

Friction factor smooth wall:

$$\lambda_{el} = f\left(Re, \frac{R_0}{D_0}\right)$$

([1] diagram 6.2)



Pressure loss coefficient:

$$\zeta = 0.0175 \cdot (N \cdot 360) \cdot \lambda_{el} \cdot \frac{R_0}{D_h}$$

([1] diagram 6.2)

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_0}{\lambda_{el}}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot {W_0}^2}{2}$$

([1] diagram 6.1 – 6.2)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{{W_0}^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter of the helical tube (m)
D_0	Internal diameter of the helical tube (m)
F_0	Cross-sectional area (m^2)
N	Number of turns constituting the helical tube ()
l	Length measured along the axis (m)
R_0	Radius of curvature (m)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
λ_{el}	Friction coefficient ()
ζ	Total pressure loss coefficient (based on the mean velocity in the bend) ()
L_{eq}	Straight length of equivalent pressure loss (m)
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

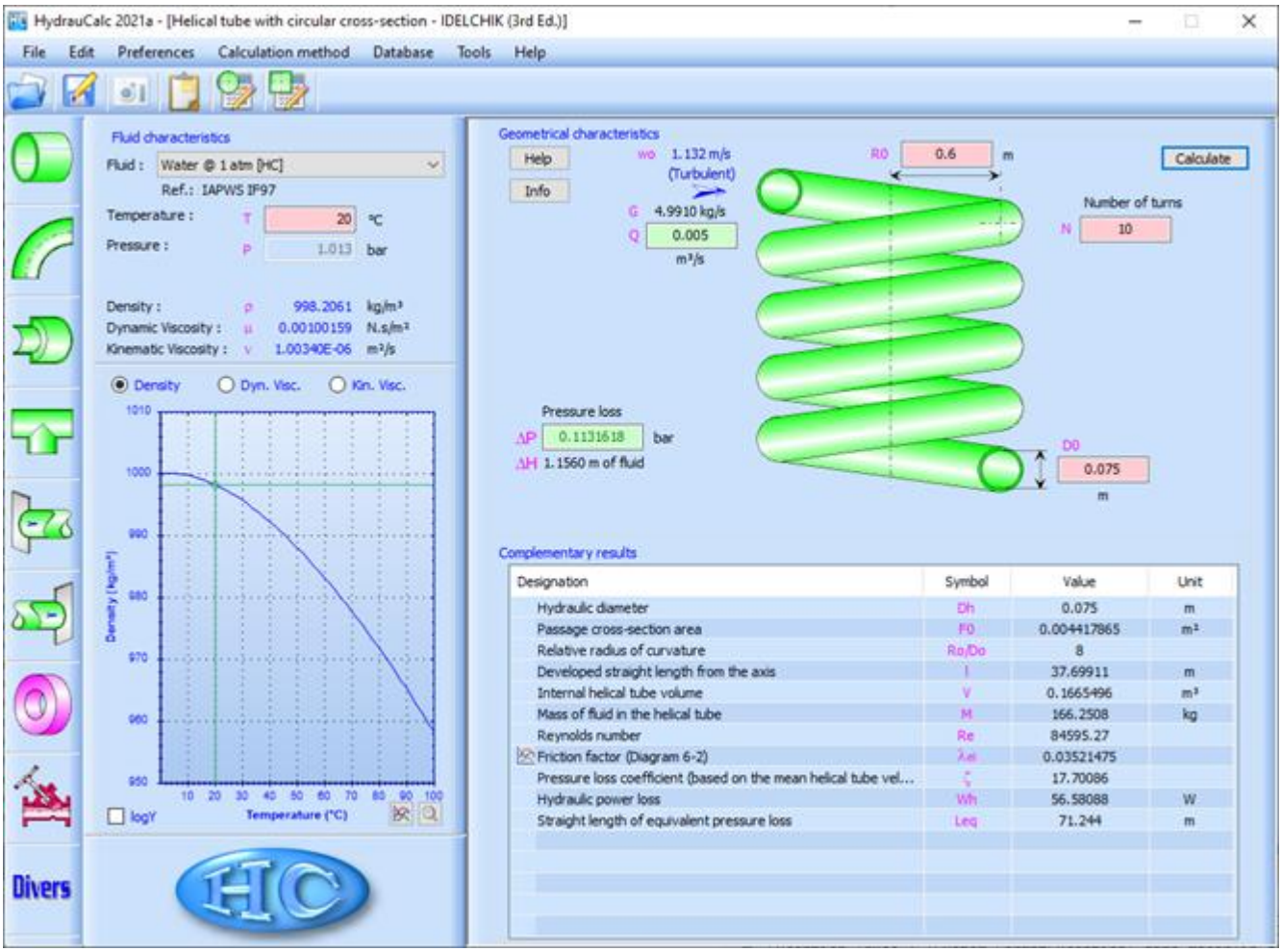
Validity range:

- flow regime: $400 \leq Re \leq 10^5$

for Reynolds number 'Re' lower than 400 or greater than 10^5, the coefficient 'λ_{el}' is linearly extrapolated.

- $R_0/D_0 \geq 3$
- hydraulically smooth flow
- stabilized flow upstream bend

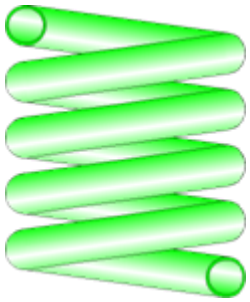
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.2.8.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) of a helical tube whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the helical tube.

Model formulation:

Cross-section area (m^2):

$$A = \pi \cdot \frac{d_i^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Length measured along the axis (m):

$$L = n \cdot \sqrt{(\pi \cdot D)^2 + P^2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

$$M = V \cdot \rho$$

Reynolds number:

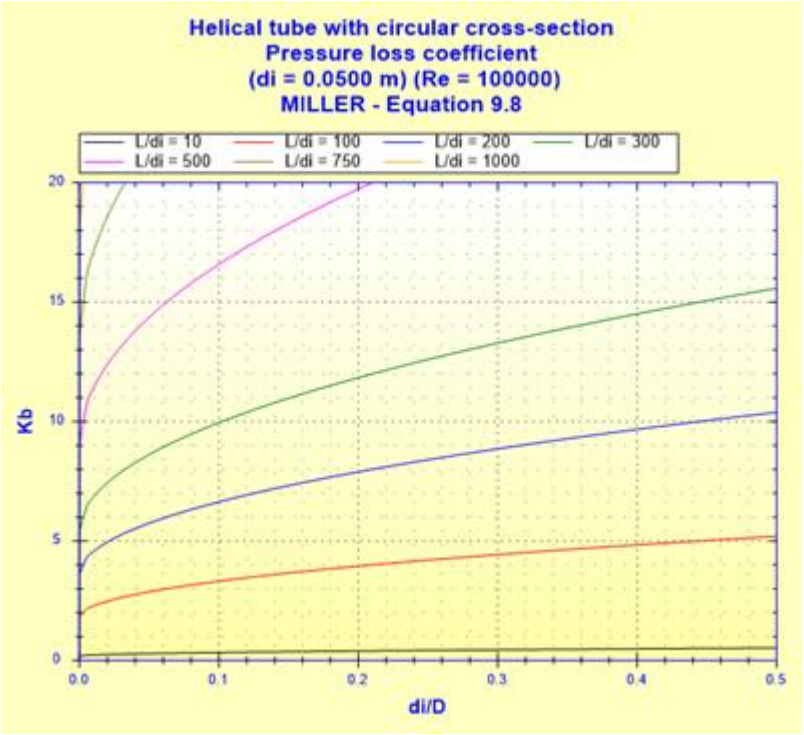
$$Re = \frac{U \cdot d_i}{\nu}$$

Local resistance coefficient:

- $Re_1 \geq 10^4$

$$K_b = \left[0.32 \cdot Re^{-0.25} + 0.048 \cdot \left(\frac{d_i}{D} \right)^{0.5} \right] \cdot \frac{L}{d_i}$$

([1] Equation 9.8)



(with d_i=0.05 m and Re=10^5)

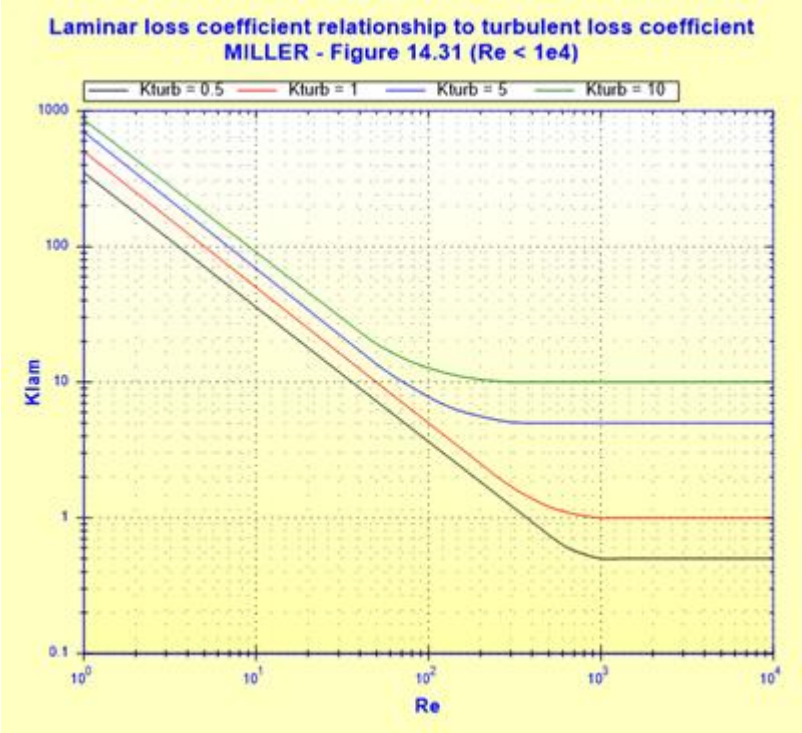
- $Re_1 < 10^4$

$$K_{lam} = f(K_{turb}, Re_1)$$

([1] figure 14.31)

where:

K_{turb} is the local resistance coefficient in turbulent regime (K_b for $Re = 10^4$ - equation 9.8)



Total pressure loss coefficient (based on the mean velocity in the helical tube)

- turbulent flow ($Re \geq 10^4$):

$$K = K_b$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

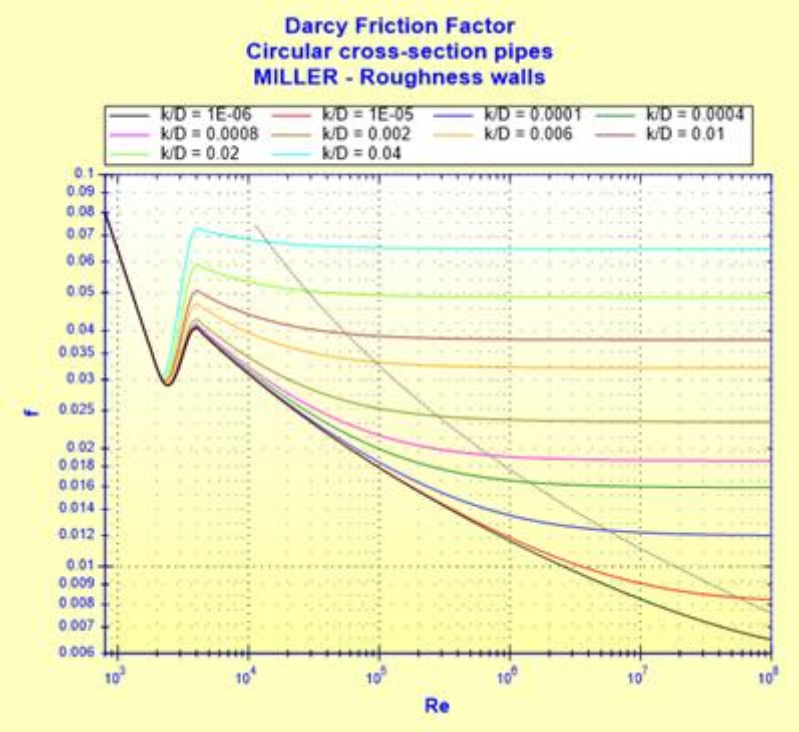
$$Wh = \Delta P \cdot Q$$

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{d_i}\right)$$

with: k = 0 (hydraulically smooth tube)

See Straight Pipe - Circular Cross-Section and Roughness Walls (MILLER)



Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{d_i}{f}$$

Symbols, Definitions, SI Units:

d_i	Helical tube internal diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)

P	Pitch of the helical tube (m)
n	Number of turns constituting the helical tube ()
L	Length measured along the axis (m)
D	Diameter of curvature of the helical tube (m)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
K_b	Local resistance coefficient for $Re = 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
K	Total pressure loss coefficient (based on the mean velocity in the helical tube) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
f	Darcy friction factor ()
L_{eq}	Straight length of equivalent pressure loss (m)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

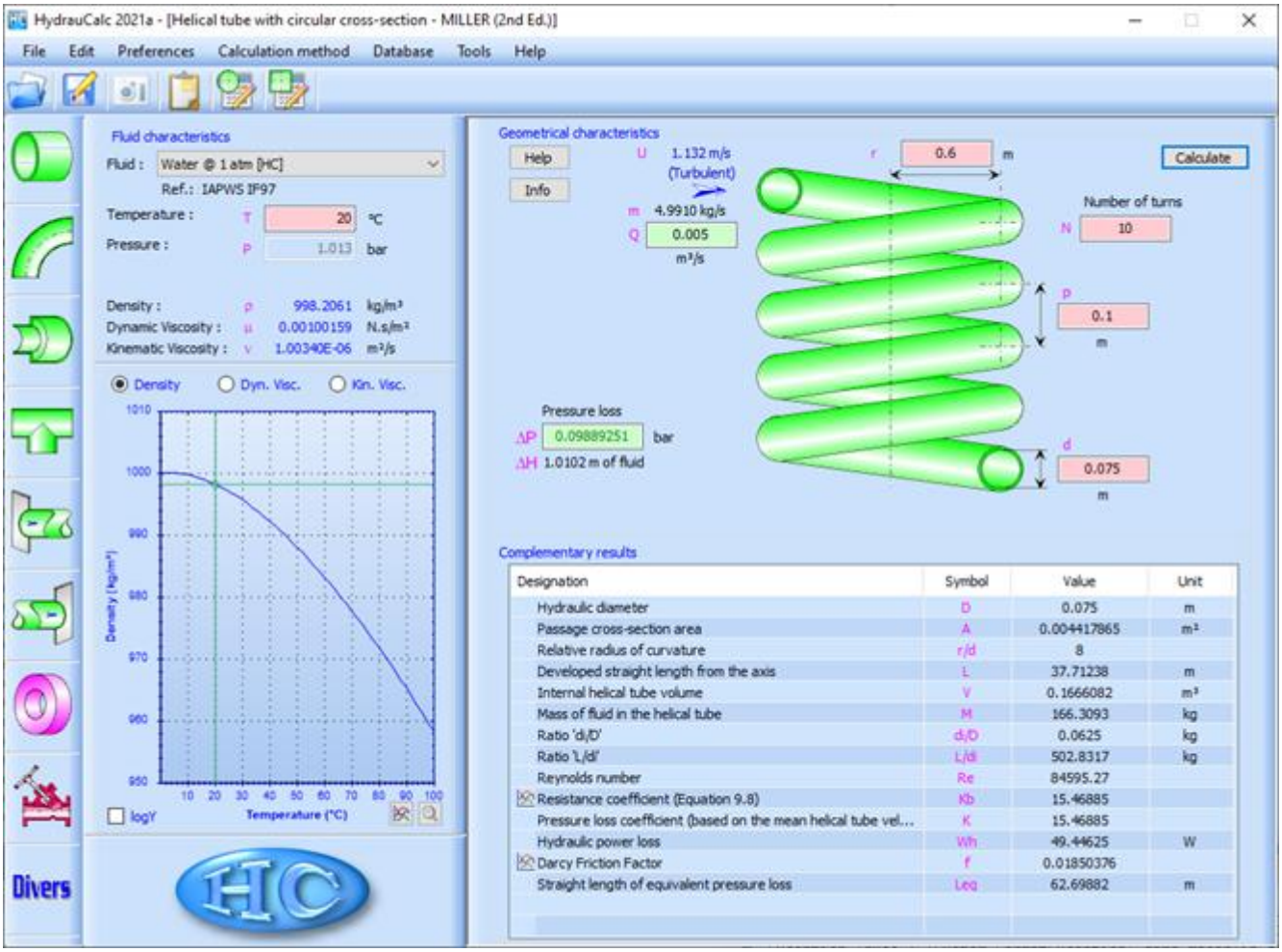
Validity range:

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

- hydraulically smooth flow
- stabilized flow upstream helical tube

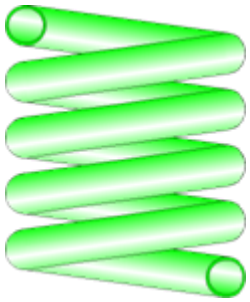
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.2.8.3 CRANE



Model description:

This model of component calculates the head loss (pressure drop) of a helical tube whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the helical tube.

Model formulation:

Cross-section area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity (m/s):

$$v = \frac{q}{A}$$

Length measured along the axis (m):

$$L = 2 \cdot \pi \cdot r \cdot N_t$$

Mass flow rate (kg/s):

$$w = q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

$$M = Vol \cdot \rho_m$$

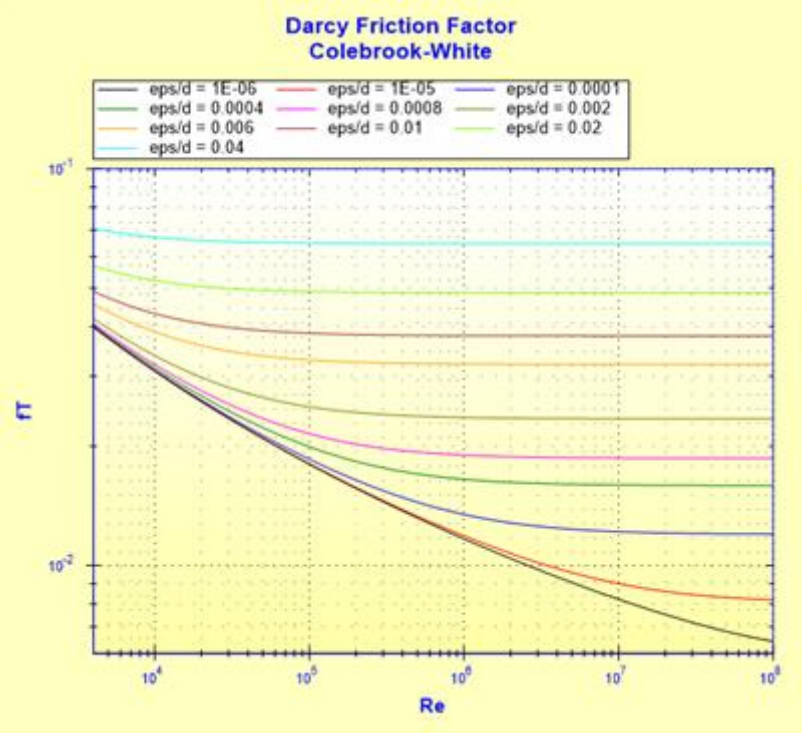
Reynolds number:

$$Re = \frac{v \cdot d}{\nu}$$

Darcy friction factor:

$$f_T = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d} + \frac{2.51}{Re \cdot \sqrt{f_T}}\right)\right]^2}$$

Colebrook-White equation

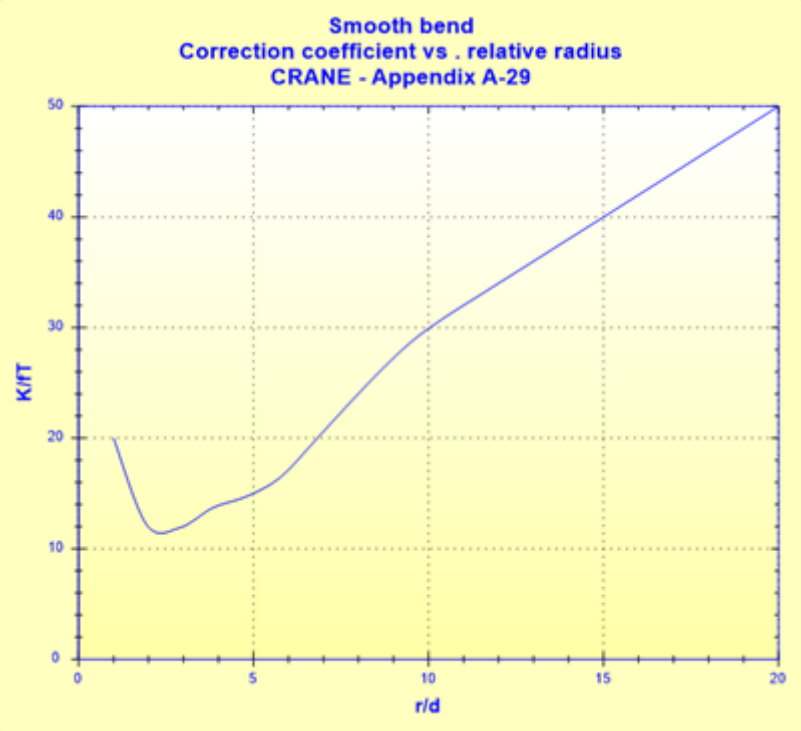


Resistance coefficient for one 90° smooth bend:

$$K = f\left(\frac{r}{d}, f_T\right)$$

([1] Appendix A-29)

r/d	K	K/f_T
1	20 f_T	20
1.5	14 f_T	14
2	12 f_T	12
3	12 f_T	12
4	14 f_T	14
6	17 f_T	17
8	24 f_T	24
10	30 f_T	30
12	34 f_T	34
14	38 f_T	38
16	42 f_T	42
20	50 f_T	50



Total pressure loss coefficient (based on mean velocity in helical tube):

$$K_B = (n-1)\left(0.25 \cdot \pi \cdot f_T \cdot \frac{r}{d} + 0.5 \cdot K_1\right) + K_1$$

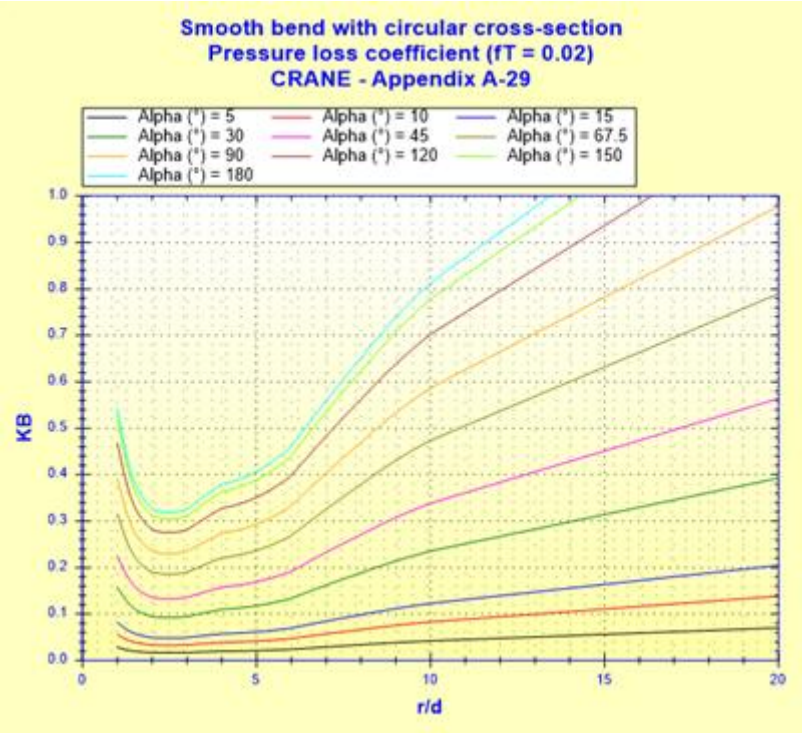
([1] Equation 2-20)

with:

$$n = 4 \cdot N_t$$

and:

$$K_1 = K \cdot F_t$$



(with $f_T = 0.02$)

Total pressure loss (Pa):

$$\Delta P = K_B \cdot \frac{\rho \cdot v^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K_B \cdot \frac{v^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K_B \cdot \frac{d}{f_T}$$

Symbols, Definitions, SI Units:

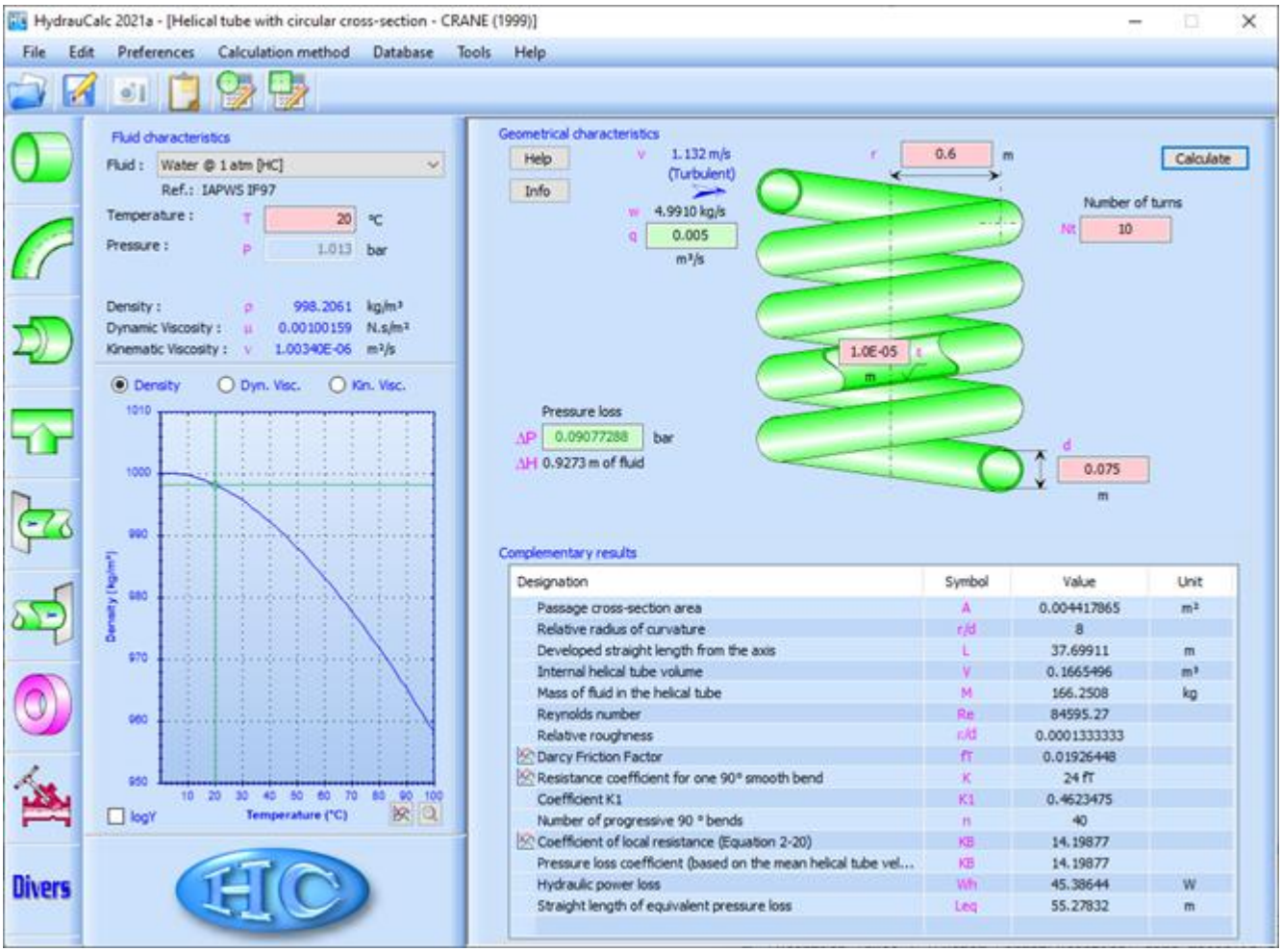
d	Internal diameter of the helical tube (m)
A	Cross-section area (m^2)
q	Volume flow rate (m^3/s)
v	Mean velocity (m/s)
N_t	Number of turns constituting the helical tube ()
r	Radius of curvature (m)
L	Length measured along the axis (m)
w	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
ε	Absolute roughness of walls (m)
f_T	Darcy friction factor ()
n	Number of 90 ° bends constituting the helical tube ()
K_1	Resistance coefficient for one 90° smooth bend ()
K_B	Total pressure loss coefficient (based on mean velocity in helical tube) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
L_{eq}	Straight length of equivalent pressure loss (m)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream of the helical tube
- relative radius of curvature (r/d) range between 1 and 20

  for relative radii 'r/d' between 0.5 and 1 or those greater than 20, the coefficient 'K' is linearly extrapolated.

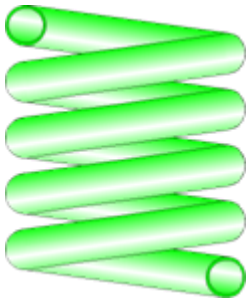
Example of application:



References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999

2.2.8.4 Pipe Flow - Guide



Model description:

This model of component calculates the head loss (pressure drop) of a helical tube whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the helical tube.

Model formulation:

Cross-section area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity (m/s):

$$V = \frac{Q}{A}$$

Length measured along the axis (m):

$$L = N \cdot \sqrt{(2 \cdot \pi \cdot r)^2 + p^2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Fluid volume (m^3):

$$Vol = A \cdot L$$

Fluid mass (kg):

$$Mas = Vol \cdot \rho_m$$

Reynolds number:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

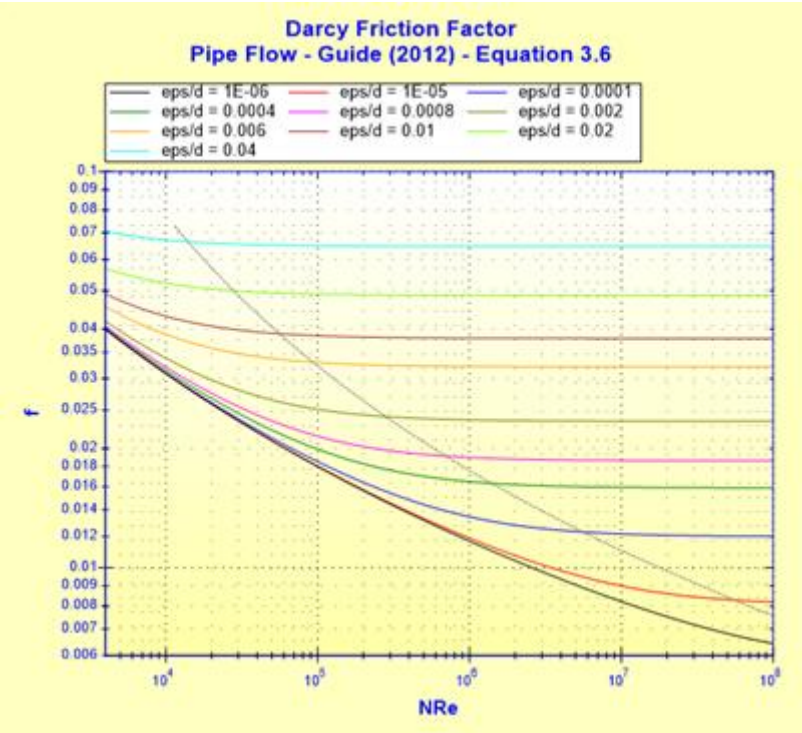
Relative roughness:

$$R_r = \frac{\varepsilon}{d}$$

Darcy friction factor:

$$f = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d} + \frac{2.51}{N_{Re} \cdot \sqrt{f}}\right)\right]^2}$$

Colebrook-White equation ([1] equation 3.6)



Total pressure loss coefficient (based on mean velocity in helical tube):

$$K = N \cdot \left[f \cdot \frac{\sqrt{(2 \cdot \pi \cdot r)^2 + p^2}}{d} + 0.2 + 4.8 \cdot f \right]$$

([1] equation 15.3)

(with d=0.05 m, Pas=0.1 m and f=0.02)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{d}{f}$$

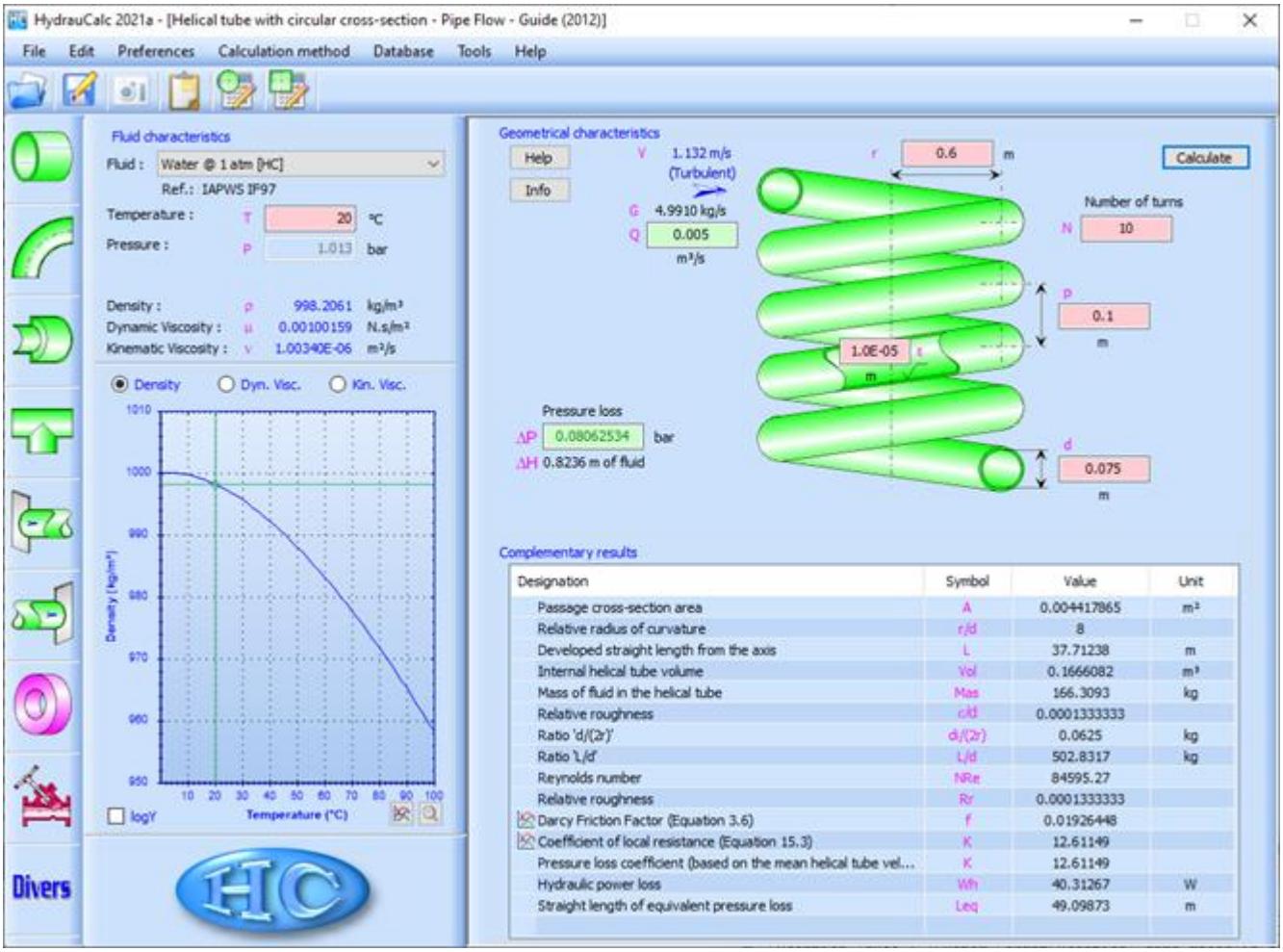
Symbols, Definitions, SI Units:

d	Internal diameter of the helical tube (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
V	Mean velocity (m/s)
N	Number of turns constituting the helical tube ()
p	Pitch of the helical tube (m)
r	Radius of curvature (m)
L	Length measured along the axis (m)
G	Mass flow rate (kg/s)
Vol	Fluid volume (m^3)
Mas	Fluid mass (kg)
N_{Re}	Reynolds number ()
R_r	Relative roughness ()
ε	Absolute roughness of walls (m)
f	Darcy friction factor ()
K	Total pressure loss coefficient (based on mean velocity in helical tube) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
L_{eq}	Straight length of equivalent pressure loss (m)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($N_{Re} \geq 10^4$)
- stabilized flow upstream of the helical tube

Example of application:



References:

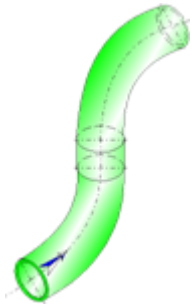
[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.2.9 S-shaped bends (1 plane) - Circular cross-section

S-shaped Bends

(with flow in one plane)

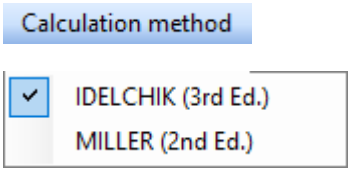
Circular Cross-Section



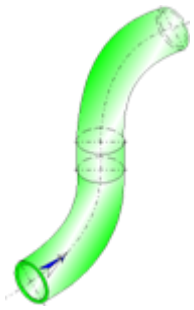
For the calculation of the pressure loss coefficient of S-shaped bends with circular cross-section (with flow in one plane), the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.2.9.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) of S-shaped bends (with flow in one plane) whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the first bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Total length measured along the axis (m):

$$l = 2 \cdot \left(2 \cdot \pi \cdot R_0 \cdot \frac{\delta}{360} \right) + l_{el}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = F_0 \cdot l$$

Fluid mass (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\overline{\Delta} = \frac{\Delta}{D_h}$$

■ Case of a single bend of relative radius of curvature lower than 3 ($R_0/D_0 < 3$) ([1] diagram 6-1)

Coefficient of effect of the roughness:

$$k_\Delta = f\left(\frac{R_0}{D_0}, Re, \overline{\Delta}\right)$$

([1] diagram 6-1)

- $0.50 \leq R_0/D_0 \leq 0.55$

$\overline{\Delta}$	Re	
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$
0	1.0	1.0
0 - 0.001	1.0	$1 + 0.5 \cdot 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	1.5

- $R_0/D_0 > 0.55$

$\overline{\Delta}$	Re		
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$ - $2 \cdot 10^5$	> $2 \cdot 10^5$
0	1.0	1.0	1.0
0 - 0.001	1.0	$\lambda_\Delta / \lambda_{sm}$	$1 + 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	2.0	2.0

with:

λ_{sm} : Darcy friction factor for hydraulically smooth pipe ($\overline{\Delta} = 0$) at Re

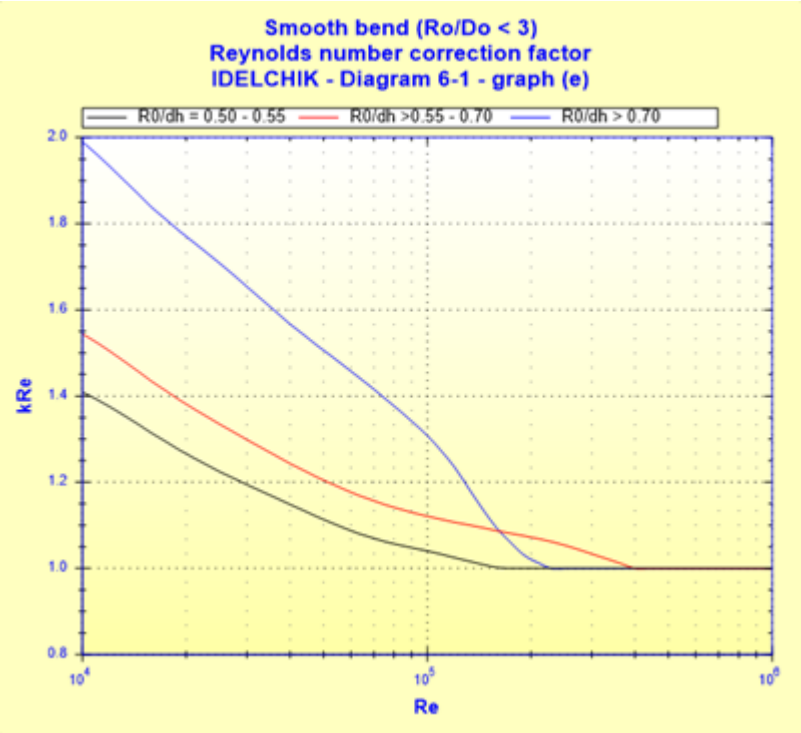
λ_Δ : Darcy friction factor for rough pipe ($\overline{\Delta} = \Delta/D_h$) at Re

---

Coefficient of effect of the Reynolds number ($Re \geq 10^4$):

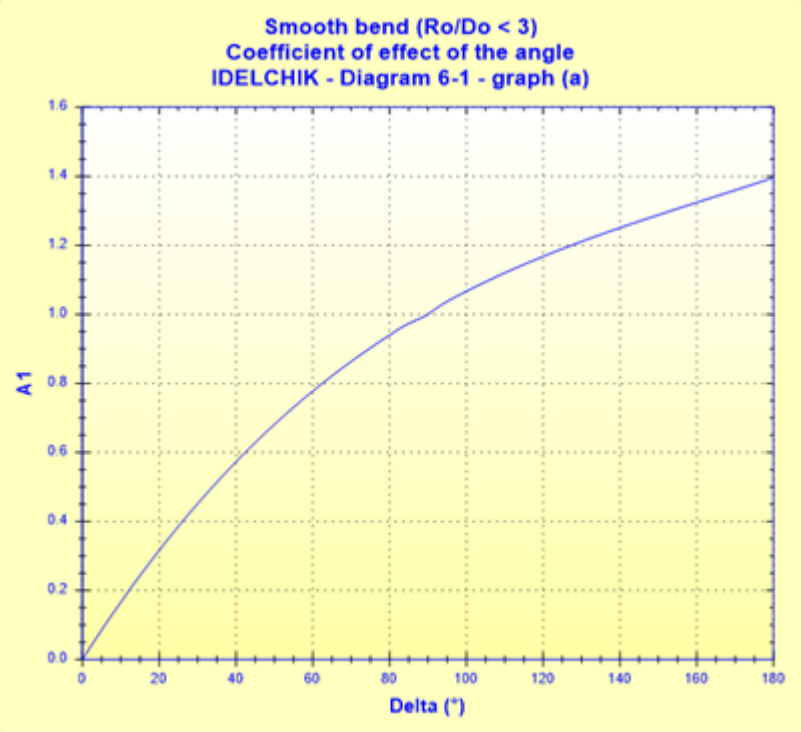
$$k_{Re} = f\left(Re, \frac{R_0}{D_h}\right)$$

([1] diagram 6-1)



Coefficient of effect of the angle:

$A1 = f(\delta)$ ([1] diagram 6-1)

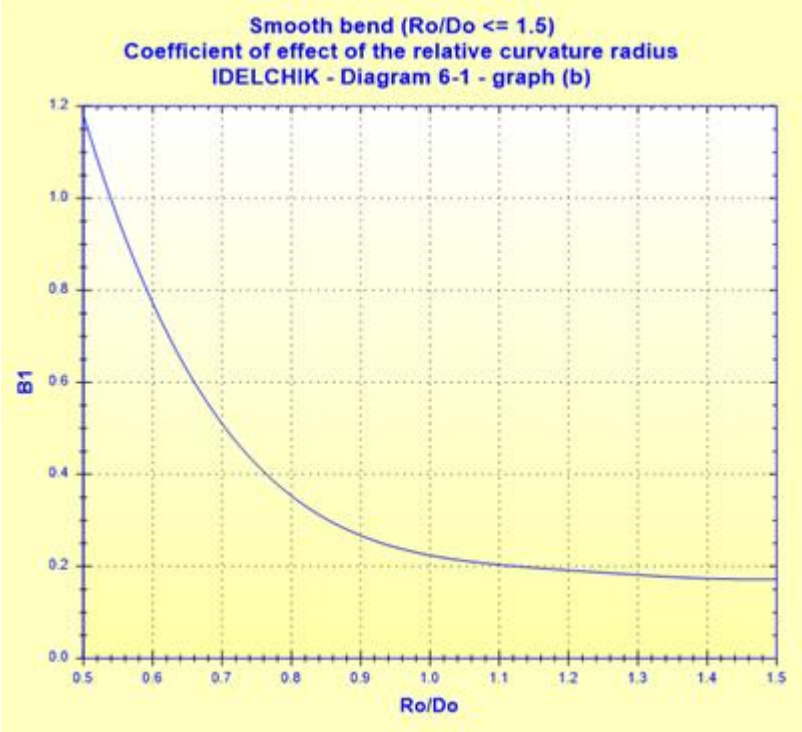


Coefficient of effect of the relative curvature radius:

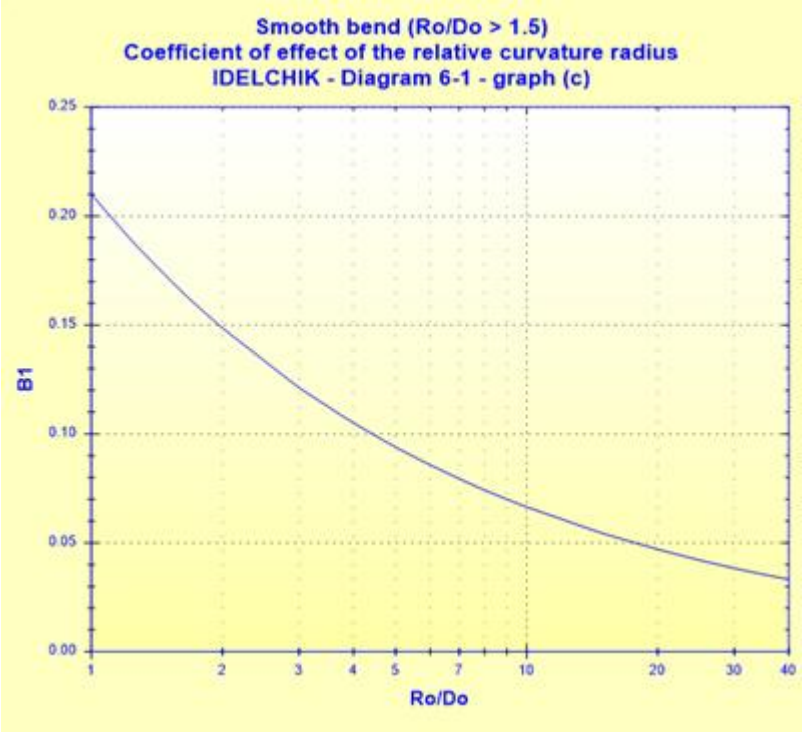
$$B1 = f\left(\frac{R_0}{D_h}\right)$$

([1] diagram 6-1)

- $0.5 \le R_0/D_0 \le 1.5$



- $R_0/D_0 > 1.5$



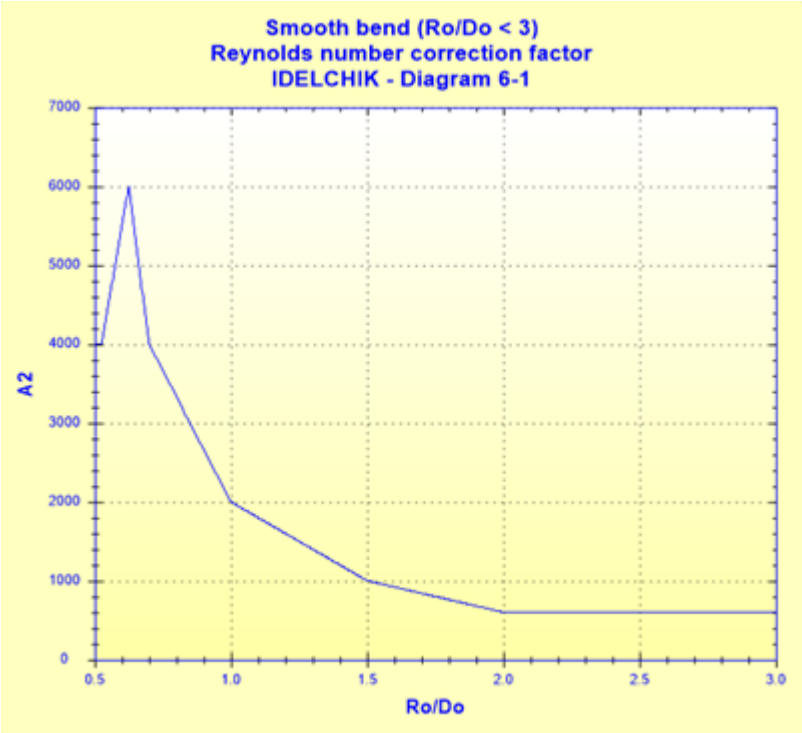
Coefficient of effect of the relative elongation of the cross section:

$$C1 = 1$$ ([1] diagram 6-1)

Reynolds number correction factor that depends on the relative curvature radius:

$$A2 = f\left(\frac{R_0}{D_0}\right)$$ ([1] diagram 6-1)

R_0/D_0	0.50 - 0.55	>0.55 - 0.70	>0.70 - 1.0	>1.0 - 2.0	>2.0
$A2 \times 10^{-3}$	4.0	6.0	4.0 - 2.0	1.0	0.6



Pressure loss coefficient (without friction):

- $Re \geq 10^4$

$$\zeta'_{loc} = k_{\Delta} \cdot k_{Re} \cdot A1 \cdot B1 \cdot C1$$ ([1] diagram 6-1)

- $3 \cdot 10^3 < Re < 10^4$

$$\zeta'_{loc} = \frac{A2}{Re} + A1 \cdot B1 \cdot C1$$ ([1] diagram 6-1)

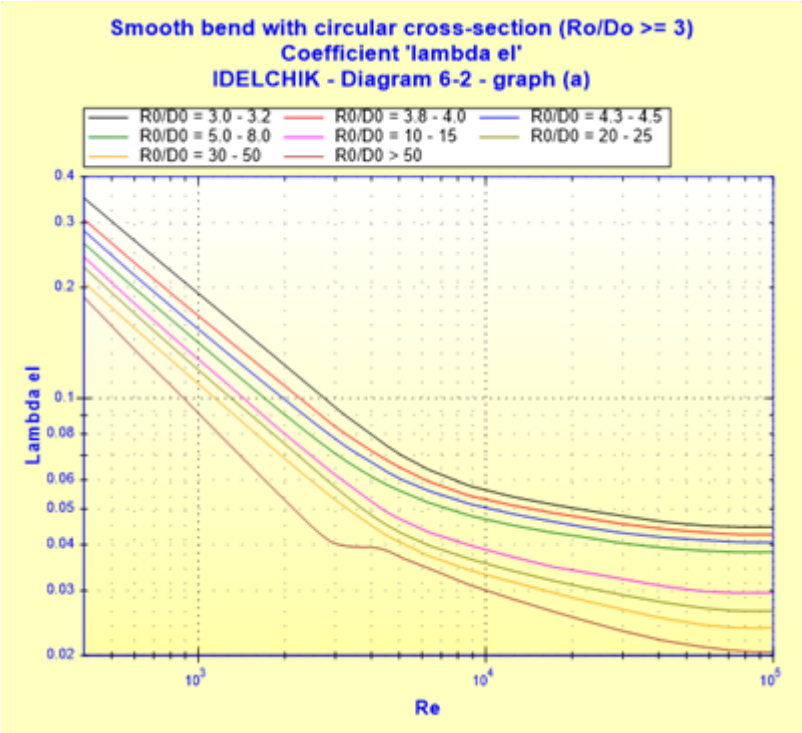
■ Case of a single bend of relative radius of curvature greater than or equal to 3 ($R_0/D_0 \geq 3$) ([1] diagram 6-2)

Total friction factor with smooth wall:

- $4 \cdot 10^2 \leq Re < 10^5$

$$\lambda_{el} = f\left(Re, \frac{R_0}{D_0}\right)$$

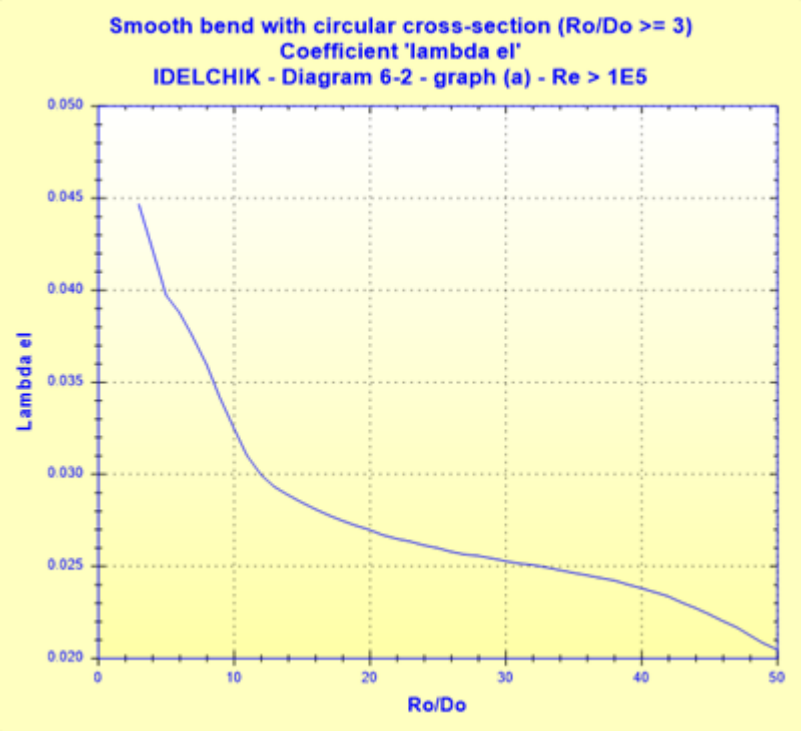
([1] diagram 6-2)



- $Re \geq 10^5$

$$\lambda_{el} = f\left(\frac{R_0}{D_0}\right)$$

([1] diagram 6-2)



Estimation of the coefficient of local resistance

$$\zeta'_{loc} = (\lambda_{el} - \lambda_s) \cdot \frac{2 \cdot \pi \cdot R_0 \cdot \delta / 360}{D_h}$$

with:

λ_s : Darcy friction factor for hydraulically smooth pipe ($\overline{\Delta} = 0$) at Re

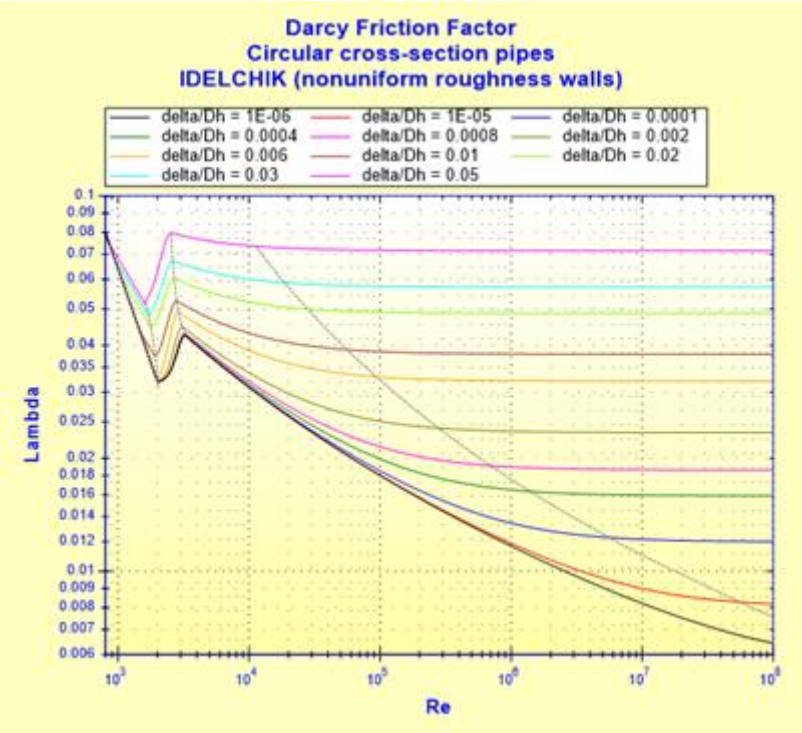
---

■ Case of the S-shaped Bends ([1] diagram 6-18)

Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}, \frac{\Delta}{D_h}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



Pressure loss friction factor:

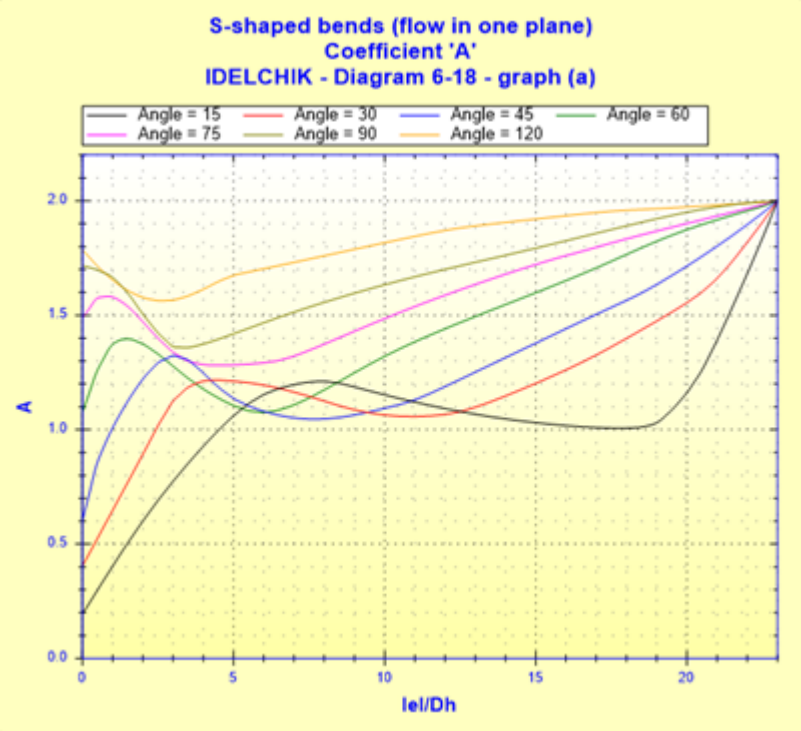
$$\zeta_{fr} = \lambda \cdot \left[2 \cdot \left(0.0175 \cdot \delta \cdot \frac{R_0}{D_h} \right) + \frac{l_{el}}{D_h} \right]$$

([1] diagram 6-18)

Interaction correction factor:

$$A = f\left(\frac{L_{el}}{D_h}, \delta \right)$$

([1] diagram 6-18 graph a)



Total pressure loss coefficient (based on the mean velocity in the bends):

$$\zeta = A \cdot \zeta'_{loc} + \zeta_{fr}$$

([1] diagram 6-18)

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_0}{\lambda}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

([1] diagram 6-18)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Bend hydraulic diameter (m)
D_0	Bend internal diameter (m)
F_0	Cross-sectional area (m^2)
l	Total length measured along the axis (m)
l_{el}	Straight length between bends (m)
R_0	Radius of curvature (m)
δ	Curvature angle of each bend (°)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()
k_Δ	Coefficient that allows for the effect of the roughness ()
k_{Re}	Coefficient that allows for the effect of the Reynolds number ()
A1	Coefficient that allows for the effect of the angle ()
B1	Coefficient that allows for the effect of the relative curvature radius ()
C1	Coefficient that allows for the effect of the relative elongation of the cross section ()
A2	Reynolds number correction factor that depends on the relative curvature radius ()
ζ'_{loc}	Coefficient of local resistance ()
λ_{el}	Total friction factor with smooth wall ()
λ	Darcy friction coefficient ()

ζ_{fr}	Pressure loss friction factor ()
A	Interaction correction factor ()
ζ	Total pressure loss coefficient (based on the mean velocity in the bend) ()
L_{eq}	Straight length of equivalent pressure loss (m)
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m³)
ν	Fluid kinematic viscosity (m²/s)
g	Gravitational acceleration (m/s²)

Validity range:

- stabilized flow upstream bend
- length of the straight section downstream: $\geq 10\ D_0$
- relative radius of curvature: greater than or equal to 1 ($R_0/D_0 \geq 1$)
- curvature angle of one bend: between 0° and 180°

  for 'δ' angles less than 15° the pressure loss coefficient 'ζ' is estimated by taking into account an interaction correction factor '*A*' corresponding to that of an angle of 15°.

  for 'δ' angles greater than 120° the pressure loss coefficient 'ζ' is estimated by taking into account an interaction correction factor '*A*' corresponding to that of an angle of 120°.

■ case of relative radius of curvature: lower than 3 ($R_0/D_0 < 3$)

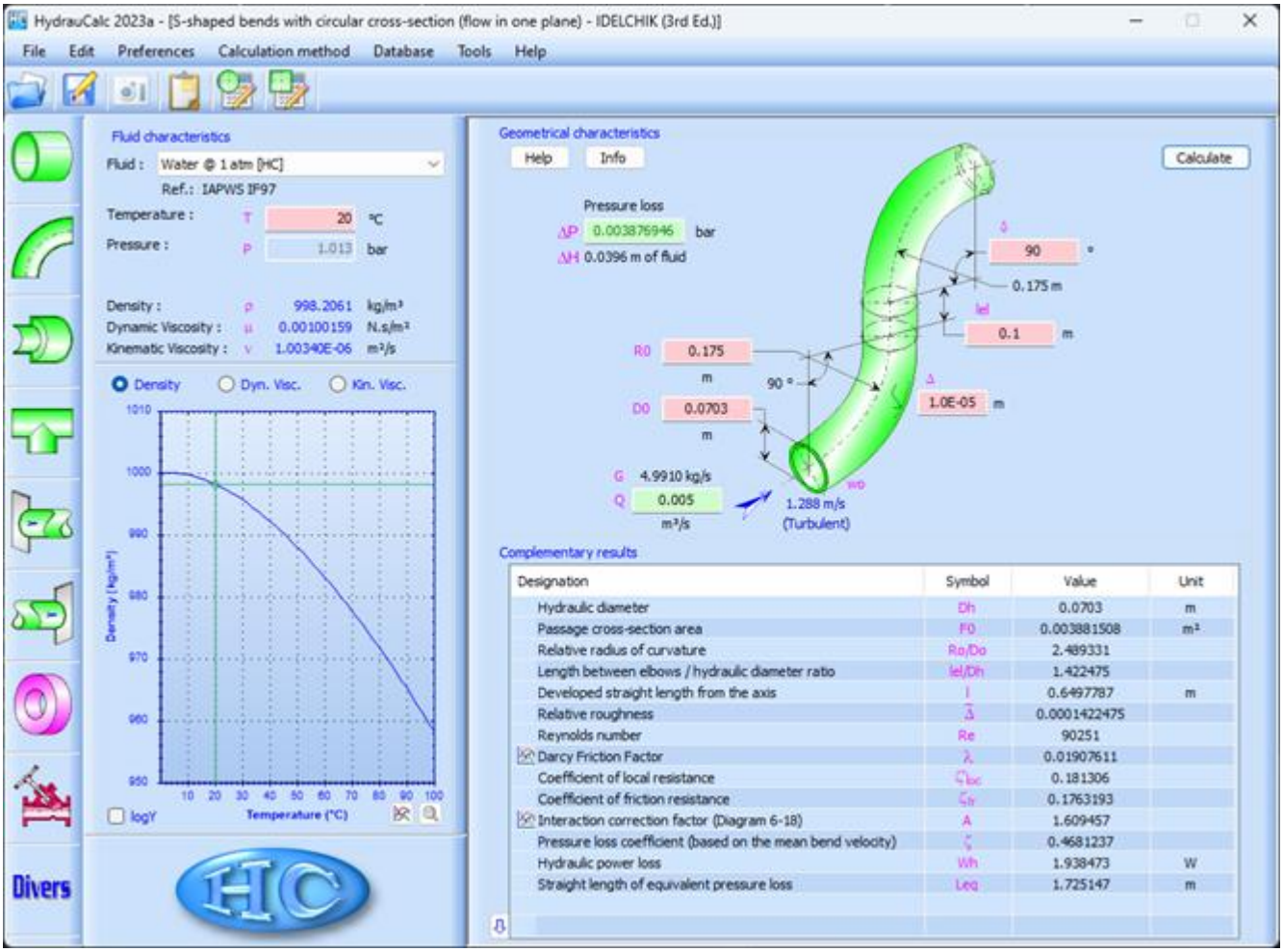
- flow regime: $Re \geq 3 \cdot 10^3$

■ case of relative radius of curvature: greater than or equal to 3 ($R_0/D_0 \geq 3$)

- flow regime: $Re \geq 400$

  for Reynolds number 'Re' lower than 400 the coefficient 'λ_{el}' is linearly extrapolated.

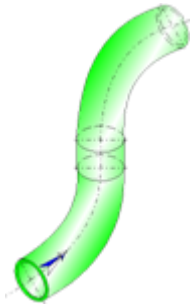
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.2.9.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) of S-shaped bends (with flow in one plane) whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the first bend.

An option allows to take into account the effect of the straight length at the exit of the second bend.

Model formulation:

Hydraulic diameter (m):

$$D = d$$

Cross-section area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Total length measured along the axis (m):

$$L = 2 \cdot \left(2 \cdot \pi \cdot r \cdot \frac{\theta_b}{360} \right) + L_s$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

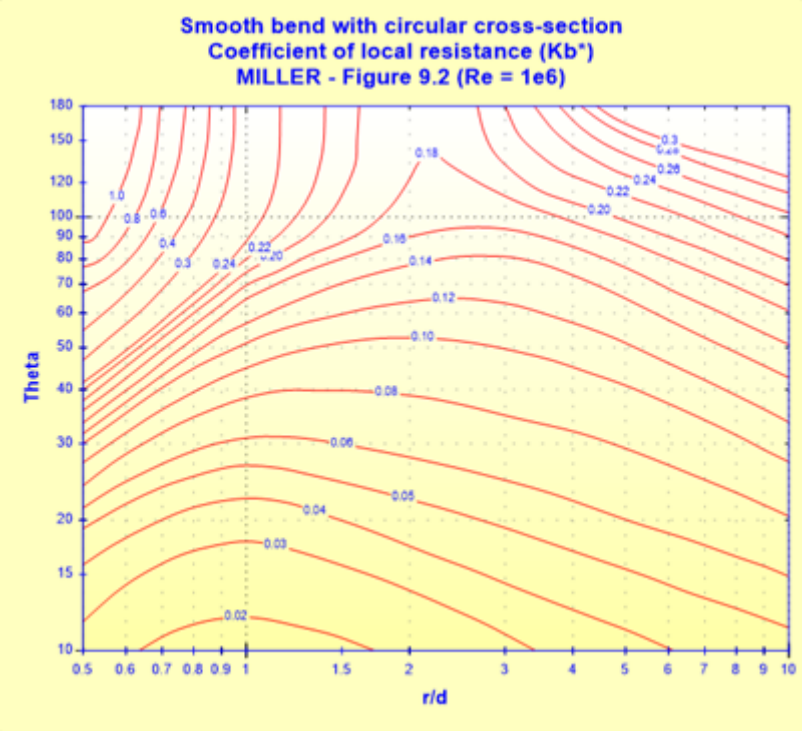
$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

Basic resistance coefficient for one bend:

$$K_b^* = f\left(\frac{r}{d}, \theta_b \right)$$ ([1] figure 9.2)



Reynolds number correction factor:

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$

([1] figure 9.3)

■ $r/d \geq 1$

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3)

- r/d < 1
  - r/d > 0.7 or K_b^* < 0.4

    $$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3 with r/d=1)

  - otherwise (r/d ≤ 0.7 and K_b^* ≥ 0.4)

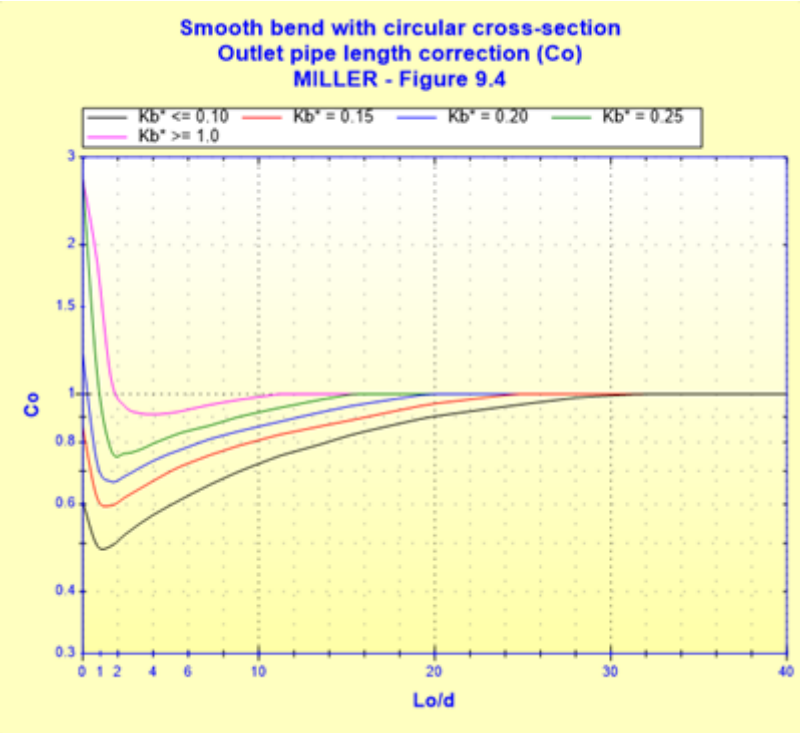
    $$C_{Re} = \frac{K_b^*}{K_b^* - 0.2C'_{Re} + 0.2}$$ ([1] equation 9.2)

    with:

    $$C'_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3 with r/d=1)

Outlet pipe length correction factor (optional):

$$C_o = f\left(\frac{L_o}{d}, K_b^*\right)$$ ([1] figure 9.4)



- r/d < 3 et θ_b < 100°

$$C_o = f\left(\frac{L_o}{d}, K_b^*\right)$$ ([1] figure 9.4)

■ otherwise (r/d > 3 and/or θ_b > 100°)

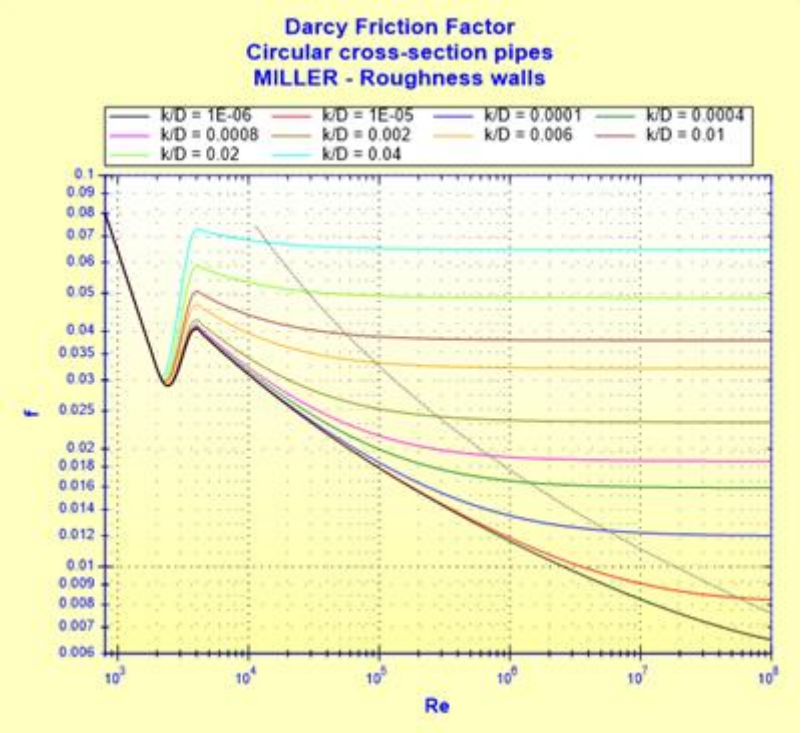
$$C_o = 1$$ (negligible effect)

If this option is not activated, the factor C_o is equal to unity.

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{D}\right)$$

See Straight Pipe - Circular Cross-Section and Roughness Walls (MILLER)



Roughness correction factor:

$$C_f = \frac{f_{rough}}{f_{smooth}}$$ ([1] equation 9.3)

with:

f_{rough}: Darcy friction factor for rough pipe at Re

f_{smooth}: Darcy friction factor for smooth pipe (k = 0) at Re

For Re > 10^6, C_f is calculated from equation (9.3) for Re = 10^6

Corrected loss coefficient for the first bend:

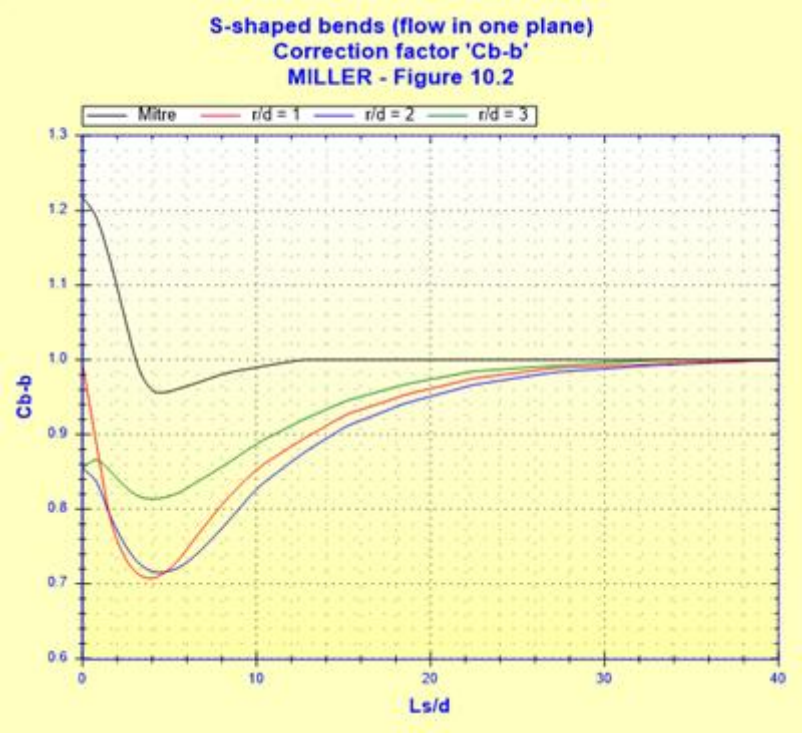
$$K_{b1} = K_b^* \cdot C_{Re} \cdot C_f$$ ([1] equation 9.4)

Corrected loss coefficient for the second bend:

$$K_{b2} = K_b^* \cdot C_{Re} \cdot C_f \cdot C_o$$ ([1] equation 9.4)

Interaction correction factor:

$$C_{b-b} = f\left(\frac{L_s}{d}, \frac{r}{d}\right)$$ ([1] figure 10.2)



Pressure loss coefficient of the two bends:

$$K_{b-b} = (K_{b1} + K_{b2}) \cdot C_{b-b}$$ ([1] equation 10.1)

Friction loss coefficient of the straight length between bends:

$$K_f = f \cdot \frac{L_s}{d}$$ ([1] equation 8.3)

Total pressure loss coefficient (based on the mean velocity in the bend):

$$K = K_{b-b} + K_f$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{d}{f}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Bend hydraulic diameter (m)
d	Bend internal diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
L_s	Straight length between the two bends (m)
L	Total length measured along the axis (m)

r	Radius of curvature (m)
θ_b	Curvature angle of each bend (°)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
K_b^*	Basic loss coefficient of one bend ()
C_{Re}	Reynolds number correction factor ()
C_o	Outlet pipe length correction factor ()
L_0	Length of the straight section downstream of the bend (m)
f	Darcy friction factor ()
k	Absolute roughness of walls (m)
C_f	Roughness correction factor ()
K_{b1}	Corrected loss coefficient for the first bend ()
K_{b2}	Corrected loss coefficient for the second bend ()
C_{b-b}	Interaction correction factor ()
K_{b-b}	Pressure loss coefficient of the two bends ()
K_f	Friction loss coefficient of the straight length between bends ()
K	Total pressure loss coefficient (based on the mean velocity in the bend) ()
L_{eq}	Straight length of equivalent pressure loss (m)
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream bend
- relative radius of curvature 'r/d': greater than or egal to 0.5 and lower than or egal to 10

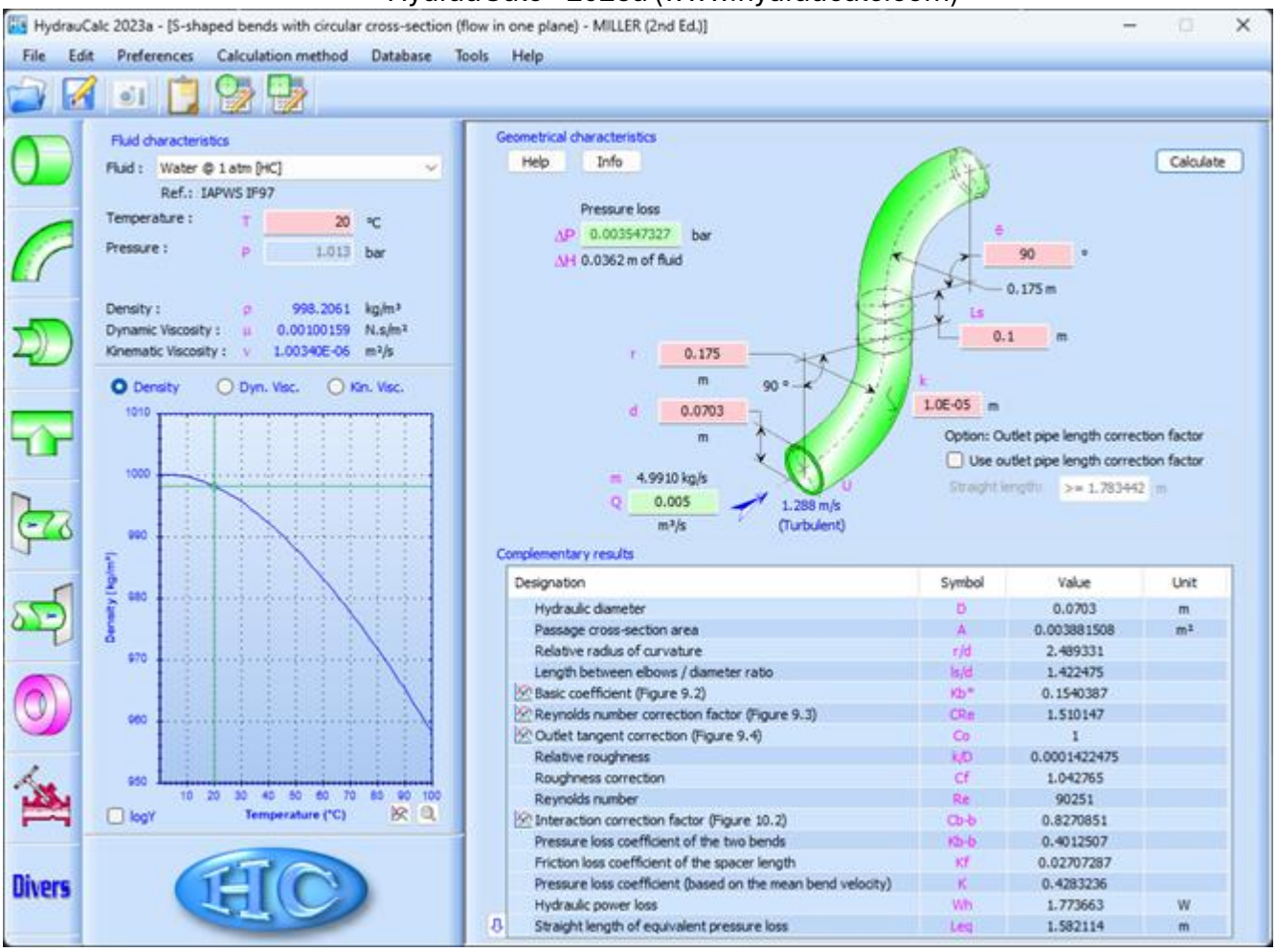
  for relative radius of curvature 'r/d' greater than 3, the pressure loss coefficient 'K' is estimated by taking into account the interaction correction factor 'Cb-b' corresponding to a relative radius of curvature 'r/d' of value 3.

- curvature angle: between 10° and 180°

  the interaction correction factor 'Cb-b' is only applicable for angles 'θ_b' between 70° and 90°,

  for angles 'θ_b' less than 70° or greater than 90°, the pressure loss coefficient 'K' is estimated by taking into account the interaction correction factor 'Cb-b' applicable to angles 'θ_b' between 70° and 90°

Example of application:



References:

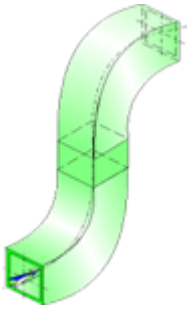
[1] Internal Flow System, Second Edition, D.S. Miller

2.2.10 S-shaped bends (1 plane) - Rectangular cross-section

S-shaped Bends

(with flow in one plane)

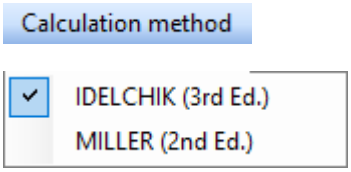
Rectangular Cross-Section



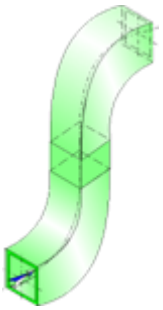
For the calculation of the pressure loss coefficient of S-shaped bends with rectangular cross-section (with flow in one plane), the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.2.10.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) of S-shaped bends (with flow in one plane) whose cross-section is rectangular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the first bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = \frac{2 \cdot a_0 \cdot b_0}{a_0 + b_0}$$ ([1] diagram 6-1)

Cross-section area (m^2):

$$F_0 = a_0 \cdot b_0$$

Total length measured along the axis (m):

$$l = 2 \cdot \left(2 \cdot \pi \cdot R_0 \cdot \frac{\delta}{360} \right) + l_{el}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = F_0 \cdot l$$

Fluid mass (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\overline{\Delta} = \frac{\Delta}{D_h}$$

■ Case of relative radius of curvature lower than 3 ($R_0/b_0 < 3$) ([1] diagram 6-1)

Coefficient of effect of the roughness:

$$k_\Delta = f\left(\frac{R_0}{b_0}, Re, \overline{\Delta}\right)$$ ([1] diagram 6-1)

● $0.50 \leq R_0/b_0 \leq 0.55$

$\overline{\Delta}$	Re	
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$
0	1.0	1.0
0 - 0.001	1.0	$1 + 0.5 \cdot 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	1.5

- $R_0/b_0 > 0.55$

$\overline{\Delta}$	Re		
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$ - $2 \cdot 10^5$	> $2 \cdot 10^5$
0	1.0	1.0	1.0
0 - 0.001	1.0	$\lambda_\Delta / \lambda_{sm}$	$1 + 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	2.0	2.0

with:

λ_{sm} : Darcy friction factor for hydraulically smooth pipe ($\overline{\Delta} = 0$) at Re

λ_Δ : Darcy friction factor for rough pipe ($\overline{\Delta} = \Delta/D_h$) at Re

---

Coefficient of effect of the Reynolds number ($Re \geq 10^4$):

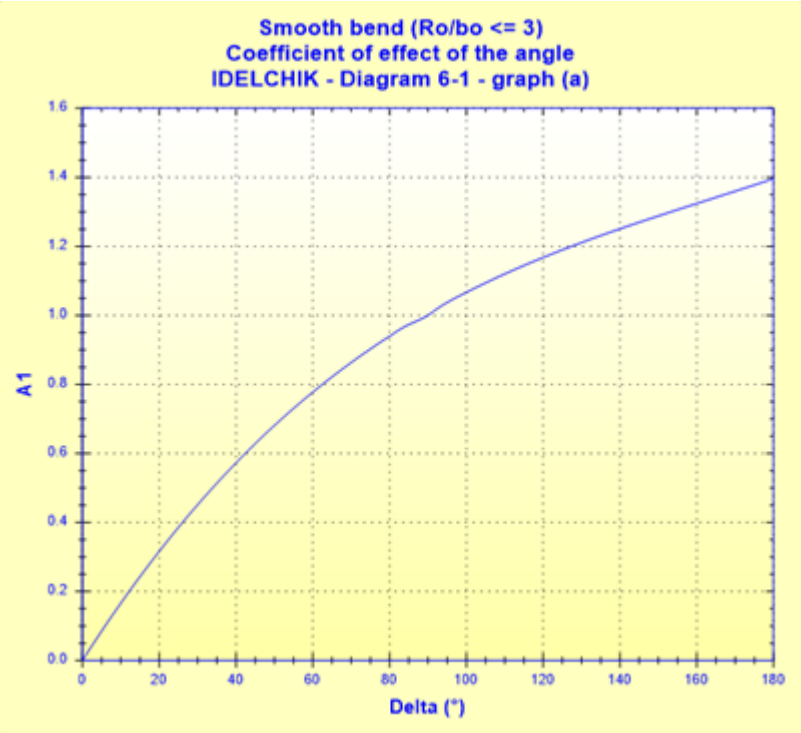
$$k_{Re} = f\left(\mathrm{Re}, \frac{R_0}{b_0}\right)$$

([1] diagram 6-1)

Coefficient of effect of the angle:

$$A1 = f(\delta)$$

([1] diagram 6-1)

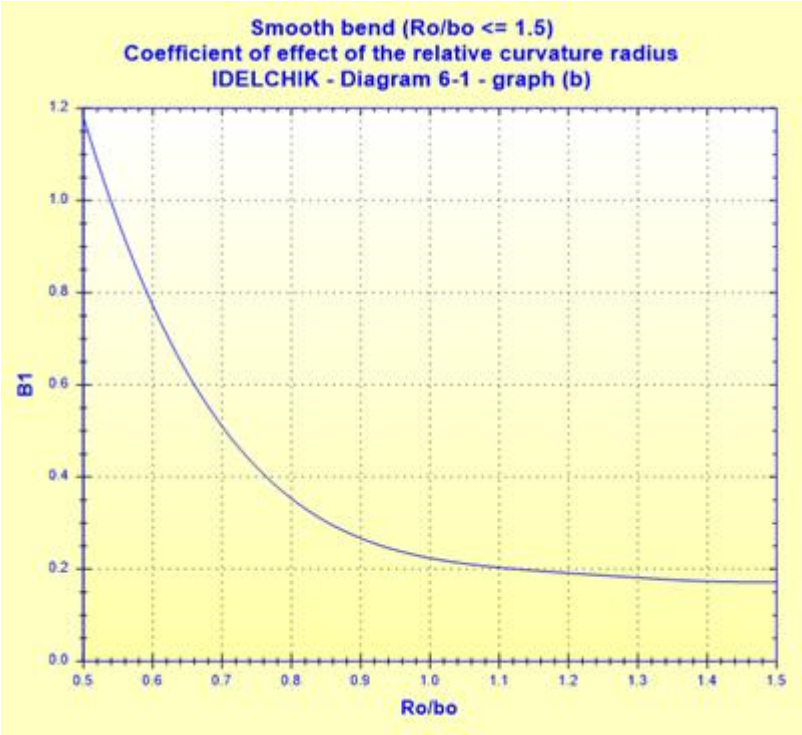


Coefficient of effect of the relative curvature radius:

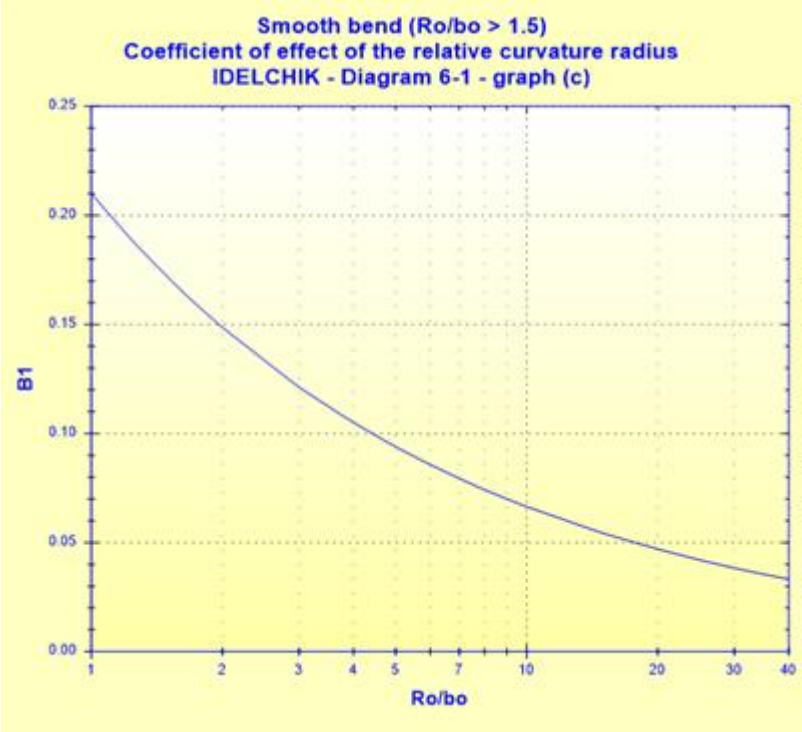
$$B1 = f\left(\frac{R_0}{b_0}\right)$$

([1] diagram 6-1)

- $0.5 \le R_0/b_0 \le 1.5$



- $R_0/b_0 > 1.5$



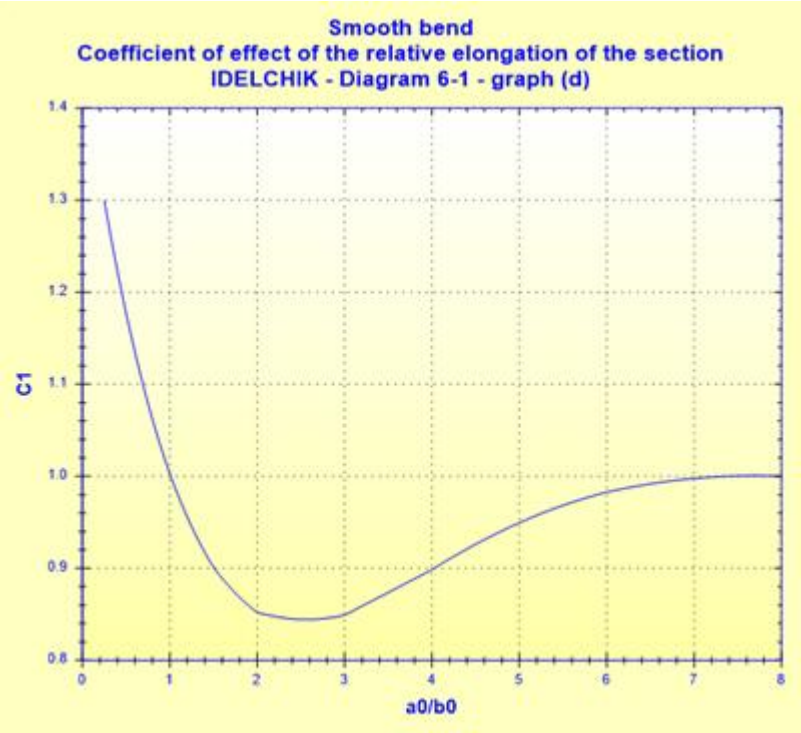
Coefficient of effect of the relative elongation of the cross section:

- $a_0 \geq b_0$

$$C1 = f\left(\frac{a_0}{b_0}\right)$$ ([1] diagram 6-1)

- $a_0 < b_0$

$$C1 = f\left(\frac{b_0}{a_0}\right)$$ ([1] diagram 6-1)

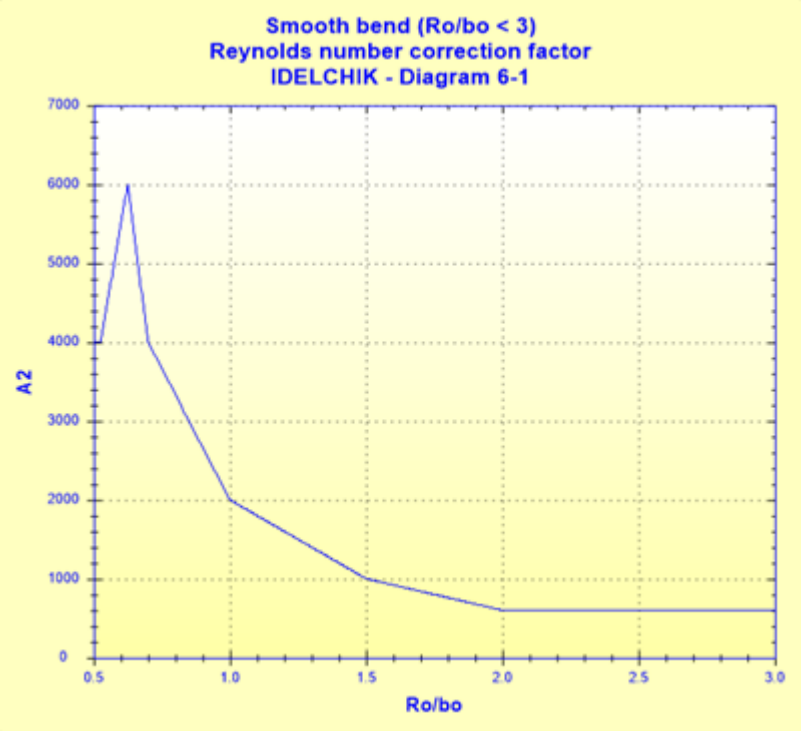


Reynolds number correction factor that depends on the relative curvature radius:

$$A2 = f\left(\frac{R_0}{b_0}\right)$$

([1] diagram 6-1)

R_0/b_0	0.50 - 0.55	>0.55 - 0.70	>0.70 - 1.0	>1.0 - 2.0	>2.0
$A2 \times 10^{-3}$	4.0	6.0	4.0 - 2.0	1.0	0.6



Pressure loss coefficient (without friction):

- $Re \geq 10^4$

$$\zeta'_{loc} = k_{\Delta} \cdot k_{Re} \cdot A1 \cdot B1 \cdot C1$$ ([1] diagram 6-1)

- $3 \cdot 10^3 < Re < 10^4$

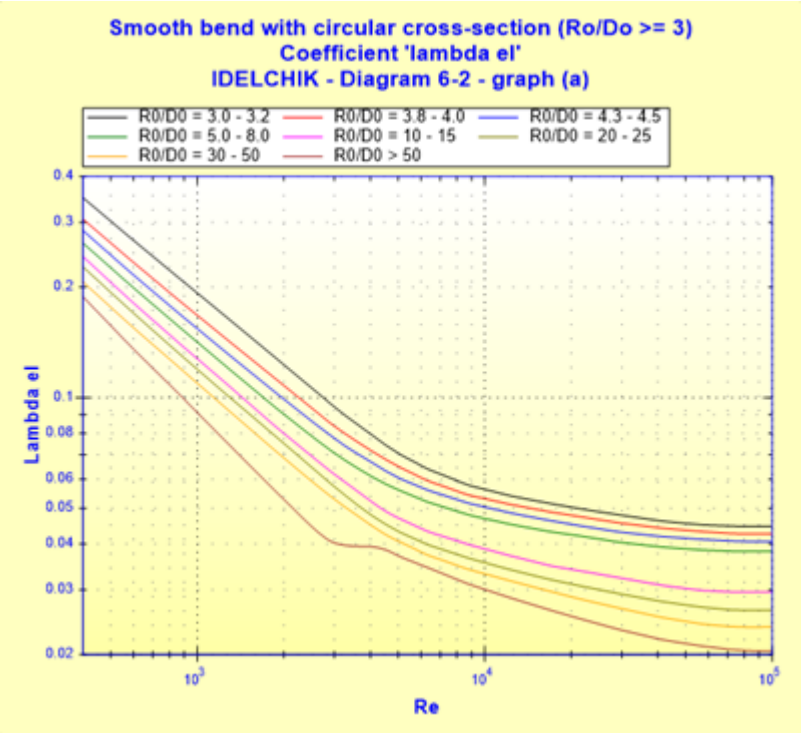
$$\zeta'_{loc} = \frac{A2}{Re} + A1 \cdot B1 \cdot C1$$ ([1] diagram 6-1)

■ Case of relative radius of curvature greater than or equal to 3 ($R_0/b_0 \geq 3$) ([1] diagram 6-2)

Total friction factor with smooth wall:

- $4 \cdot 10^2 \leq Re < 10^5$

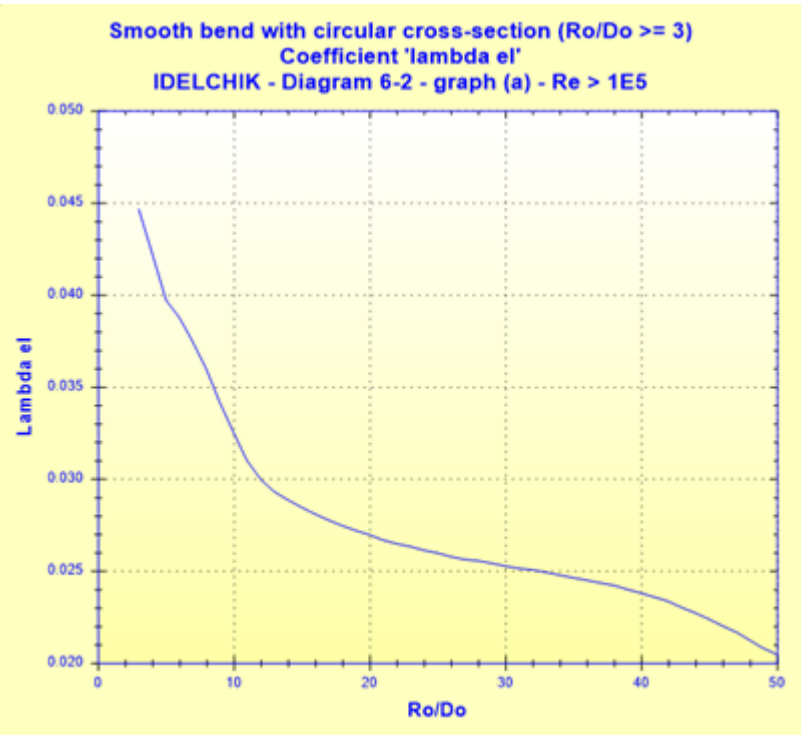
$$\lambda_{el} = f\left(Re, \frac{R_0}{D_0}\right)$$ ([1] diagram 6-2)



- Re ≥ 10^5

$$\lambda_{el} = f\left(\frac{R_0}{D_0}\right)$$

([1] diagramme 6-2)



Estimation of the coefficient of local resistance

$$\zeta'_{loc} = (\lambda_{el} - \lambda_s) \cdot \frac{2 \cdot \pi \cdot R_0 \cdot \delta / 360}{D_h}$$

with:

λ_s : Darcy friction factor for hydraulically smooth pipe ($\bar{\Delta} = 0$) at Re

---

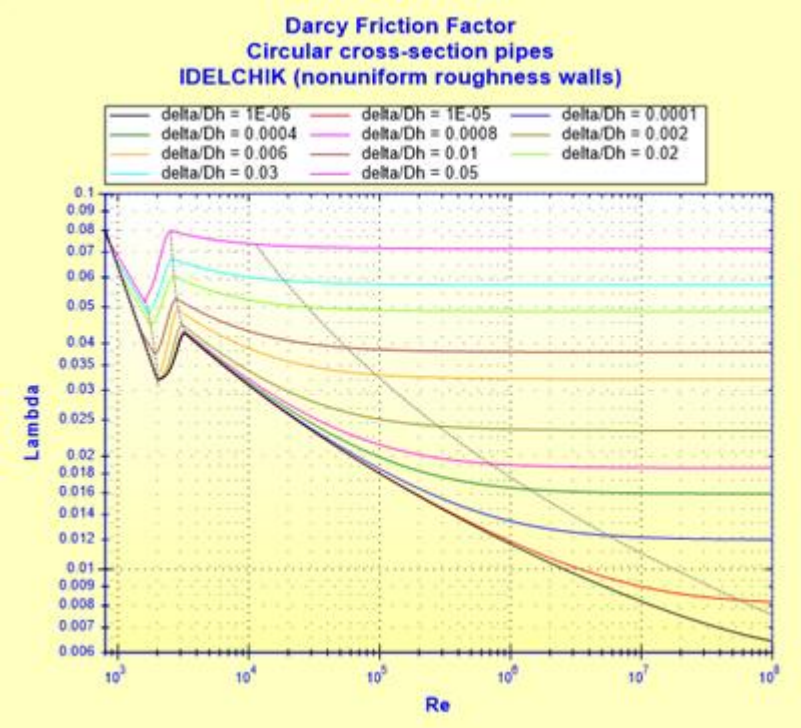
■ Case of the S-shaped Bends ([1] diagram 6-18)

Darcy friction factor:

See Straight Pipe - Rectangular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)

■ Darcy friction factor for circular cross-section

$$\lambda_{circ} = f\left(\mathrm{Re}, \frac{\Delta}{D_h}\right)$$



■ Correction for Darcy friction factor for noncircular cross-section

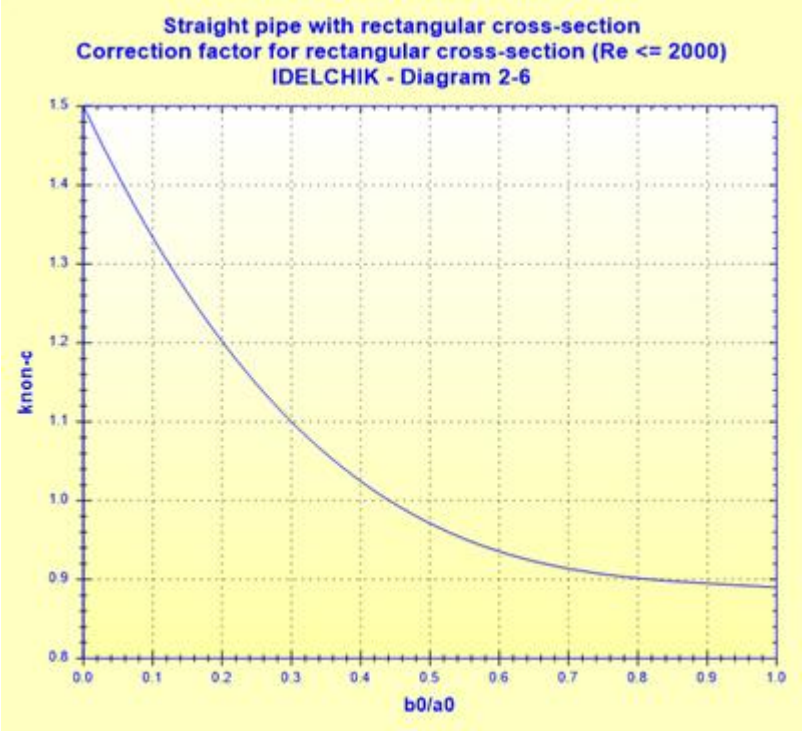
♦ $a_0 \geq b_0$

$$k_{non-c} = f(b_0/a_0)$$ ([1] diagram 2-6)

♦ $a_0 < b_0$

$$k_{non-c} = f(a_0/b_0)$$ ([1] diagram 2-6)

- laminar flow (Re ≤ 2000):



- turbulent flow (Re > 2000):

■ Darcy friction factor for rectangular cross-section

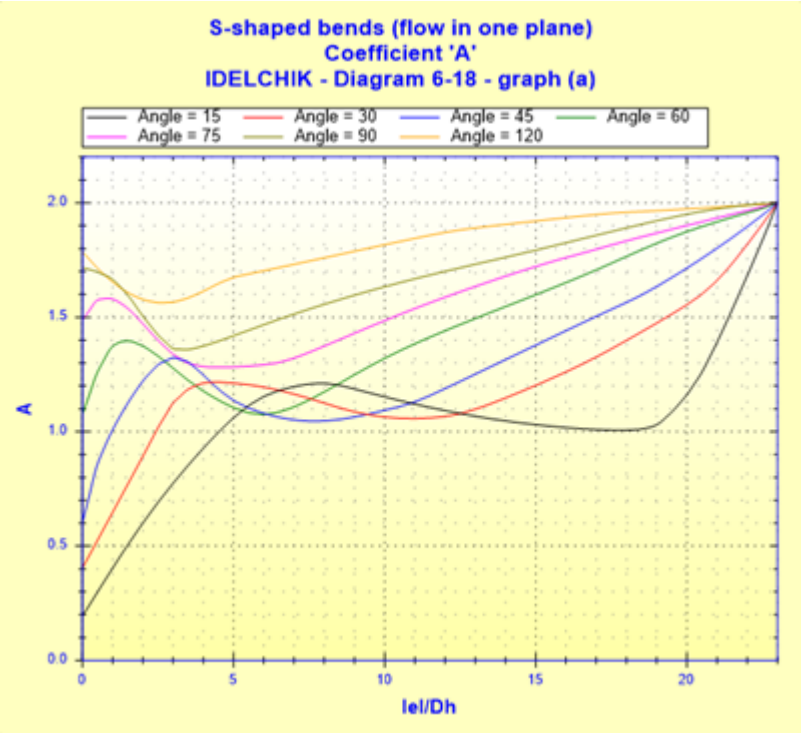
$$\lambda_{rect} = \lambda_{circ} \cdot k_{non-c}$$ ([1] diagram 2-6)

Pressure loss friction factor:

$$\zeta_{fr} = \lambda \cdot \left[2 \cdot \left(0.0175 \cdot \delta \cdot \frac{R_0}{D_h} \right) + \frac{l_{el}}{D_h} \right]$$ ([1] diagram 6-18)

Interaction correction factor:

$$A = f\left(\frac{L_{el}}{D_h}, \delta \right)$$ ([1] diagram 6-18 graph a)



Total pressure loss coefficient (based on the mean velocity in the bends):

$$\zeta = A \cdot \zeta'_{loc} + \zeta_{fr}$$

([1] diagram 6-18)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$

([1] diagram 6-18)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_h}{\lambda_{rect}}$$

Symbols, Definitions, SI Units:

a_0	Rectangular cross-section width (m)
b_0	Rectangular cross-section height (m)
D_h	Bend hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
l	Total length measured along the axis (m)
R_0	Radius of curvature (m)
δ	Curvature angle of each bend (°)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()
k_Δ	Coefficient that allows for the effect of the roughness ()
k_{Re}	Coefficient that allows for the effect of the Reynolds number ()
A1	Coefficient that allows for the effect of the angle ()
B1	Coefficient that allows for the effect of the relative curvature radius ()
C1	Coefficient that allows for the effect of the relative elongation of the cross section ()
A2	Reynolds number correction factor that depends on the relative curvature radius ()
ζ'_{loc}	Coefficient of local resistance ()
λ_{circ}	Darcy friction coefficient for circular cross-section ()
k_{non-c}	Correction for Darcy friction factor for noncircular cross-section ()

λ_{rect}	Darcy friction coefficient for rectangular cross-section ()
λ_{el}	Friction coefficient ()
ζ_{fr}	Pressure loss friction factor ()
A	Interaction correction factor ()
ζ	Total pressure loss coefficient (based on the mean velocity in the bend) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
L_{eq}	Straight length of equivalent pressure loss (m)
ρ	Fluid density (kg/m³)
ν	Fluid kinematic viscosity (m²/s)
g	Gravitational acceleration (m/s²)

Validity range:

- stabilized flow upstream bend
- length of the straight section downstream: $\geq 10\ D_h$
- relative radius of curvature: greater than or equal to 1 ($R_0/b_0 \geq 1$)
- curvature angle of one bend: between 0° and 180°

for 'δ' angles less than 15° the pressure loss coefficient 'ζ' is estimated by taking into account an interaction correction factor '*A*' corresponding to that of an angle of 15°.

for 'δ' angles greater than 120° the pressure loss coefficient 'ζ' is estimated by taking into account an interaction correction factor '*A*' corresponding to that of an angle of 120°.

■ case of relative radius of curvature: lower than 3 ($R_0/b_0 < 3$)

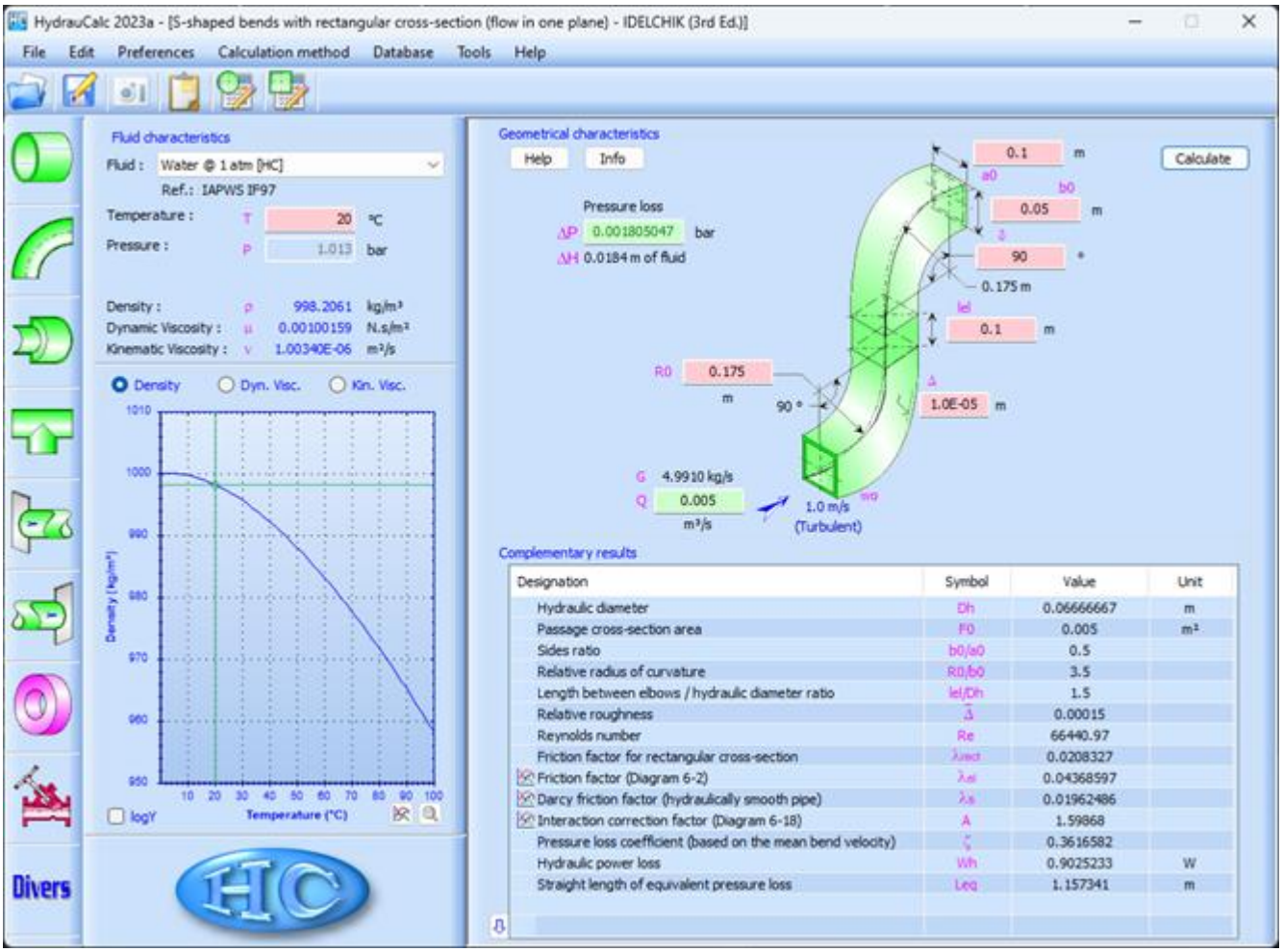
- flow regime: $Re \geq 3 \cdot 10^3$

■ case of relative radius of curvature: greater than or equal to 3 ($R_0/b_0 \geq 3$)

- flow regime: $500 \leq Re \leq 38 \cdot 10^3$

for Reynolds number 'Re' lower than 500 or greater than $38 \cdot 10^3$, the coefficient 'λ_{el}' is linearly extrapolated.

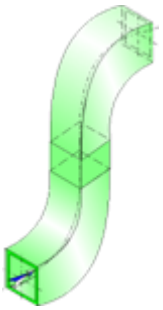
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.2.10.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) of S-shaped bends (with flow in one plane) whose cross-section is rectangular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the first bend.

An option allows to take into account the effect of the straight length at the exit of the second bend.

Model formulation:

Hydraulic diameter (m):

$$D = \frac{2 \cdot b \cdot W}{b + W}$$ ([1] equation 9.5)

Cross-section area (m^2):

$$A = b \cdot W$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Total length measured along the axis (m):

$$L = 2 \cdot \left(2 \cdot \pi \cdot r \cdot \frac{\theta_b}{360} \right) + L_s$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

$$M = V \cdot \rho$$

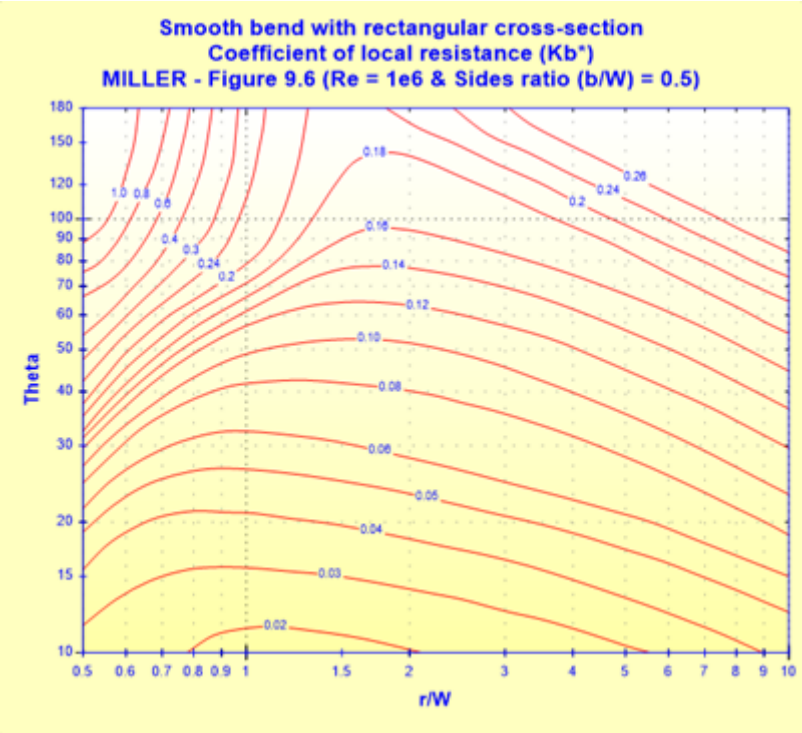
Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$ ([1] equation 9.6)

Basic resistance coefficient:

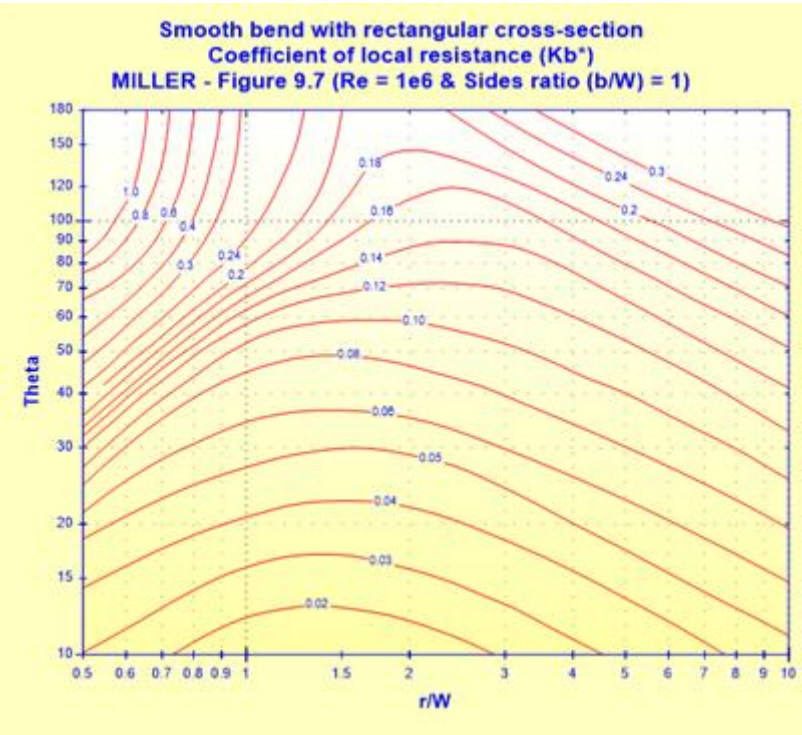
$$K_b^* = f\left(\frac{r}{W}, \theta_b \right)$$ ([1] figures 9.6 – 9.7 – 9.8)

- Sides ratio b/W = 0.5



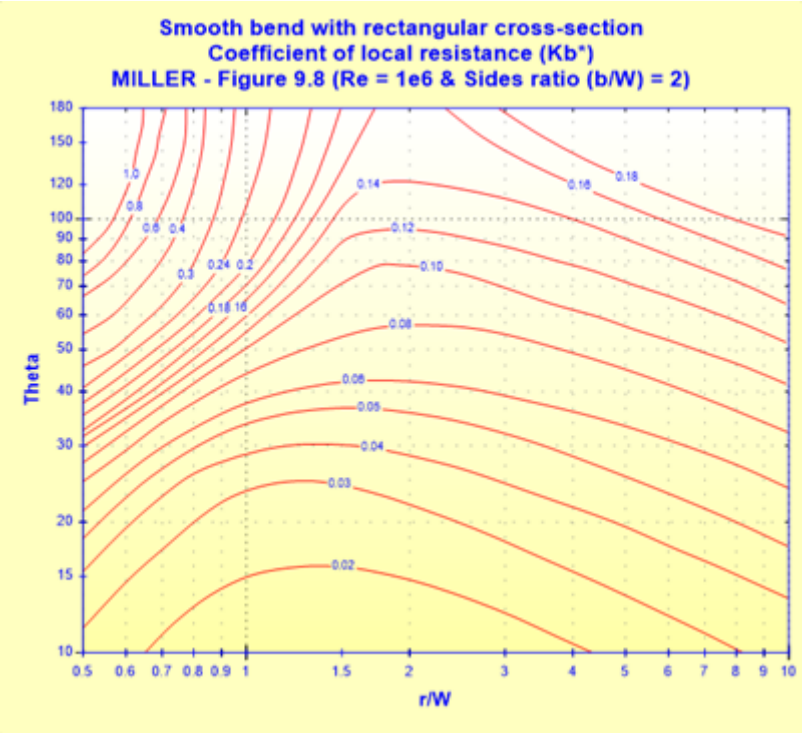
([1] figure 9.6)

■ Sides ratio b/W = 1



([1] figure 9.7)

■ Sides ratio b/W = 2



([1] figure 9.8)

For any sides ratio 'b/W' between 0.5 and 2, the coefficient K_b^* is obtained by curvilinear interpolation between the values of K_b^* calculated for aspect ratios of 0.5, 1 and 2.

Reynolds number correction factor:

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{W}\right)$$

([1] figure 9.3)

- $r/W \geq 1$

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{D}\right)$$ ([1] figure 9.3)

- $r/W < 1$
  - $r/W > 0.7$ or $K_b^* < 0.4$

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{D}\right)$$ ([1] figure 9.3 with r/W=1)

  - otherwise ($r/W \leq 0.7$ and $K_b^* \geq 0.4$)

$$C_{Re} = \frac{K_b^*}{K_b^* - 0.2C'_{Re} + 0.2}$$ ([1] equation 9.2)

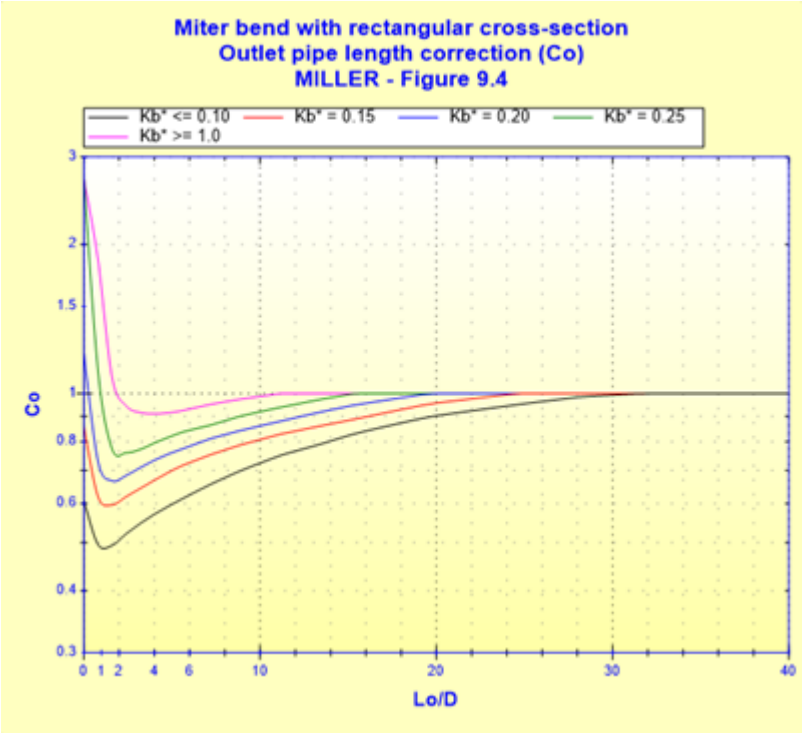
with:

$$C'_{Re} = f\left(\mathrm{Re}, \frac{r}{D}\right)$$ ([1] figure 9.3 with r/W=1)

Outlet pipe length correction factor (optional):

- correction factor for circular cross-section
  - $\theta_b < 100°$

$$C_o = f\left(\frac{L_o}{D}, K_b^*\right)$$ ([1] figure 9.4)



- $\theta_b \geq 100°$

$$C_o = 1$$ (negligible effect)

■ correction factor for rectangular cross-section

- b/W < 0.7 and Lo/D > 1

$$C_{or} = 1 - \frac{1 - C_o}{2}$$

- b/W > 1 and Lo/D < 1
  - ♦ 1.5 < r/W < 3

$$C_{or} = 2$$

  - ♦ r/W ≤ 1.5 or r/W ≥ 3

$$C_{or} = C_o$$

- otherwise

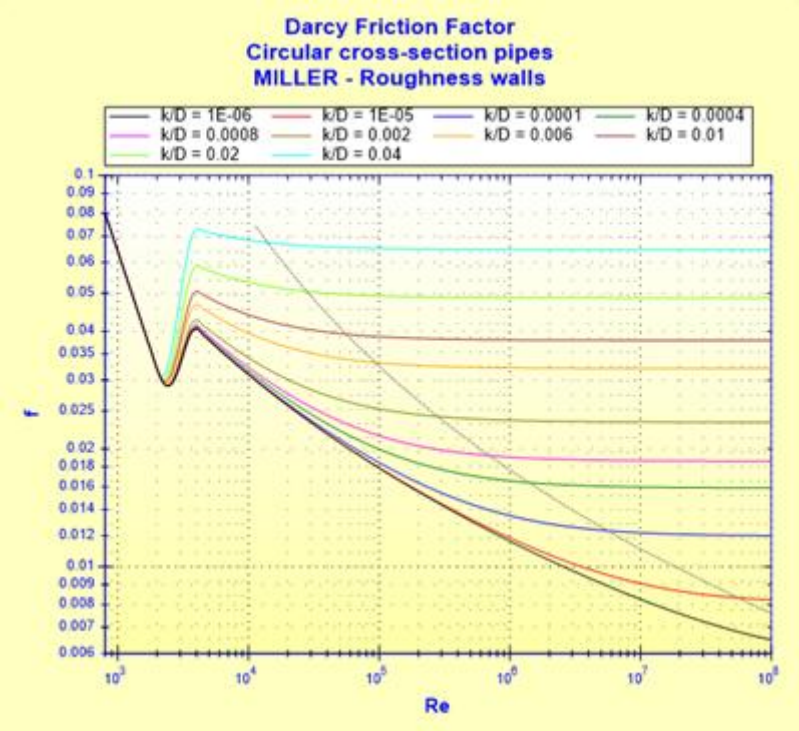
$$C_{or} = C_o$$

If this option is not activated, the factors C_o and C_{or} are equal to unity.

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{D}\right)$$

See Straight Pipe - Rectangular Cross-Section and Roughness Walls (MILLER)



Roughness correction factor:

$$C_f = \frac{f_{rough}}{f_{smooth}}$$ ([1] equation 9.3)

with:

f_{rough}: Darcy friction factor for rough pipe at Re

f_{smooth}: Darcy friction factor for smooth pipe (k = 0) at Re

For $Re > 10^6$, C_f is calculated from equation (9.3) for $Re = 10^6$

Corrected loss coefficient for the first bend:

$$K_{b1} = K_b^* \cdot C_{Re} \cdot C_f$$ ([1] equation 9.4)

Corrected loss coefficient for the second bend:

$$K_{b2} = K_b^{\circ} \cdot C_{Re} \cdot C_f \cdot C_o$$

([1] equation 9.4)

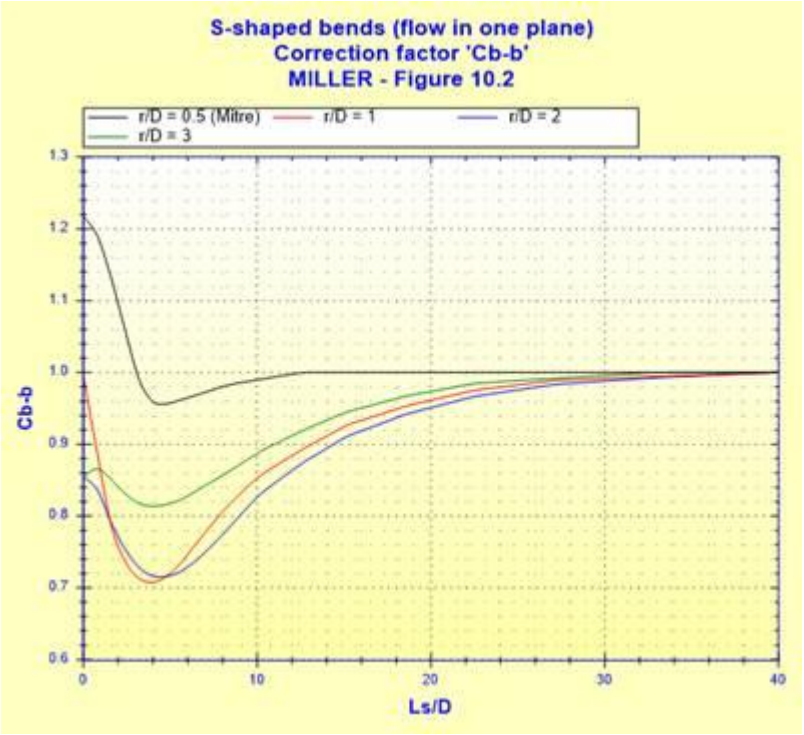
Interaction correction factor:

$$C_{b-c} = f\left(\frac{L_s}{D}, \frac{r}{D}\right)$$

- Aspect ratio b/W < 0.7

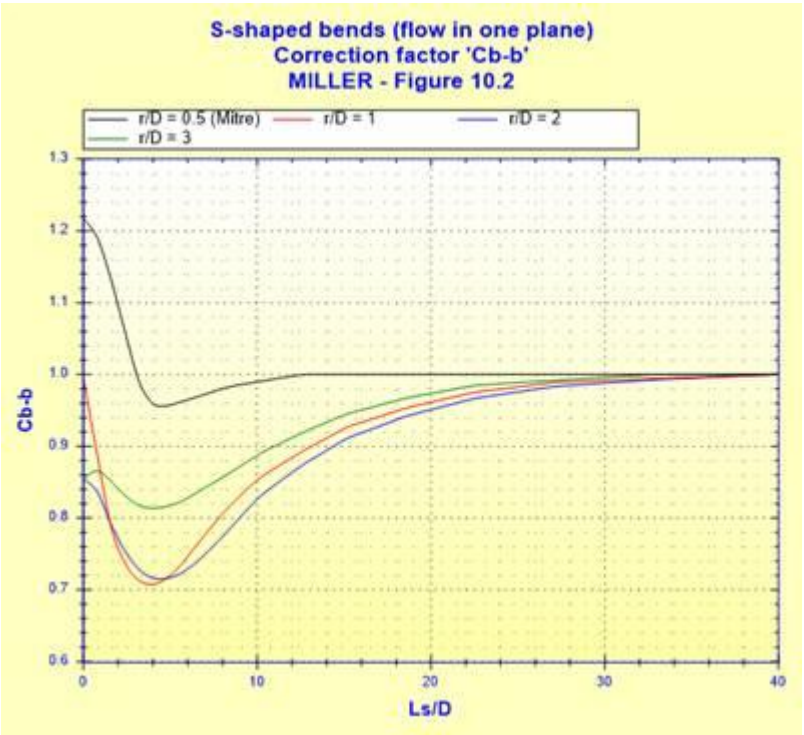
([1] figure 10.4)

- Aspect ratio 0.7 ≤ b/W ≤ 1.5



([1] figure 10.2)

- Aspect ratio b/W > 1.5



([1] figure 10.2)

Pressure loss coefficient of the two bends:

- Aspect ratio b/W < 0.7

$$K_{b-b} = (K_{b1} + K_{b2}) \cdot \left[1 - \frac{1 - C_{b-b}}{2}\right]$$

- Aspect ratio b/W ≥ 0.7

$$K_{b-b} = (K_{b1} + K_{b2}) \cdot C_{b-b}$$

Friction loss coefficient of the straight length between bends:

$$K_f = f_{rough} \cdot \frac{L_s}{D}$$ ([1] equation 8.3)

Total pressure loss coefficient (based on the mean velocity in the bend):

$$K = K_{b-b} + K_f$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{D}{f_{rough}}$$

Symbols, Definitions, SI Units:

W	Cross-section height (m)
b	Cross-section width (m)

D	Bend hydraulic diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
L_s	Straight length between the two bends (m)
L	Total length measured along the axis (m)
r	Radius of curvature (m)
θ_b	Curvature angle of each bend (°)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
K_b^*	Basic loss coefficient ()
C_{Re}	Reynolds number correction factor ()
C_o	Outlet pipe length correction factor for circular cross-section ()
C_{or}	Outlet pipe length correction factor for rectangular cross-section ()
L_0	Length of the straight section downstream of the bend (m)
f	Darcy friction factor ()
k	Absolute roughness of walls (m)
C_f	Roughness correction factor ()
K_{b1}	Corrected loss coefficient for the first bend ()
K_{b2}	Corrected loss coefficient for the second bend ()
$C_{b\text{-}b}$	Interaction correction factor ()
$K_{b\text{-}b}$	Pressure loss coefficient of the two bends ()
K_f	Friction loss coefficient of the straight length between bends ()
K	Total pressure loss coefficient (based on the mean velocity in the bend) ()
ΔP	Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

L_{eq} Straight length of equivalent pressure loss (m)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream bend
- radius of curvature / hydraulic diameter ratio 'r/D': greater than or egal to 0.5 and lower than or egal to 10

  for ratio 'r/D' greater than 3, the pressure loss coefficient 'K' is estimated by taking into account the interaction correction factor 'Cb-b' corresponding to a ratio 'r/D' of value 3.

- curvature angle: between 10° and 180°

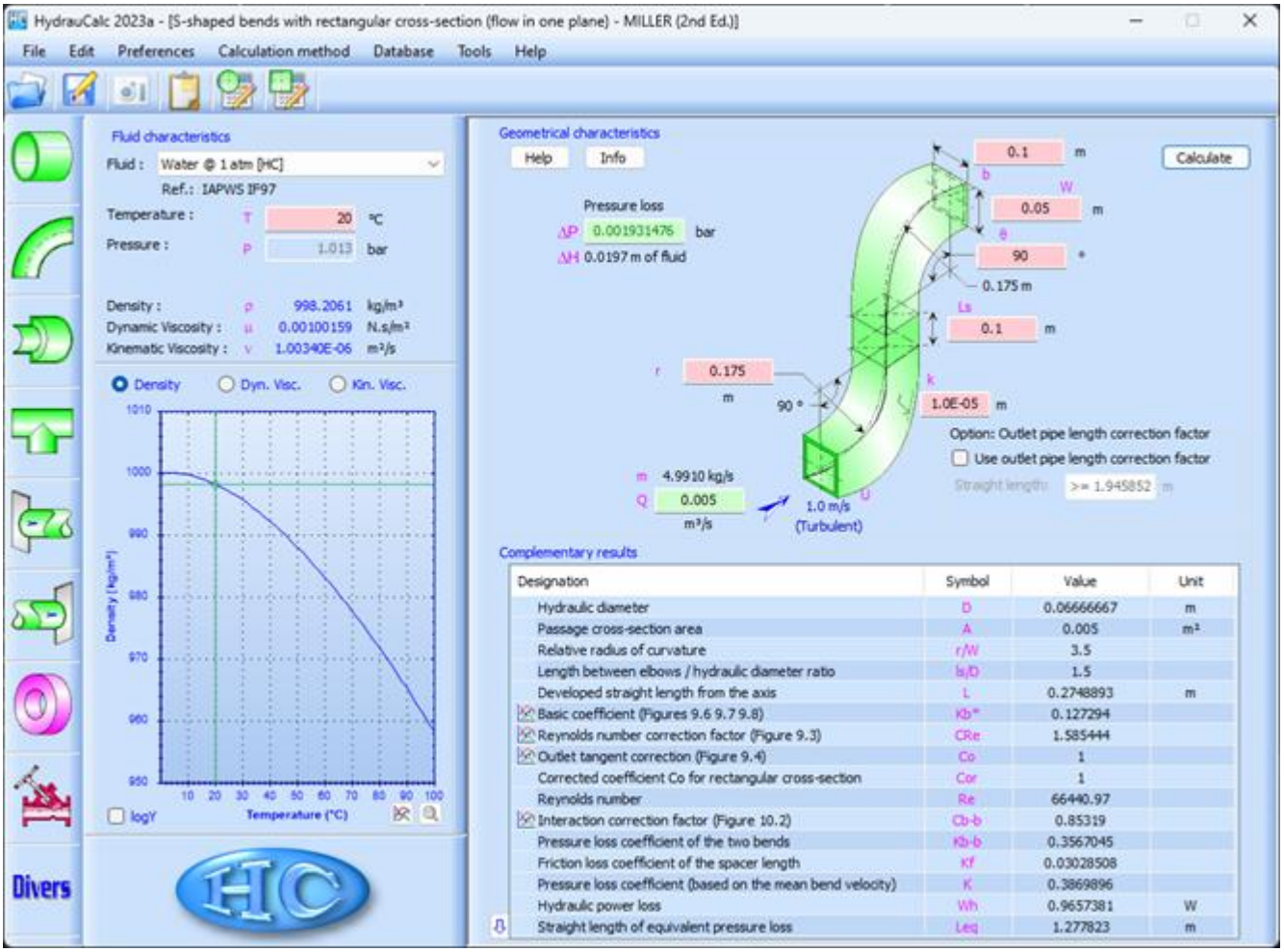
  the interaction correction factor 'Cb-b' is applicable for angles 'θ_b' between 70° and 90°.

  for angles 'θ_b' less than 70° or greater than 90°, the pressure loss coefficient 'K' is estimated by taking into account the interaction factor coefficient 'Cb-b' applicable to angles 'θ_b' between 70° and 90°

- relative radius of curvature 'r/W': between 0.5 and 10
- sides ratio 'b/W': between 0.5 and 2

  note: for any sides ratio 'b/W' less than 0.5, the resistance coefficients K_b^* are obtained by linear extrapolation from the values of K_b^* calculated for sides ratios of 0.5 and 1.
  for any sides ratio 'b/W' greater than 0.5 and 2, the resistance coefficients K_b^* are obtained by linear extrapolation from the values of K_b^* calculated for sides ratios of 1 and 2.

Example of application:



References:

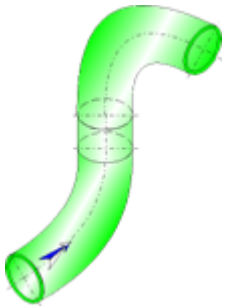
[1] Internal Flow System, Second Edition, D.S. Miller

2.2.11 S-shaped bends (2 planes) - Circular cross-section

S-shaped Bends

(with flow in two perpendicular planes)

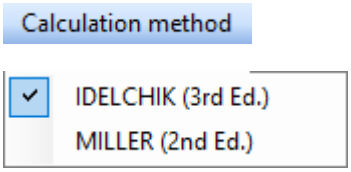
Circular Cross-Section



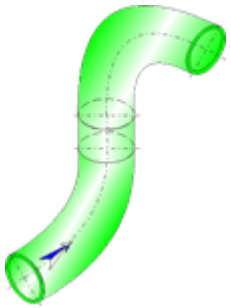
For the calculation of the pressure loss coefficient of S-shaped bends with circular cross-section (with flow in two perpendicular planes), the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.2.11.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) of S-shaped bends (with flow in two perpendicular planes) whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the first bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Total length measured along the axis (m):

$$l = 2 \cdot \left(2 \cdot \pi \cdot R_0 \cdot \frac{\delta}{360} \right) + l_{el}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = F_0 \cdot l$$

Fluid mass (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\overline{\Delta} = \frac{\Delta}{D_h}$$

■ Case of a single bend of relative radius of curvature lower than 3 ($R_0/D_0 < 3$) ([1] diagram 6-1)

Coefficient of effect of the roughness:

$$k_\Delta = f\left(\frac{R_0}{D_0}, Re, \overline{\Delta}\right)$$ ([1] diagram 6-1)

- $0.50 \leq R_0/D_0 \leq 0.55$

$\overline{\Delta}$	Re	
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$
0	1.0	1.0
0 - 0.001	1.0	$1 + 0.5 \cdot 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	1.5

- $R_0/D_0 > 0.55$

$\overline{\Delta}$	Re		
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$ - $2 \cdot 10^5$	> $2 \cdot 10^5$
0	1.0	1.0	1.0
0 - 0.001	1.0	$\lambda_\Delta / \lambda_{sm}$	$1 + 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	2.0	2.0

with:

λ_{sm} : Darcy friction factor for hydraulically smooth pipe ($\overline{\Delta} = 0$) at Re

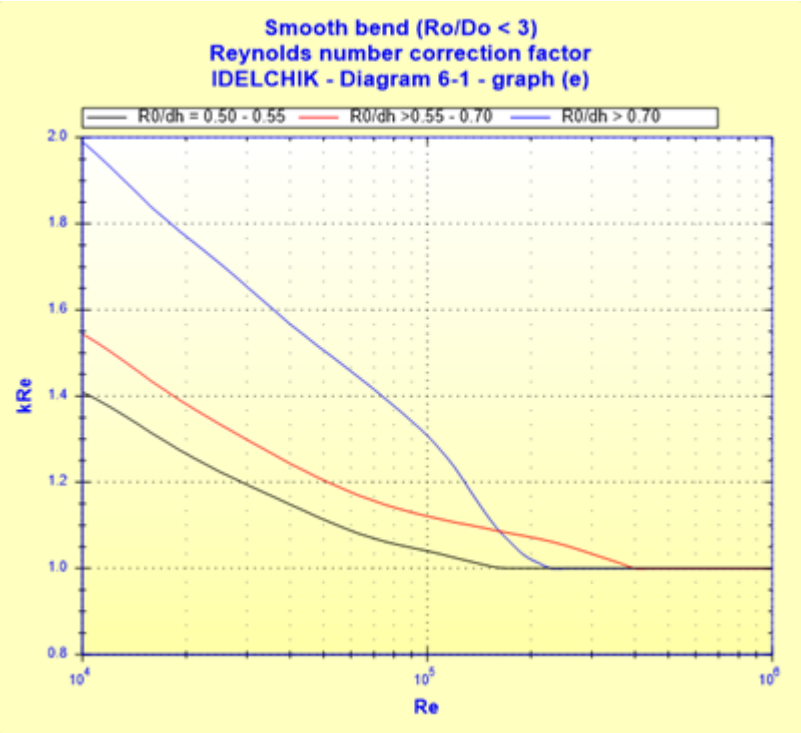
λ_Δ : Darcy friction factor for rough pipe ($\overline{\Delta} = \Delta/D_h$) at Re

---

Coefficient of effect of the Reynolds number ($Re \geq 10^4$):

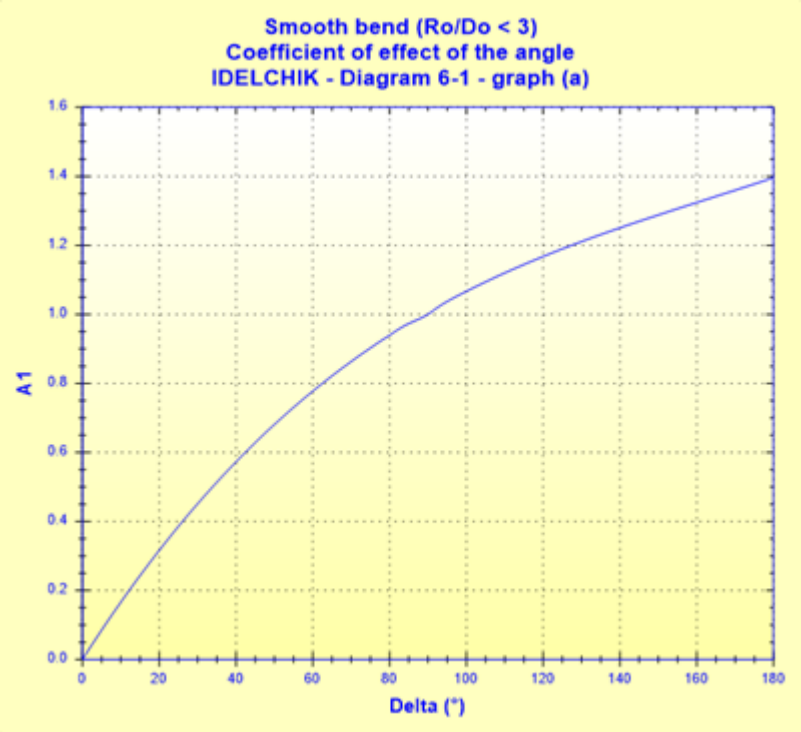
$$k_{Re} = f\left(Re, \frac{R_0}{D_h}\right)$$

([1] diagram 6-1)



Coefficient of effect of the angle:

$A1 = f(\delta)$ ([1] diagram 6-1)

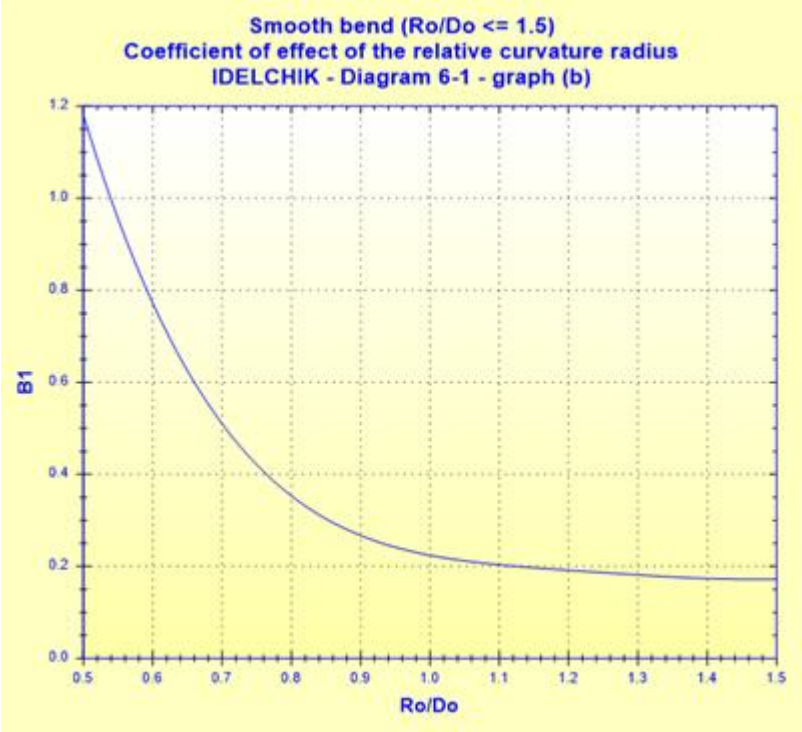


Coefficient of effect of the relative curvature radius:

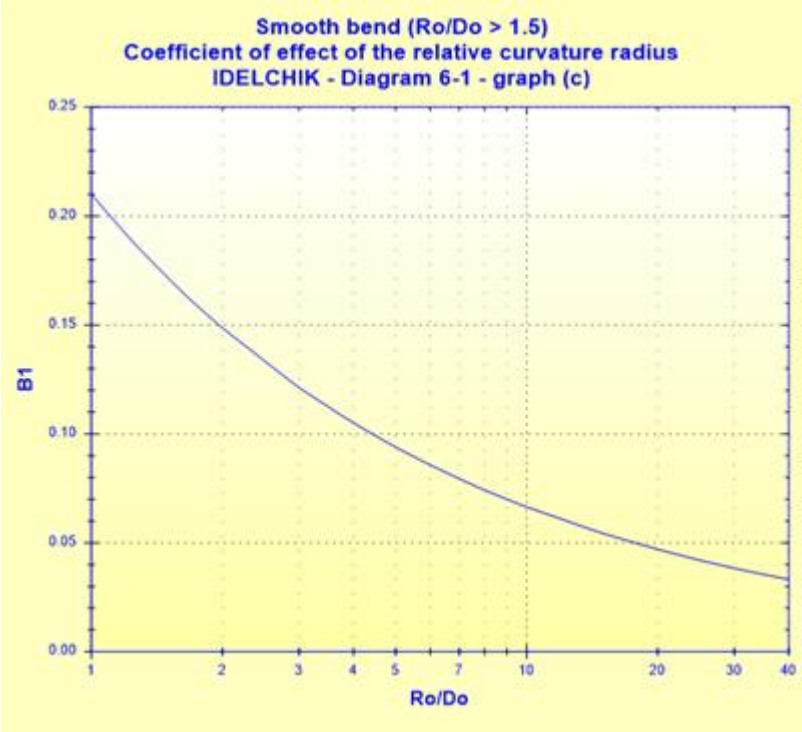
$$B1 = f\left(\frac{R_0}{D_h}\right)$$

([1] diagram 6-1)

- $0.5 \leq R_0/D_0 \leq 1.5$



- $R_0/D_0 > 1.5$



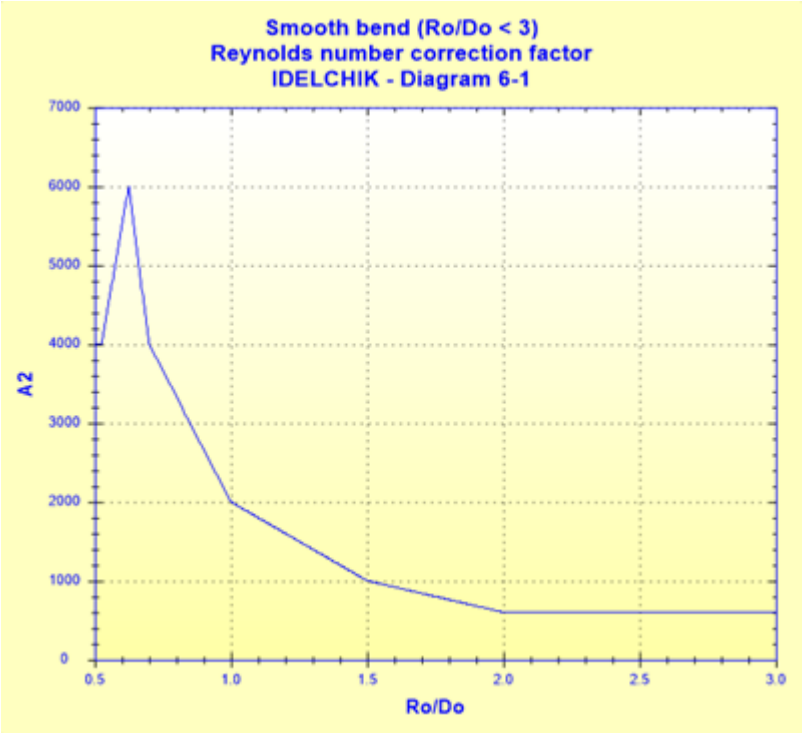
Coefficient of effect of the relative elongation of the cross section:

$C1 = 1$ ([1] diagram 6-1)

Reynolds number correction factor that depends on the relative curvature radius:

$$A2 = f\left(\frac{R_0}{D_0}\right)$$ ([1] diagram 6-1)

R_0/D_0	0.50 - 0.55	>0.55 - 0.70	>0.70 - 1.0	>1.0 - 2.0	>2.0
$A2 \times 10^{-3}$	4.0	6.0	4.0 - 2.0	1.0	0.6



Pressure loss coefficient (without friction):

- $Re \geq 10^4$

$$\zeta'_{loc} = k_{\Delta} \cdot k_{Re} \cdot A1 \cdot B1 \cdot C1$$ ([1] diagram 6-1)

- $3 \cdot 10^3 < Re < 10^4$

$$\zeta'_{loc} = \frac{A2}{Re} + A1 \cdot B1 \cdot C1$$ ([1] diagram 6-1)

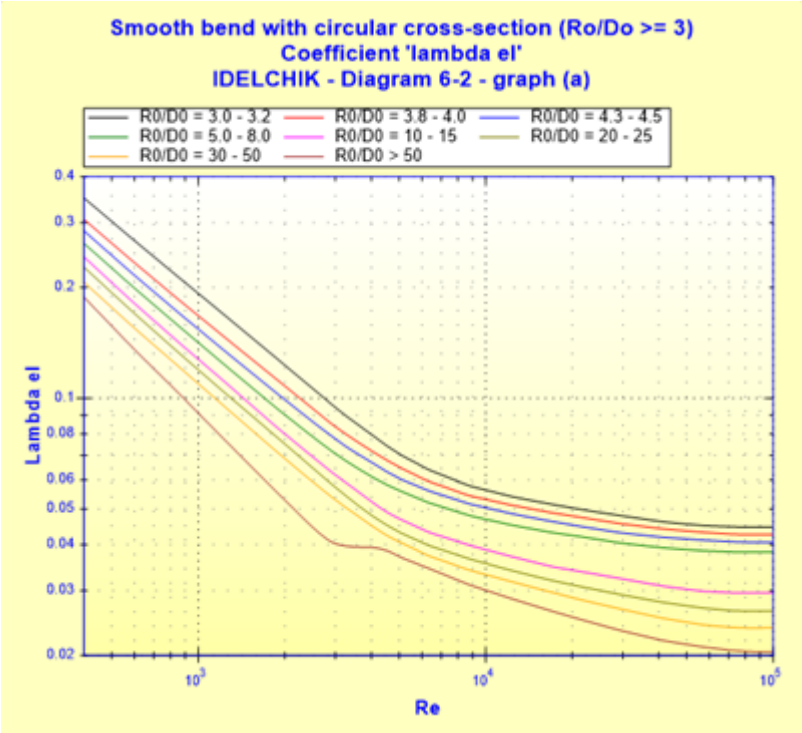
■ Case of a single bend of relative radius of curvature greater than or equal to 3 ($R_0/D_0 \geq 3$) ([1] diagram 6-2)

Total friction factor with smooth wall:

- $4 \cdot 10^2 \leq Re < 10^5$

$$\lambda_{el} = f\left(Re, \frac{R_0}{D_0}\right)$$

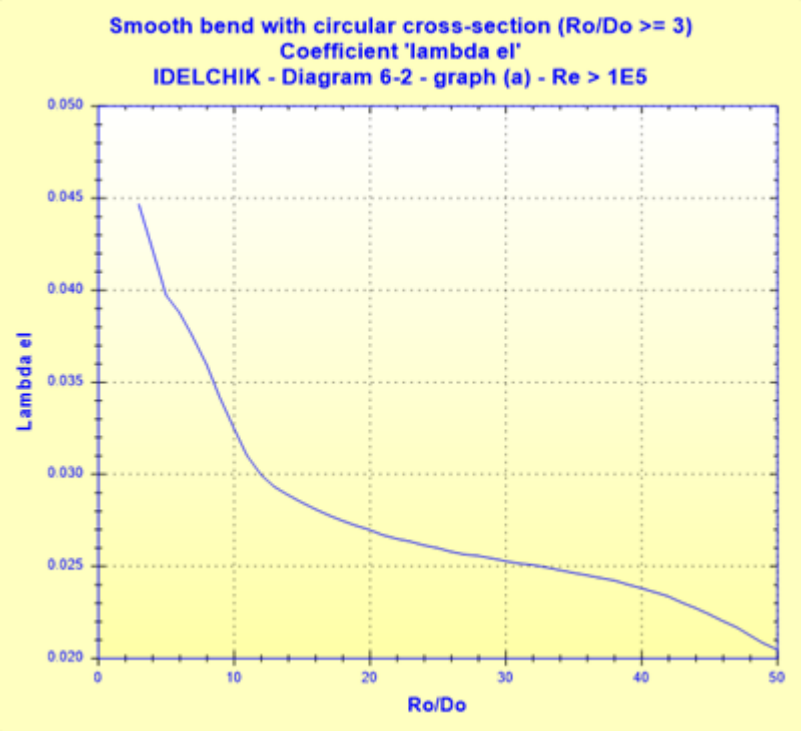
([1] diagram 6-2)



- $Re \geq 10^5$

$$\lambda_{el} = f\left(\frac{R_0}{D_0}\right)$$

([1] diagram 6-2)



Estimation of the coefficient of local resistance

$$\zeta'_{loc} = (\lambda_{el} - \lambda_s) \cdot \frac{2 \cdot \pi \cdot R_0 \cdot \delta / 360}{D_h}$$

with:

λ_s : Darcy friction factor for hydraulically smooth pipe ($\overline{\Delta} = 0$) at Re

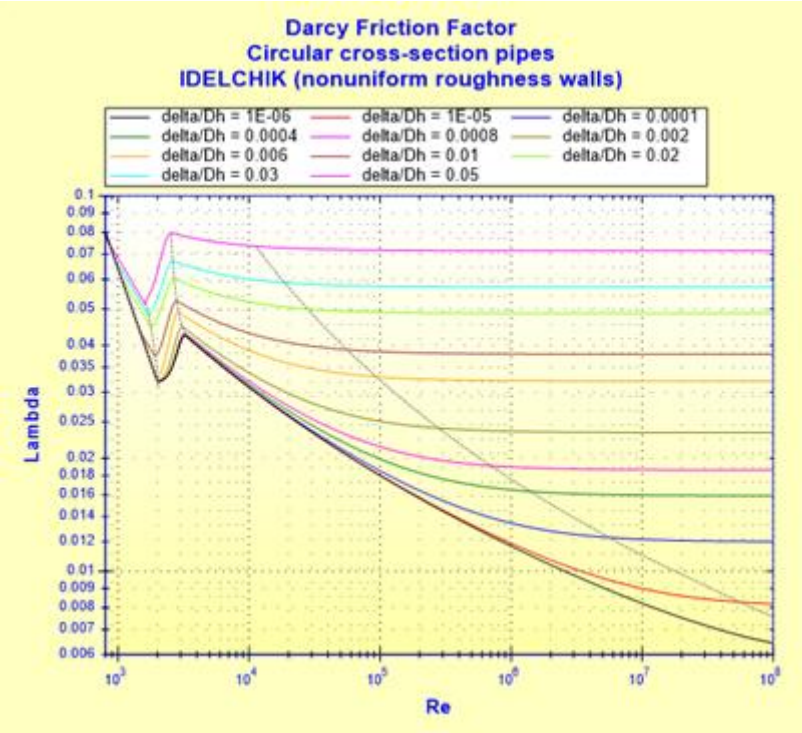
---

■ Case of the S-shaped Bends ([1] diagram 6-19)

Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}, \frac{\Delta}{D_h}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



Pressure loss friction factor:

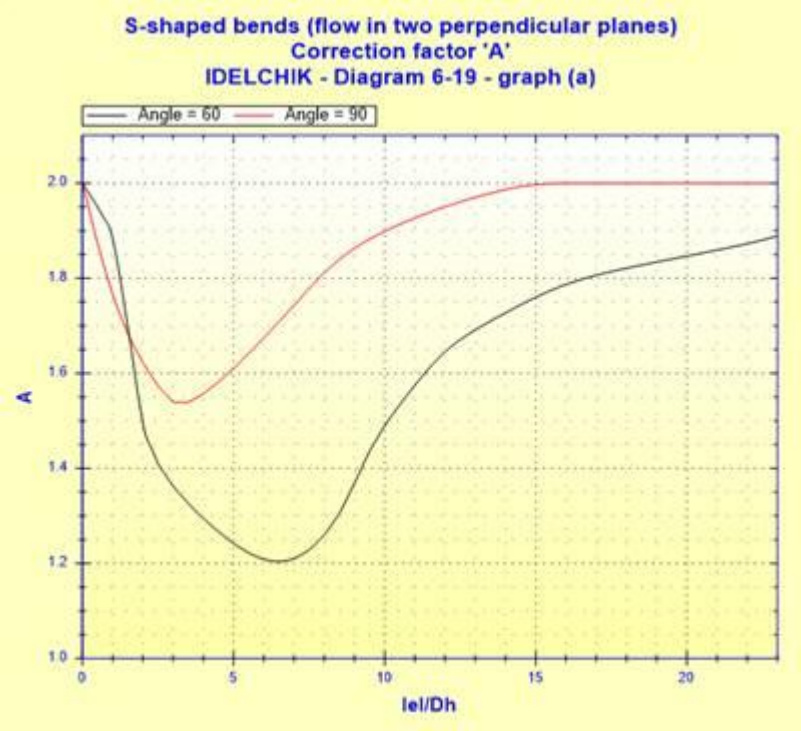
$$\zeta_{fr} = \lambda \cdot \left[2 \cdot \left(0.0175 \cdot \delta \cdot \frac{R_0}{D_h} \right) + \frac{l_{el}}{D_h} \right]$$

([1] diagram 6-19)

Coefficient of correction:

$$A = f\left(\frac{L_{el}}{D_h}, \delta \right)$$

([1] diagram 6-19 graph a)



Total pressure loss coefficient (based on the mean velocity in the bends):

$$\zeta = A \cdot \zeta'_{loc} + \zeta_{fr}$$ ([1] diagram 6-19)

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_0}{\lambda}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$ ([1] diagram 6-19)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Bend hydraulic diameter (m)
D_0	Bend internal diameter (m)
F_0	Cross-sectional area (m^2)
l	Total length measured along the axis (m)
l_{el}	Straight length between bends (m)
R_0	Radius of curvature (m)
δ	Curvature angle of each bend (°)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()
k_Δ	Coefficient that allows for the effect of the roughness ()
k_{Re}	Coefficient that allows for the effect of the Reynolds number ()
A1	Coefficient that allows for the effect of the angle ()
B1	Coefficient that allows for the effect of the relative curvature radius ()
C1	Coefficient that allows for the effect of the relative elongation of the cross section ()
A2	Reynolds number correction factor that depends on the relative curvature radius ()
ζ'_{loc}	Coefficient of local resistance ()
λ_{el}	Total friction factor with smooth wall ()
λ	Darcy friction coefficient ()

ζ_{fr}	Pressure loss friction factor ()
A	Coefficient of correction ()
ζ	Total pressure loss coefficient (based on the mean velocity in the bend) ()
L_{eq}	Straight length of equivalent pressure loss (m)
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m³)
ν	Fluid kinematic viscosity (m²/s)
g	Gravitational acceleration (m/s²)

Validity range:

- stabilized flow upstream bend
- length of the straight section downstream: $\geq 10\ D_0$
- relative radius of curvature: greater than or equal to 1 ($R_0/D_0 \geq 1$)
- curvature angle of one bend: 0 to 180°

for 'δ' angles less than 60° the pressure loss coefficient 'ζ' is estimated by taking into account an interaction correction factor 'A' corresponding to that of an angle of 60°.

for 'δ' angles greater than 90° the pressure loss coefficient 'ζ' is estimated by taking into account an interaction correction factor 'A' corresponding to that of an angle of 90°.

■ case of relative radius of curvature lower than 3 ($R_0/D_0 < 3$)

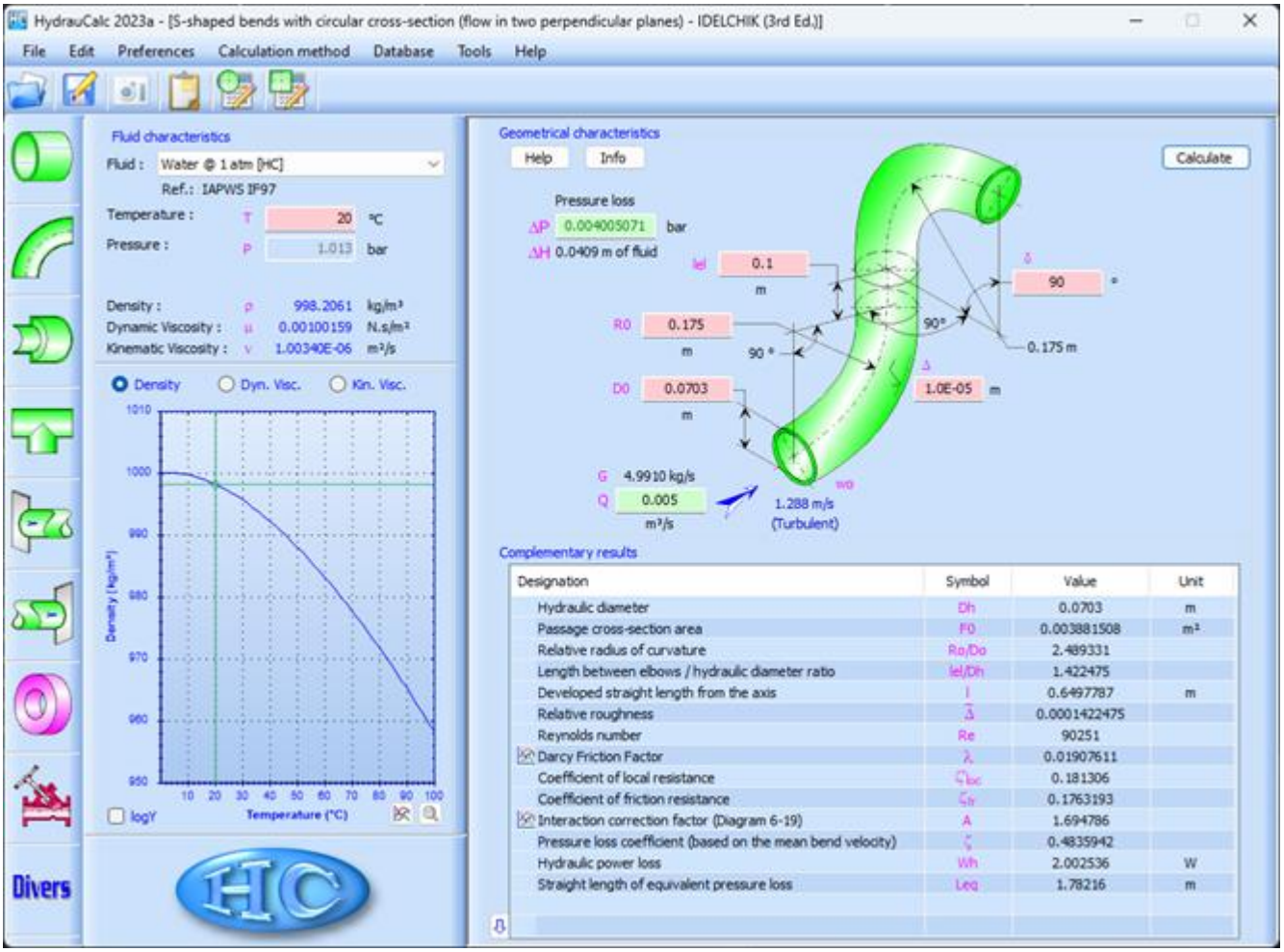
- flow regime: $Re \geq 3 \cdot 10^3$

■ case of relative radius of curvature greater than or equal to 3 ($R_0/D_0 \geq 3$)

- flow regime: $Re \geq 400$

  for Reynolds number 'Re' lower than 400 the coefficient 'λ_{el}' is linearly extrapolated.

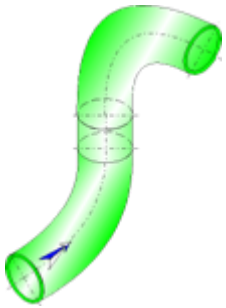
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.2.11.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) of S-shaped bends (with flow in two perpendicular planes) whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the first bend.

An option allows to take into account the effect of the straight length at the exit of the second bend.

Model formulation:

Hydraulic diameter (m):

$$D = d$$

Cross-section area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Total length measured along the axis (m):

$$L = 2 \cdot \left(2 \cdot \pi \cdot r \cdot \frac{\theta_b}{360} \right) + L_s$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

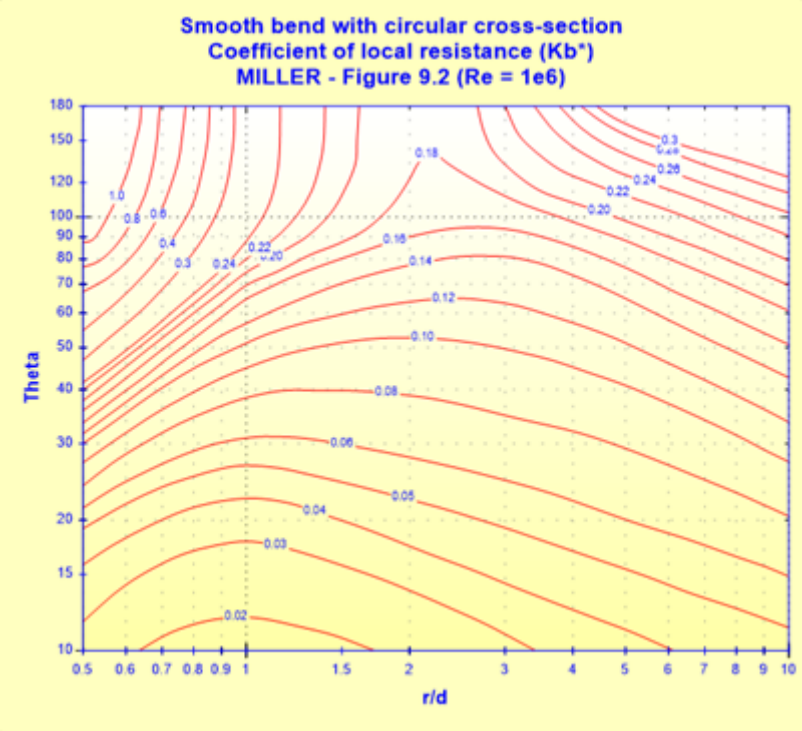
$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

Basic resistance coefficient for one bend:

$$K_b^* = f\left(\frac{r}{d}, \theta_b \right)$$ ([1] figure 9.2)



Reynolds number correction factor:

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$

([1] figure 9.3)

■ $r/d \geq 1$

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3)

- r/d < 1
  - r/d > 0.7 or K_b^* < 0.4

    $$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3 with r/d=1)

  - otherwise (r/d ≤ 0.7 and K_b^* ≥ 0.4)

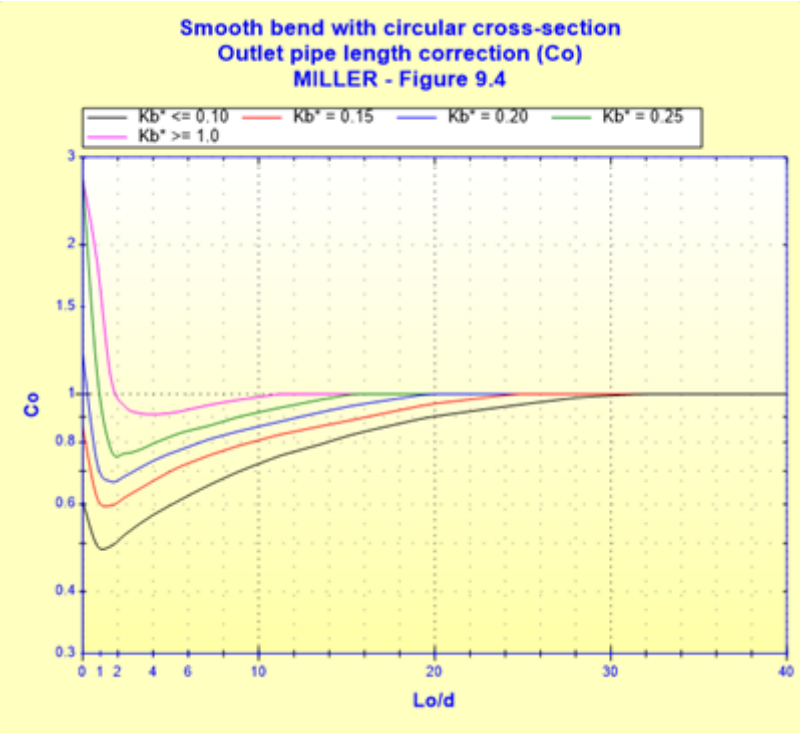
    $$C_{Re} = \frac{K_b^*}{K_b^* - 0.2C'_{Re} + 0.2}$$ ([1] equation 9.2)

    with:

    $$C'_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3 with r/d=1)

Outlet pipe length correction factor (optional):

$$C_o = f\left(\frac{L_o}{d}, K_b^*\right)$$ ([1] figure 9.4)



- r/d < 3 et θ_b < 100°

$$C_o = f\left(\frac{L_o}{d}, K_b^*\right)$$ ([1] figure 9.4)

■ otherwise (r/d > 3 and/or θ_b > 100°)

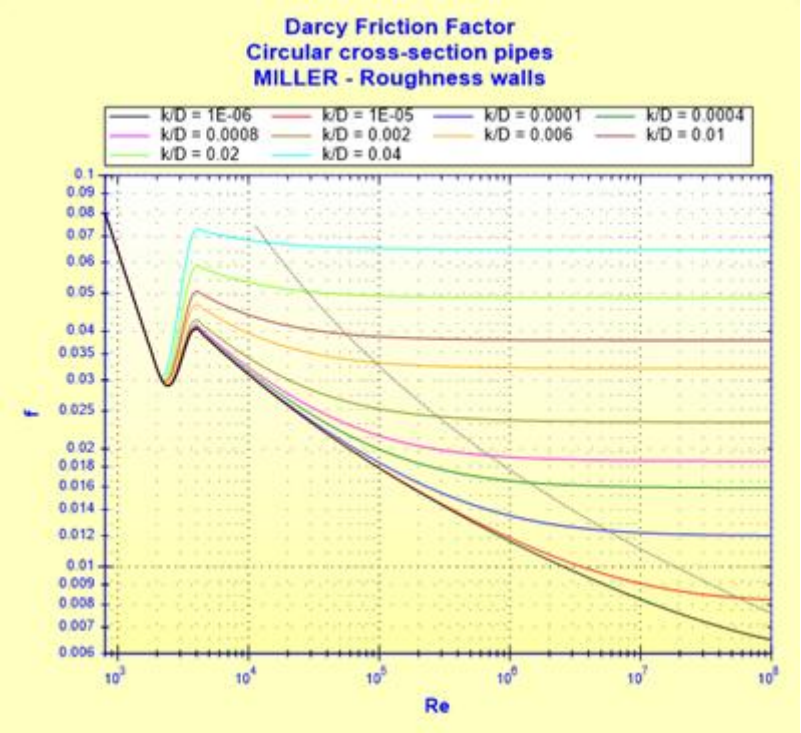
$$C_o = 1$$ (negligible effect)

If this option is not activated, the factor C_o is equal to unity.

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{D}\right)$$

See Straight Pipe - Circular Cross-Section and Roughness Walls (MILLER)



Roughness correction factor:

$$C_f = \frac{f_{rough}}{f_{smooth}}$$ ([1] equation 9.3)

with:

f_{rough}: Darcy friction factor for rough pipe at Re

f_{smooth}: Darcy friction factor for smooth pipe (k = 0) at Re

For Re > 10^6, C_f is calculated from equation (9.3) for Re = 10^6

Corrected loss coefficient for the first bend:

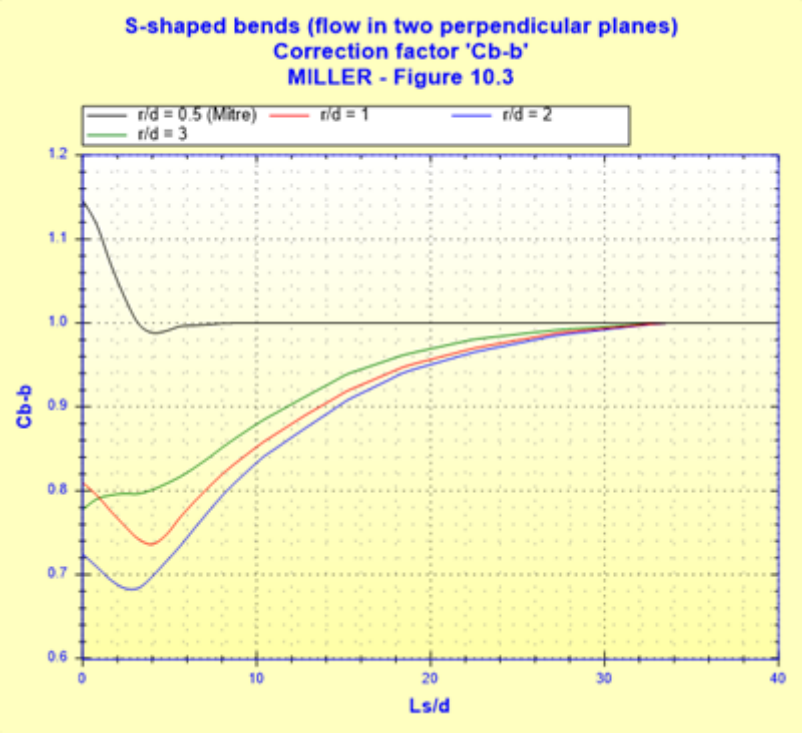
$$K_{b1} = K_b^* \cdot C_{Re} \cdot C_f$$ ([1] equation 9.4)

Corrected loss coefficient for the second bend:

$$K_{b2} = K_b^* \cdot C_{Re} \cdot C_f \cdot C_o$$ ([1] equation 9.4)

Interaction correction factor:

$$C_{b-b} = f\left(\frac{L_s}{d}, \frac{r}{d}\right)$$ ([1] figure 10.3)



Pressure loss coefficient of the two bends:

$$K_{b-b} = (K_{b1} + K_{b2}) \cdot C_{b-b}$$ ([1] equation 10.1)

Friction loss coefficient of the straight length between bends:

$$K_f = f \cdot \frac{L_s}{d}$$ ([1] equation 8.3)

Total pressure loss coefficient (based on the mean velocity in the bend):

$$K = K_{b-b} + K_f$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{d}{f}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Bend hydraulic diameter (m)
d	Bend internal diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
L_s	Straight length between the two bends (m)
L	Total length measured along the axis (m)

r	Radius of curvature (m)
θ_b	Curvature angle of each bend (°)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
K_b^*	Basic loss coefficient of one bend ()
C_{Re}	Reynolds number correction factor ()
C_o	Outlet pipe length correction factor ()
L_0	Length of the straight section downstream of the bend (m)
f	Darcy friction factor ()
k	Absolute roughness of walls (m)
C_f	Roughness correction factor ()
K_{b1}	Corrected loss coefficient for the first bend ()
K_{b2}	Corrected loss coefficient for the second bend ()
C_{b-b}	Interaction correction factor ()
K_{b-b}	Pressure loss coefficient of the two bends ()
K_f	Friction loss coefficient of the straight length between bends ()
K	Total pressure loss coefficient (based on the mean velocity in the bend) ()
L_{eq}	Straight length of equivalent pressure loss (m)
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream bend
- relative radius of curvature 'r/d': greater than or egal to 0.5 and lower than or egal to 10

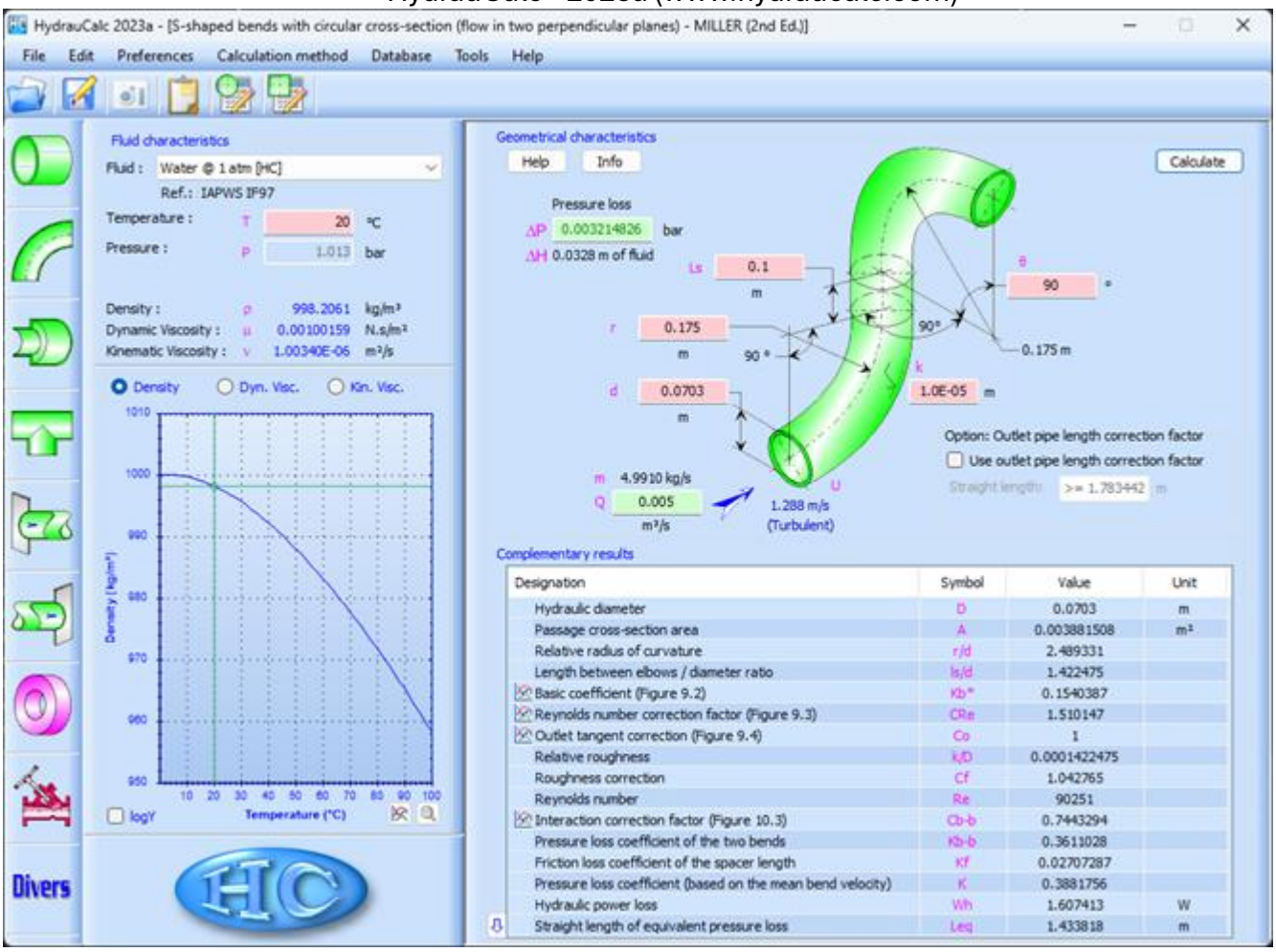
  for relative radius of curvature 'r/d' greater than 3, the pressure loss coefficient 'K' is estimated by taking into account the interaction correction factor 'Cb-b' corresponding to a relative radius of curvature 'r/d' of value 3.

- curvature angle: between 10° and 180°

  the interaction correction factor 'Cb-b' is applicable for angles 'θ_b' between 70° and 90°.

  for angles 'θ_b' less than 70° or greater than 90°, the pressure loss coefficient 'K' is estimated by taking into account the interaction factor coefficient 'Cb-b' applicable to angles 'θ_b' between 70° and 90°

Example of application:



References:

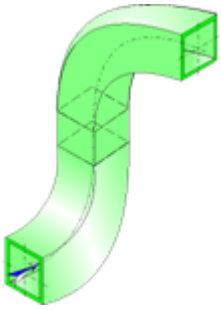
[1] Internal Flow System, Second Edition, D.S. Miller

2.2.12 S-shaped bends (2 planes) - Rectangular cross-section

S-shaped Bends

(with flow in two perpendicular planes)

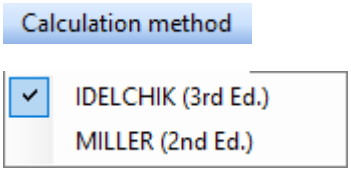
Rectangular Cross-Section



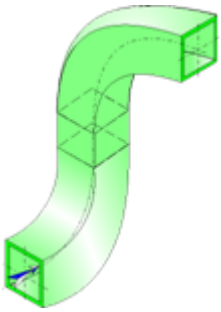
For the calculation of the pressure loss coefficient of S-shaped bends with rectangular cross-section (with flow in two perpendicular planes), the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.2.12.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) of S-shaped bends (with flow in two perpendicular planes) whose cross-section is rectangular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the first bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = \frac{2 \cdot a_0 \cdot b_0}{a_0 + b_0}$$ ([1] diagram 6-1)

Cross-section area (m^2):

$$F_0 = a_0 \cdot b_0$$

Total length measured along the axis (m):

$$l = 2 \cdot \left(2 \cdot \pi \cdot R_0 \cdot \frac{\delta}{360} \right) + l_{el}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = F_0 \cdot l$$

Fluid mass (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\overline{\Delta} = \frac{\Delta}{D_h}$$

■ Case of relative radius of curvature lower than 3 ($R_0/b_0 < 3$) ([1] diagram 6-1)

Coefficient of effect of the roughness:

$$k_\Delta = f\left(\frac{R_0}{b_0}, Re, \overline{\Delta}\right)$$ ([1] diagram 6-1)

● $0.50 \leq R_0/b_0 \leq 0.55$

$\overline{\Delta}$	Re	
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$
0	1.0	1.0
0 - 0.001	1.0	$1 + 0.5 \cdot 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	1.5

- $R_0/b_0 > 0.55$

$\overline{\Delta}$	Re		
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$ - $2 \cdot 10^5$	> $2 \cdot 10^5$
0	1.0	1.0	1.0
0 - 0.001	1.0	$\lambda_\Delta / \lambda_{sm}$	$1 + 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	2.0	2.0

with:

λ_{sm} : Darcy friction factor for hydraulically smooth pipe ($\overline{\Delta} = 0$) at Re

λ_Δ : Darcy friction factor for rough pipe ($\overline{\Delta} = \Delta/D_h$) at Re

---

Coefficient of effect of the Reynolds number ($Re \geq 10^4$):

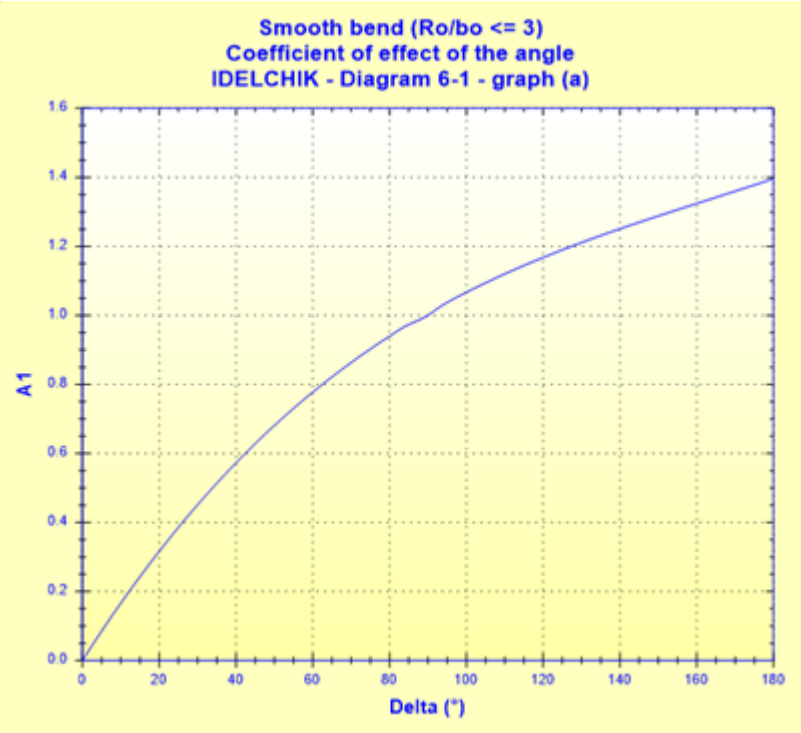
$$k_{Re} = f\left(\mathrm{Re}, \frac{R_0}{b_0}\right)$$

([1] diagram 6-1)

Coefficient of effect of the angle:

$$A1 = f(\delta)$$

([1] diagram 6-1)

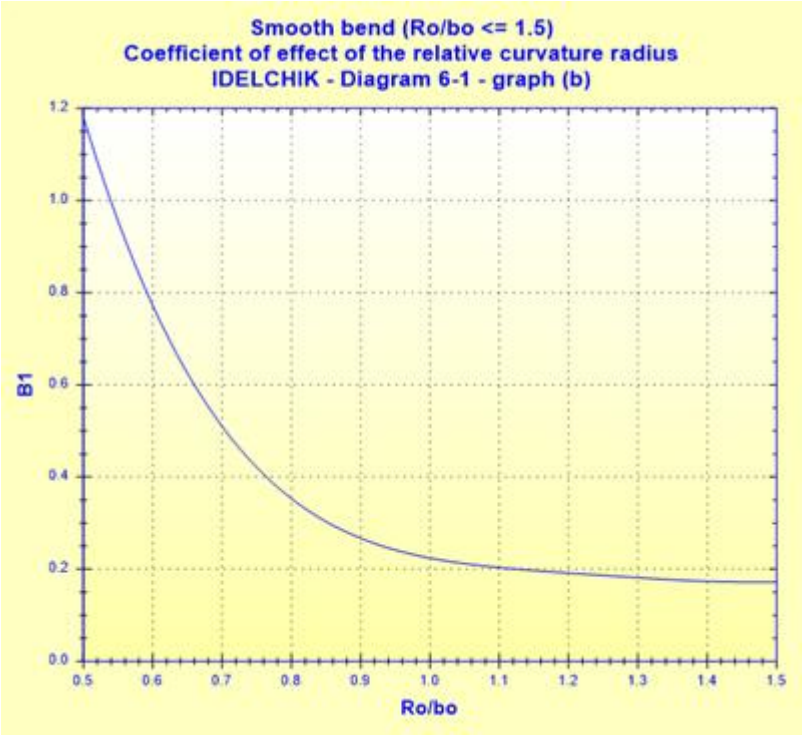


Coefficient of effect of the relative curvature radius:

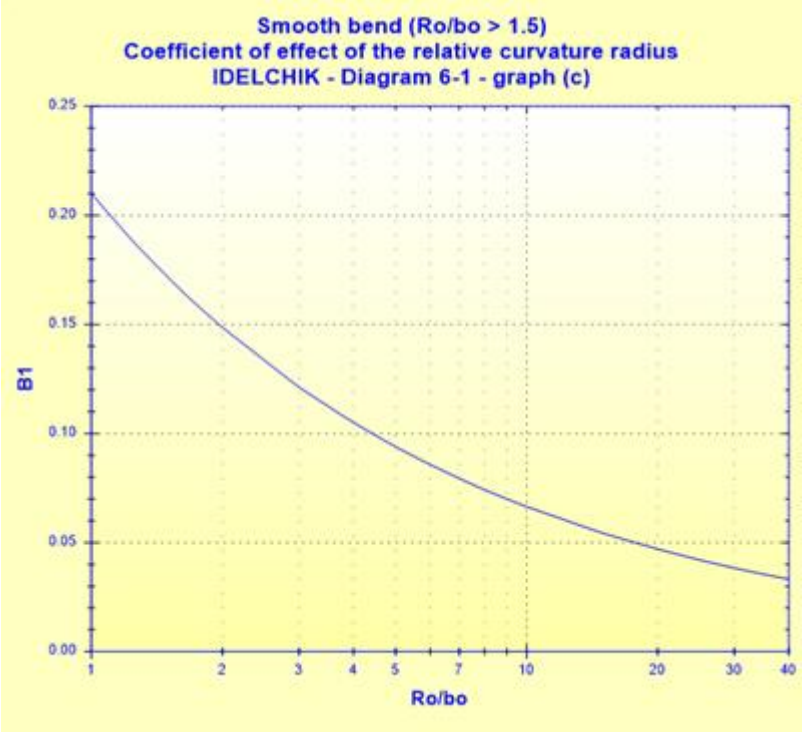
$$B1 = f\left(\frac{R_0}{b_0}\right)$$

([1] diagram 6-1)

- $0.5 \le R_0/b_0 \le 1.5$



- $R_0/b_0 > 1.5$



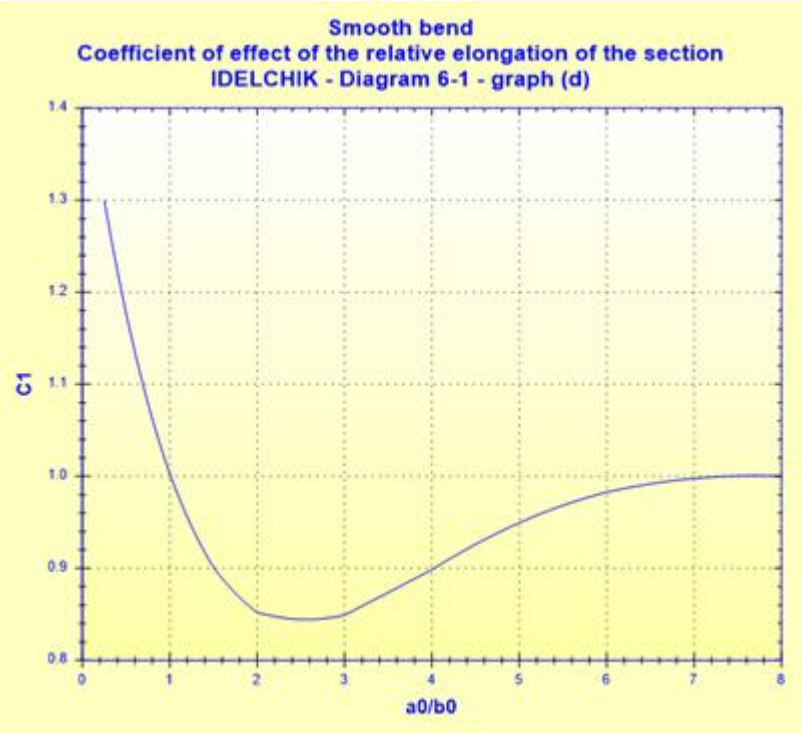
Coefficient of effect of the relative elongation of the cross section:

- $a_0 \geq b_0$

$$C1 = f\left(\frac{a_0}{b_0}\right)$$ ([1] diagram 6-1)

- $a_0 < b_0$

$$C1 = f\left(\frac{b_0}{a_0}\right)$$ ([1] diagram 6-1)

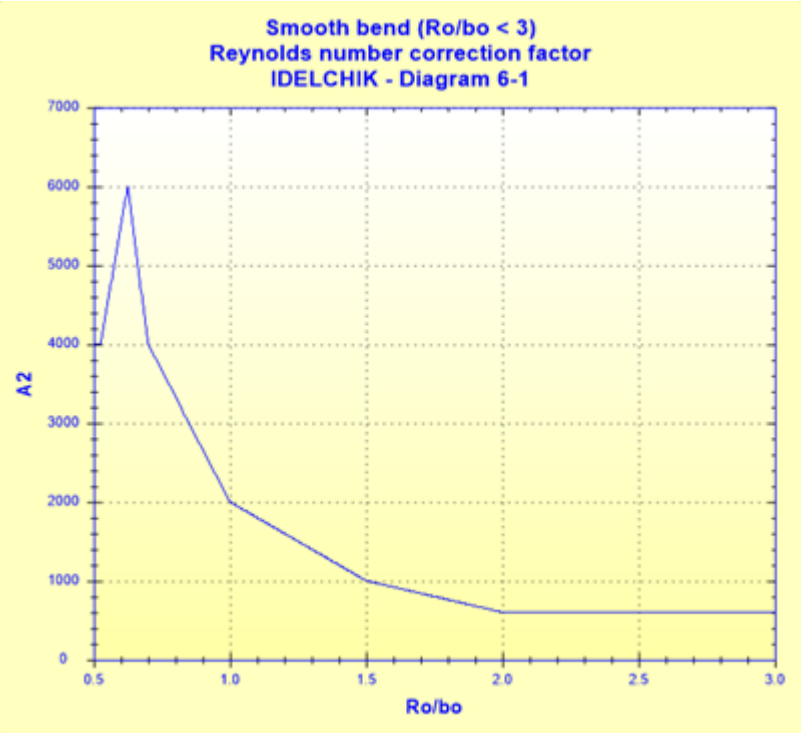


Reynolds number correction factor that depends on the relative curvature radius:

$$A2 = f\left(\frac{R_0}{b_0}\right)$$

([1] diagram 6-1)

R_0/b_0	0.50 - 0.55	>0.55 - 0.70	>0.70 - 1.0	>1.0 - 2.0	>2.0
$A2 \times 10^{-3}$	4.0	6.0	4.0 - 2.0	1.0	0.6



Pressure loss coefficient (without friction):

- $Re \geq 10^4$

$$\zeta'_{loc} = k_{\Delta} \cdot k_{Re} \cdot A1 \cdot B1 \cdot C1$$ ([1] diagram 6-1)

- $3 \cdot 10^3 < Re < 10^4$

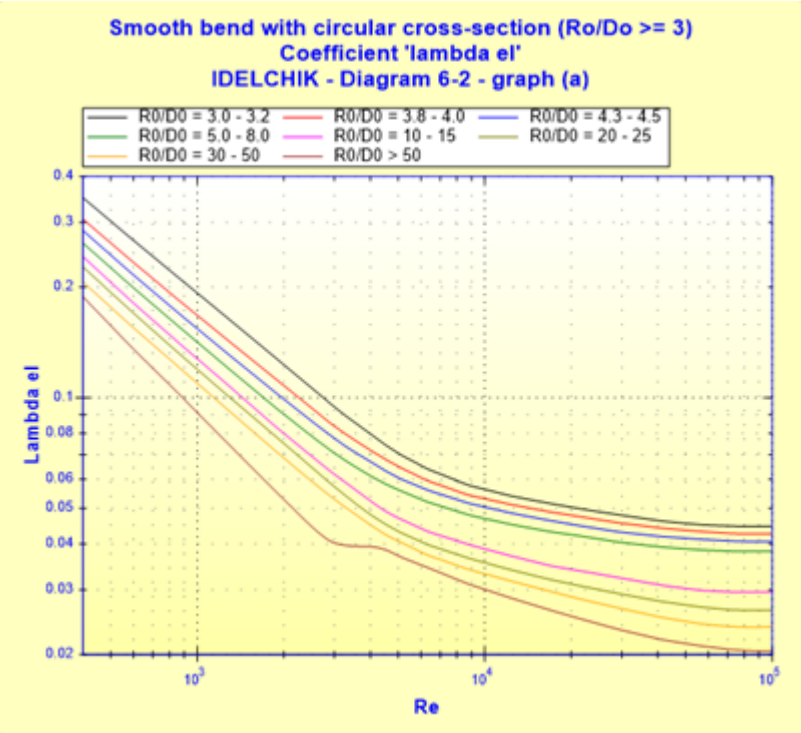
$$\zeta'_{loc} = \frac{A2}{Re} + A1 \cdot B1 \cdot C1$$ ([1] diagram 6-1)

■ Case of relative radius of curvature greater than or equal to 3 ($R_0/b_0 \geq 3$) ([1] diagram 6-2)

Total friction factor with smooth wall:

- $4 \cdot 10^2 \leq Re < 10^5$

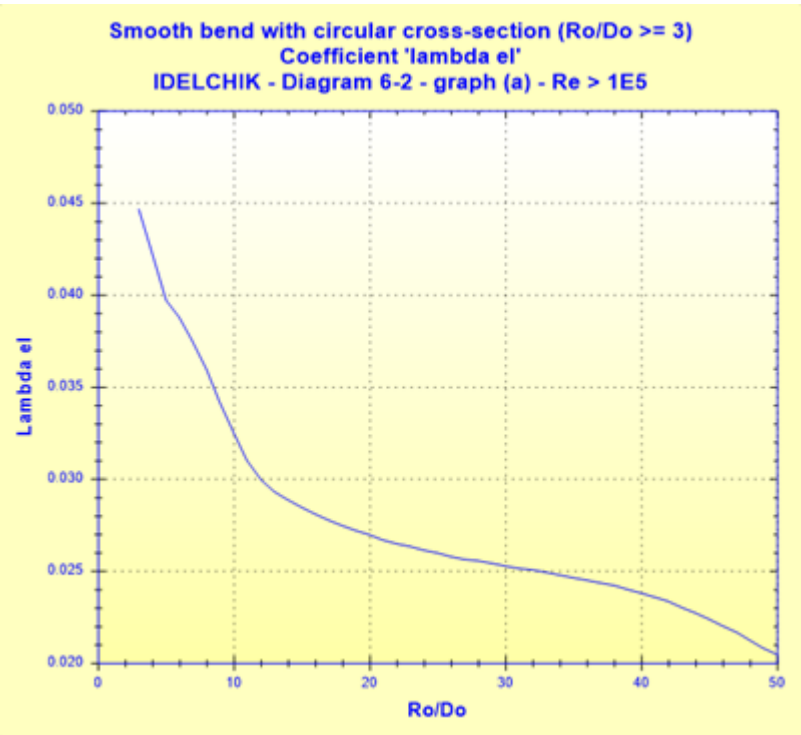
$$\lambda_{el} = f\left(Re, \frac{R_0}{D_0}\right)$$ ([1] diagram 6-2)



- Re ≥ 10^5

$$\lambda_{el} = f\left(\frac{R_0}{D_0}\right)$$

([1] diagramme 6-2)



Estimation of the coefficient of local resistance

$$\zeta'_{loc} = (\lambda_{el} - \lambda_s) \cdot \frac{2 \cdot \pi \cdot R_0 \cdot \delta / 360}{D_h}$$

with:

λ_s : Darcy friction factor for hydraulically smooth pipe ($\bar{\Delta} = 0$) at Re

---

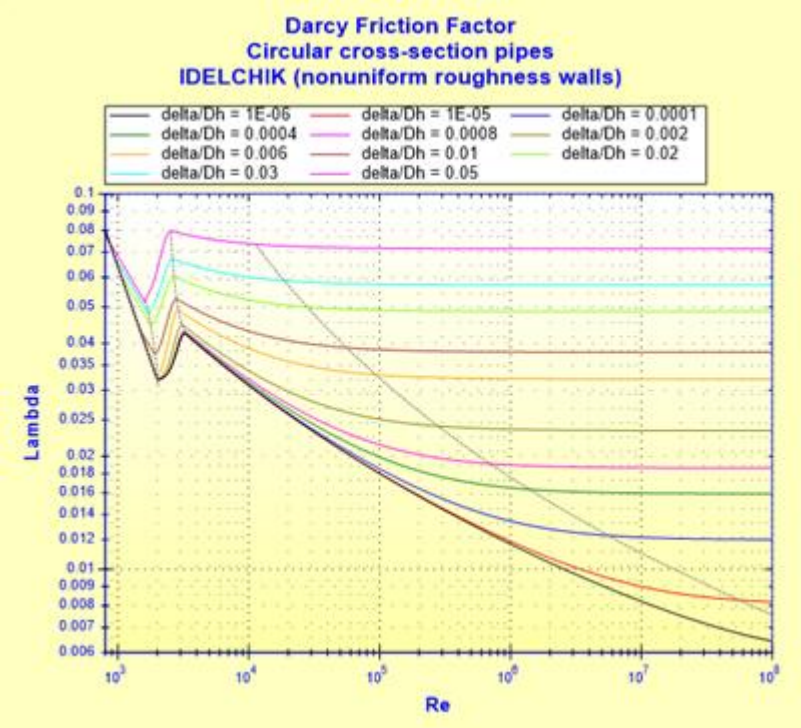
■ Case of the S-shaped Bends ([1] diagram 6-19)

Darcy friction factor:

See Straight Pipe - Rectangular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)

■ Darcy friction factor for circular cross-section

$$\lambda_{circ} = f\left(\mathrm{Re}, \frac{\Delta}{D_h}\right)$$



■ Correction for Darcy friction factor for noncircular cross-section

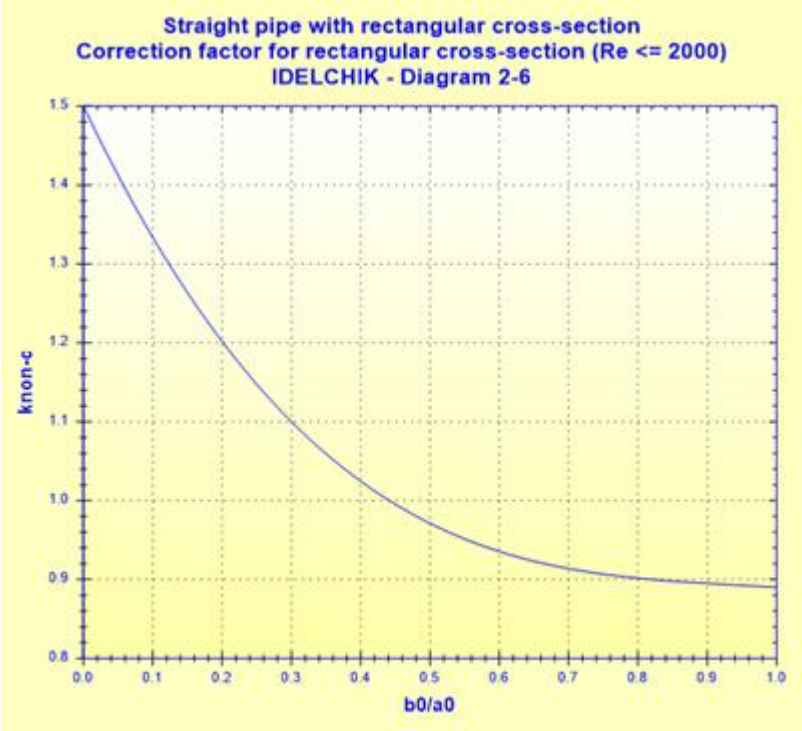
♦ $a_0 \geq b_0$

$$k_{non-c} = f(b_0/a_0)$$ ([1] diagram 2-6)

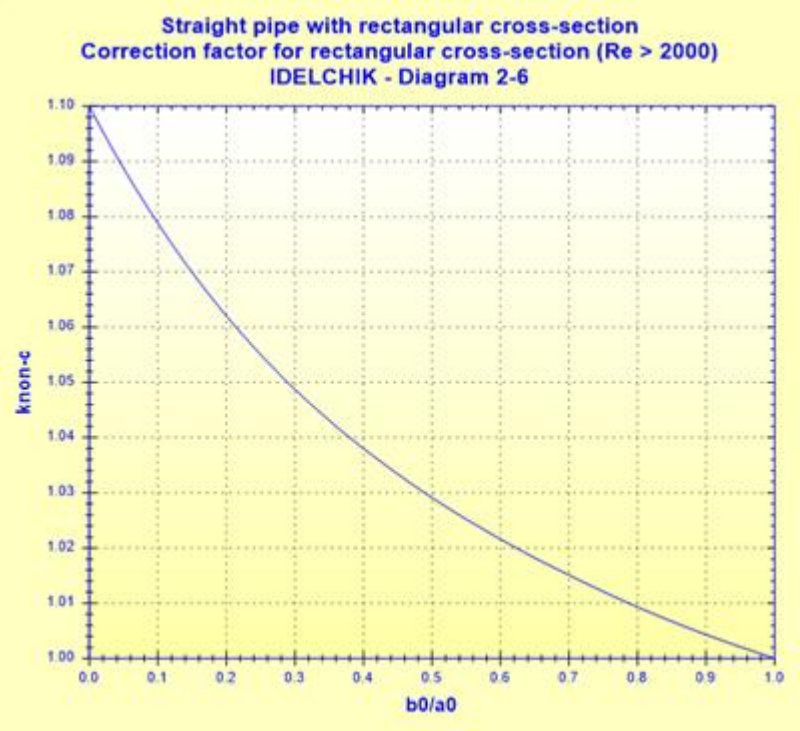
♦ $a_0 < b_0$

$$k_{non-c} = f(a_0/b_0)$$ ([1] diagram 2-6)

- laminar flow (Re ≤ 2000):



- turbulent flow (Re > 2000):



■ Darcy friction factor for rectangular cross-section

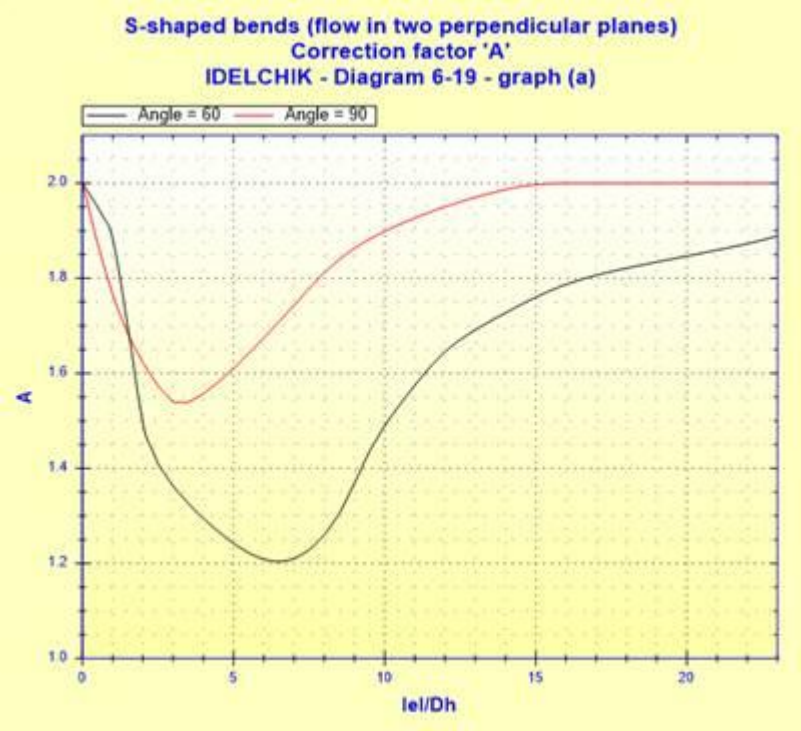
$$\lambda_{rect} = \lambda_{circ} \cdot k_{non-c}$$ ([1] diagram 2-6)

Pressure loss friction factor:

$$\zeta_{fr} = \lambda \cdot \left[2 \cdot \left(0.0175 \cdot \delta \cdot \frac{R_0}{D_h} \right) + \frac{l_{el}}{D_h} \right]$$ ([1] diagram 6-19)

Interaction correction factor:

$$A = f\left(\frac{L_{el}}{D_h}, \delta \right)$$ ([1] diagram 6-19 graph a)



Total pressure loss coefficient (based on the mean velocity in the bends):

$$\zeta = A \cdot \zeta'_{loc} + \zeta_{fr}$$ ([1] diagram 6-19)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$ ([1] diagram 6-19)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_h}{\lambda_{rect}}$$

Symbols, Definitions, SI Units:

a_0	Rectangular cross-section width (m)
b_0	Rectangular cross-section height (m)
D_h	Bend hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
l	Total length measured along the axis (m)
R_0	Radius of curvature (m)
δ	Curvature angle of each bend (°)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()
k_Δ	Coefficient that allows for the effect of the roughness ()
k_{Re}	Coefficient that allows for the effect of the Reynolds number ()
A1	Coefficient that allows for the effect of the angle ()
B1	Coefficient that allows for the effect of the relative curvature radius ()
C1	Coefficient that allows for the effect of the relative elongation of the cross section ()
A2	Reynolds number correction factor that depends on the relative curvature radius ()
ζ'_{loc}	Coefficient of local resistance ()
λ_{circ}	Darcy friction coefficient for circular cross-section ()
k_{non-c}	Correction for Darcy friction factor for noncircular cross-section ()

λ_{rect}	Darcy friction coefficient for rectangular cross-section ()
λ_{el}	Friction coefficient ()
ζ_{fr}	Pressure loss friction factor ()
A	Interaction correction factor ()
ζ	Total pressure loss coefficient (based on the mean velocity in the bend) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
L_{eq}	Straight length of equivalent pressure loss (m)
ρ	Fluid density (kg/m³)
ν	Fluid kinematic viscosity (m²/s)
g	Gravitational acceleration (m/s²)

Validity range:

- stabilized flow upstream bend
- length of the straight section downstream: $\geq 10\ D_h$
- relative radius of curvature: greater than or equal to 1 ($R_0/b_0 \geq 1$)
- curvature angle of one bend: 0 to 180°

for 'δ' angles less than 60° the pressure loss coefficient 'ζ' is estimated by taking into account an interaction correction factor '*A*' corresponding to that of an angle of 60°.

for 'δ' angles greater than 90° the pressure loss coefficient 'ζ' is estimated by taking into account an interaction correction factor '*A*' corresponding to that of an angle of 90°.

■ case of relative radius of curvature lower than 3 ($R_0/b_0 < 3$)

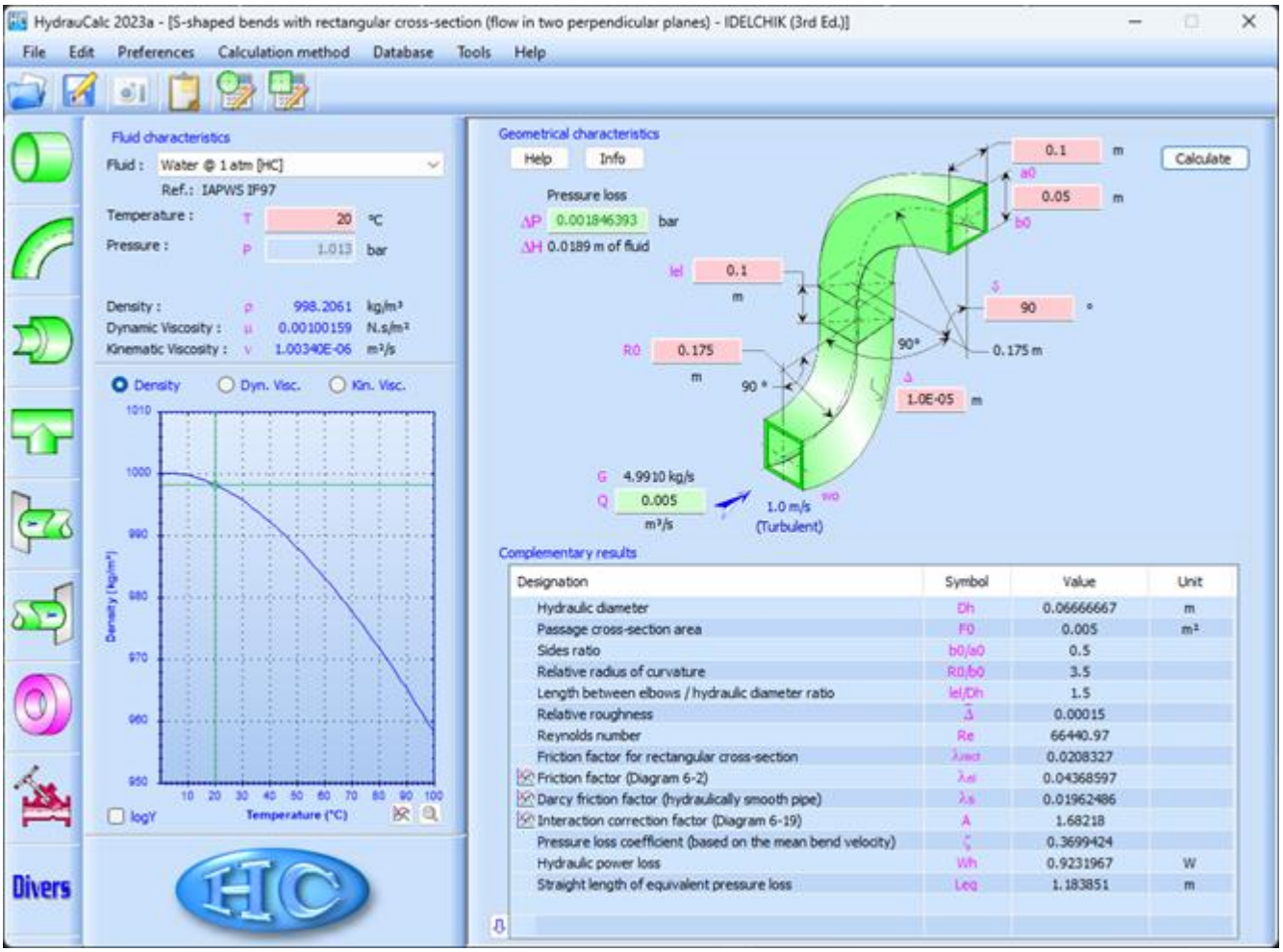
- flow regime: $Re \geq 3 \cdot 10^3$

■ case of relative radius of curvature greater than or equal to 3 ($R_0/b_0 \geq 3$)

- flow regime: $500 \leq Re \leq 38 \cdot 10^3$

for Reynolds number 'Re' lower than 500 or greater than $38 \cdot 10^3$, the coefficient 'λ_{el}' is linearly extrapolated.

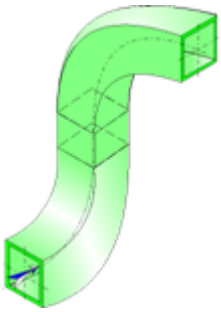
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.2.12.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) of S-shaped bends (with flow in two perpendicular planes) whose cross-section is rectangular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the first bend.

An option allows to take into account the effect of the straight length at the exit of the second bend.

Model formulation:

Hydraulic diameter (m):

$$D = \frac{2 \cdot b \cdot W}{b + W}$$ ([1] equation 9.5)

Cross-section area (m^2):

$$A = b \cdot W$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Total length measured along the axis (m):

$$L = 2 \cdot \left(2 \cdot \pi \cdot r \cdot \frac{\theta_b}{360} \right) + L_s$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

$$M = V \cdot \rho$$

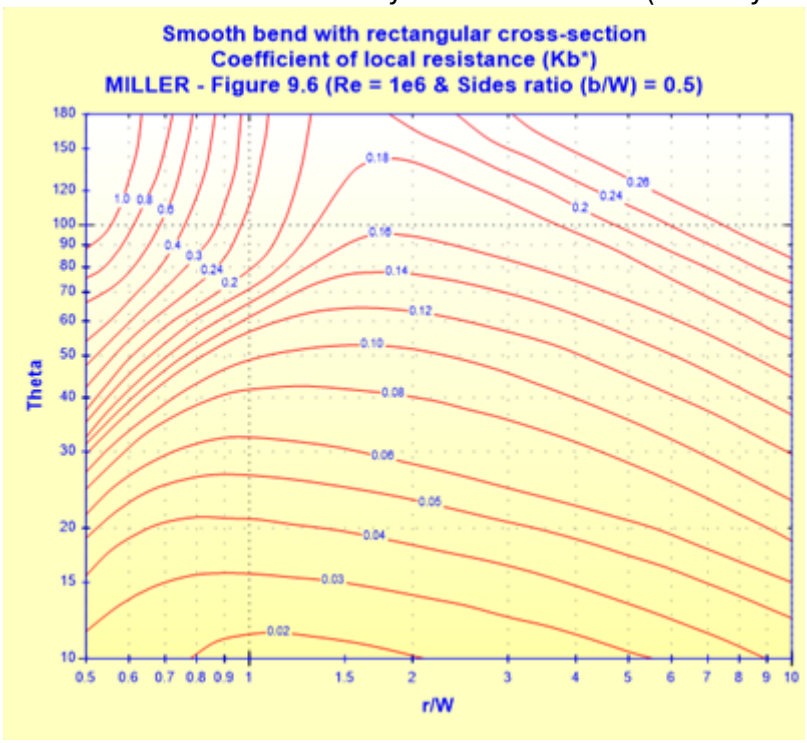
Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$ ([1] equation 9.6)

Basic resistance coefficient:

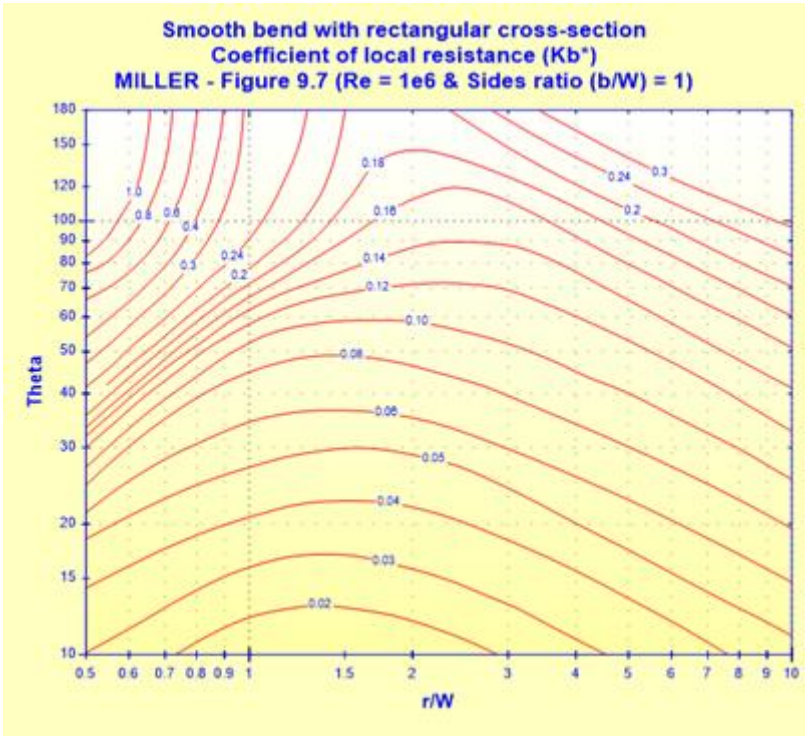
$$K_b^* = f\left(\frac{r}{W}, \theta_b \right)$$ ([1] figures 9.6 – 9.7 – 9.8)

- Sides ratio b/W = 0.5



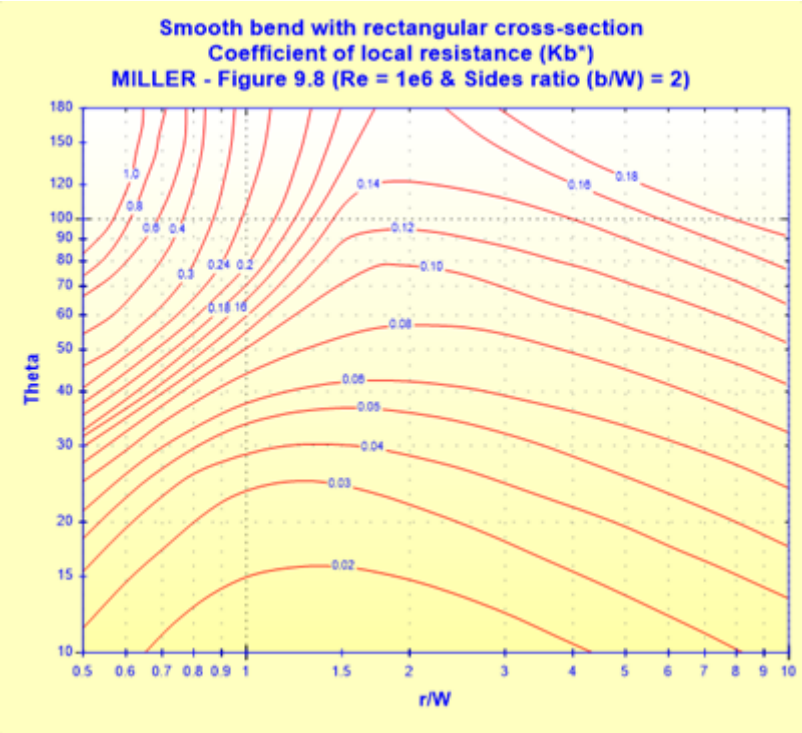
([1] figure 9.6)

■ Sides ratio b/W = 1



([1] figure 9.7)

■ Sides ratio b/W = 2



([1] figure 9.8)

For any sides ratio 'b/W' between 0.5 and 2, the coefficient K_b^* is obtained by curvilinear interpolation between the values of K_b^* calculated for aspect ratios of 0.5, 1 and 2.

Reynolds number correction factor:

$$C_{Re} = f\left(Re, \frac{r}{W}\right)$$

([1] figure 9.3)

- $r/W \geq 1$

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{D}\right)$$ ([1] figure 9.3)

- $r/W < 1$
  - $r/W > 0.7$ or $K_b^* < 0.4$

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{D}\right)$$ ([1] figure 9.3 with r/W=1)

  - otherwise ($r/W \leq 0.7$ and $K_b^* \geq 0.4$)

$$C_{Re} = \frac{K_b^*}{K_b^* - 0.2C'_{Re} + 0.2}$$ ([1] equation 9.2)

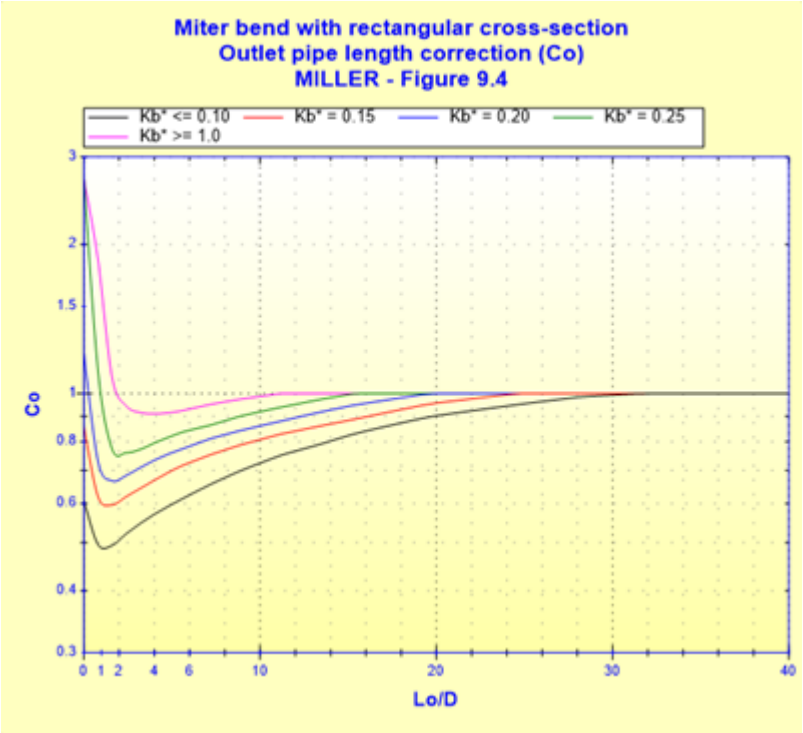
with:

$$C'_{Re} = f\left(\mathrm{Re}, \frac{r}{D}\right)$$ ([1] figure 9.3 with r/W=1)

Outlet pipe length correction factor (optional):

- correction factor for circular cross-section
  - $\theta_b < 100°$

$$C_o = f\left(\frac{L_o}{D}, K_b^*\right)$$ ([1] figure 9.4)



- $\theta_b \geq 100°$

$$C_o = 1$$ (negligible effect)

■ correction factor for rectangular cross-section

- b/W < 0.7 and Lo/D > 1

$$C_{or} = 1 - \frac{1 - C_o}{2}$$

- b/W > 1 and Lo/D < 1
  - ♦ 1.5 < r/W < 3

$$C_{or} = 2$$

  - ♦ r/W ≤ 1.5 or r/W ≥ 3

$$C_{or} = C_o$$

- otherwise

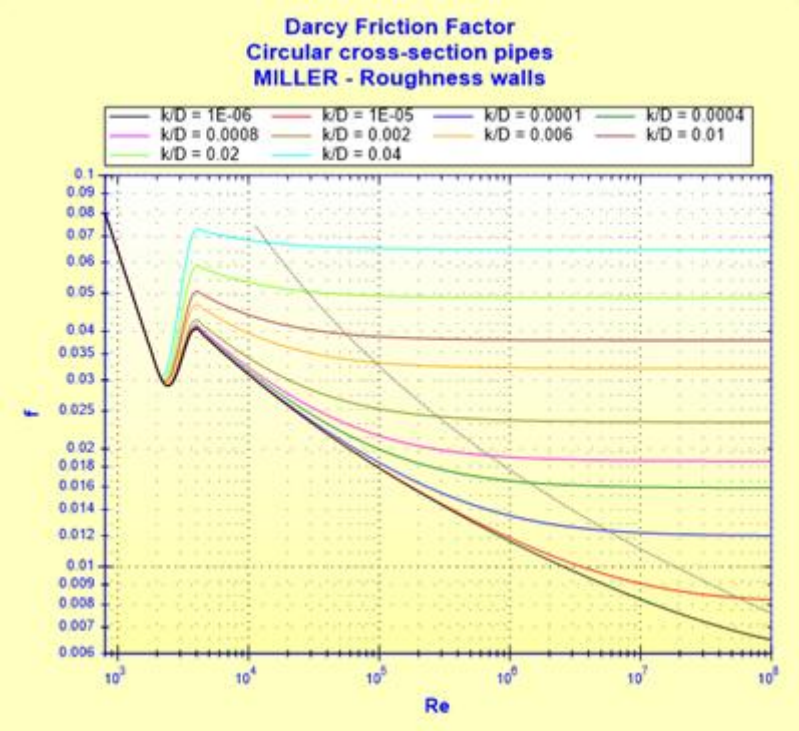
$$C_{or} = C_o$$

If this option is not activated, the factors C_o and C_{or} are equal to unity.

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{D}\right)$$

See Straight Pipe - Rectangular Cross-Section and Roughness Walls (MILLER)



Roughness correction factor:

$$C_f = \frac{f_{rough}}{f_{smooth}}$$ ([1] equation 9.3)

with:

f_{rough}: Darcy friction factor for rough pipe at Re

f_{smooth}: Darcy friction factor for smooth pipe (k = 0) at Re

For Re > 10^6, C_f is calculated from equation (9.3) for Re = 10^6

Corrected loss coefficient for the first bend:

$$K_{b1} = K_b^* \cdot C_{Re} \cdot C_f$$ ([1] equation 9.4)

Corrected loss coefficient for the second bend:

$$K_{b2} = K_b^{\circ} \cdot C_{Re} \cdot C_f \cdot C_o$$

([1] equation 9.4)

Interaction correction factor:

$$C_{b-c} = f\left(\frac{L_s}{D}, \frac{r}{D}\right)$$

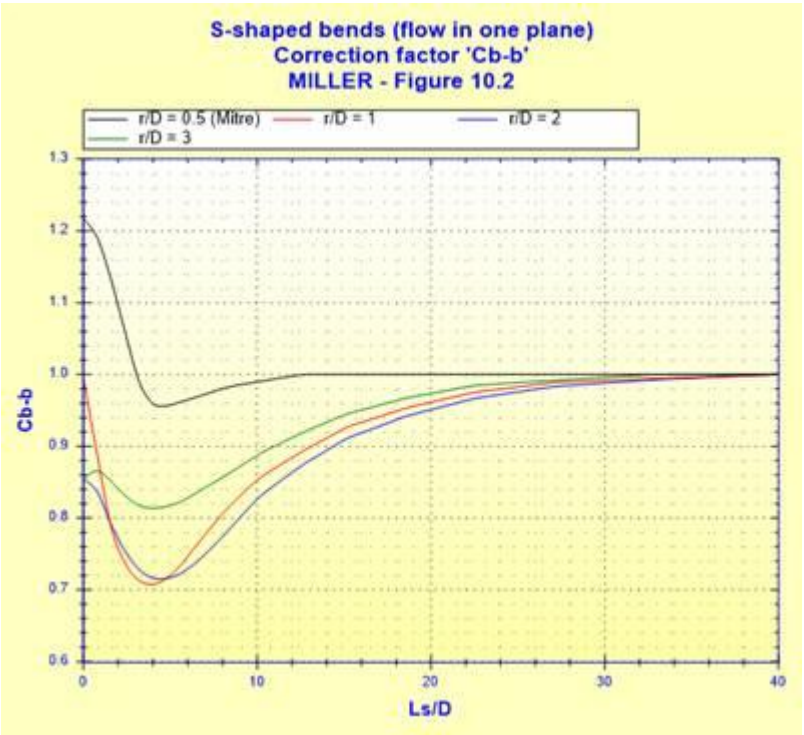
- Aspect ratio b/W < 0.7

([1] figure 10.4)

- Aspect ratio 0.7 ≤ b/W ≤ 1.5

([1] figure 10.3)

- Aspect ratio b/W > 1.5



([1] figure 10.2)

Pressure loss coefficient of the two bends:

- Aspect ratio b/W < 0.7

$$K_{b-b} = (K_{b1} + K_{b2}) \cdot \left[1 - \frac{1 - C_{b-b}}{2}\right]$$

([1] equation 10.1 with correction factor § 10.4)

- Aspect ratio b/W ≥ 0.7

$$K_{b-b} = (K_{b1} + K_{b2}) \cdot C_{b-b}$$

([1] equation 10.1)

Friction loss coefficient of the straight length between bends:

$$K_f = f_{rough} \cdot \frac{L_s}{D}$$

([1] equation 8.3)

Total pressure loss coefficient (based on the mean velocity in the bend):

$$K = K_{b-b} + K_f$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{D}{f_{rough}}$$

Symbols, Definitions, SI Units:

W	Cross-section height (m)
b	Cross-section width (m)

D	Bend hydraulic diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
L_s	Straight length between the two bends (m)
L	Total length measured along the axis (m)
r	Radius of curvature (m)
θ_b	Curvature angle of each bend (°)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
K_b^*	Basic loss coefficient ()
C_{Re}	Reynolds number correction factor ()
C_o	Outlet pipe length correction factor for circular cross-section ()
C_{or}	Outlet pipe length correction factor for rectangular cross-section ()
L_0	Length of the straight section downstream of the bend (m)
f	Darcy friction factor ()
k	Absolute roughness of walls (m)
C_f	Roughness correction factor ()
K_{b1}	Corrected loss coefficient for the first bend ()
K_{b2}	Corrected loss coefficient for the second bend ()
$C_{b\text{-}b}$	Interaction correction factor ()
$K_{b\text{-}b}$	Pressure loss coefficient of the two bends ()
K_f	Friction loss coefficient of the straight length between bends ()
K	Total pressure loss coefficient (based on the mean velocity in the bend) ()
ΔP	Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

L_{eq} Straight length of equivalent pressure loss (m)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream bend
- radius of curvature / hydraulic diameter ratio 'r/D': greater than or egal to 0.5 and lower than or egal to 10

  for ratio 'r/D' greater than 3, the pressure loss coefficient 'K' is estimated by taking into account the interaction correction factor 'Cb-b' corresponding to a ratio 'r/D' of value 3.

- curvature angle: between 10° and 180°

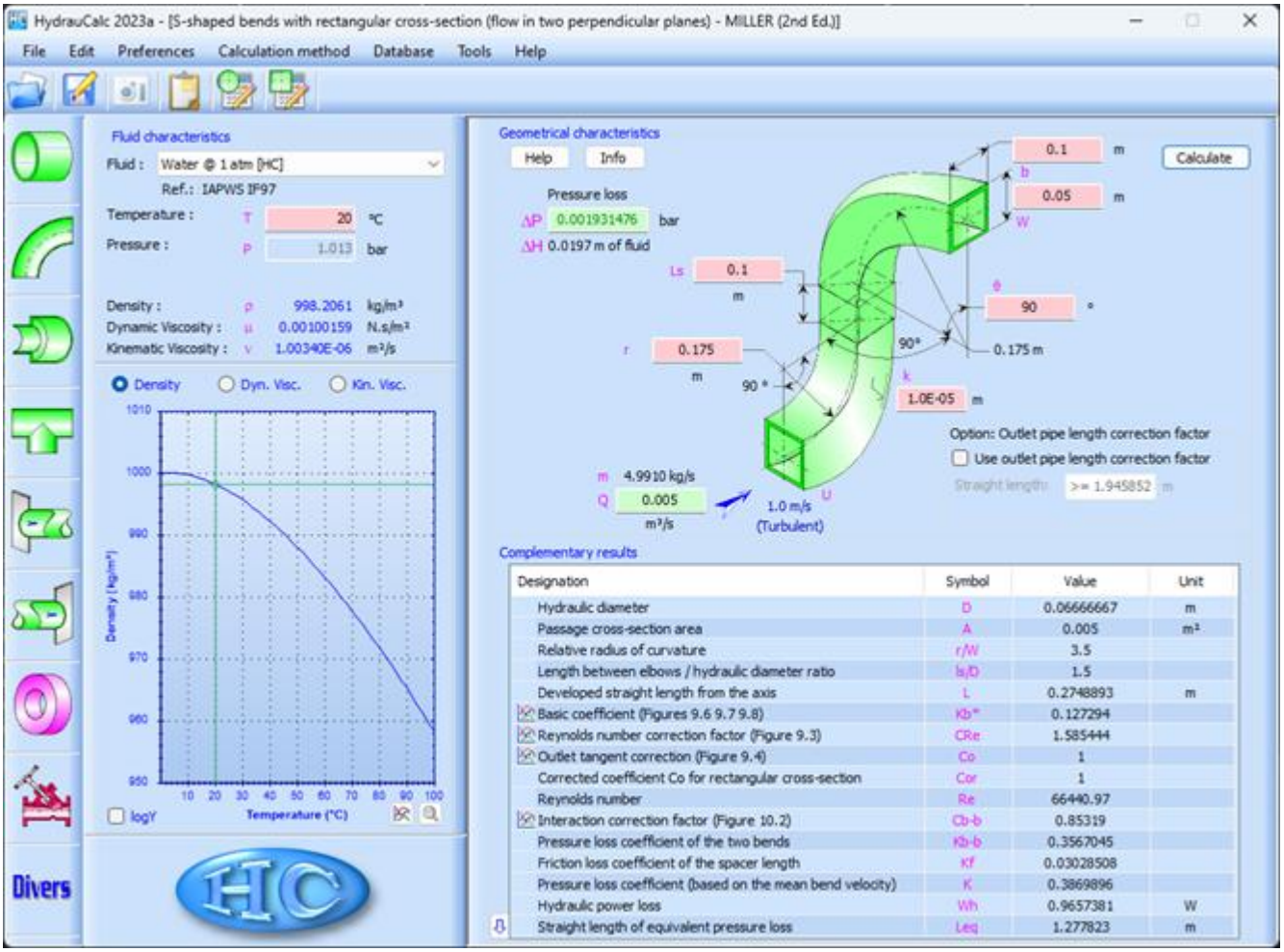
  the interaction correction factor 'Cb-b' is applicable for angles 'θ_b' between 70° and 90°.

  for angles 'θ_b' less than 70° or greater than 90°, the pressure loss coefficient 'K' is estimated by taking into account the interaction factor coefficient 'Cb-b' applicable to angles 'θ_b' between 70° and 90°

- relative radius of curvature 'r/W': between 0.5 and 10
- sides ratio 'b/W': between 0.5 and 2

  note: for any sides ratio 'b/W' less than 0.5, the resistance coefficients K_b^* are obtained by linear extrapolation from the values of K_b^* calculated for sides ratios of 0.5 and 1.
  for any sides ratio 'b/W' greater than 0.5 and 2, the resistance coefficients K_b^* are obtained by linear extrapolation from the values of K_b^* calculated for sides ratios of 1 and 2.

Example of application:



References:

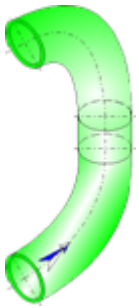
[1] Internal Flow System, Second Edition, D.S. Miller

2.2.13 U-shaped bends (1 plane) - Circular cross-section

U-shaped Bends

(with flow in one plane)

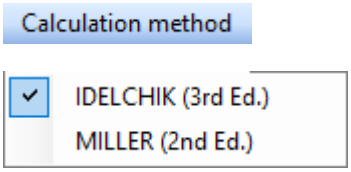
Circular Cross-Section



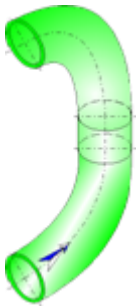
For the calculation of the pressure loss coefficient of U-shaped bends with circular cross-section (with flow in one plane), the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.2.13.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) of U-shaped bends (with flow in one plane) whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized at the entrance bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Total length measured along the axis (m):

$$l = 2 \cdot \left(2 \cdot \pi \cdot R_0 \cdot \frac{\delta}{360} \right) + l_{el}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = F_0 \cdot l$$

Fluid mass (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\overline{\Delta} = \frac{\Delta}{D_h}$$

■ Case of a single bend of relative radius of curvature lower than 3 ($R_0/D_0 < 3$) ([1] diagram 6-1)

Coefficient of effect of the roughness:

$$k_\Delta = f\left(\frac{R_0}{D_0}, Re, \overline{\Delta}\right)$$ ([1] diagram 6-1)

- $0.50 \leq R_0/D_0 \leq 0.55$

$\overline{\Delta}$	Re	
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$
0	1.0	1.0
0 - 0.001	1.0	$1 + 0.5 \cdot 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	1.5

- $R_0/D_0 > 0.55$

$\overline{\Delta}$	Re		
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$ - $2 \cdot 10^5$	> $2 \cdot 10^5$
0	1.0	1.0	1.0
0 - 0.001	1.0	$\lambda_\Delta / \lambda_{sm}$	$1 + 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	2.0	2.0

with:

λ_{sm} : Darcy friction factor for hydraulically smooth pipe ($\overline{\Delta} = 0$) at Re

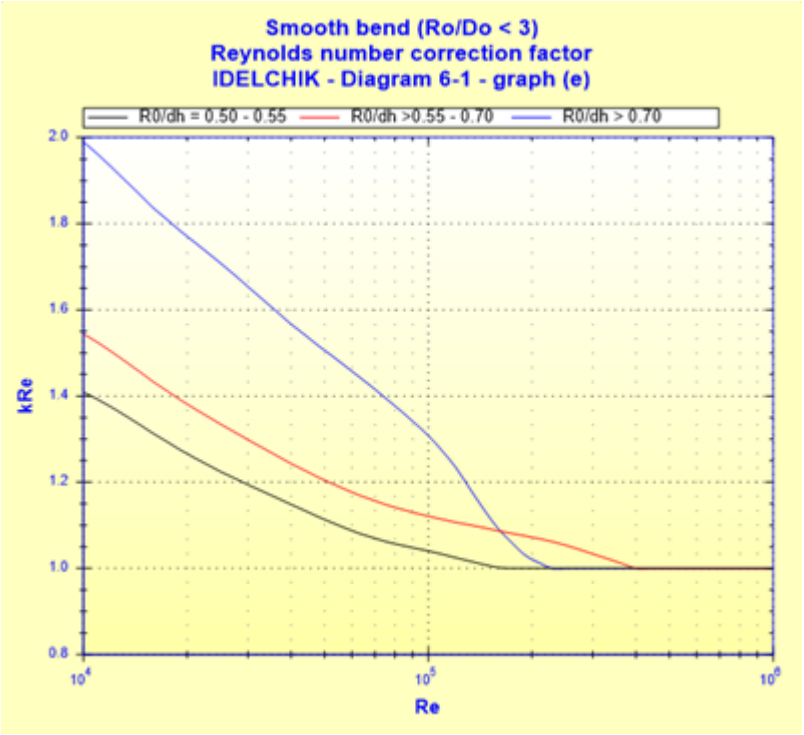
λ_Δ : Darcy friction factor for rough pipe ($\overline{\Delta} = \Delta/D_h$) at Re

---

Coefficient of effect of the Reynolds number ($Re \geq 10^4$):

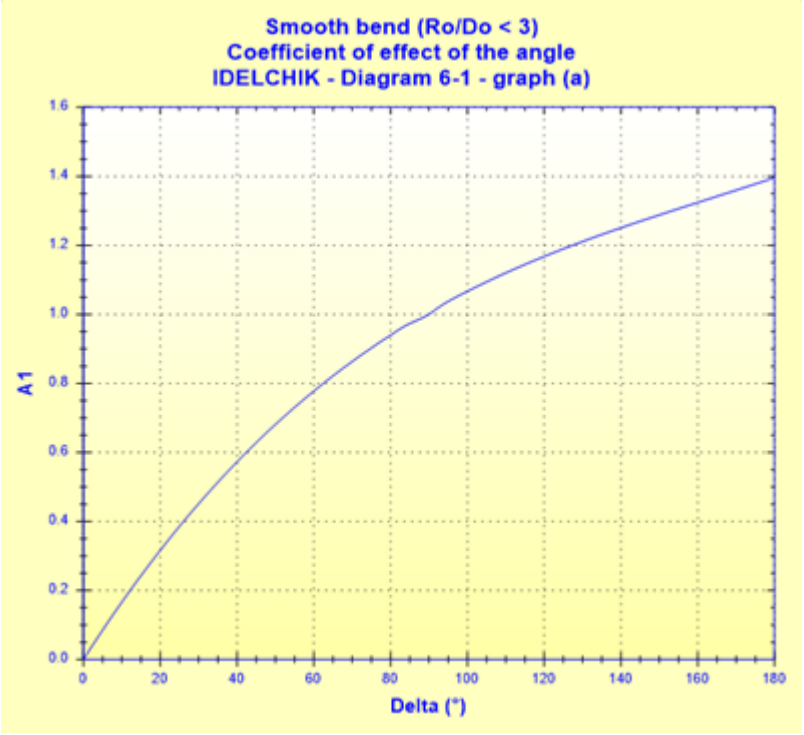
$$k_{Re} = f\left(Re, \frac{R_0}{D_h}\right)$$

([1] diagram 6-1)



Coefficient of effect of the angle:

$A1 = f(\delta)$ ([1] diagram 6-1)

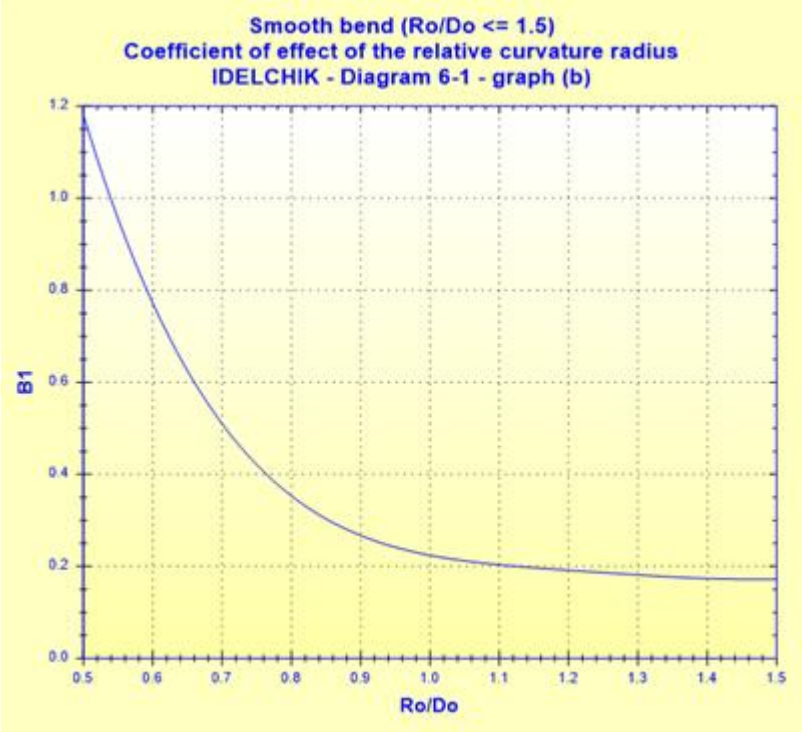


Coefficient of effect of the relative curvature radius:

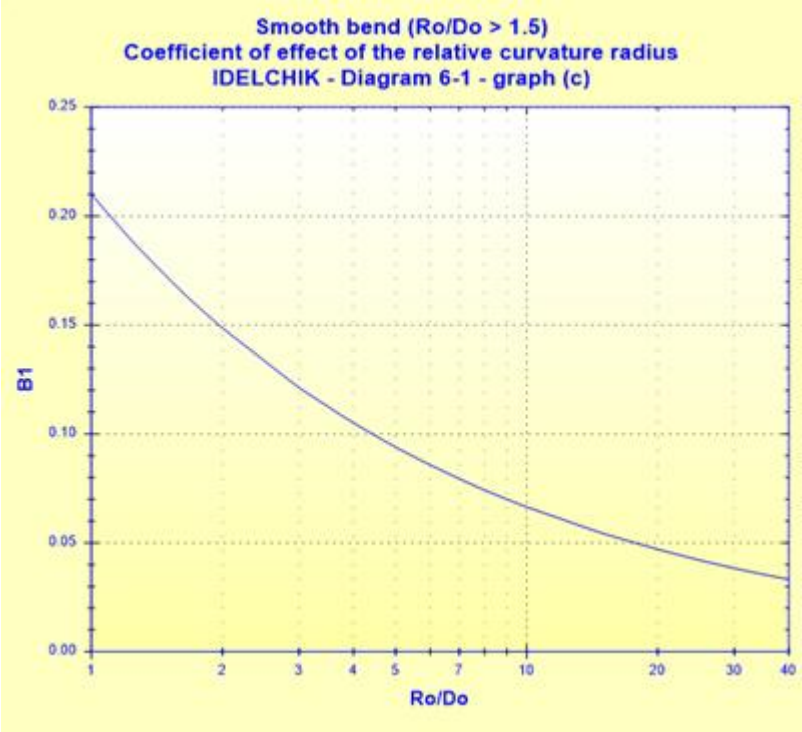
$$B1 = f\left(\frac{R_0}{D_h}\right)$$

([1] diagram 6-1)

- $0.5 \le R_0/D_0 \le 1.5$



- $R_0/D_0 > 1.5$



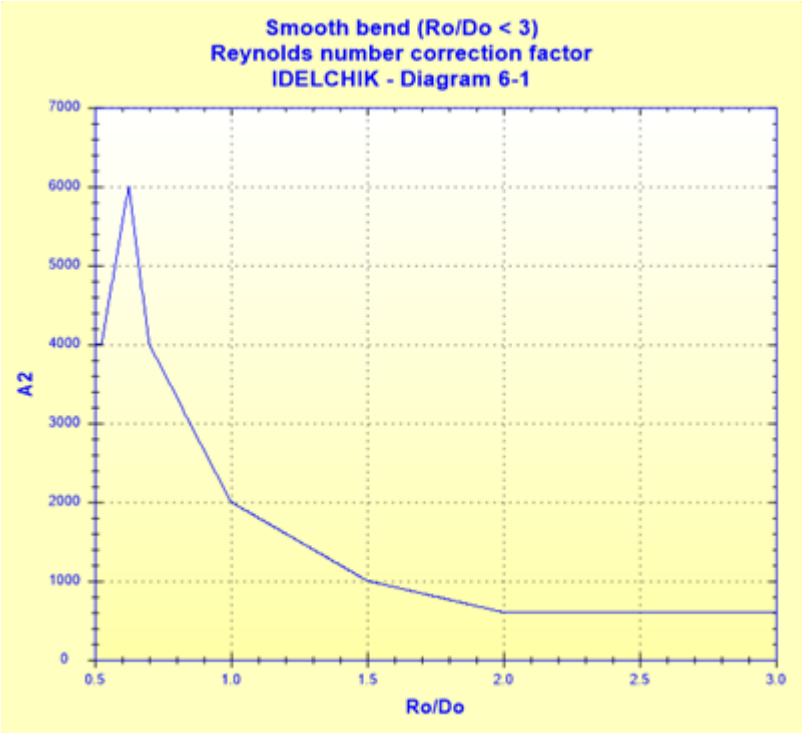
Coefficient of effect of the relative elongation of the cross section:

$C1 = 1$ ([1] diagram 6-1)

Reynolds number correction factor that depends on the relative curvature radius:

$$A2 = f\left(\frac{R_0}{D_0}\right)$$ ([1] diagram 6-1)

R_0/D_0	0.50 - 0.55	>0.55 - 0.70	>0.70 - 1.0	>1.0 - 2.0	>2.0
$A2 \times 10^{-3}$	4.0	6.0	4.0 - 2.0	1.0	0.6



Pressure loss coefficient (without friction):

- $Re \geq 10^4$

$$\zeta'_{loc} = k_{\Delta} \cdot k_{Re} \cdot A1 \cdot B1 \cdot C1$$ ([1] diagram 6-1)

- $3 \cdot 10^3 < Re < 10^4$

$$\zeta'_{loc} = \frac{A2}{Re} + A1 \cdot B1 \cdot C1$$ ([1] diagram 6-1)

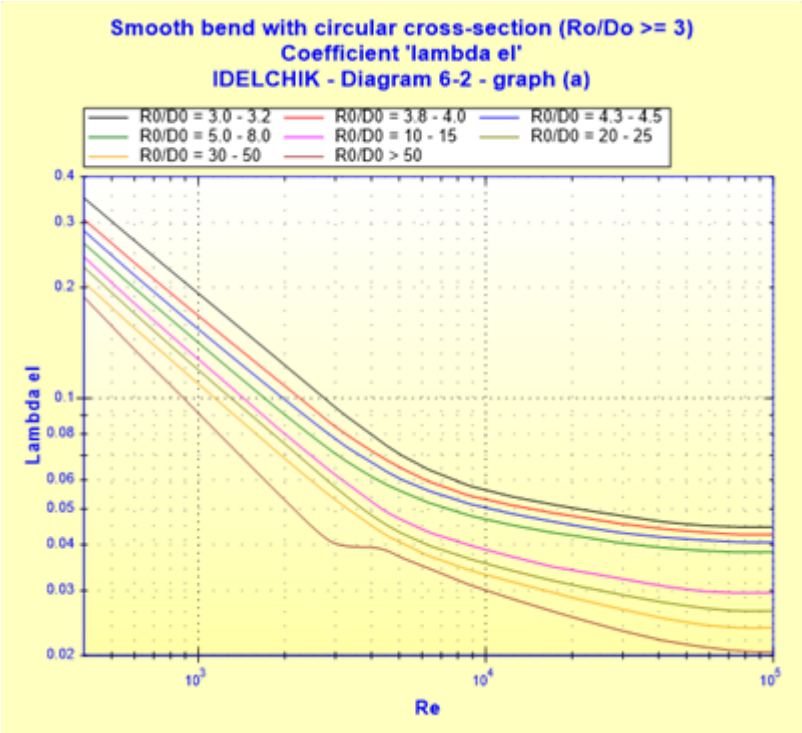
■ Case of a single bend of relative radius of curvature greater than or equal to 3 ($R_0/D_0 \geq 3$) ([1] diagram 6-2)

Total friction factor with smooth wall:

- $4 \cdot 10^2 \leq Re < 10^5$

$$\lambda_{el} = f\left(Re, \frac{R_0}{D_0}\right)$$

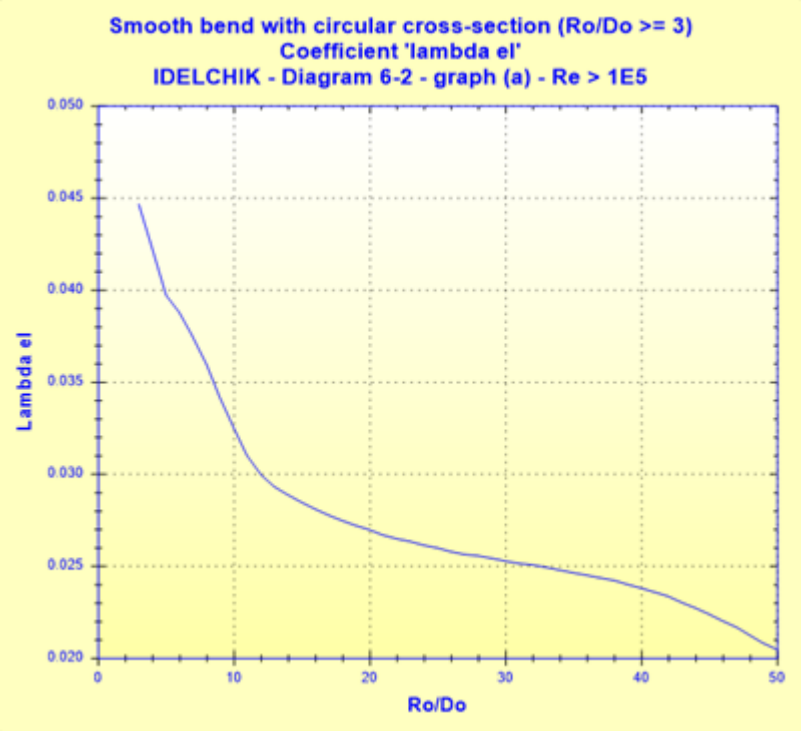
([1] diagram 6-2)



- $Re \geq 10^5$

$$\lambda_{el} = f\left(\frac{R_0}{D_0}\right)$$

([1] diagram 6-2)



Estimation of the coefficient of local resistance

$$\zeta'_{loc} = (\lambda_{el} - \lambda_s) \cdot \frac{2 \cdot \pi \cdot R_0 \cdot \delta / 360}{D_h}$$

with:

λ_s : Darcy friction factor for hydraulically smooth pipe ($\overline{\Delta} = 0$) at Re

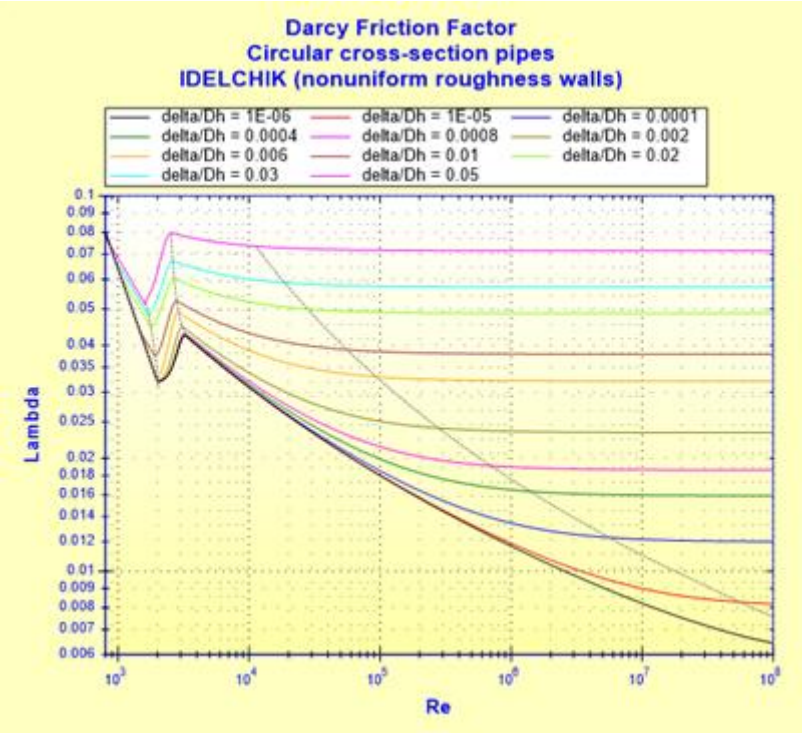
---

■ Case of the U-shaped Bends ([1] diagram 6-20)

Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}, \frac{\Delta}{D_h}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



Pressure loss friction factor:

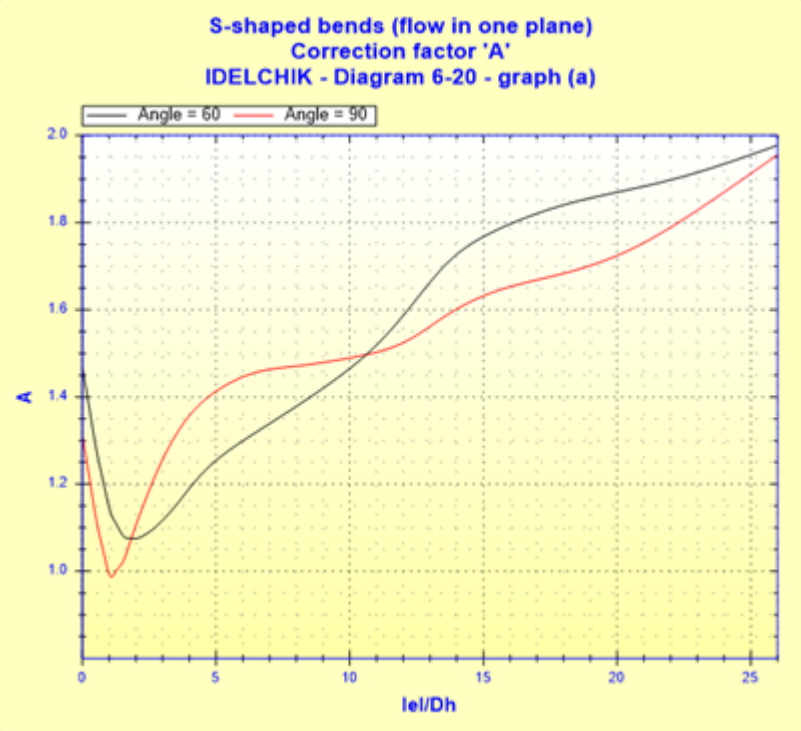
$$\zeta_{fr} = \lambda \cdot \left[2 \cdot \left(0.0175 \cdot \delta \cdot \frac{R_0}{D_h} \right) + \frac{l_{el}}{D_h} \right]$$

([1] diagram 6-20)

Coefficient of correction:

$$A = f\left(\frac{L_{el}}{D_h}, \delta \right)$$

([1] diagram 6-20 graph a)



Total pressure loss coefficient (based on the mean velocity in the bends):

$$\zeta = A \cdot \zeta'_{loc} + \zeta_{fr}$$

([1] diagram 6-20)

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_0}{\lambda}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

([1] diagram 6-20)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Bend hydraulic diameter (m)
D_0	Bend internal diameter (m)
F_0	Cross-sectional area (m^2)
l	Total length measured along the axis (m)
l_{el}	Straight length between bends (m)
R_0	Radius of curvature (m)
δ	Curvature angle of each bend (°)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()
k_Δ	Coefficient that allows for the effect of the roughness ()
k_{Re}	Coefficient that allows for the effect of the Reynolds number ()
A1	Coefficient that allows for the effect of the angle ()
B1	Coefficient that allows for the effect of the relative curvature radius ()
C1	Coefficient that allows for the effect of the relative elongation of the cross section ()
A2	Reynolds number correction factor that depends on the relative curvature radius ()
ζ'_{loc}	Coefficient of local resistance ()
λ_{el}	Total friction factor with smooth wall ()
λ	Darcy friction coefficient ()

ζ_{fr}	Pressure loss friction factor ()
A	Coefficient of correction ()
ζ	Total pressure loss coefficient (based on the mean velocity in the bend) ()
L_{eq}	Straight length of equivalent pressure loss (m)
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m³)
ν	Fluid kinematic viscosity (m²/s)
g	Gravitational acceleration (m/s²)

Validity range:

- stabilized flow upstream bend
- length of the straight section downstream: $\geq 10\ D_0$
- relative radius of curvature: greater than or equal to 1 ($R_0/D_0 \geq 1$)
- curvature angle of one bend: 0 to 180°

for 'δ' angles less than 60° the pressure loss coefficient 'ζ' is estimated by taking into account an interaction correction factor 'A' corresponding to that of an angle of 60°.

for 'δ' angles greater than 90° the pressure loss coefficient 'ζ' is estimated by taking into account an interaction correction factor 'A' corresponding to that of an angle of 90°.

■ case of relative radius of curvature lower than 3 ($R_0/D_0 < 3$)

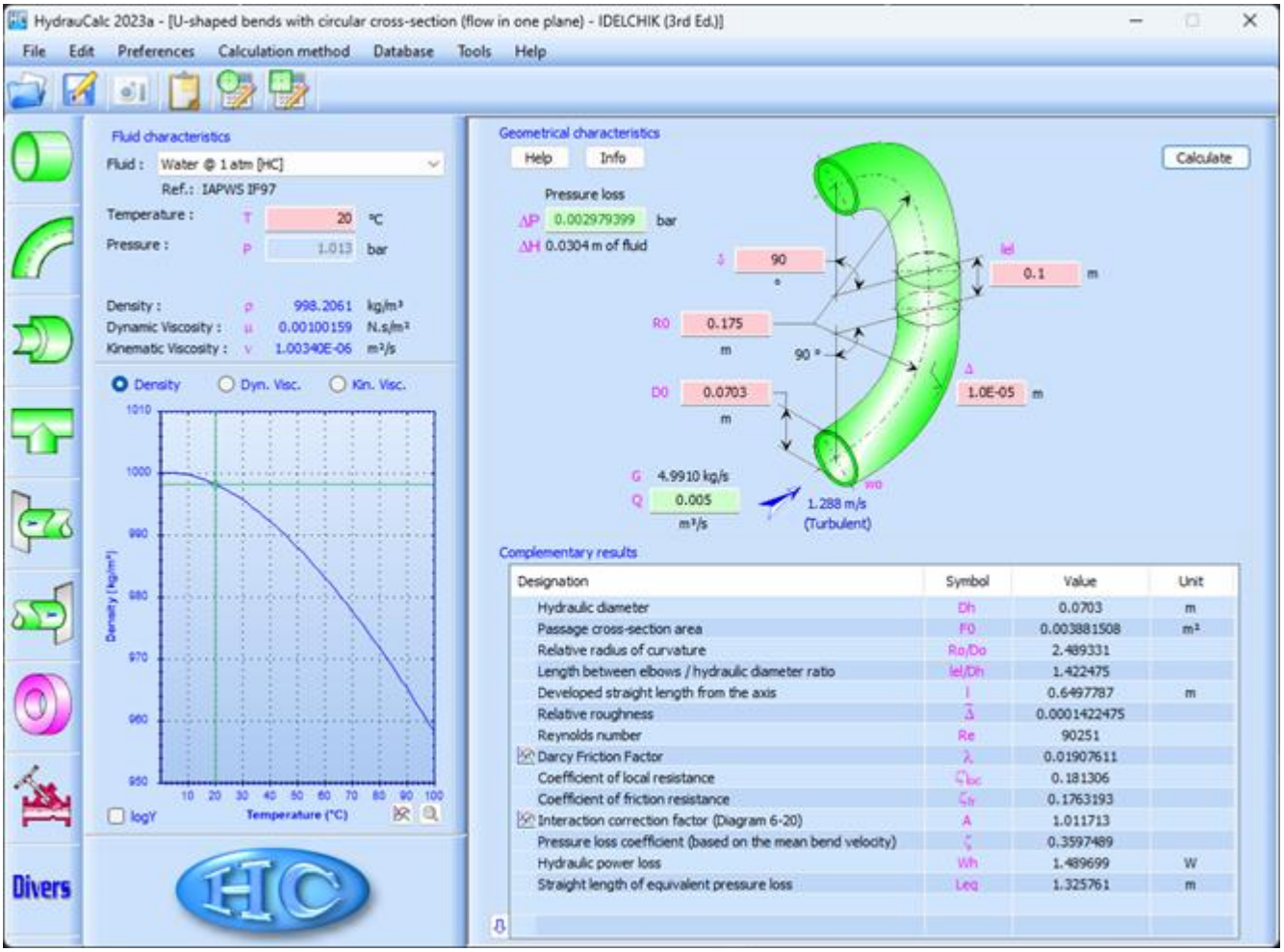
- flow regime: $Re \geq 3 \cdot 10^3$

■ case of relative radius of curvature greater than or equal to 3 ($R_0/D_0 \geq 3$)

- flow regime: $Re \geq 400$

  for Reynolds number 'Re' lower than 400 the coefficient 'λ_{el}' is linearly extrapolated.

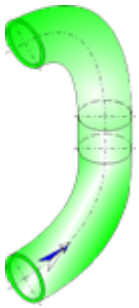
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.2.13.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) of U-shaped bends (with flow in one plane) whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

An option allows to take into account the effect of the straight length at the exit of the bend.

Model formulation:

Hydraulic diameter (m):

$$D = d$$

Cross-section area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Total length measured along the axis (m):

$$L = 2 \cdot \left(2 \cdot \pi \cdot r \cdot \frac{\theta_b}{360} \right) + L_s$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

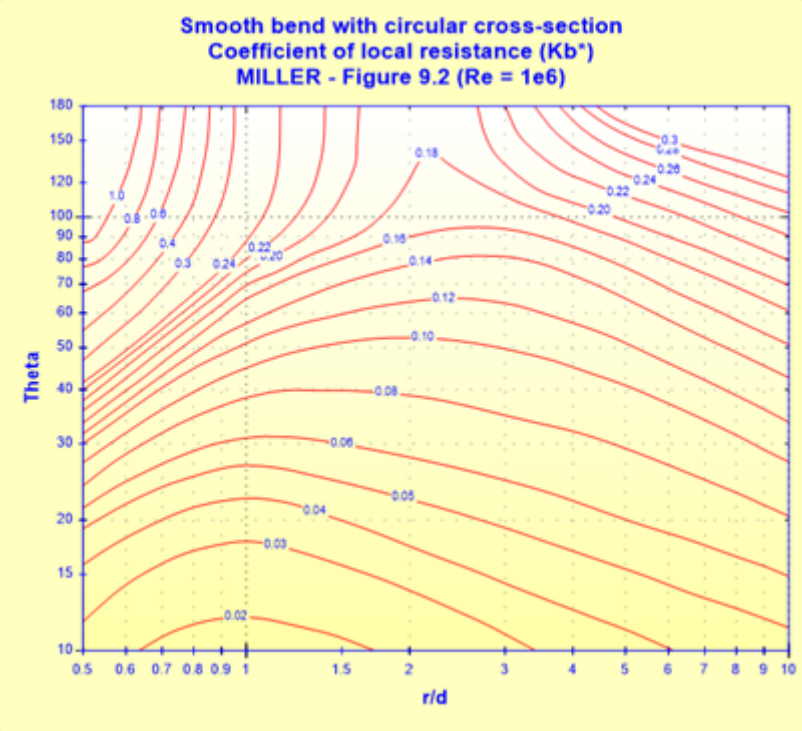
$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

Basic resistance coefficient for one bend:

$$K_b^* = f\left(\frac{r}{d}, \theta_b \right)$$ ([1] figure 9.2)



Reynolds number correction factor:

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$

([1] figure 9.3)

■ $r/d \geq 1$

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3)

- r/d < 1
  - r/d > 0.7 or K_b^* < 0.4

    $$C_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3 with r/d=1)

  - otherwise (r/d ≤ 0.7 and K_b^* ≥ 0.4)

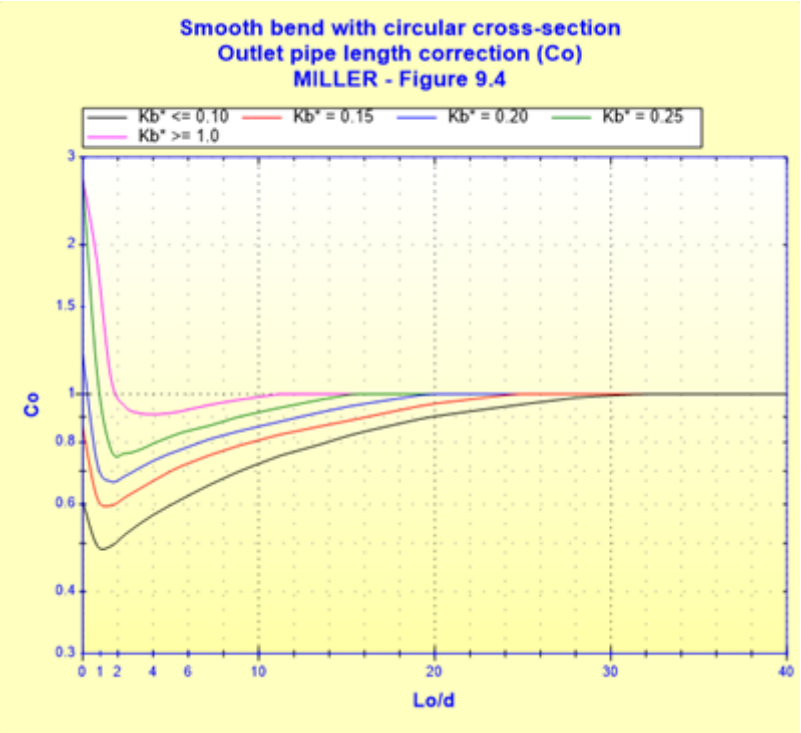
    $$C_{Re} = \frac{K_b^*}{K_b^* - 0.2C'_{Re} + 0.2}$$ ([1] equation 9.2)

    with:

    $$C'_{Re} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3 with r/d=1)

Outlet pipe length correction factor (optional):

$$C_o = f\left(\frac{L_o}{d}, K_b^*\right)$$ ([1] figure 9.4)



- r/d < 3 et θ_b < 100°

$$C_o = f\left(\frac{L_o}{d}, K_b^*\right)$$ ([1] figure 9.4)

■ otherwise (r/d > 3 and/or θ_b > 100°)

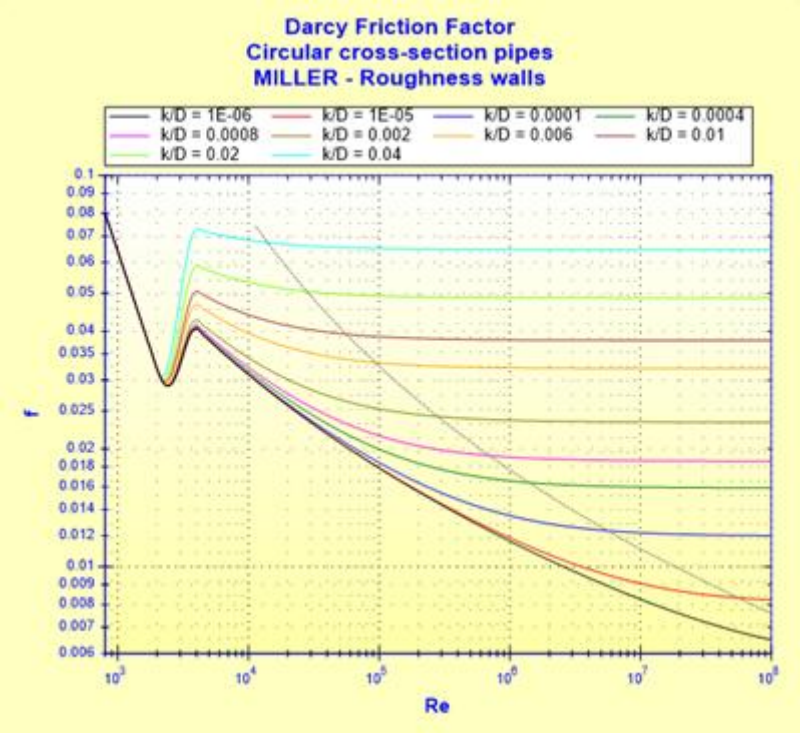
$$C_o = 1$$ (negligible effect)

If this option is not activated, the factor C_o is equal to unity.

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{D}\right)$$

See Straight Pipe - Circular Cross-Section and Roughness Walls (MILLER)



Roughness correction factor:

$$C_f = \frac{f_{rough}}{f_{smooth}}$$ ([1] equation 9.3)

with:

f_{rough}: Darcy friction factor for rough pipe at Re

f_{smooth}: Darcy friction factor for smooth pipe (k = 0) at Re

For Re > 10^6, C_f is calculated from equation (9.3) for Re = 10^6

Corrected loss coefficient for the first bend:

$$K_{b1} = K_b^* \cdot C_{Re} \cdot C_f$$ ([1] equation 9.4)

Corrected loss coefficient for the second bend:

$$K_{b2} = K_b^* \cdot C_{Re} \cdot C_f \cdot C_o$$ ([1] equation 9.4)

Interaction correction factor:

$$C_{b-b} = f\left(\frac{L_s}{d}, \frac{r}{d}\right)$$ ([1] figure 10.4)

Pressure loss coefficient of the two bends:

$$K_{b-b} = (K_{b1} + K_{b2}) \cdot C_{b-b}$$ ([1] equation 10.1)

Friction loss coefficient of the straight length between bends:

$$K_f = f \cdot \frac{L_s}{d}$$ ([1] equation 8.3)

Total pressure loss coefficient (based on the mean velocity in the bend):

$$K = K_{b-b} + K_f$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{d}{f}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$ ([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Bend hydraulic diameter (m)
d	Bend internal diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
L_s	Straight length between the two bends (m)
L	Total length measured along the axis (m)

r	Radius of curvature (m)
θ_b	Curvature angle of each bend (°)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
K_b^*	Basic loss coefficient of one bend ()
C_{Re}	Reynolds number correction factor ()
C_o	Outlet pipe length correction factor ()
L_0	Length of the straight section downstream of the bend (m)
f	Darcy friction factor ()
k	Absolute roughness of walls (m)
C_f	Roughness correction factor ()
K_{b1}	Corrected loss coefficient for the first bend ()
K_{b2}	Corrected loss coefficient for the second bend ()
C_{b-b}	Interaction correction factor ()
K_{b-b}	Pressure loss coefficient of the two bends ()
K_f	Friction loss coefficient of the straight length between bends ()
K	Total pressure loss coefficient (based on the mean velocity in the bend) ()
L_{eq}	Straight length of equivalent pressure loss (m)
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream bend
- relative radius of curvature 'r/d': greater than or egal to 0.5 and lower than or egal to 10

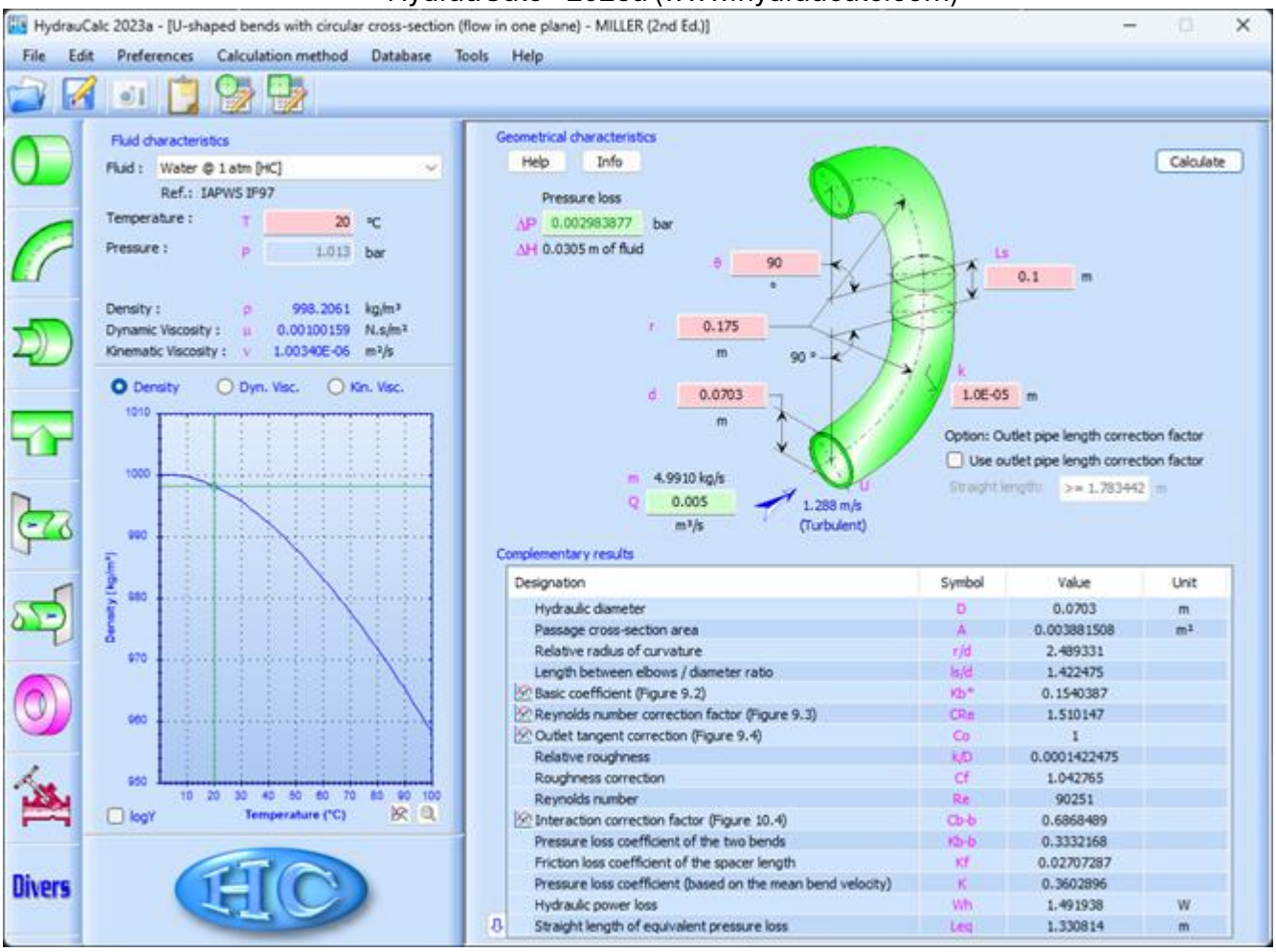
  for relative radius of curvature 'r/d' greater than 3, the pressure loss coefficient 'K' is estimated by taking into account the interaction correction factor 'Cb-b' corresponding to a relative radius of curvature 'r/d' of value 3.

- curvature angle: between 10° and 180°

  the interaction correction factor 'Cb-b' is applicable for angles 'θ_b' between 70° and 90°.

  for angles 'θ_b' less than 70° or greater than 90°, the pressure loss coefficient 'K' is estimated by taking into account the interaction factor coefficient 'Cb-b' applicable to angles 'θ_b' between 70° and 90°

Example of application:



References:

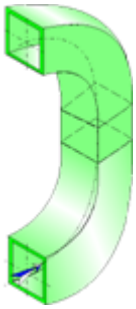
[1] Internal Flow System, Second Edition, D.S. Miller

2.2.14 U-shaped bends (1 plane) - Rectangular cross-section

U-shaped Bends

(with flow in one plane)

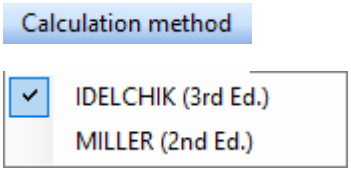
Rectangular Cross-Section



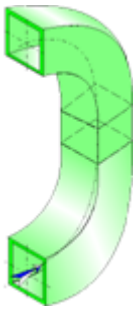
For the calculation of the pressure loss coefficient of U-shaped bends with rectangular cross-section (with flow in one plane), the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.2.14.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) of U-shaped bends (with flow in one plane) whose cross-section is rectangular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the first bend.

Model formulation:

Hydraulic diameter (m):

$$D_h = \frac{2 \cdot a_0 \cdot b_0}{a_0 + b_0}$$ ([1] diagram 6-1)

Cross-section area (m^2):

$$F_0 = a_0 \cdot b_0$$

Total length measured along the axis (m):

$$l = 2 \cdot \left(2 \cdot \pi \cdot R_0 \cdot \frac{\delta}{360} \right) + l_{el}$$

Mean velocity (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = F_0 \cdot l$$

Fluid mass (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{w_0 \cdot D_h}{\nu}$$

Relative roughness:

$$\overline{\Delta} = \frac{\Delta}{D_h}$$

■ Case of relative radius of curvature lower than 3 ($R_0/b_0 < 3$) ([1] diagram 6-1)

Coefficient of effect of the roughness:

$$k_\Delta = f\left(\frac{R_0}{b_0}, Re, \overline{\Delta}\right)$$ ([1] diagram 6-1)

● $0.50 \le R_0/b_0 \le 0.55$

$\overline{\Delta}$	Re	
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$
0	1.0	1.0
0 - 0.001	1.0	$1 + 0.5 \cdot 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	1.5

- $R_0/b_0 > 0.55$

$\overline{\Delta}$	Re		
	$3 \cdot 10^3$ - $4 \cdot 10^4$	> $4 \cdot 10^4$ - $2 \cdot 10^5$	> $2 \cdot 10^5$
0	1.0	1.0	1.0
0 - 0.001	1.0	$\lambda_\Delta / \lambda_{sm}$	$1 + 10^3 \cdot \overline{\Delta}$
> 0.001	1.0	2.0	2.0

with:

λ_{sm} : Darcy friction factor for hydraulically smooth pipe ($\overline{\Delta} = 0$) at Re

λ_Δ : Darcy friction factor for rough pipe ($\overline{\Delta} = \Delta/D_h$) at Re

---

Coefficient of effect of the Reynolds number ($Re \geq 10^4$):

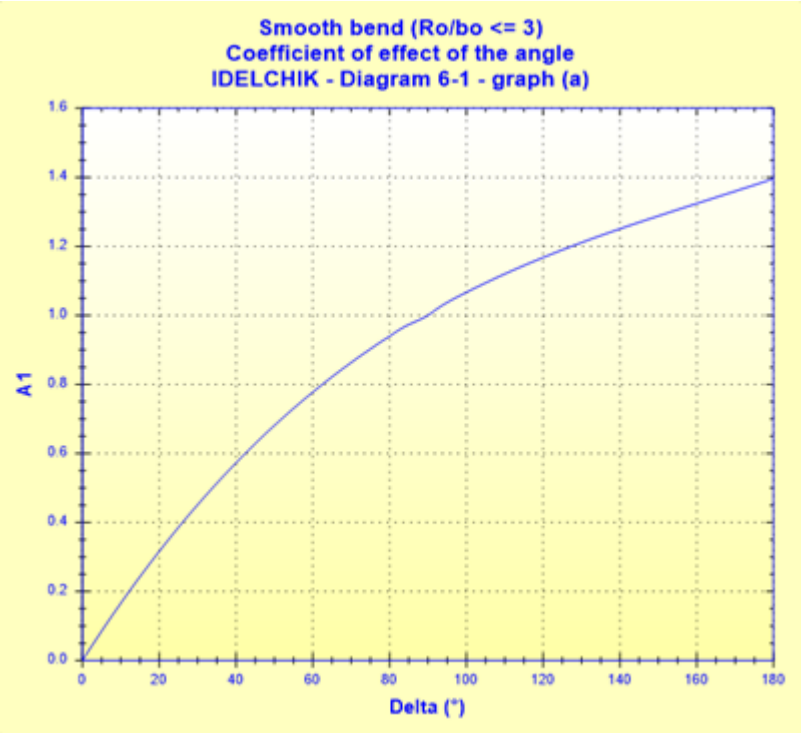
$$k_{Re} = f\left(\mathrm{Re}, \frac{R_0}{b_0}\right)$$

([1] diagram 6-1)

Coefficient of effect of the angle:

$$A1 = f(\delta)$$

([1] diagram 6-1)

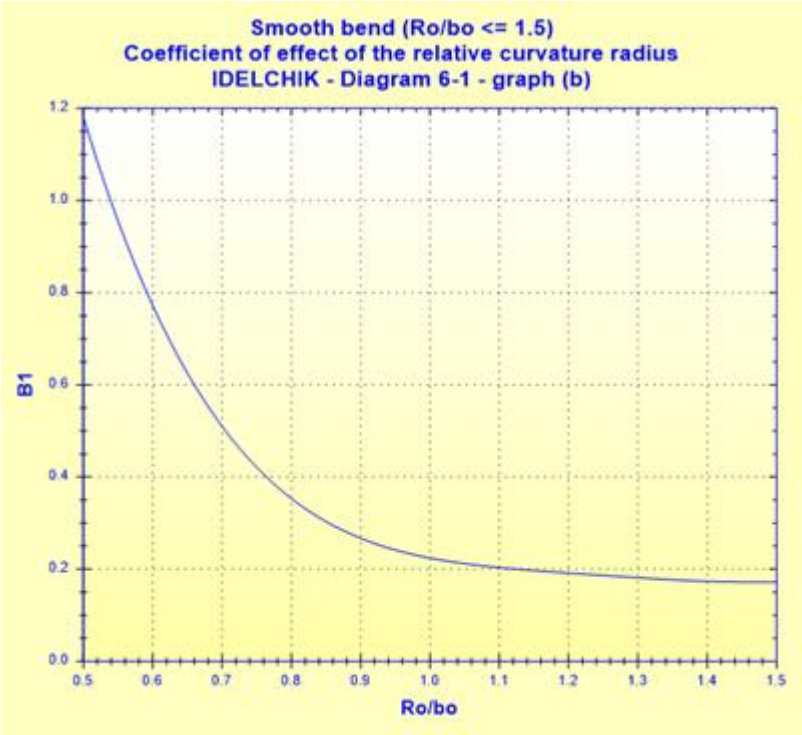


Coefficient of effect of the relative curvature radius:

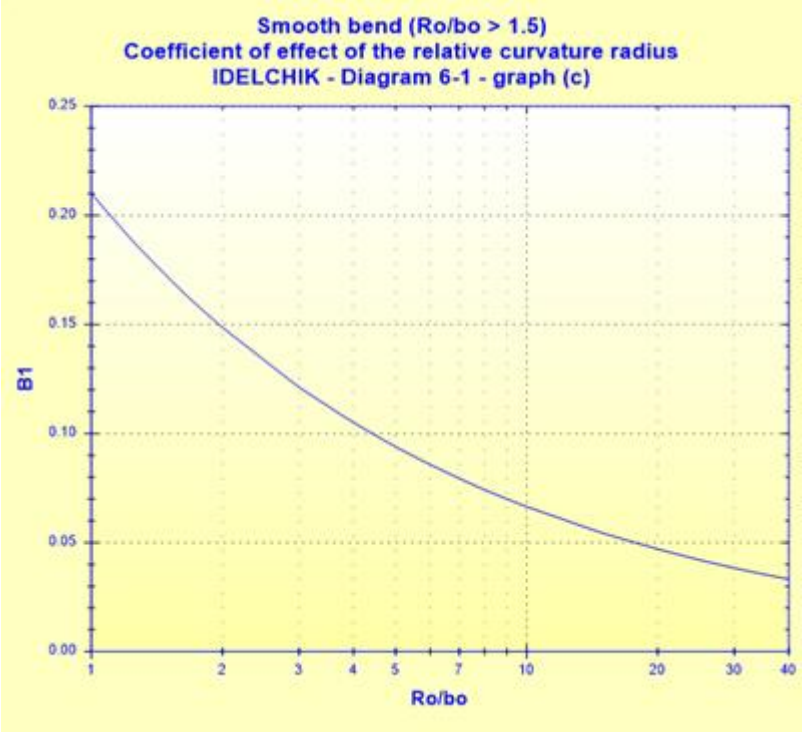
$$B1 = f\left(\frac{R_0}{b_0}\right)$$

([1] diagram 6-1)

- $0.5 \le R_0/b_0 \le 1.5$



- $R_0/b_0 > 1.5$



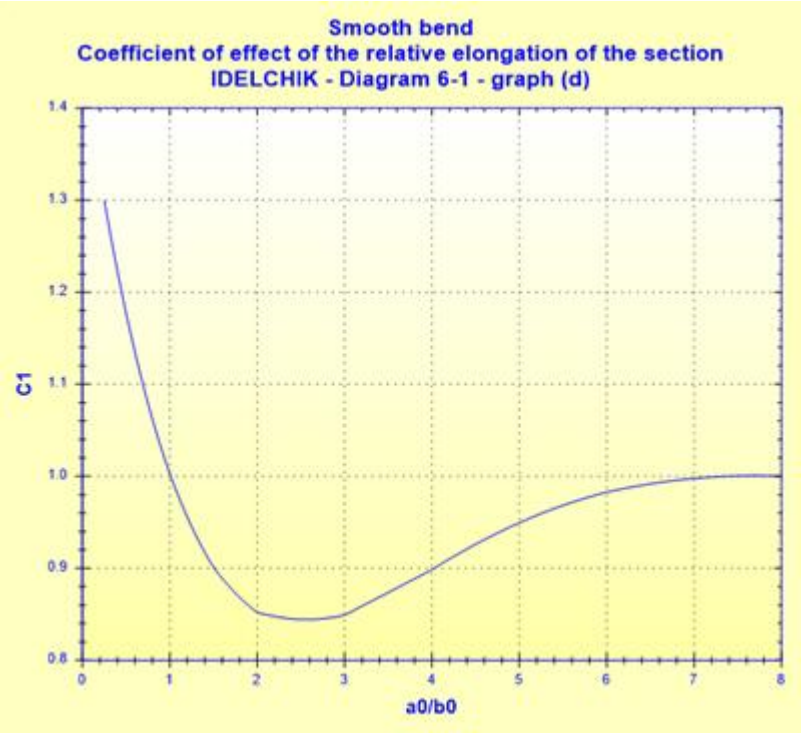
Coefficient of effect of the relative elongation of the cross section:

- $a_0 \geq b_0$

$$C1 = f\left(\frac{a_0}{b_0}\right)$$ ([1] diagram 6-1)

- $a_0 < b_0$

$$C1 = f\left(\frac{b_0}{a_0}\right)$$ ([1] diagram 6-1)

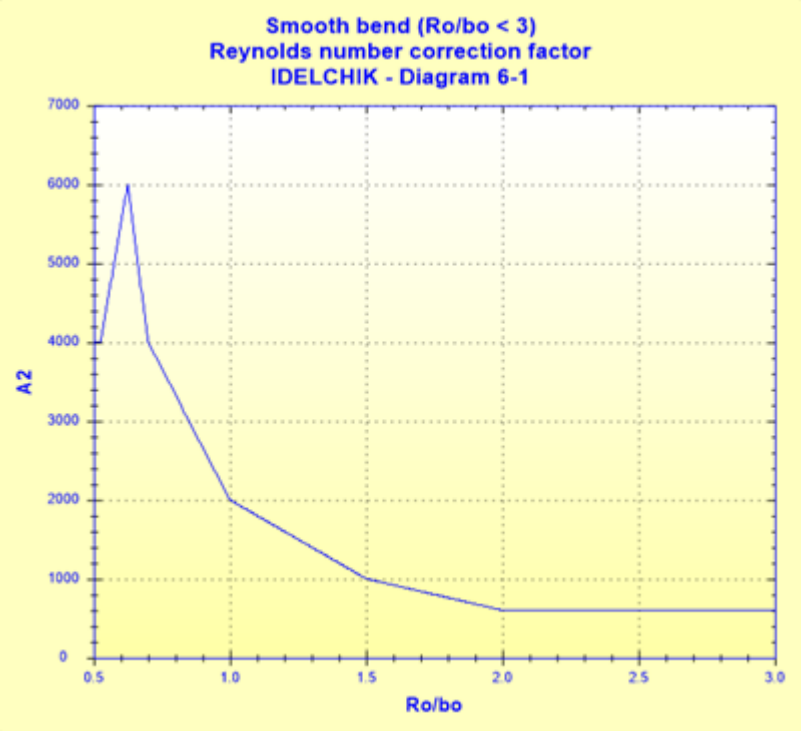


Reynolds number correction factor that depends on the relative curvature radius:

$$A2 = f\left(\frac{R_0}{b_0}\right)$$

([1] diagram 6-1)

R_0/b_0	0.50 - 0.55	>0.55 - 0.70	>0.70 - 1.0	>1.0 - 2.0	>2.0
$A2 \times 10^{-3}$	4.0	6.0	4.0 - 2.0	1.0	0.6



Pressure loss coefficient (without friction):

- $Re \geq 10^4$

$$\zeta'_{loc} = k_{\Delta} \cdot k_{Re} \cdot A1 \cdot B1 \cdot C1$$ ([1] diagram 6-1)

- $3 \cdot 10^3 < Re < 10^4$

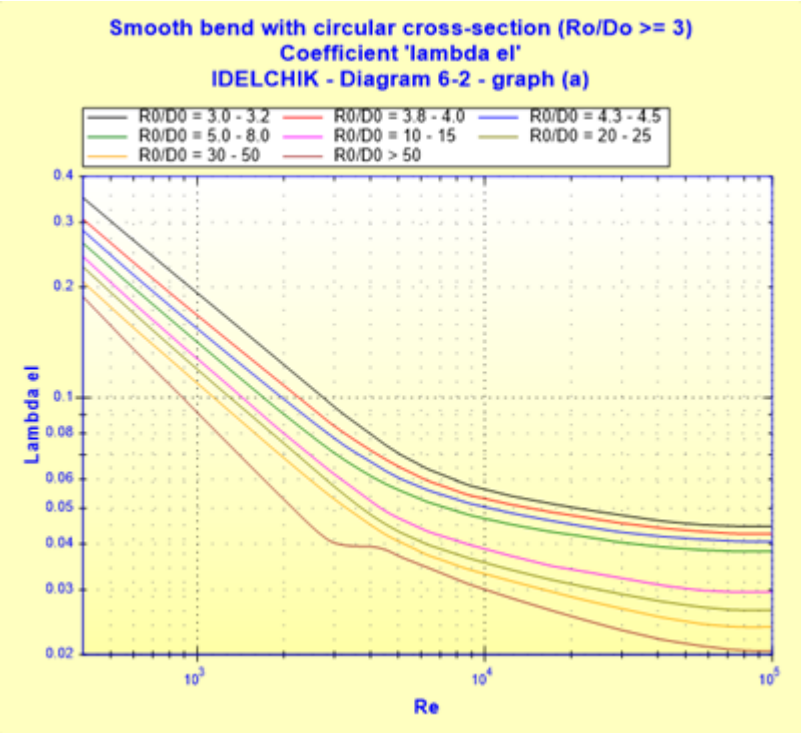
$$\zeta'_{loc} = \frac{A2}{Re} + A1 \cdot B1 \cdot C1$$ ([1] diagram 6-1)

■ Case of relative radius of curvature greater than or equal to 3 ($R_0/b_0 \geq 3$) ([1] diagram 6-2)

Total friction factor with smooth wall:

- $4 \cdot 10^2 \leq Re < 10^5$

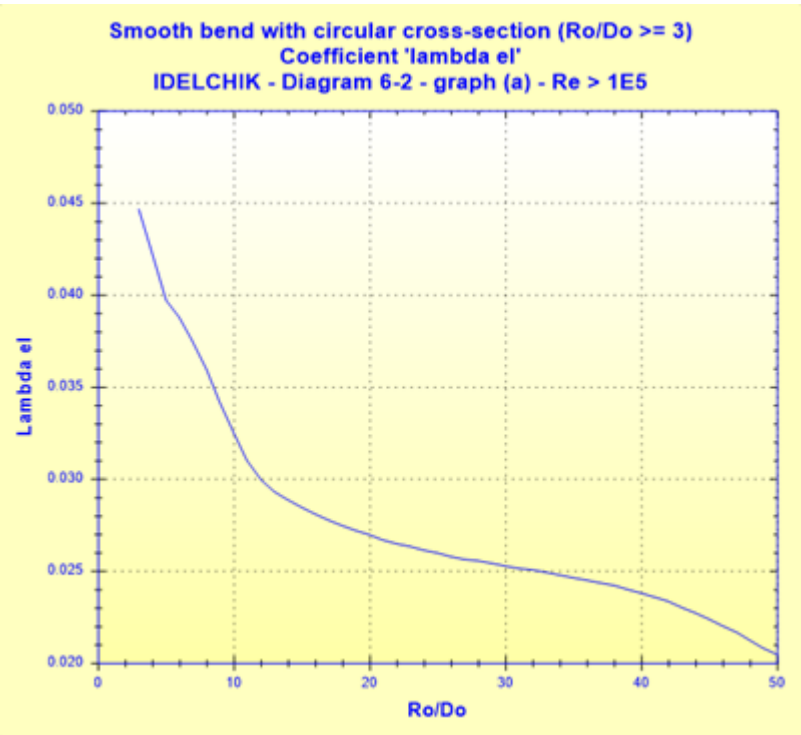
$$\lambda_{el} = f\left(Re, \frac{R_0}{D_0}\right)$$ ([1] diagram 6-2)



- Re ≥ 10^5

$$\lambda_{el} = f\left(\frac{R_0}{D_0}\right)$$

([1] diagramme 6-2)



Estimation of the coefficient of local resistance

$$\zeta'_{loc} = (\lambda_{el} - \lambda_s) \cdot \frac{2 \cdot \pi \cdot R_0 \cdot \delta / 360}{D_h}$$

with:

λ_s : Darcy friction factor for hydraulically smooth pipe ($\bar{\Delta} = 0$) at Re

---

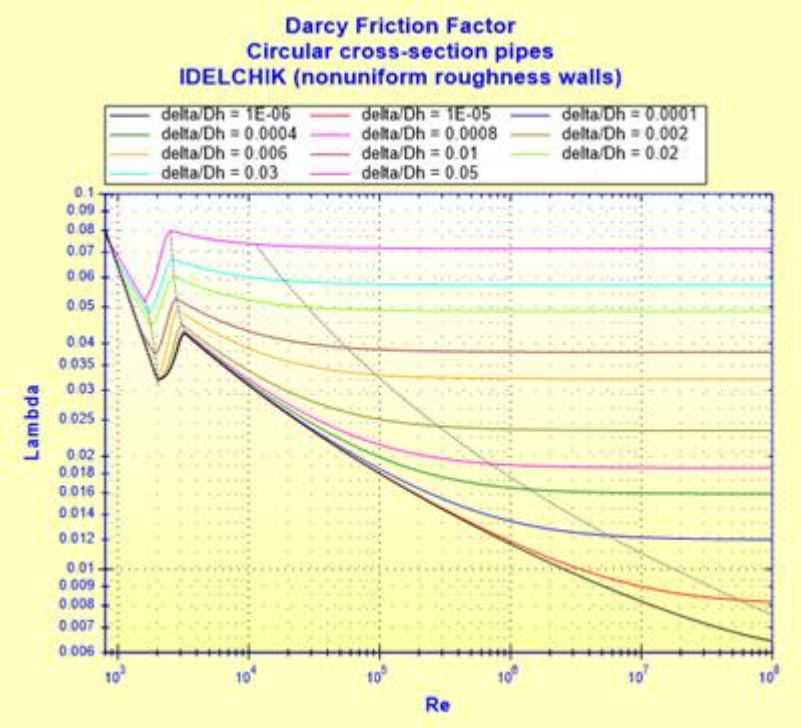
■ Case of the U-shaped Bends ([1] diagram 6-20)

Darcy friction factor:

See Straight Pipe - Rectangular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)

■ Darcy friction factor for circular cross-section

$$\lambda_{circ} = f\left(\mathrm{Re}, \frac{\Delta}{D_h}\right)$$



■ Correction for Darcy friction factor for noncircular cross-section

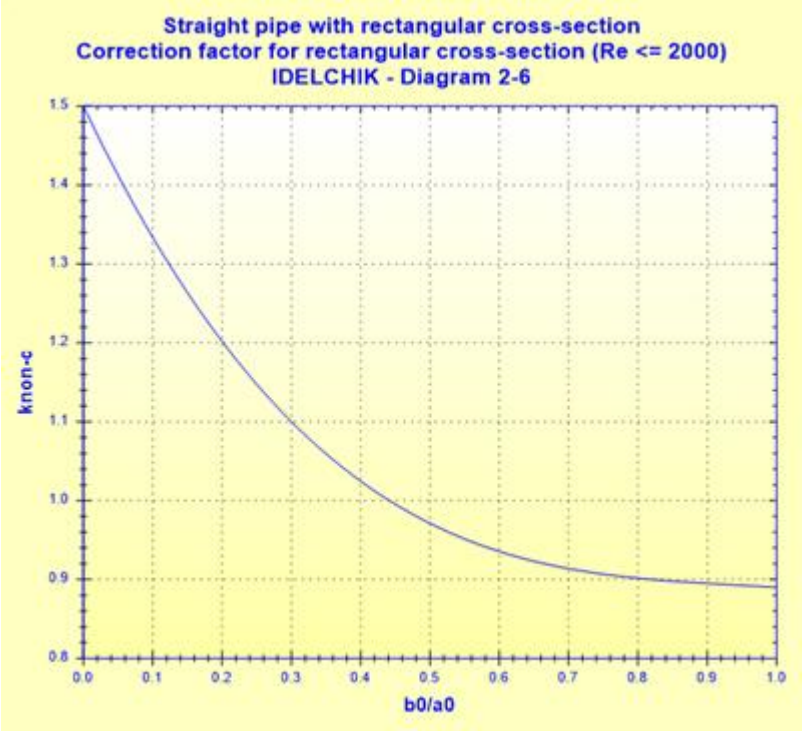
♦ $a_0 \geq b_0$

$$k_{non-c} = f(b_0/a_0)$$ ([1] diagram 2-6)

♦ $a_0 < b_0$

$$k_{non-c} = f(a_0/b_0)$$ ([1] diagram 2-6)

- laminar flow (Re ≤ 2000):



- turbulent flow (Re > 2000):

■ Darcy friction factor for rectangular cross-section

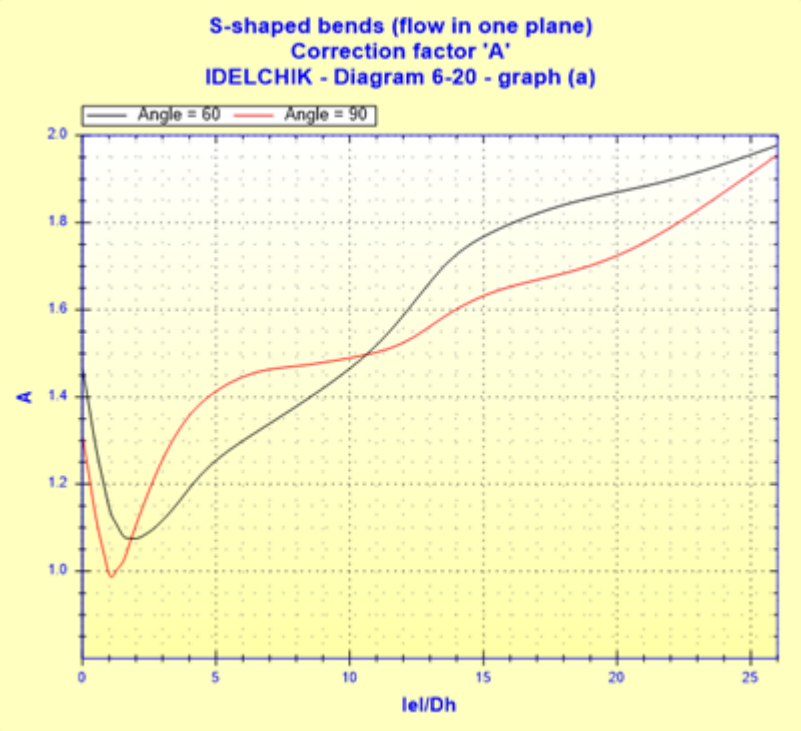
$$\lambda_{rect} = \lambda_{circ} \cdot k_{non-c}$$ ([1] diagram 2-6)

Pressure loss friction factor:

$$\zeta_{fr} = \lambda \cdot \left[2 \cdot \left(0.0175 \cdot \delta \cdot \frac{R_0}{D_h} \right) + \frac{l_{el}}{D_h} \right]$$ ([1] diagram 6-20)

Interaction correction factor:

$$A = f\left(\frac{L_{el}}{D_h}, \delta \right)$$ ([1] diagram 6-20 graph a)



Total pressure loss coefficient (based on the mean velocity in the bends):

$$\zeta = A \cdot \zeta'_{loc} + \zeta_{fr}$$

([1] diagram 6-20)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$

([1] diagram 6-20)

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = \zeta \cdot \frac{D_h}{\lambda_{rect}}$$

Symbols, Definitions, SI Units:

a_0	Rectangular cross-section width (m)
b_0	Rectangular cross-section height (m)
D_h	Bend hydraulic diameter (m)
F_0	Cross-sectional area (m^2)
l	Total length measured along the axis (m)
R_0	Radius of curvature (m)
δ	Curvature angle of each bend (°)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()
k_Δ	Coefficient that allows for the effect of the roughness ()
k_{Re}	Coefficient that allows for the effect of the Reynolds number ()
A1	Coefficient that allows for the effect of the angle ()
B1	Coefficient that allows for the effect of the relative curvature radius ()
C1	Coefficient that allows for the effect of the relative elongation of the cross section ()
A2	Reynolds number correction factor that depends on the relative curvature radius ()
ζ'_{loc}	Coefficient of local resistance ()
λ_{circ}	Darcy friction coefficient for circular cross-section ()
k_{non-c}	Correction for Darcy friction factor for noncircular cross-section ()

λ_{rect}	Darcy friction coefficient for rectangular cross-section ()
λ_{el}	Friction coefficient ()
ζ_{fr}	Pressure loss friction factor ()
A	Interaction correction factor ()
ζ	Total pressure loss coefficient (based on the mean velocity in the bend) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
L_{eq}	Straight length of equivalent pressure loss (m)
ρ	Fluid density (kg/m³)
ν	Fluid kinematic viscosity (m²/s)
g	Gravitational acceleration (m/s²)

Validity range:

- stabilized flow upstream bend
- length of the straight section downstream: $\geq 10\ D_h$
- relative radius of curvature greater than or equal to 1 ($R_0/b_0 \geq 1$)
- curvature angle of one bend: 0 to 180°

for 'δ' angles less than 60° the pressure loss coefficient 'ζ' is estimated by taking into account an interaction correction factor '*A*' corresponding to that of an angle of 60°.

for 'δ' angles greater than 90° the pressure loss coefficient 'ζ' is estimated by taking into account an interaction correction factor '*A*' corresponding to that of an angle of 90°.

■ case of relative radius of curvature lower than 3 ($R_0/b_0 < 3$)

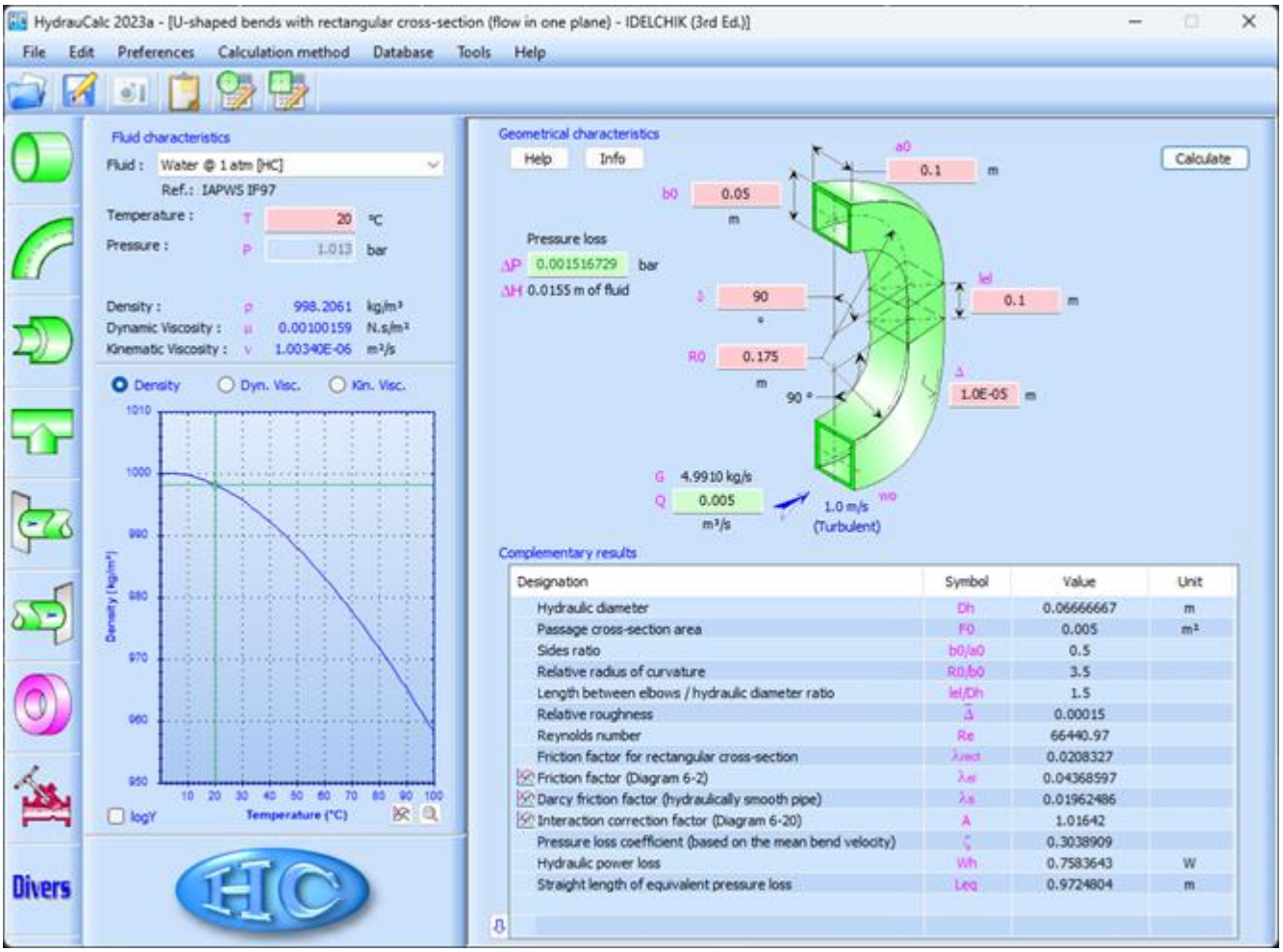
- flow regime: $Re \geq 3 \cdot 10^3$

■ case of relative radius of curvature greater than or equal to 3 ($R_0/b_0 \geq 3$)

- flow regime: $500 \leq Re \leq 38 \cdot 10^3$

for Reynolds number 'Re' lower than 500 or greater than $38 \cdot 10^3$, the coefficient 'λ_{el}' is linearly extrapolated.

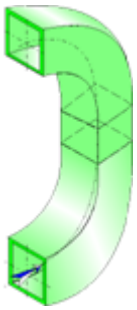
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.2.14.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) of U-shaped bends (with flow in one plane) whose cross-section is rectangular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the first bend.

An option allows to take into account the effect of the straight length at the exit of the second bend.

Model formulation:

Hydraulic diameter (m):

$$D = \frac{2 \cdot b \cdot W}{b + W}$$ ([1] equation 9.5)

Cross-section area (m^2):

$$A = b \cdot W$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Total length measured along the axis (m):

$$L = 2 \cdot \left(2 \cdot \pi \cdot r \cdot \frac{\theta_b}{360} \right) + L_s$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

$$M = V \cdot \rho$$

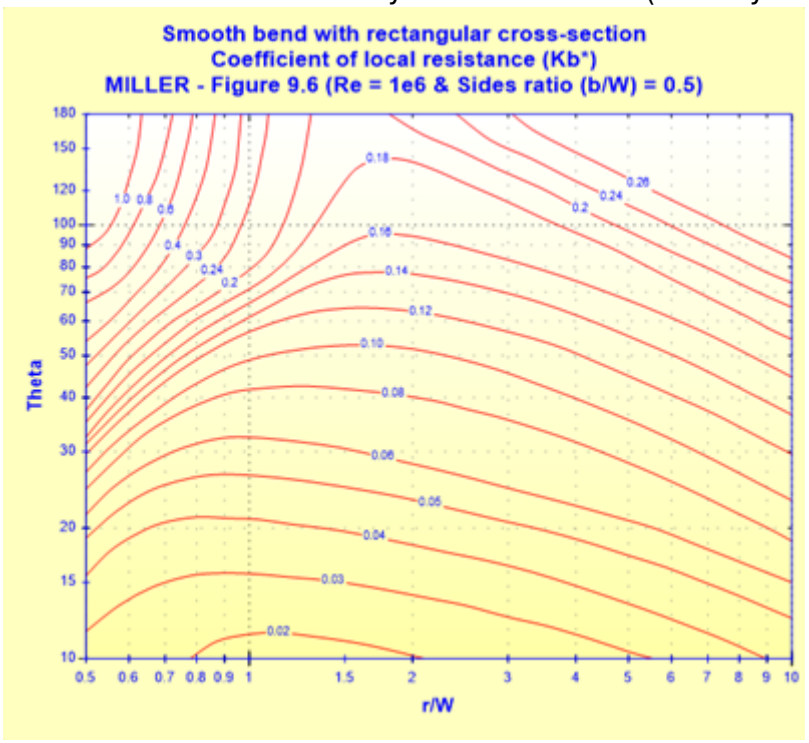
Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$ ([1] equation 9.6)

Basic resistance coefficient:

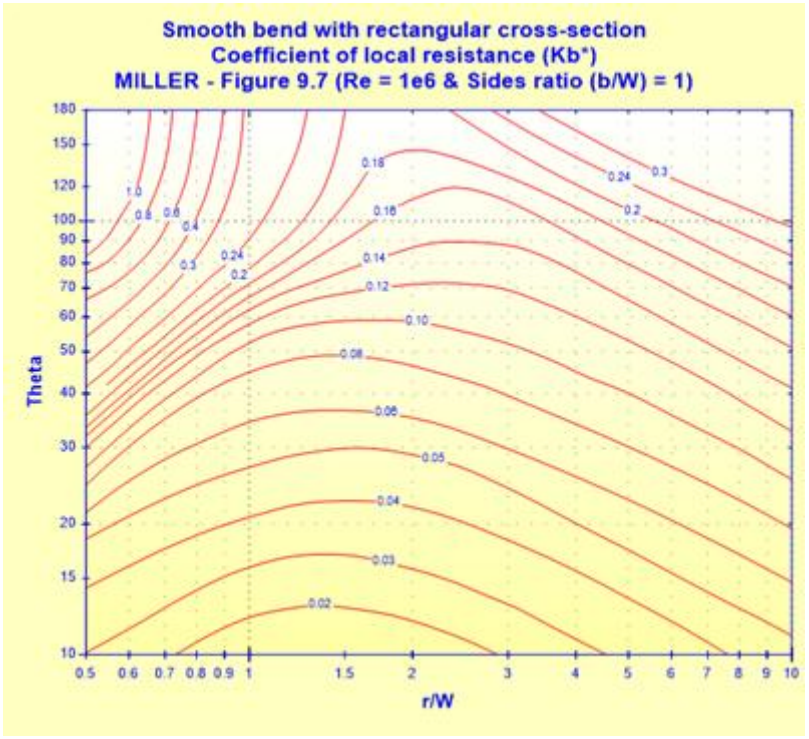
$$K_b^* = f\left(\frac{r}{W}, \theta_b \right)$$ ([1] figures 9.6 – 9.7 – 9.8)

- Sides ratio b/W = 0.5



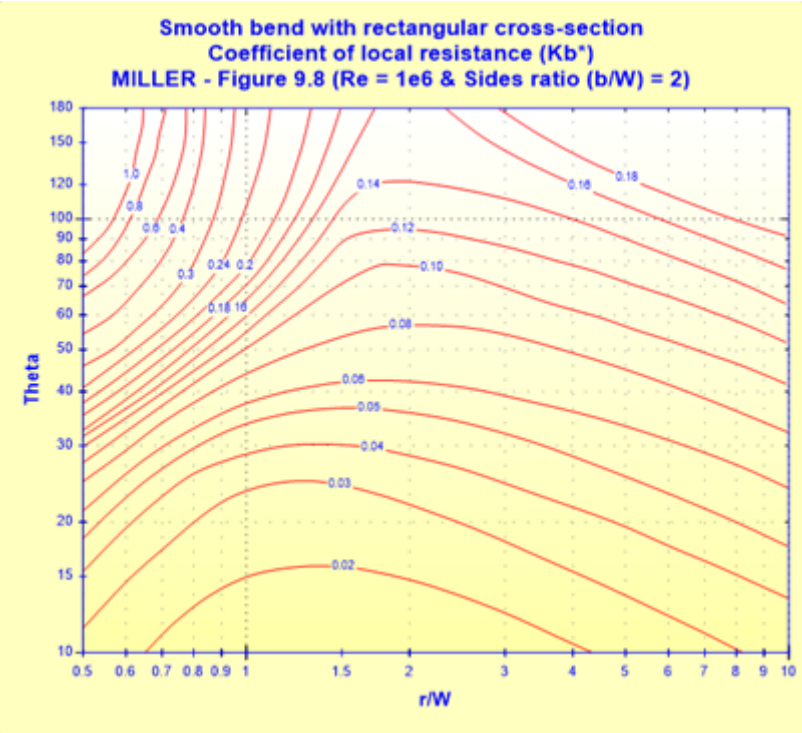
([1] figure 9.6)

■ Sides ratio b/W = 1



([1] figure 9.7)

■ Sides ratio b/W = 2



([1] figure 9.8)

For any sides ratio 'b/W' between 0.5 and 2, the coefficient K_b^* is obtained by curvilinear interpolation between the values of K_b^* calculated for aspect ratios of 0.5, 1 and 2.

Reynolds number correction factor:

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{W}\right)$$

([1] figure 9.3)

- $r/W \geq 1$

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{D}\right)$$ ([1] figure 9.3)

- $r/W < 1$
  - $r/W > 0.7$ or $K_b^* < 0.4$

$$C_{Re} = f\left(\mathrm{Re}, \frac{r}{D}\right)$$ ([1] figure 9.3 with r/W=1)

  - otherwise ($r/W \leq 0.7$ and $K_b^* \geq 0.4$)

$$C_{Re} = \frac{K_b^*}{K_b^* - 0.2C'_{Re} + 0.2}$$ ([1] equation 9.2)

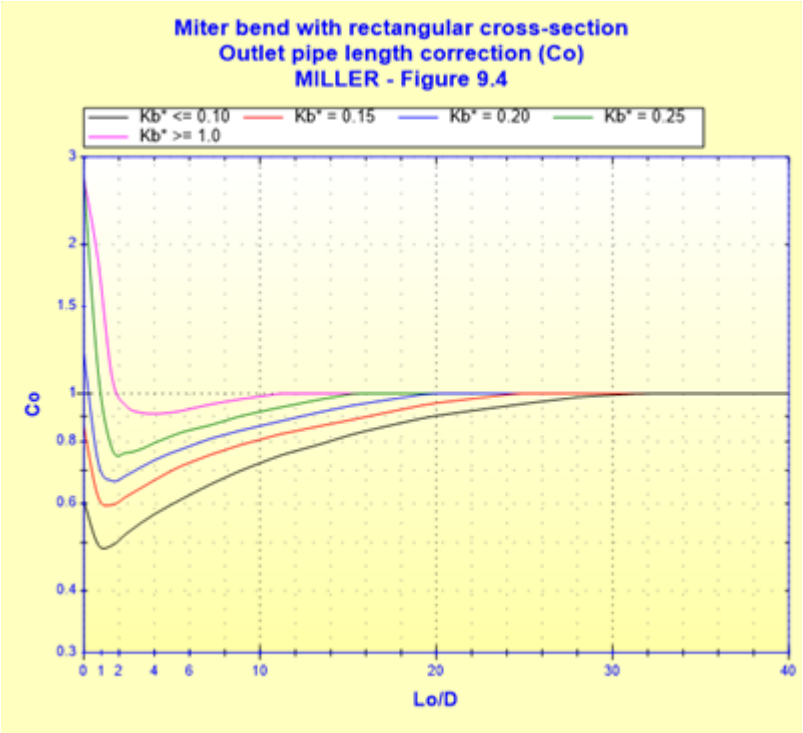
with:

$$C'_{Re} = f\left(\mathrm{Re}, \frac{r}{D}\right)$$ ([1] figure 9.3 with r/W=1)

Outlet pipe length correction factor (optional):

- correction factor for circular cross-section
  - $\theta_b < 100°$

$$C_o = f\left(\frac{L_o}{D}, K_b^*\right)$$ ([1] figure 9.4)



- $\theta_b \geq 100°$

$$C_o = 1$$ (negligible effect)

■ correction factor for rectangular cross-section

- b/W < 0.7 and Lo/D > 1

$$C_{or} = 1 - \frac{1 - C_o}{2}$$

- b/W > 1 and Lo/D < 1
  - ♦ 1.5 < r/W < 3

$$C_{or} = 2$$

  - ♦ r/W ≤ 1.5 or r/W ≥ 3

$$C_{or} = C_o$$

- otherwise

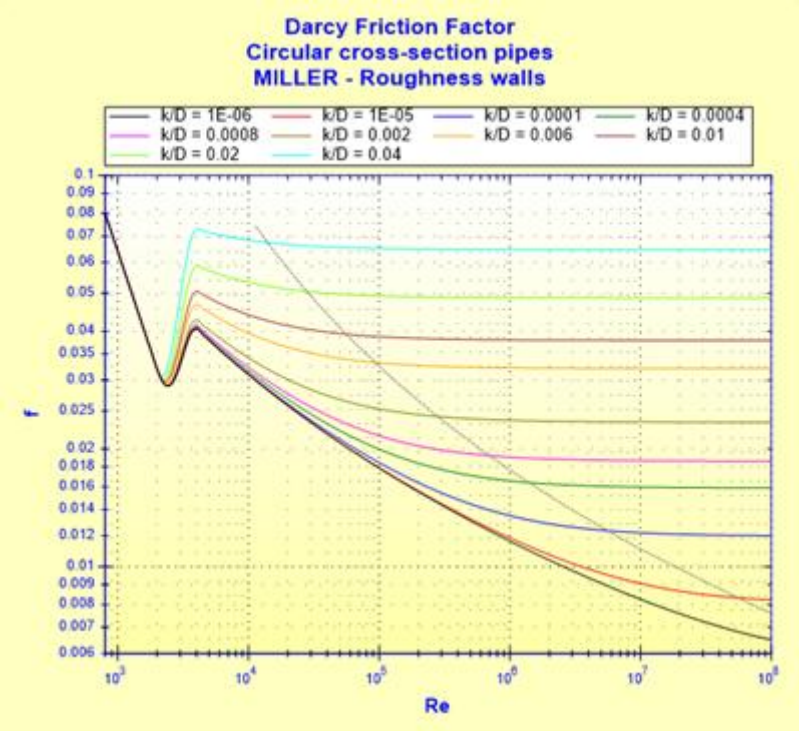
$$C_{or} = C_o$$

If this option is not activated, the factors C_o and C_{or} are equal to unity.

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{D}\right)$$

See Straight Pipe - Rectangular Cross-Section and Roughness Walls (MILLER)



Roughness correction factor:

$$C_f = \frac{f_{rough}}{f_{smooth}}$$ ([1] equation 9.3)

with:

f_{rough}: Darcy friction factor for rough pipe at Re

f_{smooth}: Darcy friction factor for smooth pipe (k = 0) at Re

For Re > 10^6, C_f is calculated from equation (9.3) for Re = 10^6

Corrected loss coefficient for the first bend:

$$K_{b1} = K_b^* \cdot C_{Re} \cdot C_f$$ ([1] equation 9.4)

Corrected loss coefficient for the second bend:

$$K_{b2} = K_b^{\circ} \cdot C_{Re} \cdot C_f \cdot C_o$$

([1] equation 9.4)

Interaction correction factor:

$$C_{b-c} = f\left(\frac{L_s}{D}, \frac{r}{D}\right)$$

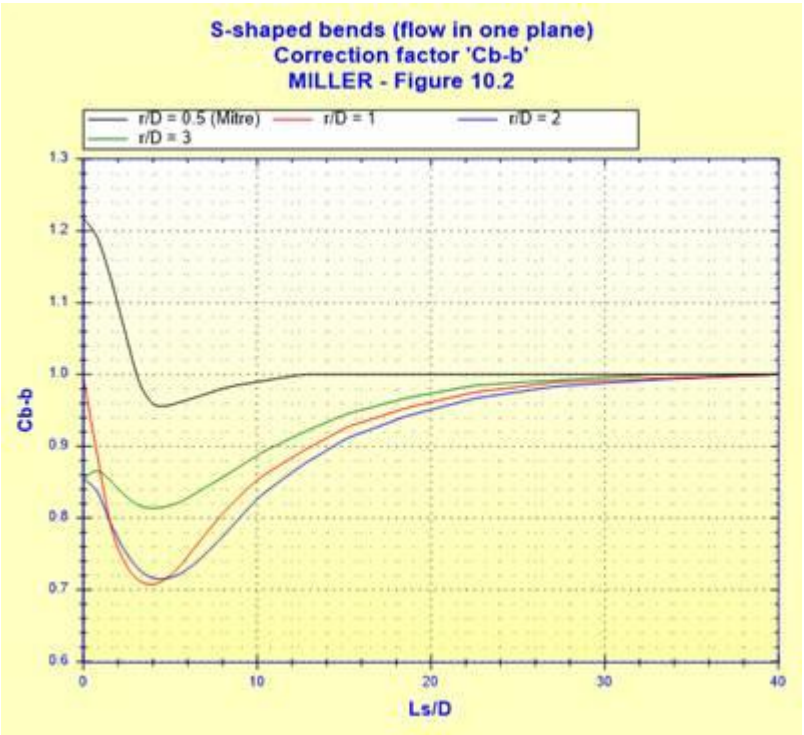
- Aspect ratio b/W < 0.7

([1] figure 10.4)

- Aspect ratio 0.7 ≤ b/W ≤ 1.5

([1] figure 10.4)

- Aspect ratio b/W > 1.5



([1] figure 10.2)

Pressure loss coefficient of the two bends:

- Aspect ratio b/W < 0.7

$$K_{b-b} = (K_{b1} + K_{b2}) \cdot \left[1 - \frac{1 - C_{b-b}}{2}\right]$$

([1] equation 10.1 with correction factor § 10.4)

- Aspect ratio b/W ≥ 0.7

$$K_{b-b} = (K_{b1} + K_{b2}) \cdot C_{b-b}$$

([1] equation 10.1)

Friction loss coefficient of the straight length between bends:

$$K_f = f_{rough} \cdot \frac{L_s}{D}$$

([1] equation 8.3)

Total pressure loss coefficient (based on the mean velocity in the bend):

$$K = K_{b-b} + K_f$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{D}{f_{rough}}$$

Symbols, Definitions, SI Units:

W	Cross-section height (m)
b	Cross-section width (m)

D	Bend hydraulic diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
L_s	Straight length between the two bends (m)
L	Total length measured along the axis (m)
r	Radius of curvature (m)
θ_b	Curvature angle of each bend (°)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
K_b^*	Basic loss coefficient ()
C_{Re}	Reynolds number correction factor ()
C_o	Outlet pipe length correction factor for circular cross-section ()
C_{or}	Outlet pipe length correction factor for rectangular cross-section ()
L_0	Length of the straight section downstream of the bend (m)
f	Darcy friction factor ()
k	Absolute roughness of walls (m)
C_f	Roughness correction factor ()
K_{b1}	Corrected loss coefficient for the first bend ()
K_{b2}	Corrected loss coefficient for the second bend ()
$C_{b\text{-}b}$	Interaction correction factor ()
$K_{b\text{-}b}$	Pressure loss coefficient of the two bends ()
K_f	Friction loss coefficient of the straight length between bends ()
K	Total pressure loss coefficient (based on the mean velocity in the bend) ()
ΔP	Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

L_{eq} Straight length of equivalent pressure loss (m)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream bend
- radius of curvature / hydraulic diameter ratio 'r/D': greater than or egal to 0.5 and lower than or egal to 10

  for ratio 'r/D' greater than 3, the pressure loss coefficient 'K' is estimated by taking into account the interaction correction factor 'Cb-b' corresponding to a ratio 'r/D' of value 3.

- curvature angle: between 10° and 180°

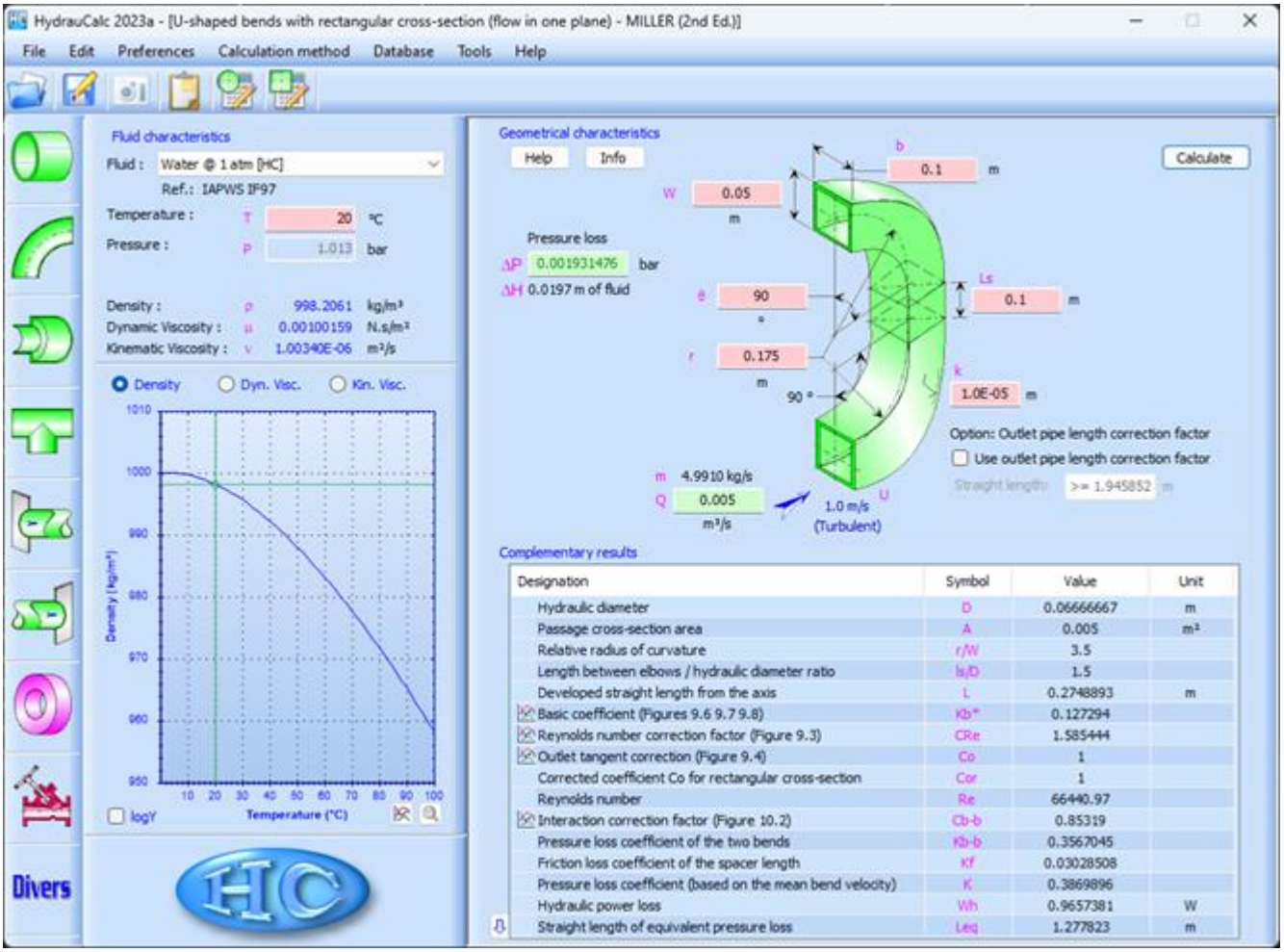
  the interaction correction factor 'Cb-b' is applicable for angles 'θ_b' between 70° and 90°.

  for angles 'θ_b' less than 70° or greater than 90°, the pressure loss coefficient 'K' is estimated by taking into account the interaction factor coefficient 'Cb-b' applicable to angles 'θ_b' between 70° and 90°

- relative radius of curvature 'r/W': between 0.5 and 10
- sides ratio 'b/W': between 0.5 and 2

  note: for any sides ratio 'b/W' less than 0.5, the resistance coefficients K_b^* are obtained by linear extrapolation from the values of K_b^* calculated for sides ratios of 0.5 and 1.
  for any sides ratio 'b/W' greater than 0.5 and 2, the resistance coefficients K_b^* are obtained by linear extrapolation from the values of K_b^* calculated for sides ratios of 1 and 2.

Example of application:



References:

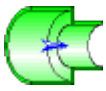
[1] Internal Flow System, Second Edition, D.S. Miller

2.3 Transitions

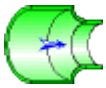
This subsection regroups the set of transitions elements that can be modeled and calculated. The types of transition available are:

- Sudden Expansion - Circular Cross-Section

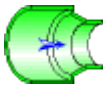
- Sudden Contraction Sharp - Circular Cross-Section



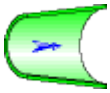
- Sudden Contraction Rounded - Circular Cross-Section



- Sudden Contraction Beveled - Circular Cross-Section

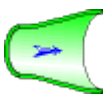


- Gradual Expansion - Circular Cross-Section



- Gradual Contraction - Circular Cross-Section

- Welded Expansion - Circular Cross-Section

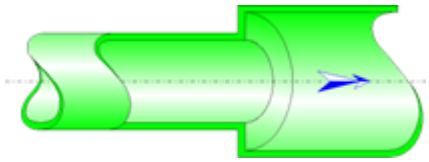


- Welded Contraction - Circular Cross-Section

2.3.1 Sudden expansion - Circular cross-section

Sudden Expansion

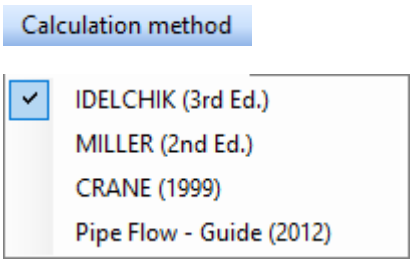
Circular Cross-Section



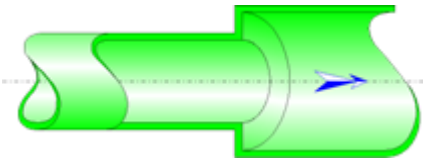
For the calculation of the pressure loss coefficient of sudden expansions, the user can choose from one of the methods described in the following four reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.3.1.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sudden expansion.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Minor cross-sectional area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Major cross-sectional area (m^2):

$$F_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity in minor diameter (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in major diameter (m/s):

$$W_2 = \frac{Q}{F_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in minor diameter:

$$Re_0 = \frac{W_0 \cdot D_0}{\nu}$$

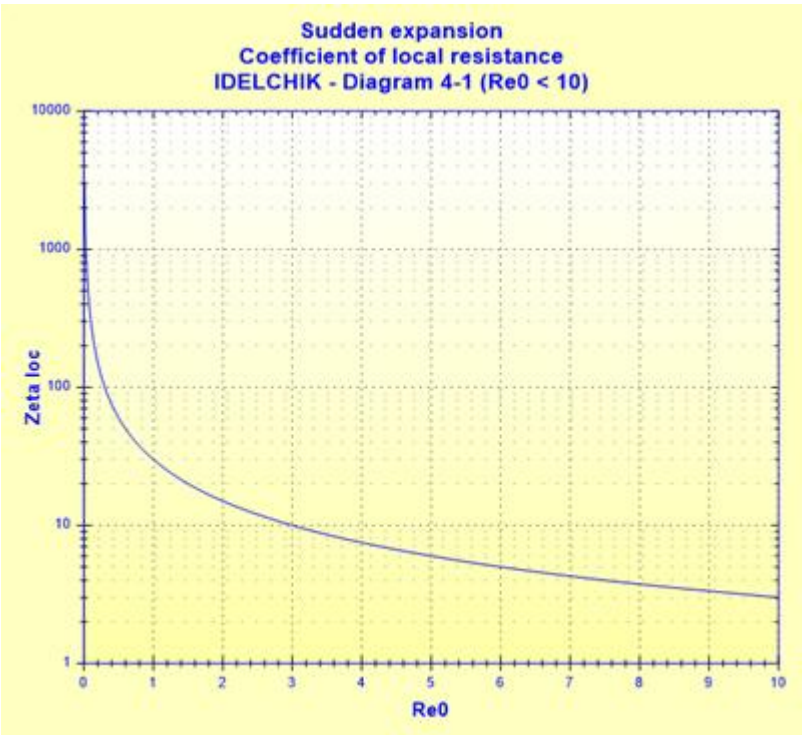
Reynolds number in major diameter:

$$Re_2 = \frac{W_2 \cdot D_2}{\nu}$$

Local resistance coefficient:

- $Re_0 < 10$

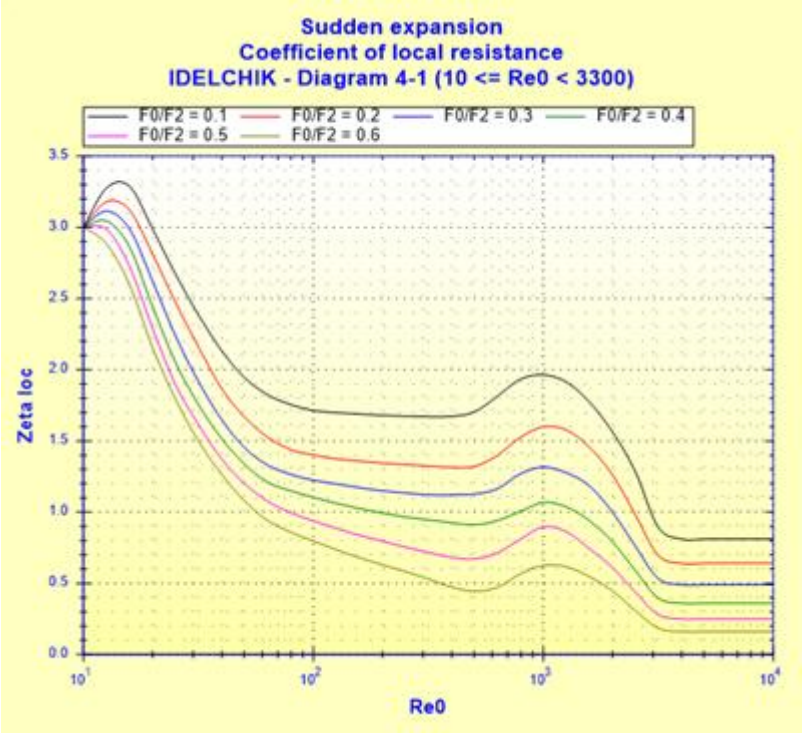
$$\zeta_{loc} = \frac{30}{Re_0}$$ ([1] diagram 4-1)



■ $10 \le Re_0 < 3300$

$$\zeta_{loc} = f\left(Re_0, \frac{F_0}{F_2}\right)$$

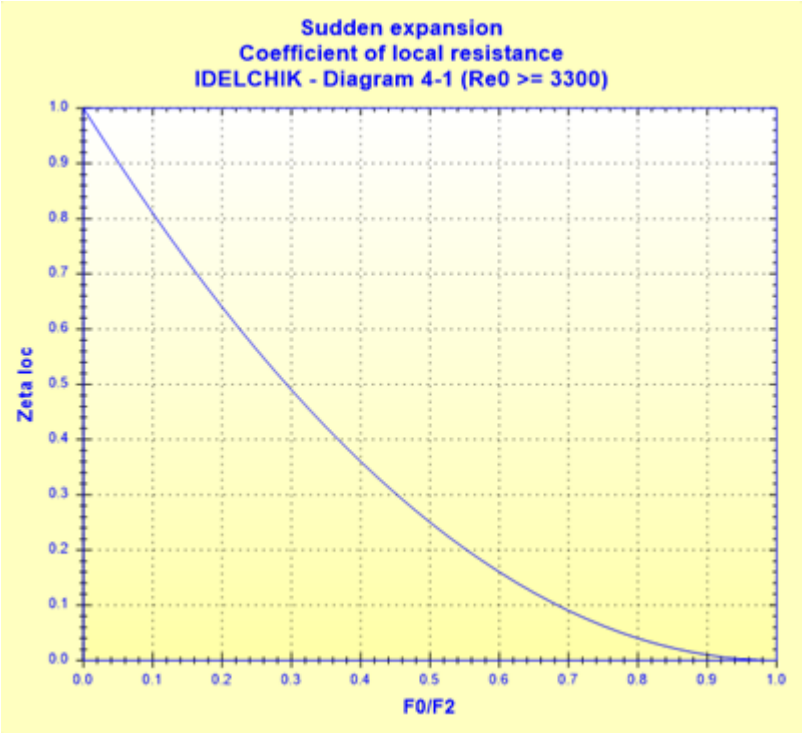
([1] diagram 4-1)



■ $Re_0 \ge 3300$

$$\zeta_{loc} = \left(1 - \frac{F_0}{F_2}\right)^2$$

([1] diagram 4-1)



Total pressure loss coefficient (based on mean velocity in minor diameter):

$$\zeta = \zeta_{loc}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_0	Minor diameter (m)
D_2	Major diameter (m)

F_0	Minor cross-sectional area (m^2)
F_2	Major cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in minor diameter (m/s)
w_2	Mean velocity in major diameter (m/s)
Re_0	Reynolds number in minor diameter ()
Re_2	Reynolds number in major diameter ()
ζ_{loc}	Local resistance coefficient ()
ζ	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

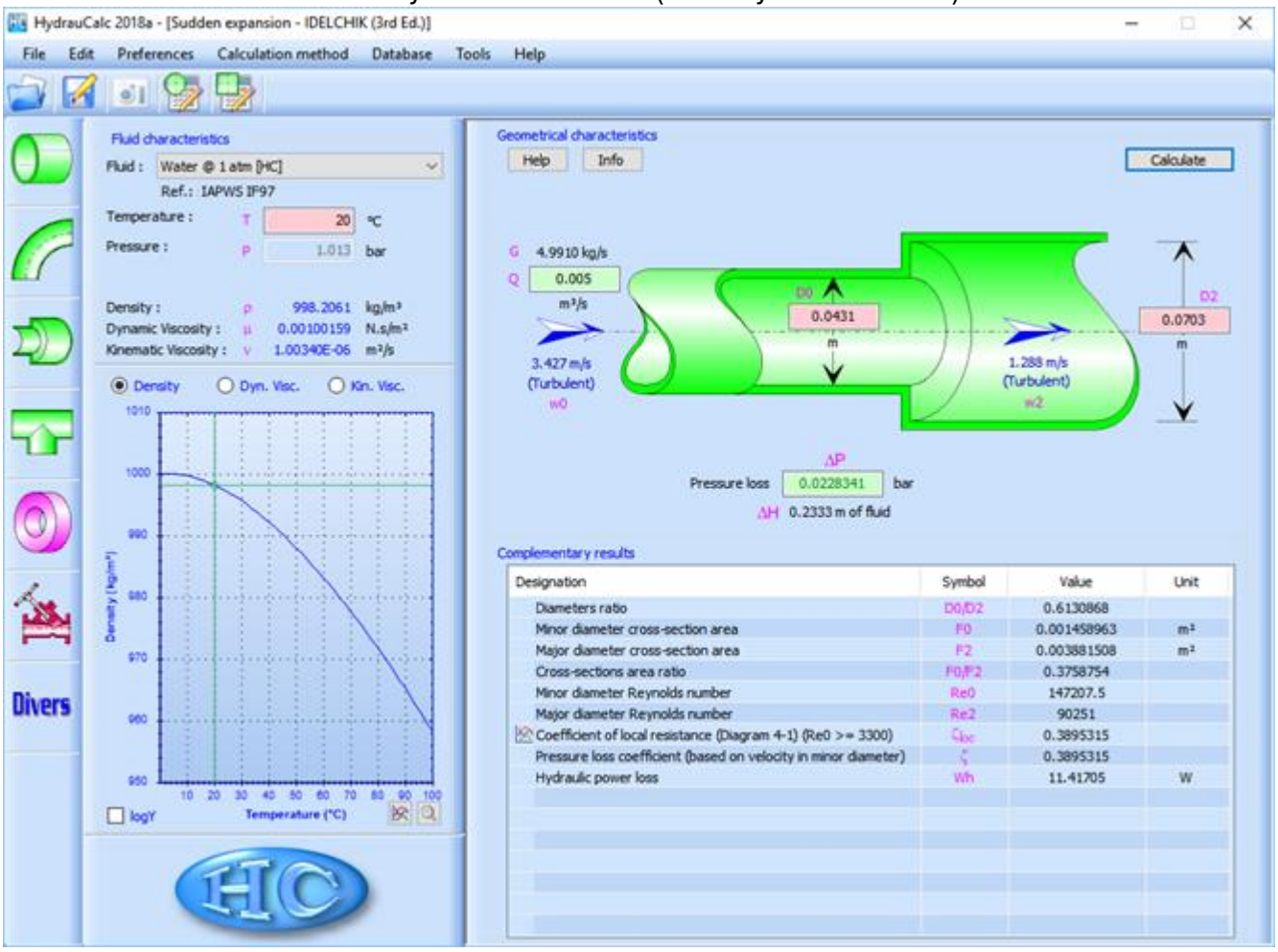
Validity range:

- any flow regime: laminar and turbulent

  note: for Reynolds number "Re_0" between 10 and 3300, and area ratio "F_0/F_2" lower than 0.1 or greater than 0.6, the local pressure loss coefficient is extrapolated

---

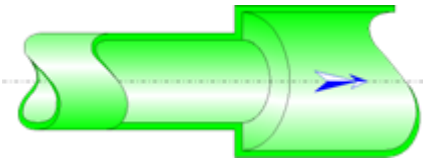
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.3.1.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sudden expansion.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Minor cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Major cross-sectional area (m^2):

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity in minor diameter (m/s):

$$U_1 = \frac{Q}{A_1}$$

Mean velocity in major diameter (m/s):

$$U_2 = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in minor diameter:

$$Re_1 = \frac{U_1 \cdot D_1}{\nu}$$

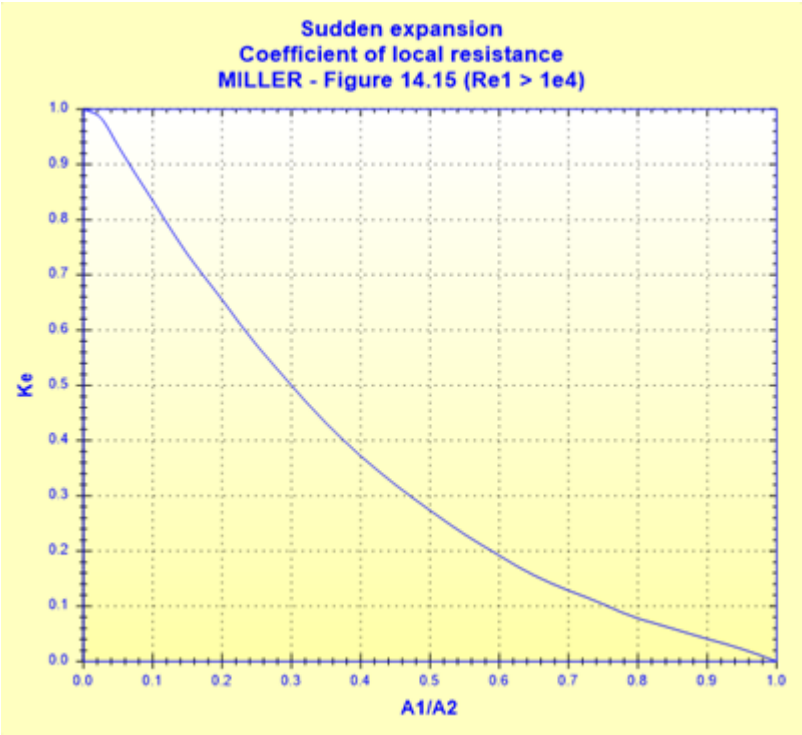
Reynolds number in major diameter:

$$Re_2 = \frac{U_2 \cdot D_2}{\nu}$$

Local resistance coefficient:

- $Re_1 \geq 10^4$

$$K_e = f(A_1 / A_2)$$ ([1] figure 14.15)

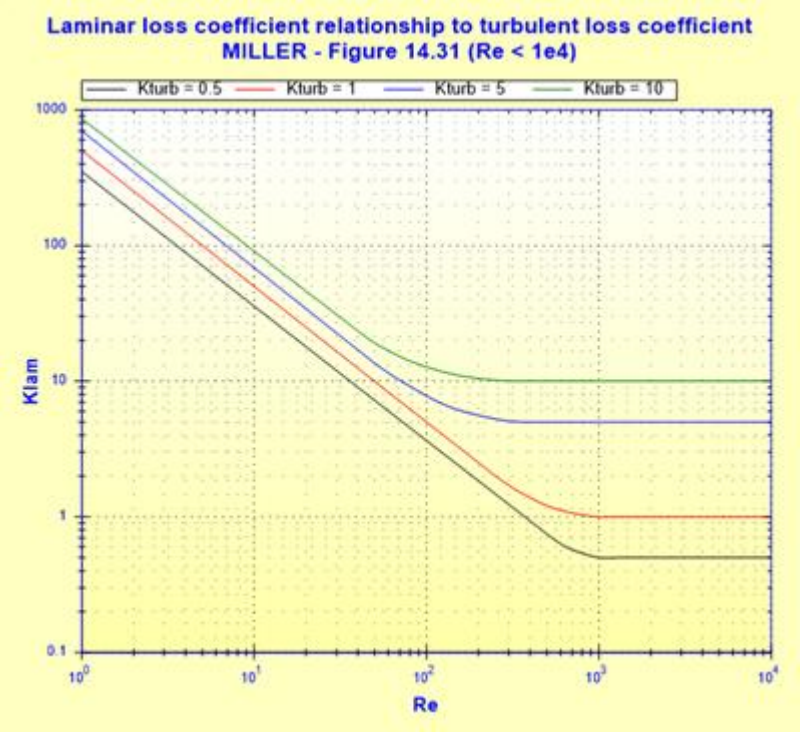


- $Re_1 < 10^4$

$$K_{lam} = f(K_{turb}, Re_1)$$ ([1] figure 14.31)

where:

K_{turb} is the local resistance coefficient in turbulent regime (K_e for $Re_1 = 10^4$ - figure 14.15)



Reynolds Number Correction ($Re_1 < 10^4$):

$$C_{Re} = \frac{K_{lam}}{K_{turb}}$$

Total pressure loss coefficient (based on mean velocity in minor diameter):

- turbulent flow ($Re_1 \geq 10^4$):

$$K = K_e$$

- laminar flow ($Re_1 < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_1	Minor diameter (m)
D_2	Major diameter (m)
A_1	Minor cross-sectional area (m^2)
A_2	Major cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U_1	Mean velocity in minor diameter (m/s)
U_2	Mean velocity in major diameter (m/s)
Re_1	Reynolds number in minor diameter ()
Re_2	Reynolds number in major diameter ()
K_e	Local resistance coefficient for $Re_1 \geq 10^4$ ()
K_{turb}	Local resistance coefficient for $Re_1 = 10^4$ ()
K_{lam}	Local resistance coefficient for $Re_1 < 10^4$ ()
C_{Re}	Reynolds number correction for $Re_1 < 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar and turbulent

  note: for Reynolds number "Re_1" lower than 10^4, and coefficients "K_{turb}" lower than 0.5 or greater than 10, the laminar pressure loss coefficient "K_{lam}" is extrapolated

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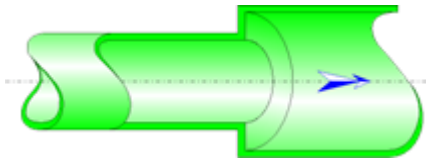
Example of application:

References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.3.1.3 CRANE



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sudden expansion.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of small to large diameter:

$$\beta = \frac{D_1}{D_2}$$

Minor cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Major cross-sectional area (m^2):

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity in minor diameter (m/s):

$$v_1 = \frac{q}{A_1}$$

Mean velocity in major diameter (m/s):

$$v_2 = \frac{q}{A_2}$$

Mass flow rate (kg/s):

$$G = q \cdot \rho$$

Reynolds number in minor diameter:

$$\mathrm{Re}_1 = \frac{v_1 \cdot D_1}{\nu}$$

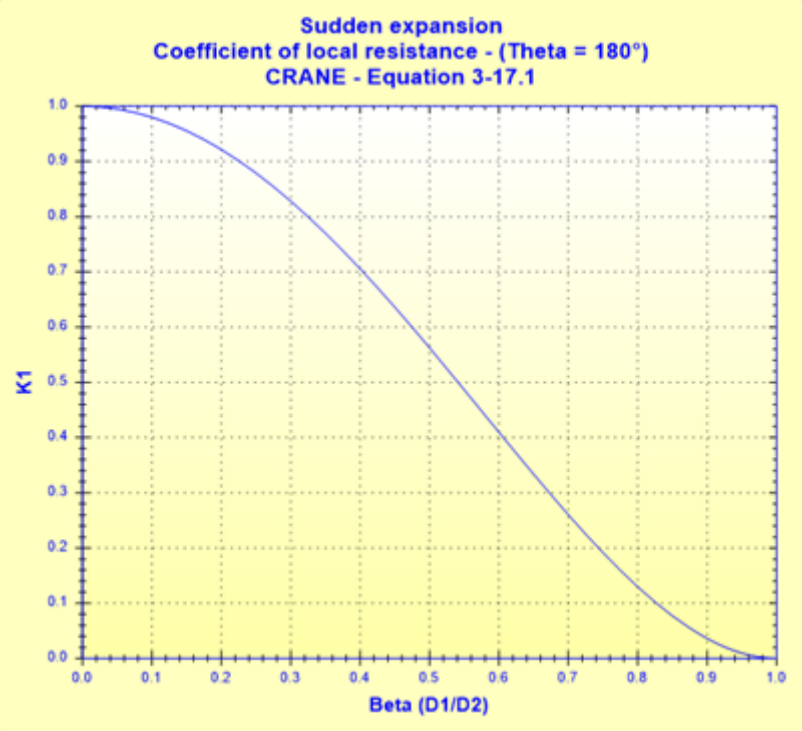
Reynolds number in major diameter:

$$\mathrm{Re}_2 = \frac{v_2 \cdot D_2}{\nu}$$

Local resistance coefficient ($Re_1 \geq 10^4$):

$$K_1 = \left(1 - \beta^2\right)^2$$

([1] equation 3-17.1 with θ=180° or equation 2-9.1)



Total pressure loss coefficient (based on mean velocity in minor diameter):

$$K = K_1$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot V_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot q$$

Symbols, Definitions, SI Units:

D_1 Minor diameter (m)

D_2 Major diameter (m)

β	Ratio of small to large diameter ()
A_1	Minor cross-sectional area (m^2)
A_2	Major cross-sectional area (m^2)
q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
v_1	Mean velocity in minor diameter (m/s)
v_2	Mean velocity in major diameter (m/s)
Re_1	Reynolds number in minor diameter ()
Re_2	Reynolds number in major diameter ()
K_1	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

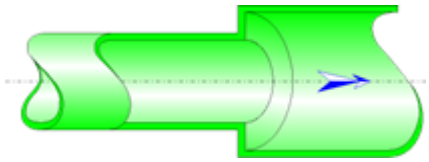
- turbulent flow regime in minor diameter ($Re_1 \geq 10^4$)

Example of application:

References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999

2.3.1.4 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sudden expansion.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of small to large diameter:

$$\beta = \frac{d_1}{d_2}$$

Minor cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Major cross-sectional area (m^2):

$$A_2 = \pi \cdot \frac{d_2^2}{4}$$

Mean velocity in minor diameter (m/s):

$$V_1 = \frac{Q}{A_1}$$

Mean velocity in major diameter (m/s):

$$V_2 = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in minor diameter:

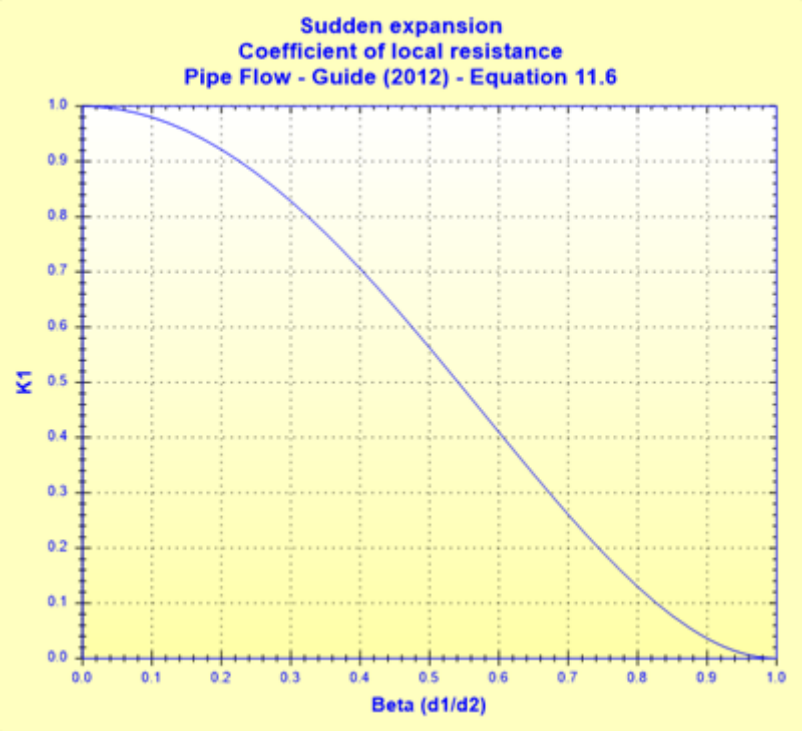
$$N_{Re_1} = \frac{V_1 \cdot d_1}{\nu}$$

Reynolds number in major diameter:

$$N_{Re_2} = \frac{V_2 \cdot d_2}{\nu}$$

Local resistance coefficient ($Re_1 \geq 10^4$):

$$K_1 = \left(1 - \beta^2\right)^2$$ ([1] equation 11.6) (Borda-Carnot equation)



Total pressure loss coefficient (based on mean velocity in minor diameter):

$$K = K_1$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_1 Minor diameter (m)

d_2 Major diameter (m)

β	Ratio of small to large diameter ()
A_1	Minor cross-sectional area (m^2)
A_2	Major cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_1	Mean velocity in minor diameter (m/s)
V_2	Mean velocity in major diameter (m/s)
NRe_1	Reynolds number in minor diameter ()
NRe_2	Reynolds number in major diameter ()
K_1	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in minor diameter ($NRe_1 \geq 10^4$)

Example of application:

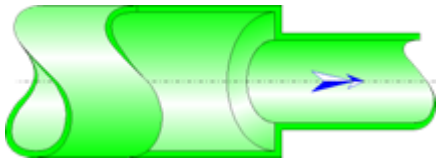
References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.3.2 Sudden contraction sharp - Circular cross-section

Sudden Contraction Sharp

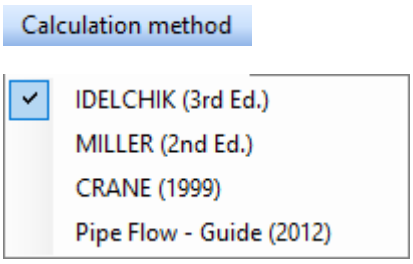
Circular Cross-Section



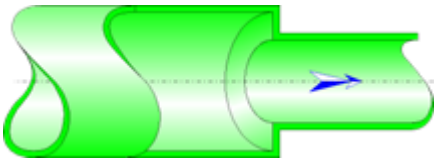
For the calculation of the pressure loss coefficient of sudden contractions sharp, the user can choose from one of the methods described in the following four reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.3.2.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sudden contraction sharp.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Minor cross-sectional area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Major cross-sectional area (m^2):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Mean velocity in minor diameter (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in major diameter (m/s):

$$W_1 = \frac{Q}{F_1}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in minor diameter:

$$Re_0 = \frac{W_0 \cdot D_0}{\nu}$$

Reynolds number in major diameter:

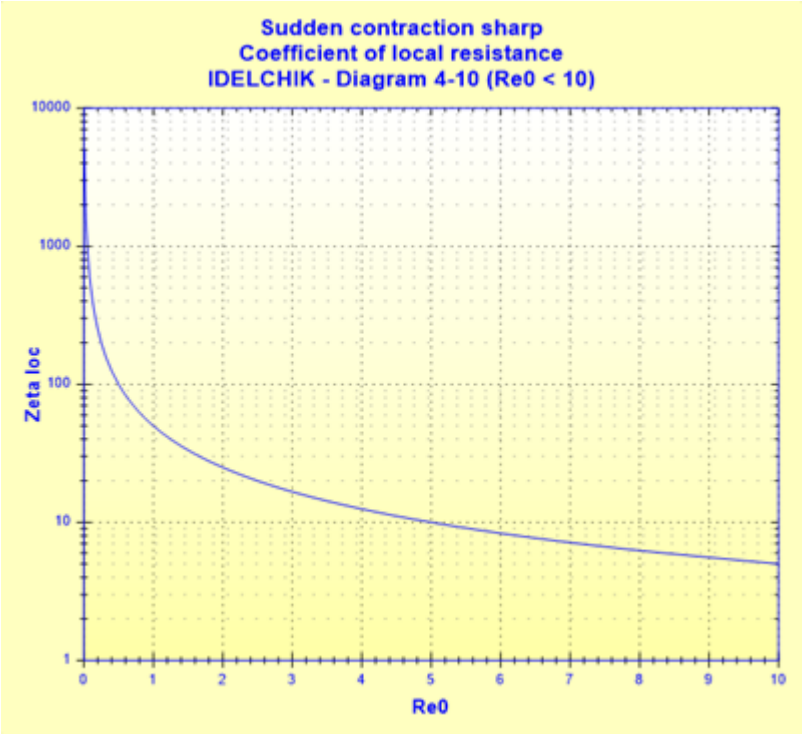
$$Re_1 = \frac{W_1 \cdot D_1}{\nu}$$

Local resistance coefficient:

- $Re_0 < 10$

$$\zeta_{loc} = \frac{50}{Re_0}$$

([1] diagram 4.10)



■ $10 \le Re_0 < 10^4$

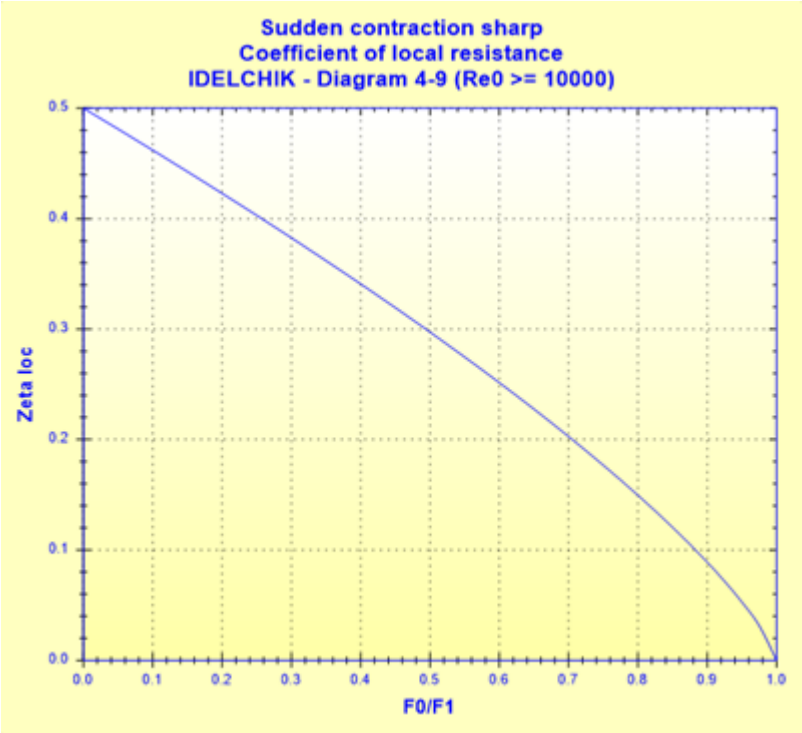
$$\zeta_{loc} = f\left(Re_0, \frac{F_0}{F_1}\right)$$

([1] diagram 4.10)

■ $Re_0 \ge 10^4$

$$\zeta_{loc} = 0.5\left(1 - \frac{F_0}{F_1}\right)^{3/4}$$

([1] diagram 4.9)



Total pressure loss coefficient (based on mean velocity in minor diameter):

$$\zeta = \zeta_{loc}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_0 Minor diameter (m)

D_1 Major diameter (m)

F_0	Minor cross-sectional area (m^2)
F_1	Major cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in minor diameter (m/s)
w_1	Mean velocity in major diameter (m/s)
Re_0	Reynolds number in minor diameter ()
Re_1	Reynolds number in major diameter ()
ζ_{loc}	Local resistance coefficient ()
ζ	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent

  note: for Reynolds number "Re_0" between 10 and 10^4, and area ratio "F_0/F_1" lower than 0.1 or greater than 0.6, the local pressure loss coefficient is extrapolated

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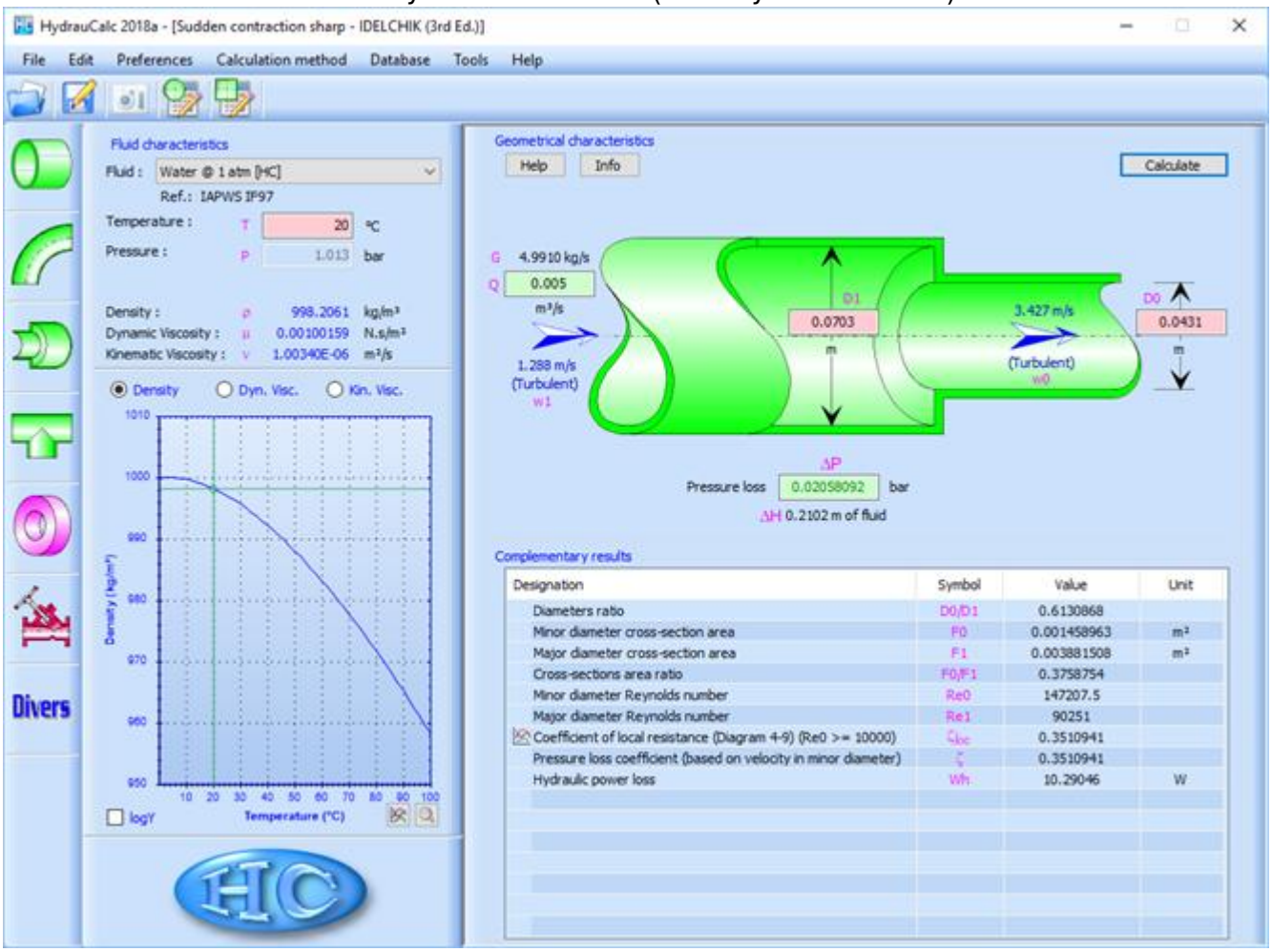
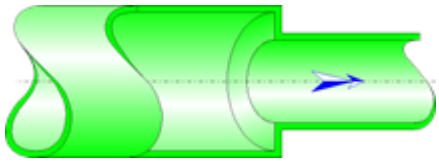
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.3.2.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sudden contraction sharp.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Major cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Minor cross-sectional area (m^2):

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity in major diameter (m/s):

$$U_1 = \frac{Q}{A_1}$$

Mean velocity in minor diameter (m/s):

$$U_2 = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in major diameter:

$$Re_1 = \frac{U_1 \cdot D_1}{\nu}$$

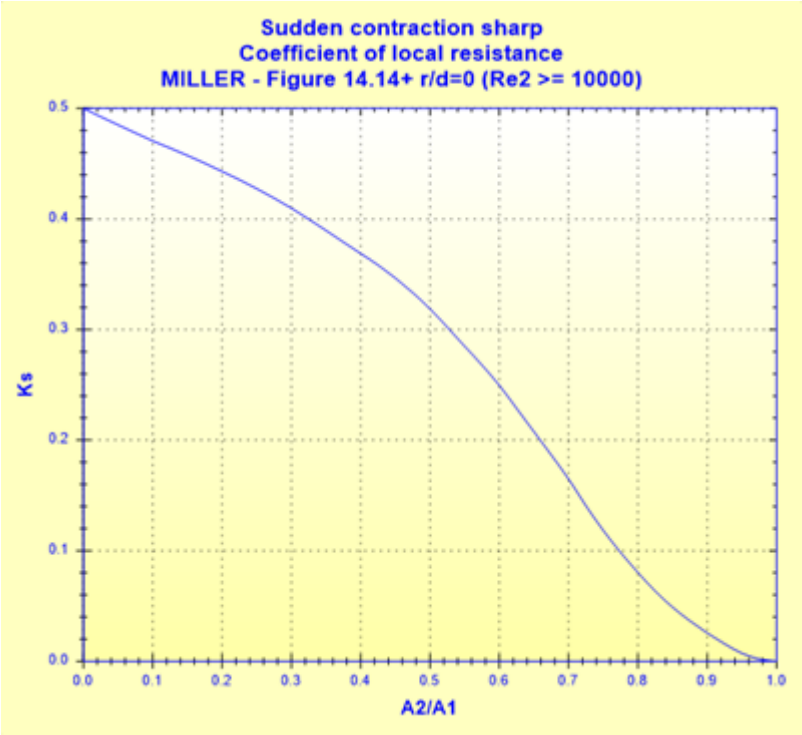
Reynolds number in minor diameter:

$$Re_2 = \frac{U_2 \cdot D_2}{\nu}$$

Local resistance coefficient :

$$K_s = f\left(\frac{A_2}{A_1}\right)$$

([1] figure 14.14+ r/d=0)

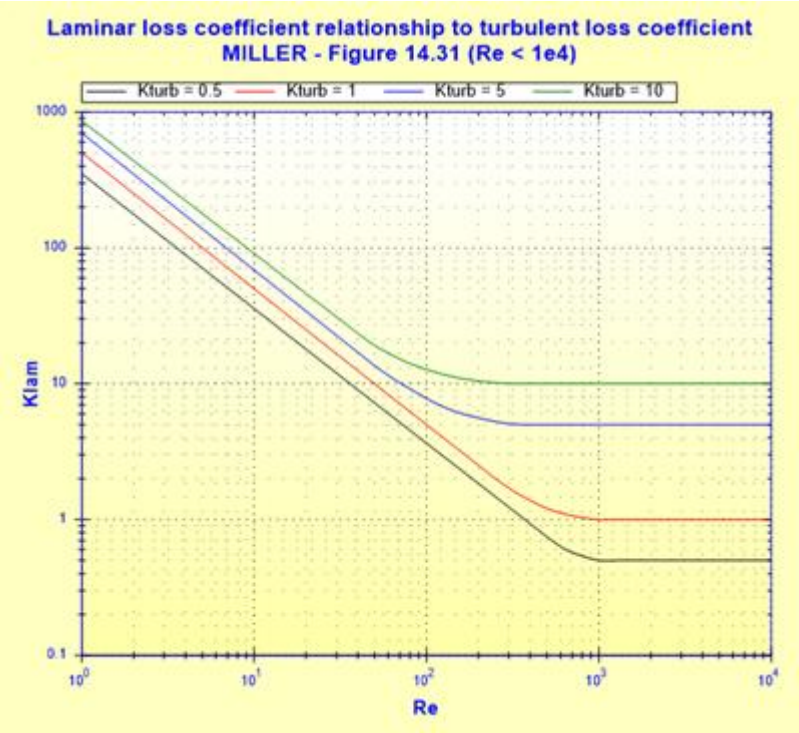


- $Re_2 < 10^4$

$$K_{lam} = f(K_{turb}, Re_2)$$ ([1] figure 14.31)

where:

K_{turb} is the local resistance coefficient in turbulent regime (K_s for $Re_2 = 10^4$ - figure 14.14+ r/d=0)



Reynolds Number Correction ($Re_2 < 10^4$):

$$C_{Re} = \frac{K_{lam}}{K_{turb}}$$

Total pressure loss coefficient (based on mean velocity in minor diameter):

- turbulent flow ($Re_2 \geq 10^4$):

$$K = K_s$$

- laminar flow ($Re_2 < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U_2^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U_2^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_1	Major diameter (m)
D_2	Minor diameter (m)
A_1	Major cross-sectional area (m^2)
A_2	Minor cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U_1	Mean velocity in major diameter (m/s)
U_2	Mean velocity in minor diameter (m/s)
Re_1	Reynolds number in major diameter ()
Re_2	Reynolds number in minor diameter ()
K_s	Local resistance coefficient for $Re_2 \geq 10^4$ ()
K_{turb}	Local resistance coefficient for $Re_2 = 10^4$ ()
K_{lam}	Local resistance coefficient for $Re_2 < 10^4$ ()
C_{Re}	Reynolds number correction for $Re_2 < 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar and turbulent
  note: for Reynolds number "Re_2" lower than 10^4, and coefficients "K_{turb}" lower than 0.5 or greater than 10, the laminar pressure loss coefficient is extrapolated

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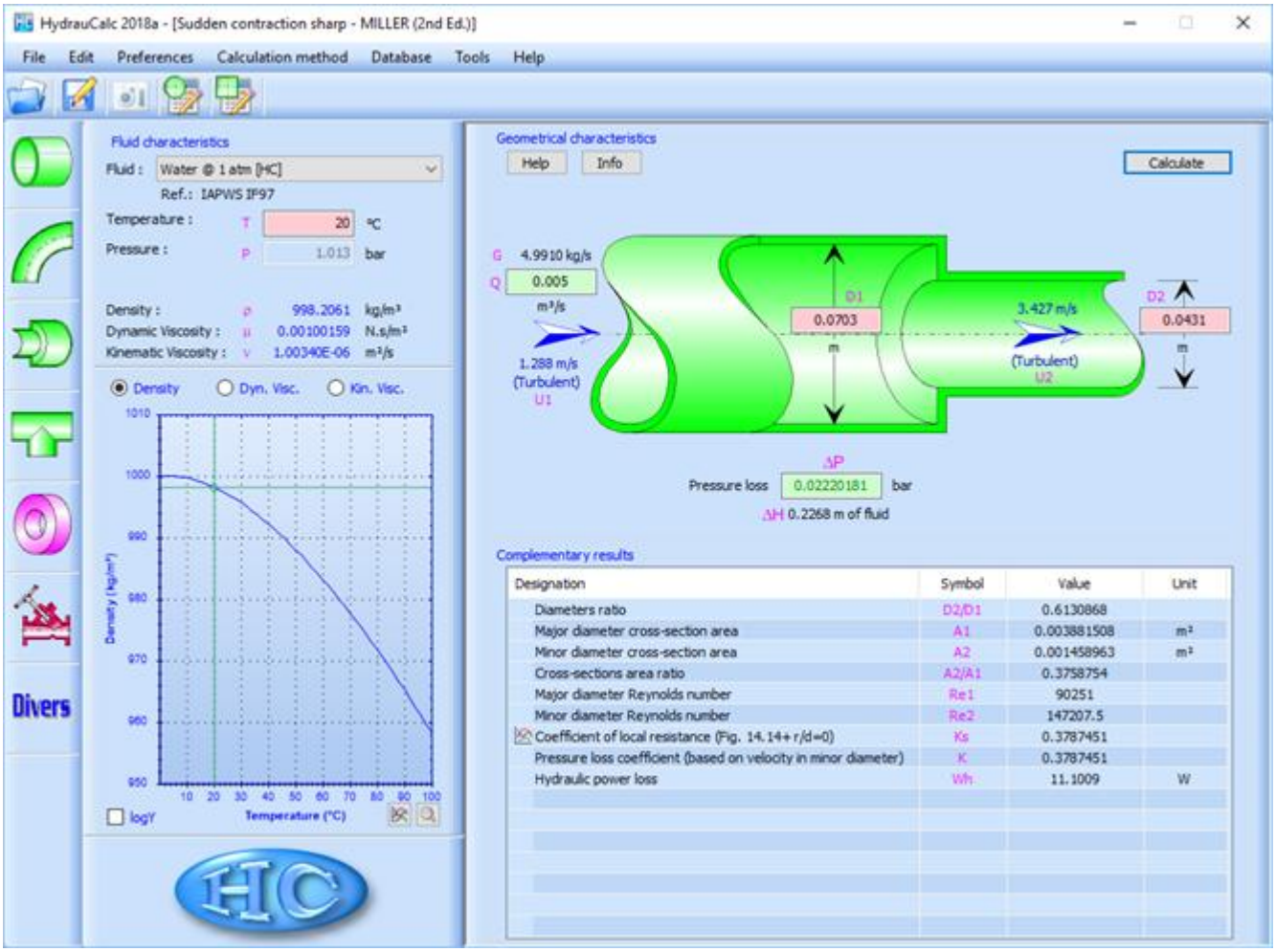
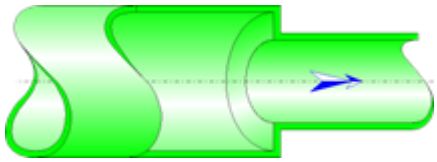
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.3.2.3 CRANE



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sudden contraction sharp.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of small to large diameter:

$$\beta = \frac{D_1}{D_2}$$

Minor cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Major cross-sectional area (m^2):

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity in minor diameter (m/s):

$$v_1 = \frac{q}{A_1}$$

Mean velocity in major diameter (m/s):

$$v_2 = \frac{q}{A_2}$$

Mass flow rate (kg/s):

$$G = q \cdot \rho$$

Reynolds number in minor diameter:

$$\mathrm{Re}_1 = \frac{v_1 \cdot D_1}{\nu}$$

Reynolds number in major diameter:

$$\mathrm{Re}_2 = \frac{v_2 \cdot D_2}{\nu}$$

Local resistance coefficient ($Re_1 \geq 10^4$):

$$K_1 = 0.5 \cdot \left(1 - \beta^2\right)$$ ([1] equation 2-10.1)

or

$$K_1 = 0.5 \sqrt{\sin\left(\frac{\theta}{2}\right)} \left(1 - \beta^2\right)$$ ([1] equation 3-18.1 with θ=180°)

Total pressure loss coefficient (based on mean velocity in minor diameter):

$$K = K_1$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot V_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_1 Minor diameter (m)

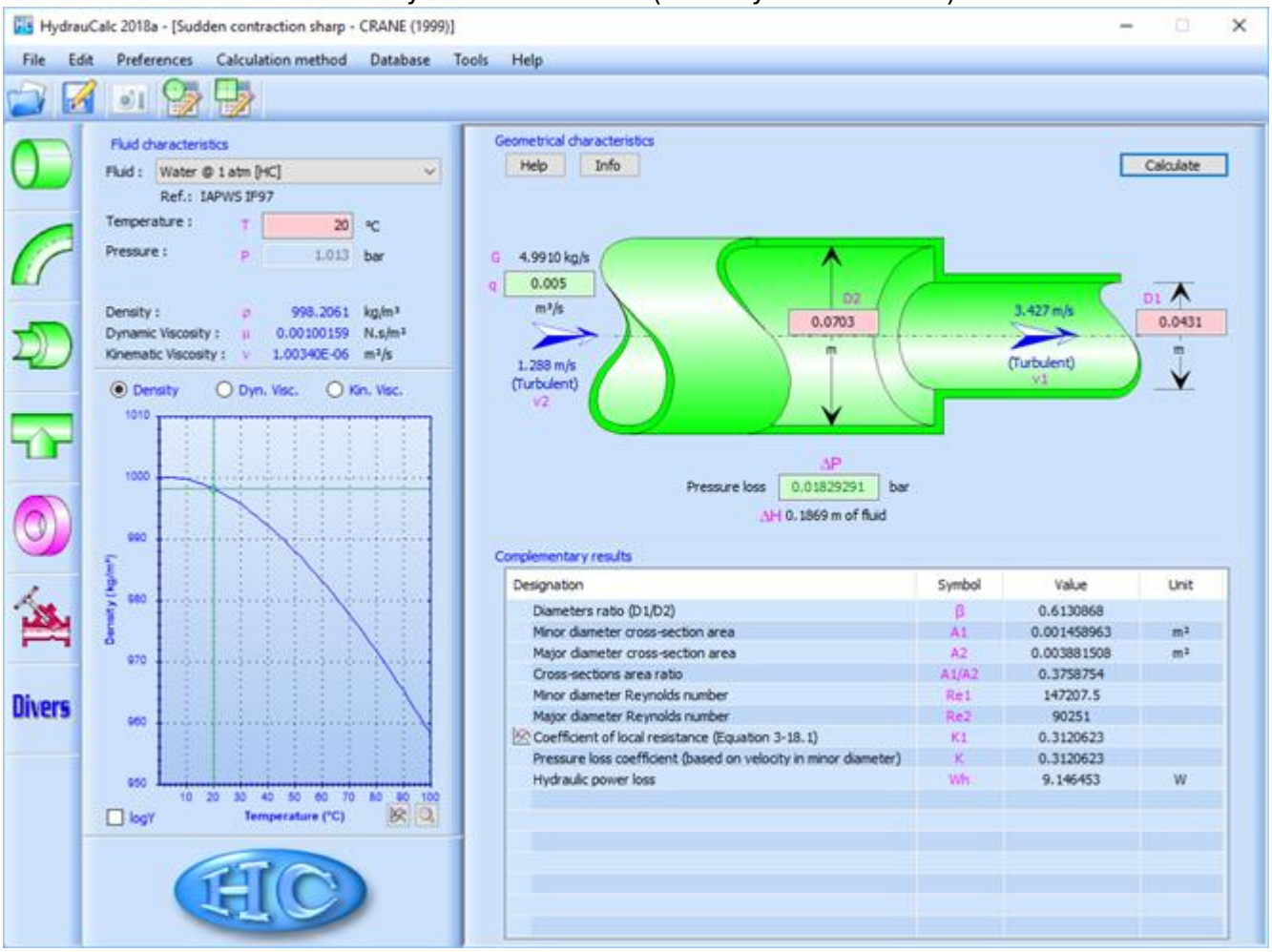
D_2 Major diameter (m)

β	Ratio of small to large diameter ()
A_1	Minor cross-sectional area (m^2)
A_2	Major cross-sectional area (m^2)
q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
v_1	Mean velocity in minor diameter (m/s)
v_2	Mean velocity in major diameter (m/s)
Re_1	Reynolds number in minor diameter ()
Re_2	Reynolds number in major diameter ()
K_1	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in minor diameter ($Re_1 \geq 10^4$)

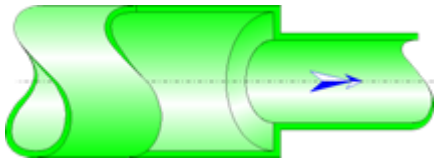
Example of application:



References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 – Edition 1999

2.3.2.4 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sudden contraction sharp.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of small to large diameter:

$$\beta = \frac{d_2}{d_1}$$

Major cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Minor cross-sectional area (m^2):

$$A_2 = \pi \cdot \frac{d_2^2}{4}$$

Mean velocity in major diameter (m/s):

$$V_1 = \frac{Q}{A_1}$$

Mean velocity in minor diameter (m/s):

$$V_2 = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in major diameter:

$$N_{Re_1} = \frac{V_1 \cdot d_1}{\nu}$$

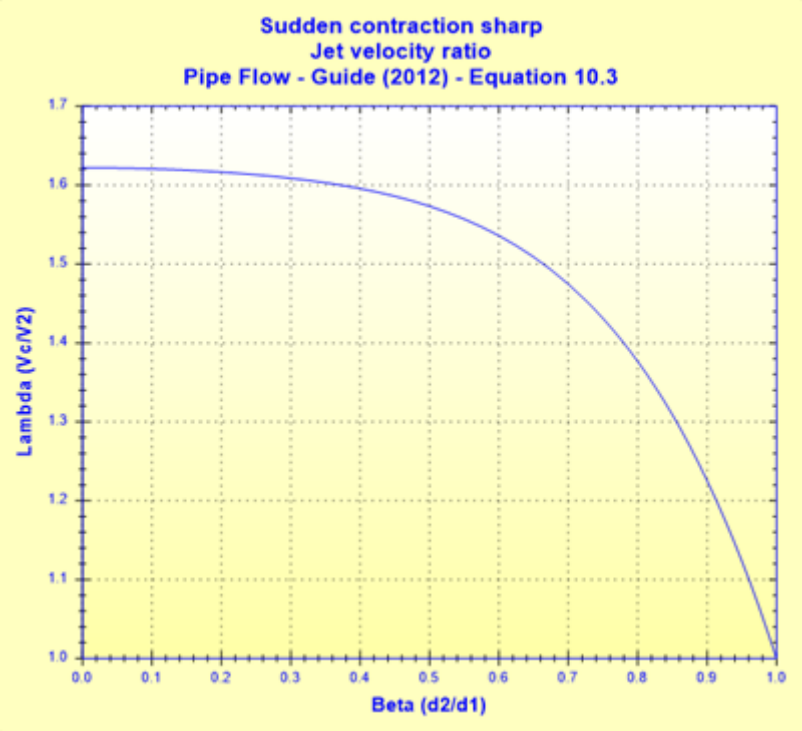
Reynolds number in minor diameter:

$$N_{Re_2} = \frac{V_2 \cdot d_2}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left(1 - 0.215\beta^2 - 0.785\beta^5\right)$$

([1] equation 10.3)



Velocity in vena contracta:

$$V_c = V_2 \cdot \lambda$$

Local resistance coefficient ($NRe_2 \geq 10^4$):

$$K_2 = 0.0696 \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + (\lambda - 1)^2$$

([1] equation 10.4)

Total pressure loss coefficient (based on mean velocity in minor diameter):

$$K = K_2$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot v_2^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v_2^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_1 Major diameter (m)

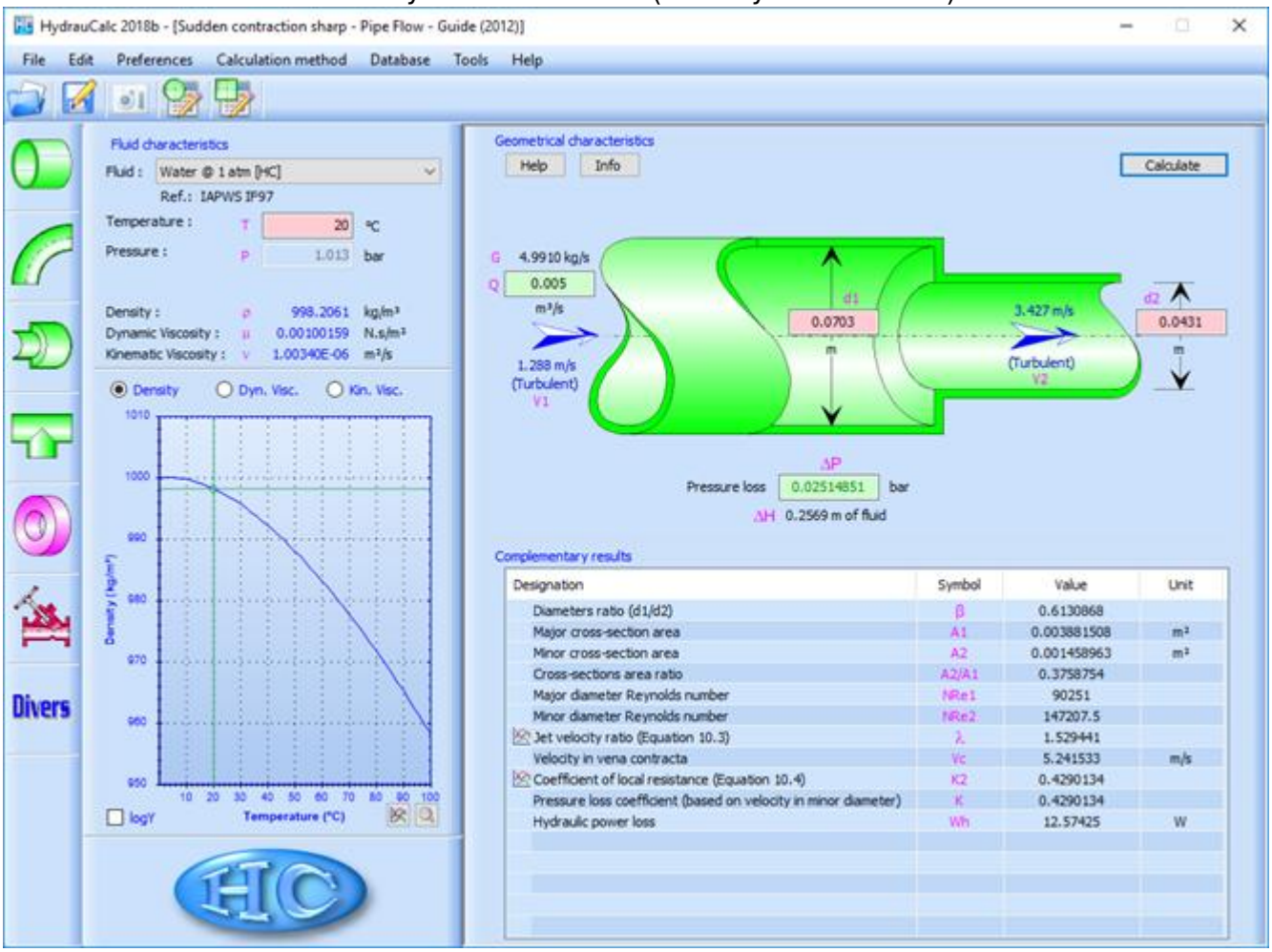
d_2 Minor diameter (m)

β	Ratio of small to large diameter ()
A_1	Major cross-sectional area (m^2)
A_2	Minor cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_1	Mean velocity in major diameter (m/s)
V_2	Mean velocity in minor diameter (m/s)
NRe_1	Reynolds number in major diameter ()
NRe_2	Reynolds number in minor diameter ()
V_c	Mean velocity in vena contracta (m/s)
λ	Jet velocity ratio ()
K_2	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in minor diameter ($NRe_2 \geq 10^4$)

Example of application:



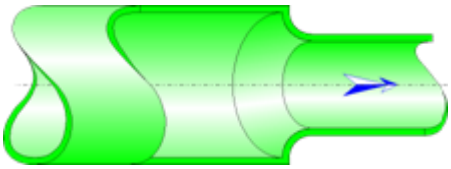
References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.3.3 Sudden contraction rounded - Circular cross-section

Sudden Contraction Rounded

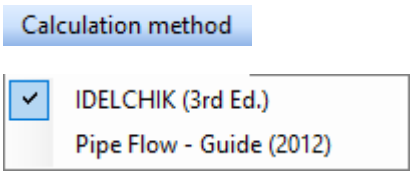
Circular Cross-Section



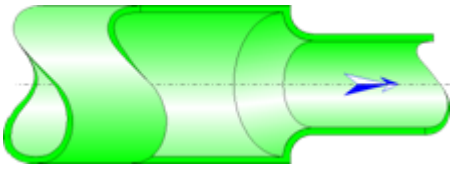
For the calculation of the pressure loss coefficient of sudden contractions rounded, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.3.3.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sudden contraction rounded.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of small to large diameter:

$$\beta = \frac{D_0}{D_1}$$

Minor cross-sectional area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Major cross-sectional area (m^2):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Mean velocity in minor diameter (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in major diameter (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in minor diameter:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

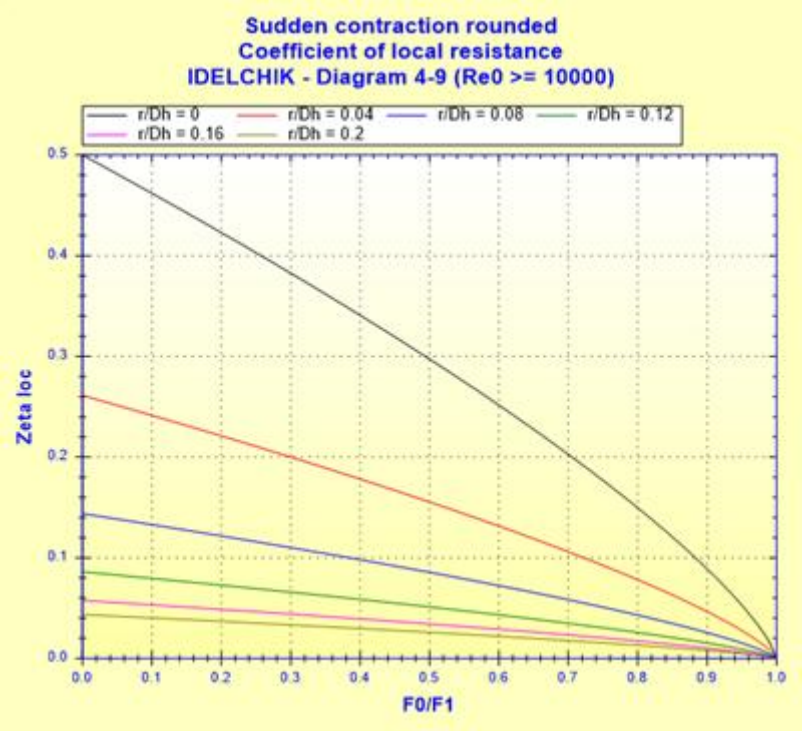
Reynolds number in major diameter:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Local resistance coefficient:

$$\zeta_{loc} = \zeta' \cdot \left(1 - \frac{F_0}{F_1}\right)^{3/4}$$

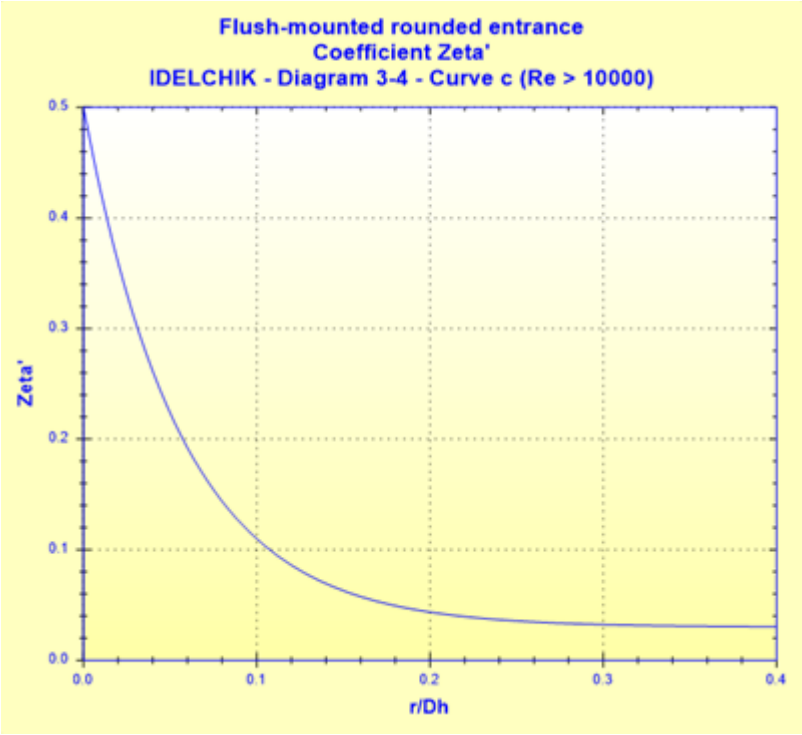
([1] diagram 4-9)



with:

$$\zeta' = 0.03 + 0.47 \cdot 10^{-7.7 \cdot \frac{r}{D_h}}$$

([1] diagram 3-4 Curve c)



Total pressure loss coefficient (based on mean velocity in minor diameter):

$$\zeta = \zeta_{loc}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_0	Minor diameter (m)
D_1	Major diameter (m)
β	Ratio of small to large diameter ()
F_0	Minor cross-sectional area (m^2)
F_1	Major cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in minor diameter (m/s)
w_1	Mean velocity in major diameter (m/s)
Re_0	Reynolds number in minor diameter ()
Re_1	Reynolds number in major diameter ()
r	Radius of the round (m)
ζ_{loc}	Local resistance coefficient ()
ζ	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

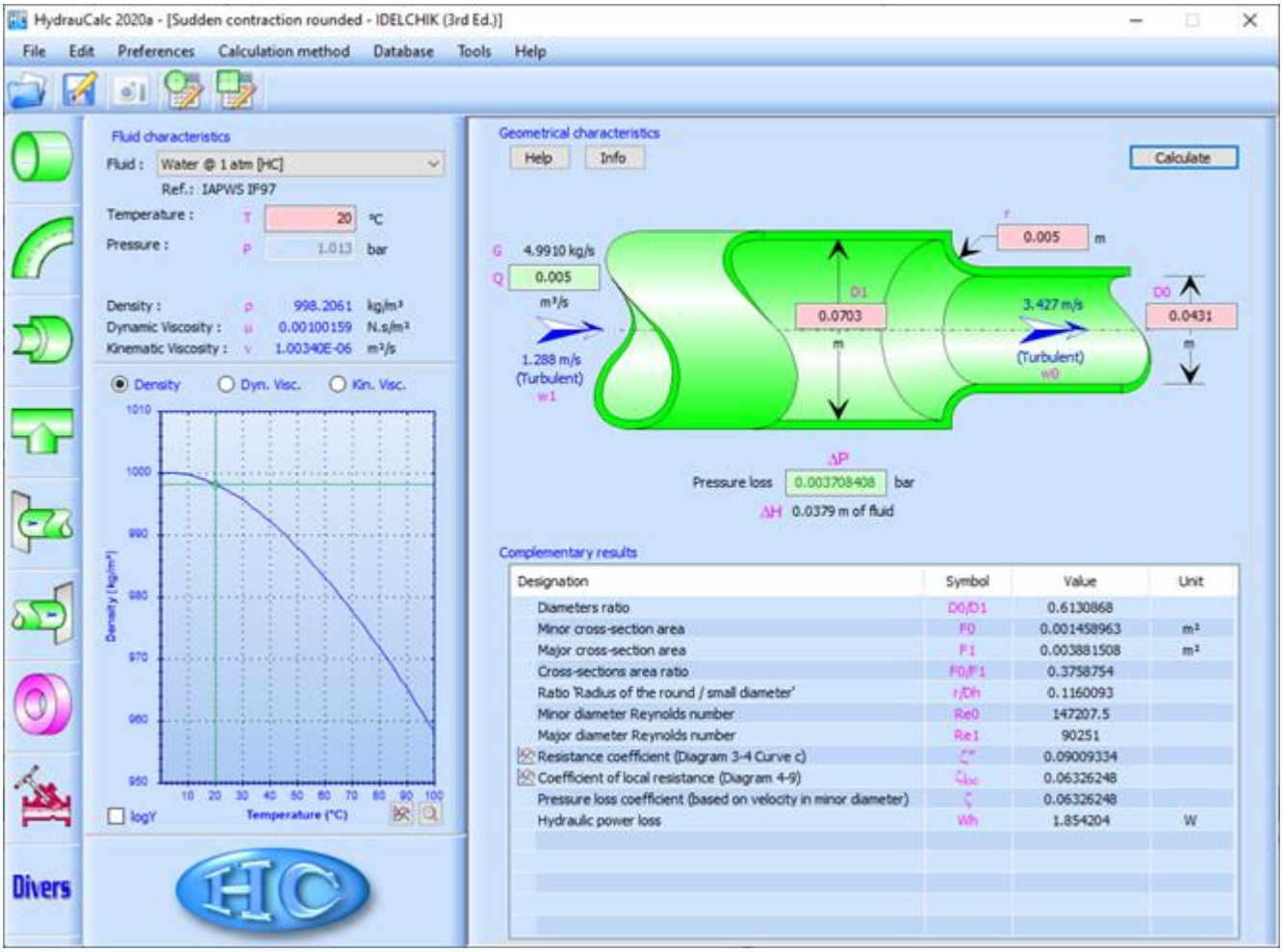
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime in minor diameter ($Re_0 \geq 10^4$)
- round radius less than the radius difference ($r < (D_1/2-D_0/2)$)

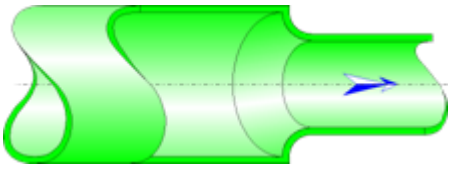
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.3.3.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sudden contraction rounded.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of small to large diameter:

$$\beta = \frac{d_2}{d_1}$$

Major cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Minor cross-sectional area (m^2):

$$A_2 = \pi \cdot \frac{d_2^2}{4}$$

Mean velocity in major diameter (m/s):

$$V_1 = \frac{Q}{A_1}$$

Mean velocity in minor diameter (m/s):

$$V_2 = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in major diameter:

$$N_{Re_1} = \frac{V_1 \cdot d_1}{\nu}$$

Reynolds number in minor diameter:

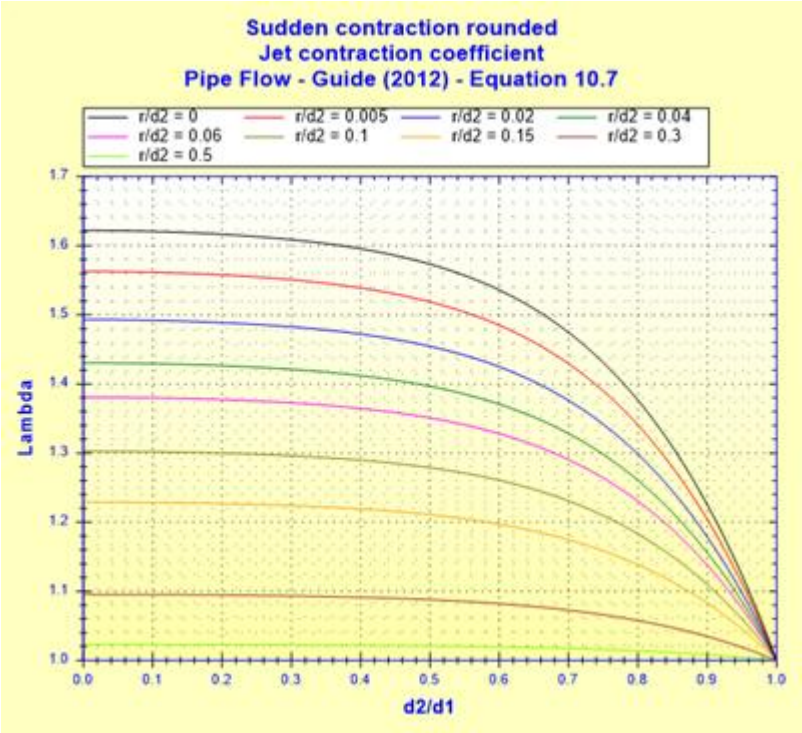
$$N_{Re_2} = \frac{V_2 \cdot d_2}{\nu}$$

Jet contraction coefficient:

- $0 \le r/d_2 \le 1$:

$$\lambda = 1 + 0.622 \cdot \left(1 - 0.30 \cdot \sqrt{\frac{r}{d_2}} - 0.70 \cdot \frac{r}{d_2} \right)^4 \cdot \left(1 - 0.215 \cdot \beta^2 - 0.785 \cdot \beta^5 \right)$$

([1] equation 10.7)



- $r/d_2 > 1$:

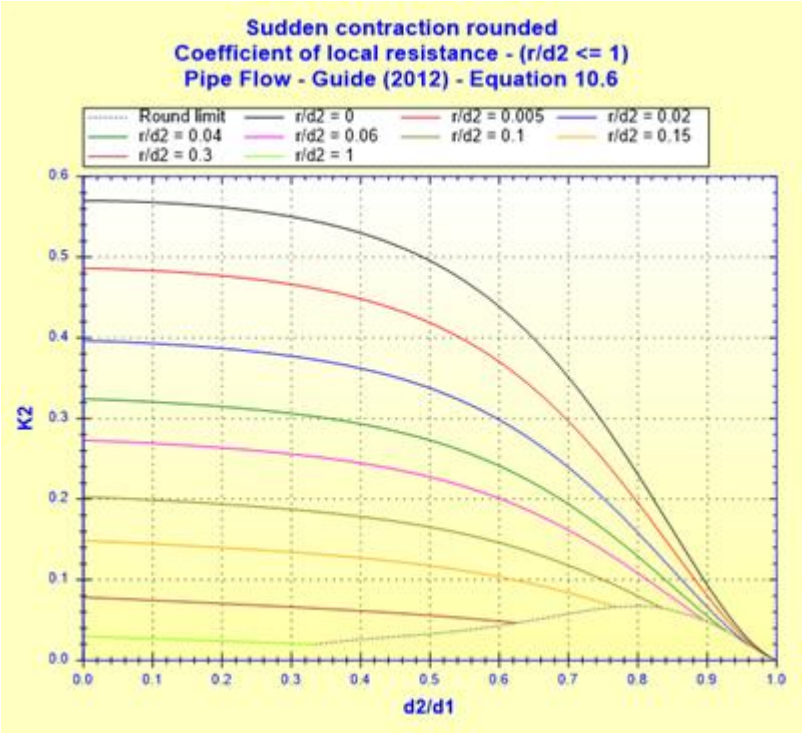
$$\lambda = 1$$

Local resistance coefficient ($NRe_2 \geq 10^4$):

- $0 \leq r/d_2 \leq 1$:

$$K_2 = 0.0696 \cdot \left(1 - 0.569 \cdot \frac{r}{d_2}\right) \cdot \left(1 - \sqrt{\frac{r}{d_2}} \cdot \beta\right) \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + (\lambda - 1)^2$$

([1] equation 10.6)



■ $r/d_2 > 1$:

$$K_2 = 0.030 \cdot (1-\beta) \cdot \left(1-\beta^4\right)$$

([1] equation 10.8)

Total pressure loss coefficient (based on mean velocity in minor diameter):

$$K = K_2$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot v_2^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v_2^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_1	Major diameter (m)
d_2	Minor diameter (m)
β	Ratio of small to large diameter ()
A_1	Major cross-sectional area (m^2)
A_2	Minor cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_1	Mean velocity in major diameter (m/s)
V_2	Mean velocity in minor diameter (m/s)
NRe_1	Reynolds number in major diameter ()
NRe_2	Reynolds number in minor diameter ()
r	Radius of the round (m)
λ	Jet contraction coefficient ()
K_2	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in minor diameter) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m³)

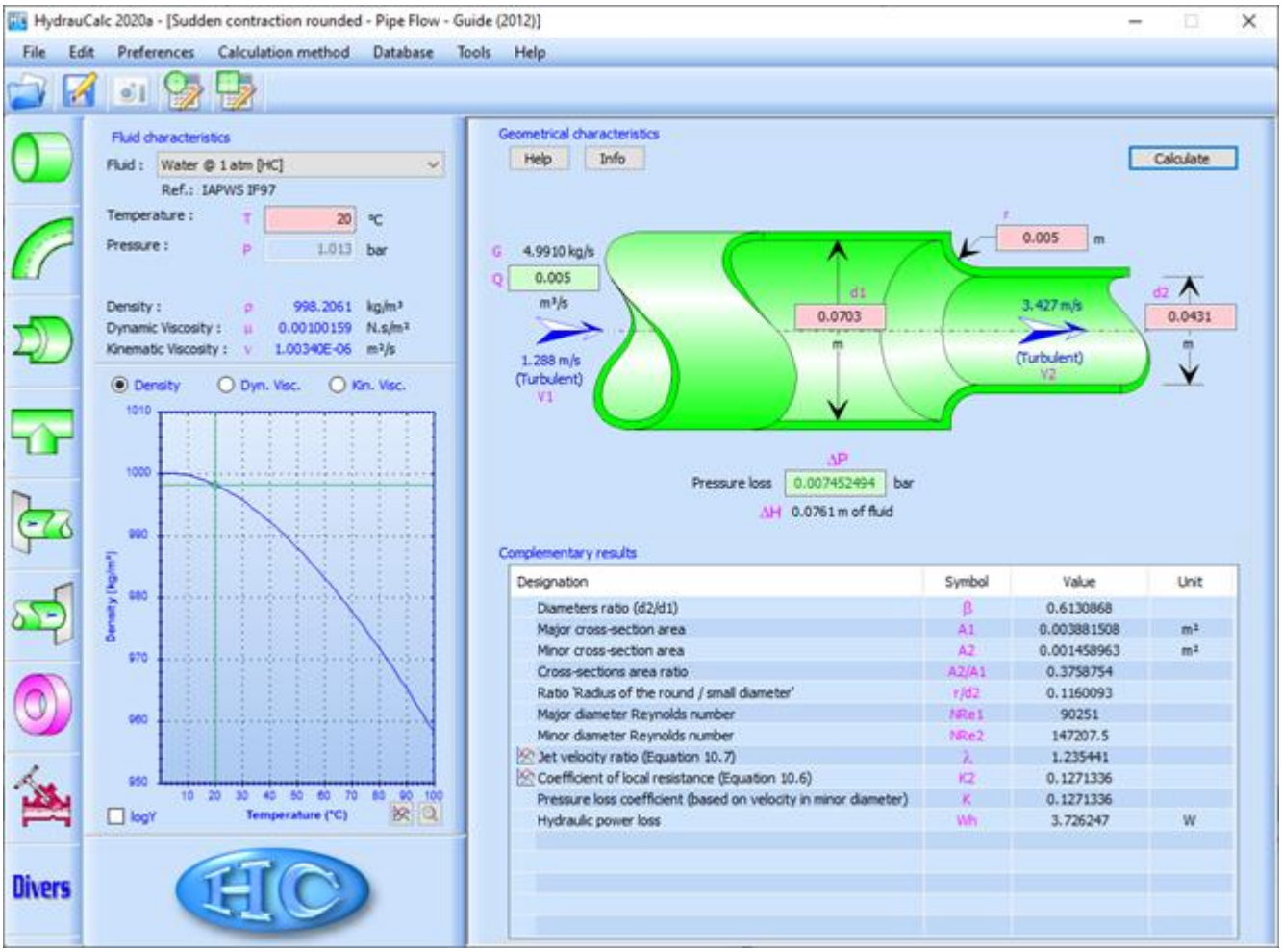
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime in minor diameter ($NRe_2 \geq 10^4$)
- round radius less than the radius difference ($r < (d_1/2-d_2/2)$)

Example of application:



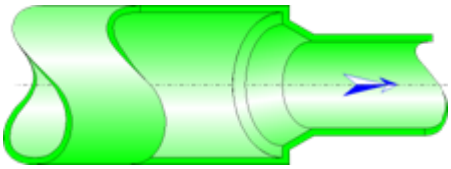
References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.3.4 Sudden contraction bevelled - Circular cross-section

Sudden Contraction Bevelled

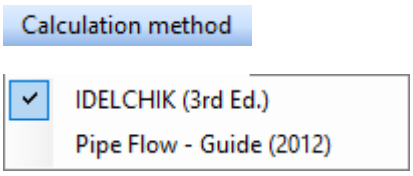
Circular Cross-Section



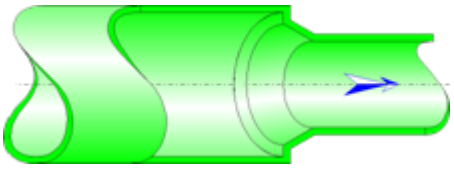
For the calculation of the pressure loss coefficient of sudden contractions bevelled, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.3.4.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sudden contraction bevelled.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of small to large diameter:

$$\beta = \frac{D_1}{D_0}$$

Top angle of cone (°):

$$\alpha = 2 \cdot \tan^{-1}\left(\frac{D_2 - D_0}{2 \cdot l}\right)$$

Minor cross-sectional area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Major cross-sectional area (m²):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Mean velocity in minor diameter (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in major diameter (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in minor diameter:

$$Re_0 = \frac{w_0 \cdot D_0}{\nu}$$

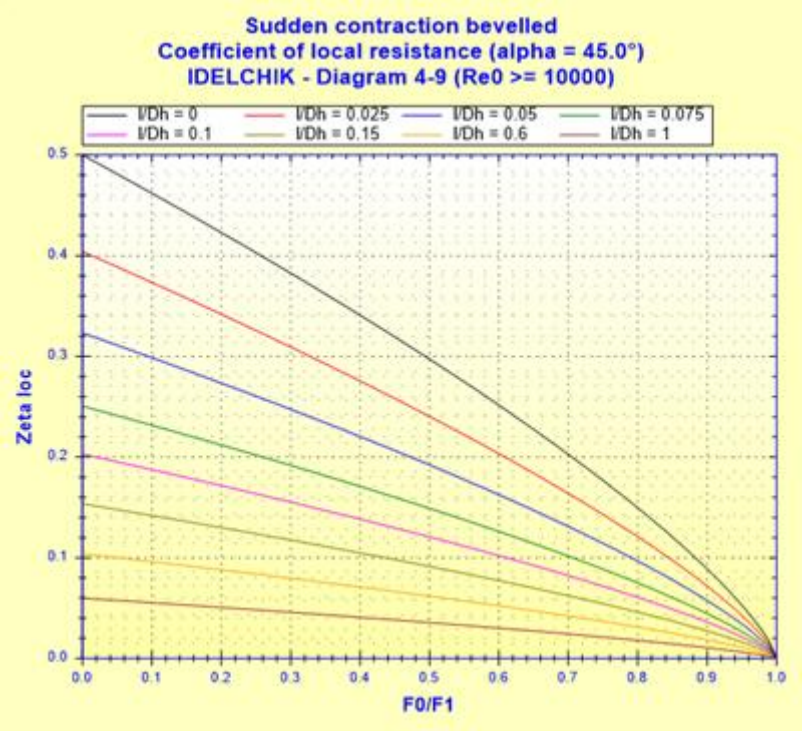
Reynolds number in major diameter:

$$Re_1 = \frac{w_1 \cdot D_1}{\nu}$$

Local resistance coefficient:

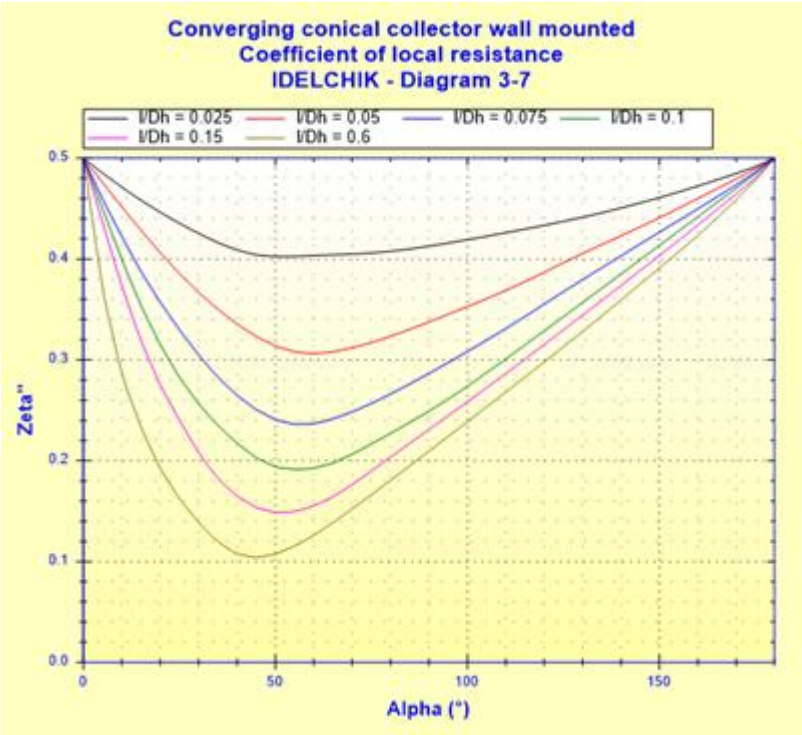
$$\zeta_{loc} = \zeta'' \cdot \left(1 - \frac{F_0}{F_1}\right)^{3/4}$$

([1] diagram 4-9)



with:

$$\zeta'' = f\left(\alpha, l/D_h\right)$$ ([1] diagram 3-7)



Total pressure loss coefficient (based on mean velocity in minor diameter):

$$\zeta = \zeta_{loc}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_0	Minor diameter (m)
D_1	Major diameter (m)
D_2	Base diameter of the cone (m)
β	Ratio of small to large diameter ()
F_0	Minor cross-sectional area (m^2)
F_1	Major cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in minor diameter (m/s)
w_1	Mean velocity in major diameter (m/s)
Re_0	Reynolds number in minor diameter ()
Re_1	Reynolds number in major diameter ()
α	Top angle of cone (2 x bevel angle) (°)
l	Bevel length (m)
ζ_{loc}	Local resistance coefficient ()

ζ Total pressure loss coefficient (based on mean velocity in minor diameter) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime in pipe ($Re_0 \geq 10^4$)
- relative length of bevel (l/D_h) equal to or lower than 0.6

note: for relative lengths of bevel "l/D_h" greater than 0.6, the local pressure loss coefficient is extrapolated

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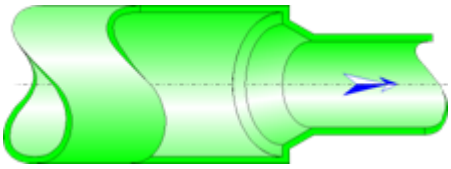
Example of application:

References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.3.4.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sudden contraction bevelled.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of small to large diameter:

$$\beta = \frac{d_2}{d_1}$$

Top angle of cone (°):

$$\alpha = 2 \cdot \tan^{-1}\left(\frac{d_0 - d_2}{2 \cdot l}\right)$$

Major cross-sectional area (m²):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Minor cross-sectional area (m²):

$$A_2 = \pi \cdot \frac{d_2^{\,2}}{4}$$

Mean velocity in major diameter (m/s):

$$V_1 = \frac{Q}{A_1}$$

Mean velocity in minor diameter (m/s):

$$V_2 = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in major diameter:

$$N_{Re_1} = \frac{V_1 \cdot d_1}{\nu}$$

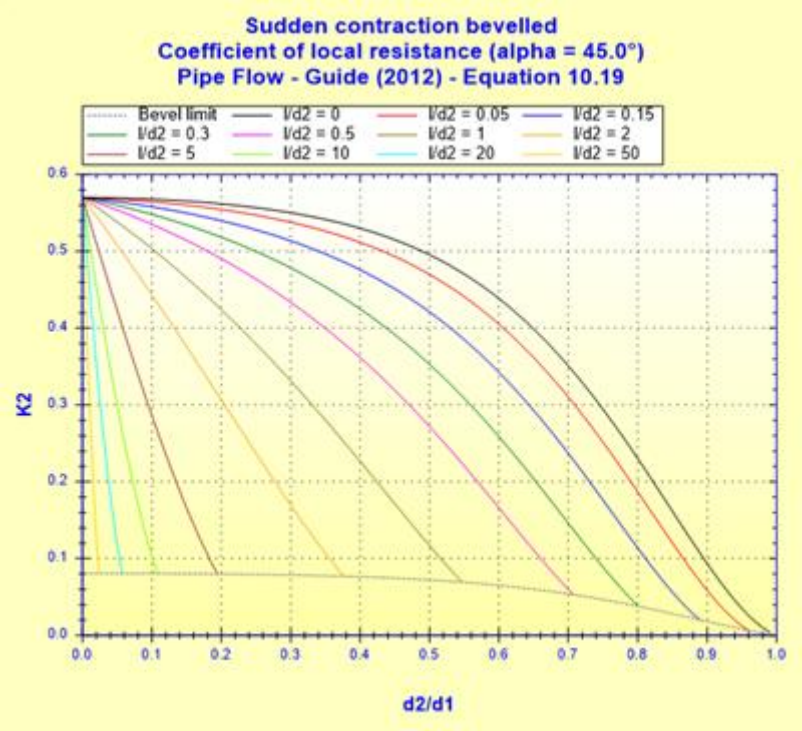
Reynolds number in minor diameter:

$$N_{Re_2} = \frac{V_2 \cdot d_2}{\nu}$$

Local resistance coefficient ($N_{Re} \geq 10^4$):

$$K_2 = 0.0696 \cdot \left[1 + C_B \cdot \left(\sin\left(\frac{\alpha}{2}\right) - 1\right)\right] \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + (\lambda - 1)^2$$

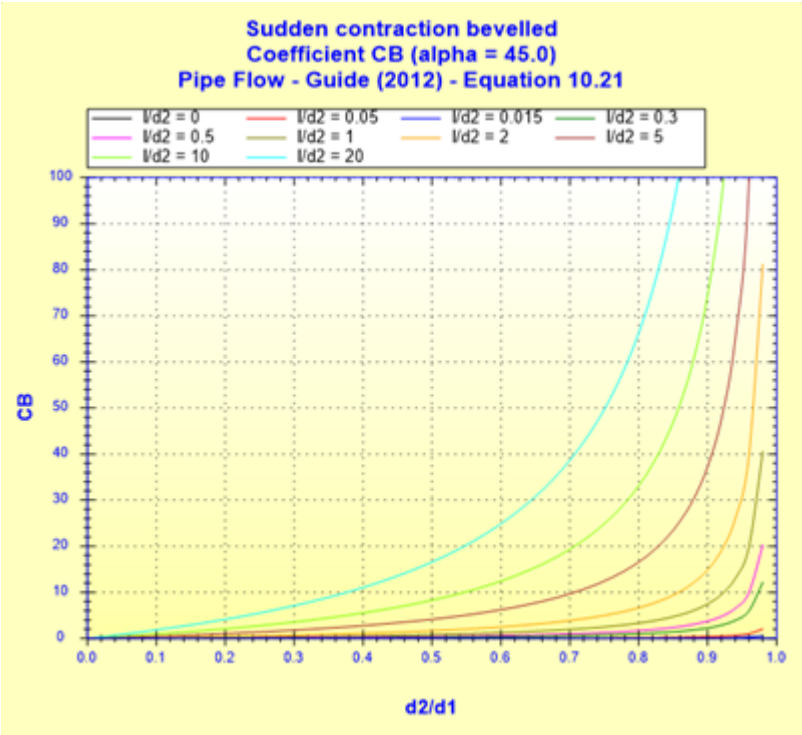
([1] equation 10.19)



With:

$$C_B = \frac{l}{d_2} \cdot \frac{2 \cdot \beta \cdot \tan\left(\frac{\alpha}{2}\right)}{1-\beta}$$

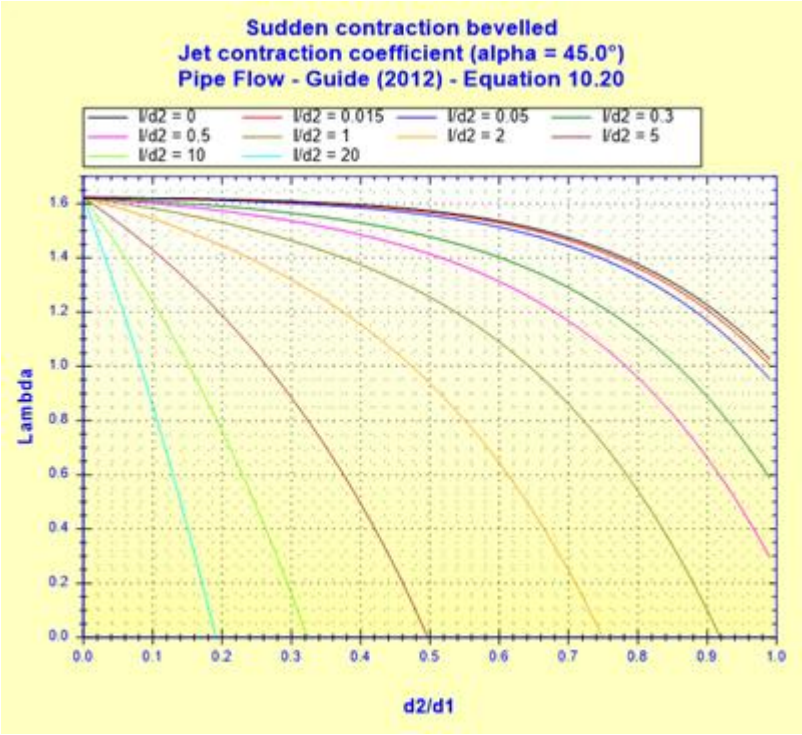
([1] equation 10.21)



And:

$$\lambda = 1 + 0.622 \cdot \left[1 + C_B \cdot \left(\left(\frac{\alpha}{180} \right)^{4/5} - 1 \right) \right] \cdot \left(1 - 0.215 \cdot \beta^2 - 0.785 \cdot \beta^5 \right)$$

([1] equation 10.20)



Total pressure loss coefficient (based on mean velocity in minor diameter):

$$K = K_2$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot v_2^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v_2^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

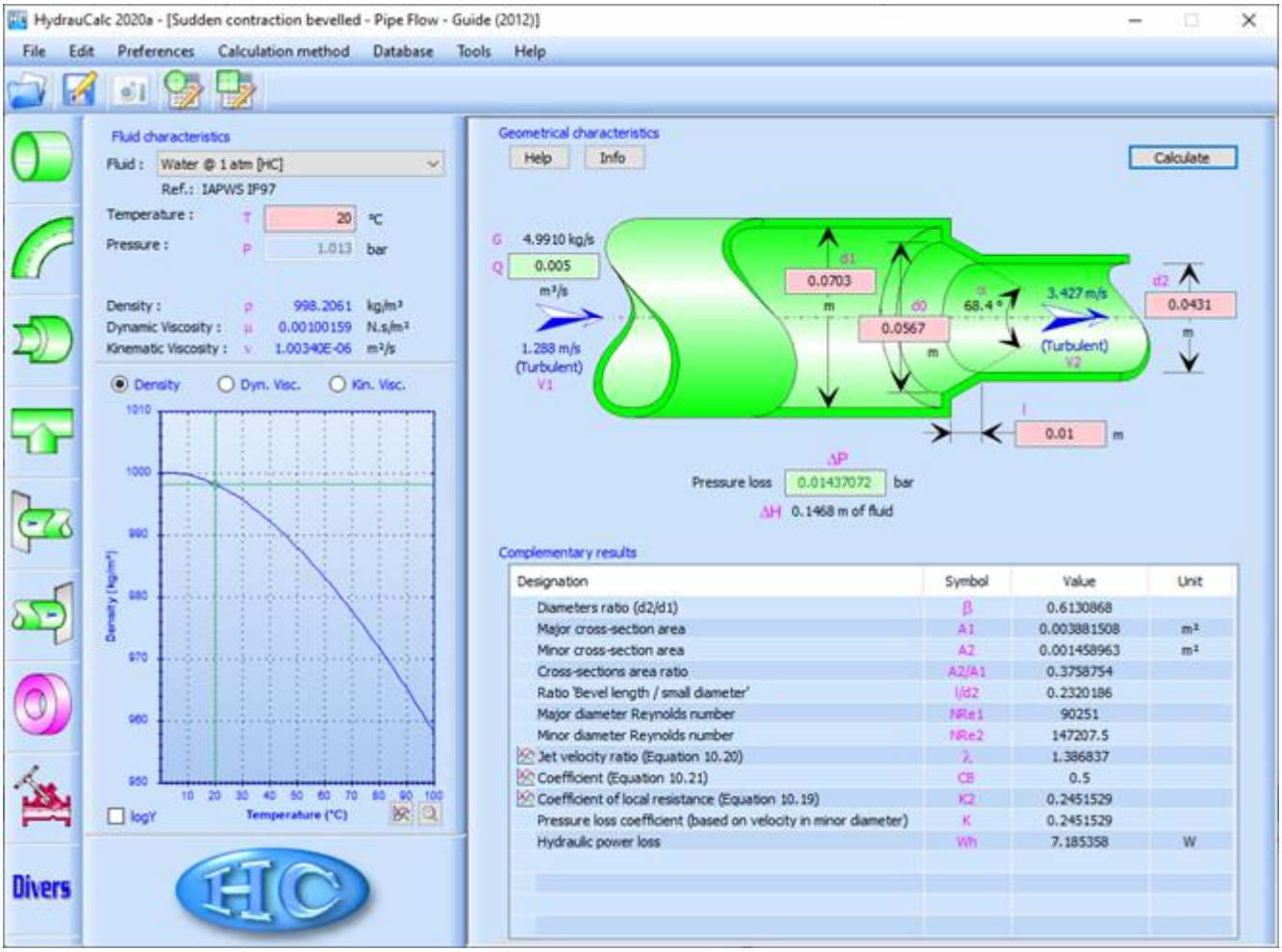
Symbols, Definitions, SI Units:

d_1	Major diameter (m)
d_2	Minor diameter (m)
d_0	Base diameter of the cone (m)
β	Ratio of small to large diameter ()
A_1	Major cross-sectional area (m^2)
A_2	Minor cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_1	Mean velocity in major diameter (m/s)
V_2	Mean velocity in minor diameter (m/s)
NRe_1	Reynolds number in major diameter ()
NRe_2	Reynolds number in minor diameter ()
K_2	Local resistance coefficient ()
C_B	Ratio of bevel length l to the length of a conical contraction of corresponding diameter ratio and included angle ()
λ	Jet contraction coefficient ()
K	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in minor diameter ($NRe_2 \geq 10^4$)

Example of application:



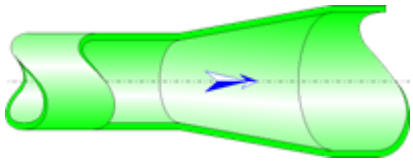
References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.3.5 Gradual expansion - Circular cross-section

Gradual Expansion

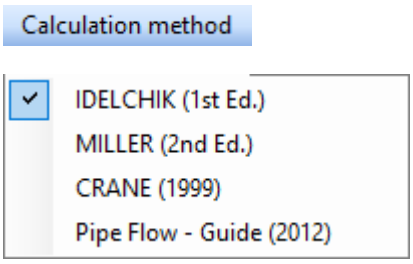
Circular Cross-section



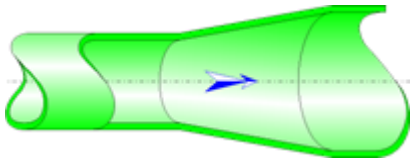
For the calculation of the pressure loss coefficient of gradual expansions, the user can choose from one of the methods described in the following four reference documents:

- Handbook of Hydraulic Resistance, 1st Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (1st Ed.)"



2.3.5.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) generated by the flow in a gradual expansion.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Top angle of cone (°):

$$\alpha = 2 \cdot \tan^{-1}\left(\frac{D_1 - D_0}{2 \cdot l}\right)$$

Minor cross-sectional area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Major cross-sectional area (m²):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Cross-sections ratio:

$$n_0 = \frac{F_0}{F_1}$$

Mean velocity in minor diameter (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in major diameter (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the truncated cone (m^3):

$$V = l \cdot \frac{\pi}{3} \cdot \left(\left(\frac{D_0}{2} \right)^2 + \left(\frac{D_1}{2} \right)^2 + \left(\frac{D_0}{2} \right) \cdot \left(\frac{D_1}{2} \right) \right)$$

Fluid mass in the truncated cone (kg):

$$M = V \cdot \rho$$

Reynolds number in minor diameter:

$$Re_0 = \frac{w_0 \cdot D_0}{\nu}$$

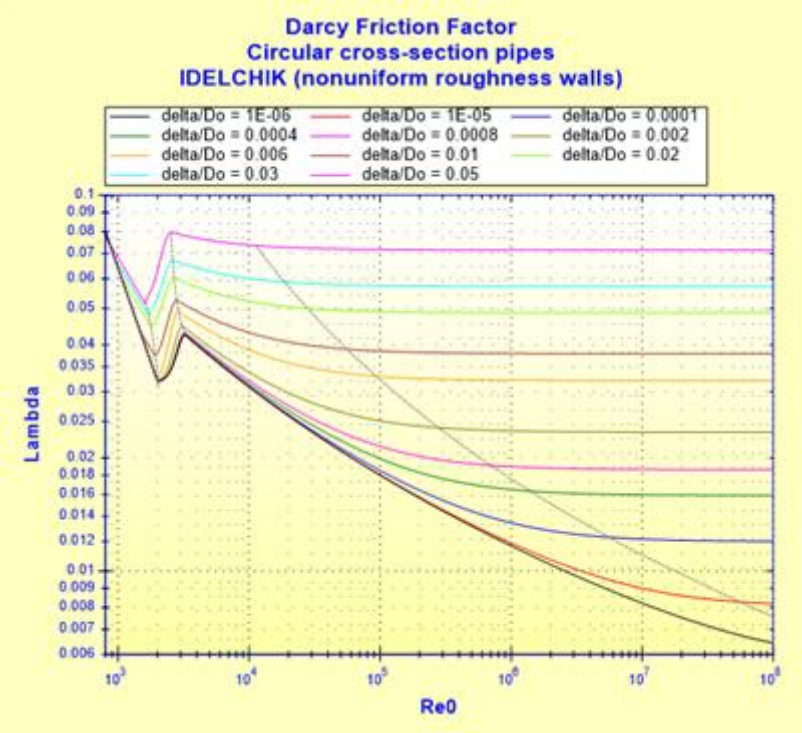
Reynolds number in major diameter:

$$Re_1 = \frac{w_1 \cdot D_1}{\nu}$$

Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}_0, \frac{\Delta}{D_0}\right)$$

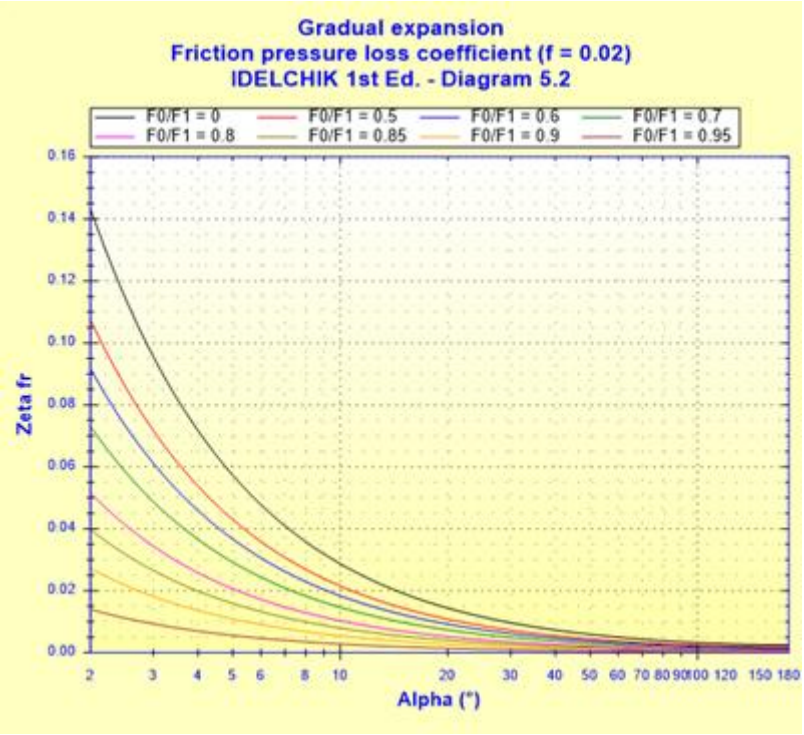
See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



Friction resistance coefficient:

$$\zeta_{fr} = \frac{\lambda}{8 \cdot \sin(\alpha/2)} \cdot \left[1 - \left(\frac{F_0}{F_1}\right)^2\right]$$

([1] diagram 5.2)

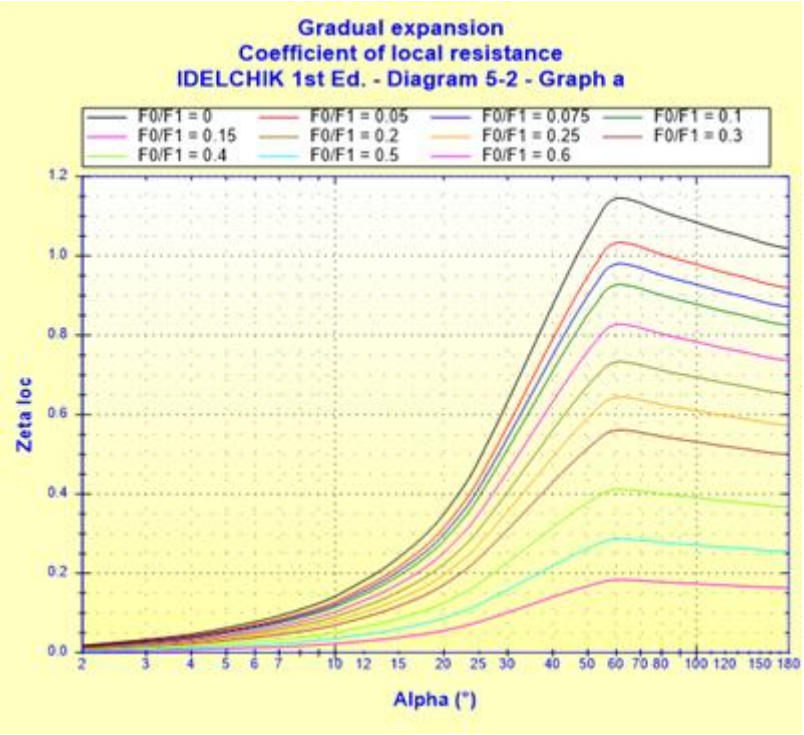


([1] diagram 5.2 with λ = 0.02)

Local resistance coefficient:

$$\zeta_{loc} = f(\alpha, \frac{F_0}{F_1})$$

([1] diagram 5.2 graph a)



Total pressure loss coefficient (based on mean velocity in minor diameter):

$$\zeta = \zeta_{loc} + \zeta_{fr}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_0	Minor diameter (m)
D_1	Major diameter (m)
α	Top angle of cone (°)
l	Truncated cone length (m)
F_0	Minor cross-sectional area (m^2)
F_1	Major cross-sectional area (m^2)
n_0	Cross-sections area ratio ()
w_0	Mean velocity in minor diameter (m/s)
w_1	Mean velocity in major diameter (m/s)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V	Fluid volume in the truncated cone (m^3)
M	Fluid mass in the truncated cone (kg)
Re_0	Reynolds number in minor diameter ()
Re_1	Reynolds number in major diameter ()

Δ Absolute roughness of walls (m)

$\bar{\Delta}$ Relative roughness of walls ()

λ Darcy friction factor ()

ζ_{loc} Local resistance coefficient ()

ζ_{fr} Friction resistance coefficient ()

ζ Total pressure loss coefficient (based on mean velocity in minor diameter) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

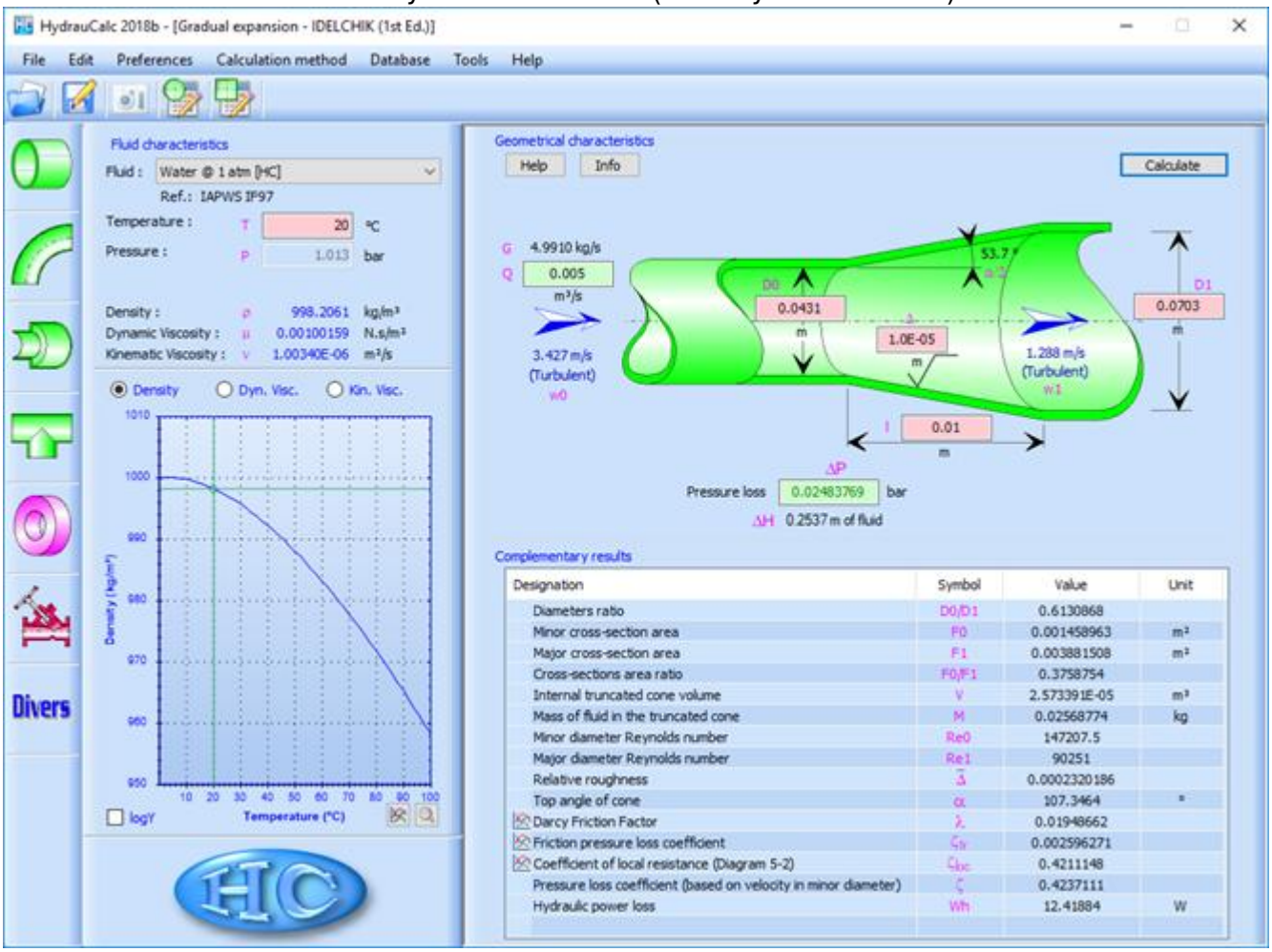
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime in minor diameter ($Re_0 \geq 10^5$)

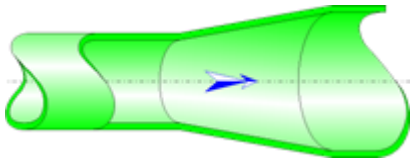
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 1st Edition, I.E. Idelchik

2.3.5.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) generated by the flow in a gradual expansion.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Half top angle of cone (°):

$$\theta = \tan^{-1}\left(\frac{D_2 - D_1}{2 \cdot N}\right)$$

Minor cross-sectional area (m²):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Major cross-sectional area (m²):

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity in minor diameter (m/s):

$$U_1 = \frac{Q}{A_1}$$

Mean velocity in major diameter (m/s):

$$U_2 = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the truncated cone (m^3):

$$V = N \cdot \frac{\pi}{3} \cdot \left(\left(\frac{D_1}{2} \right)^2 + \left(\frac{D_2}{2} \right)^2 + \left(\frac{D_1}{2} \right) \cdot \left(\frac{D_2}{2} \right) \right)$$

Fluid mass in the truncated cone (kg):

$$M = V \cdot \rho$$

Reynolds number in minor diameter:

$$Re_1 = \frac{U_1 \cdot D_1}{\nu}$$

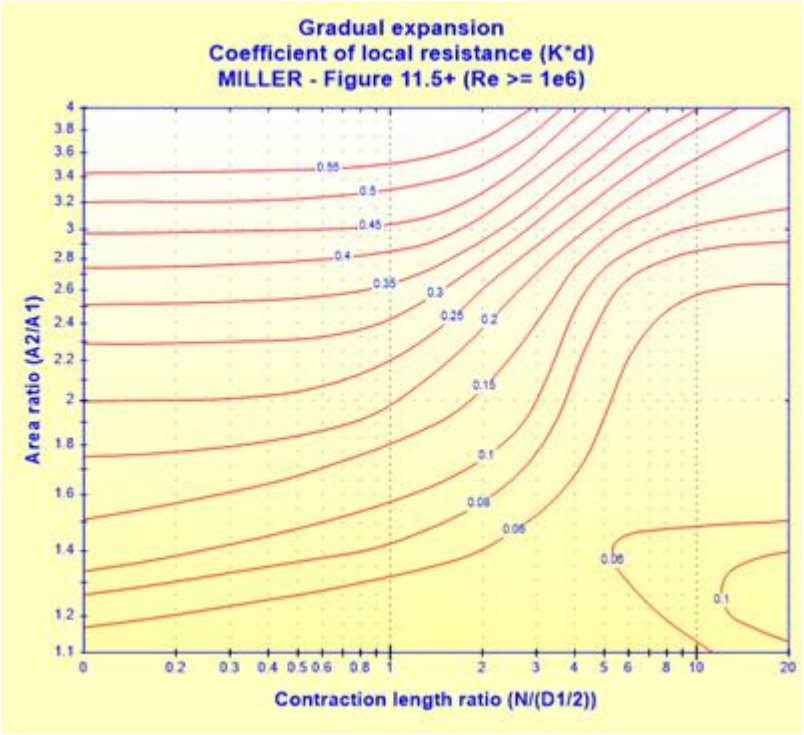
Reynolds number in major diameter:

$$Re_2 = \frac{U_2 \cdot D_2}{\nu}$$

Local resistance coefficient:

- $Re_1 \geq 10^4$

$$K_{*d} = f\left(\frac{N}{D_1/2}, \frac{A_2}{A_1} \right)$$ ([1] figure 11.5+)



■ $Re_1 < 10^4$

$$K_{lam} = f(K_{turb}, Re_1)$$ ([1] figure 14.31)

where:

K_{turb} is the local resistance coefficient in turbulent regime (K_{*d} for $Re_1 = 10^4$ - figure 11.5+)

Reynolds Number Correction ($Re_1 < 10^4$):

$$C_{Re} = \frac{K_{lam}}{K_{turb}}$$

Total pressure loss coefficient (based on mean velocity in minor diameter):

- turbulent flow ($Re_1 \geq 10^4$):

$$K = K_{*d}$$

- laminar flow ($Re_1 < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_1	Minor diameter (m)
D_2	Major diameter (m)
N	Truncated cone length (m)
θ	Half top angle of cone (°)
A_1	Minor cross-sectional area (m^2)
A_2	Major cross-sectional area (m^2)

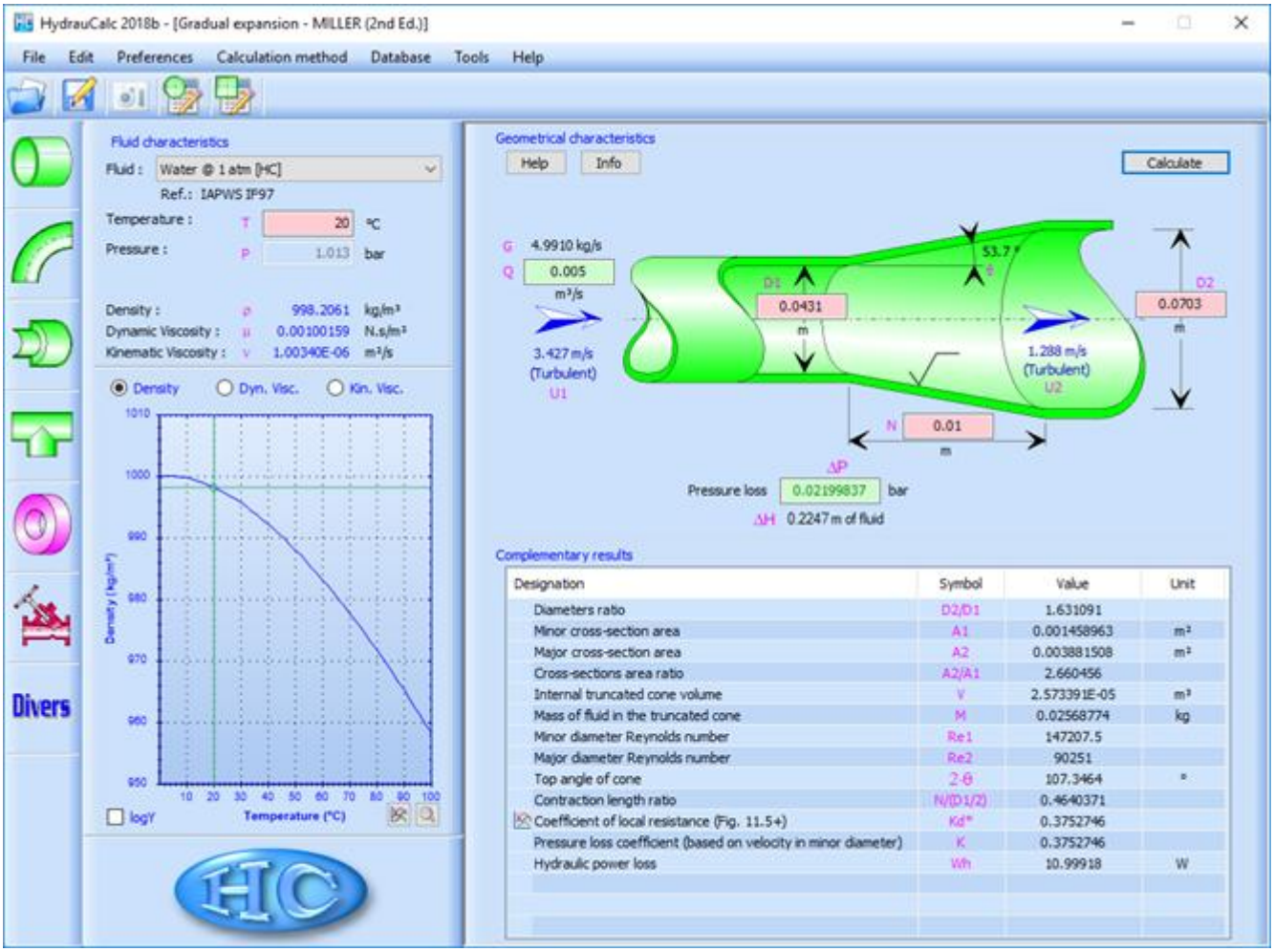
Q	Volume flow rate (m^3/s)
U_1	Mean velocity in minor diameter (m/s)
U_2	Mean velocity in major diameter (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume in the truncated cone (m^3)
M	Fluid mass in the truncated cone (kg)
Re_1	Reynolds number in minor diameter ()
Re_2	Reynolds number in major diameter ()
K^*_d	Local resistance coefficient for $Re_1 \geq 10^4$ ()
K_{turb}	Local resistance coefficient for $Re_1 = 10^4$ ()
K_{lam}	Local resistance coefficient for $Re_1 < 10^4$ ()
C_{Re}	Reynolds number correction ()
K	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- area ratio (A2/A1) between 1.1 and 4
- contraction length ratio (N/(D1/2)) less than 20

note: for Reynolds number "Re_1" lower than 10^4, and coefficients "K_{turb}" lower than 0.5 or greater than 10, the laminar pressure loss coefficient "K_{lam}" is extrapolated

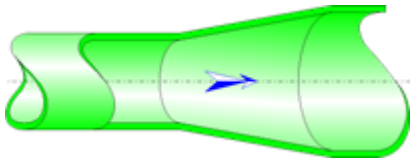
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.3.5.3 CRANE



Model description:

This model of component calculates the head loss (pressure drop) generated by the flow in a gradual expansion.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of small to large diameter:

$$\beta = \frac{D_1}{D_2}$$

Half top angle of cone (°):

$$\theta = \tan^{-1}\left(\frac{D_2 - D_1}{2 \cdot L}\right)$$

Minor cross-sectional area (m²):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Major cross-sectional area (m²):

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity in minor diameter (m/s):

$$v_1 = \frac{q}{A_1}$$

Mean velocity in major diameter (m/s):

$$v_2 = \frac{q}{A_2}$$

Mass flow rate (kg/s):

$$G = q \cdot \rho$$

Fluid volume in the truncated cone (m^3):

$$V = L \cdot \frac{\pi}{3} \cdot \left(\left(\frac{D_1}{2} \right)^2 + \left(\frac{D_2}{2} \right)^2 + \left(\frac{D_1}{2} \right) \cdot \left(\frac{D_2}{2} \right) \right)$$

Fluid mass in the truncated cone (kg):

$$M = V \cdot \rho$$

Reynolds number in minor diameter:

$$Re_1 = \frac{v_1 \cdot D_1}{\nu}$$

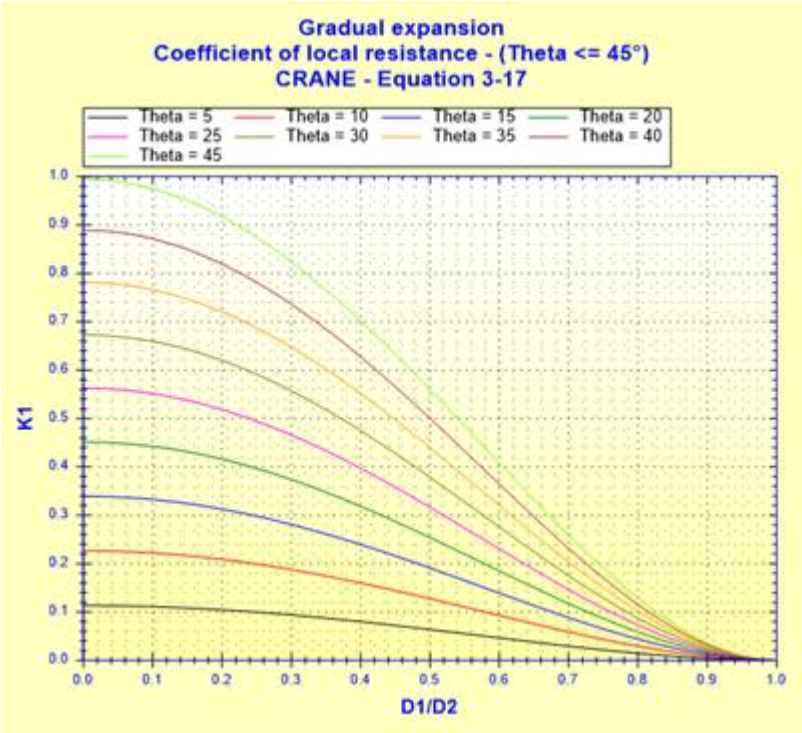
Reynolds number in major diameter:

$$Re_2 = \frac{v_2 \cdot D_2}{\nu}$$

Local resistance coefficient:

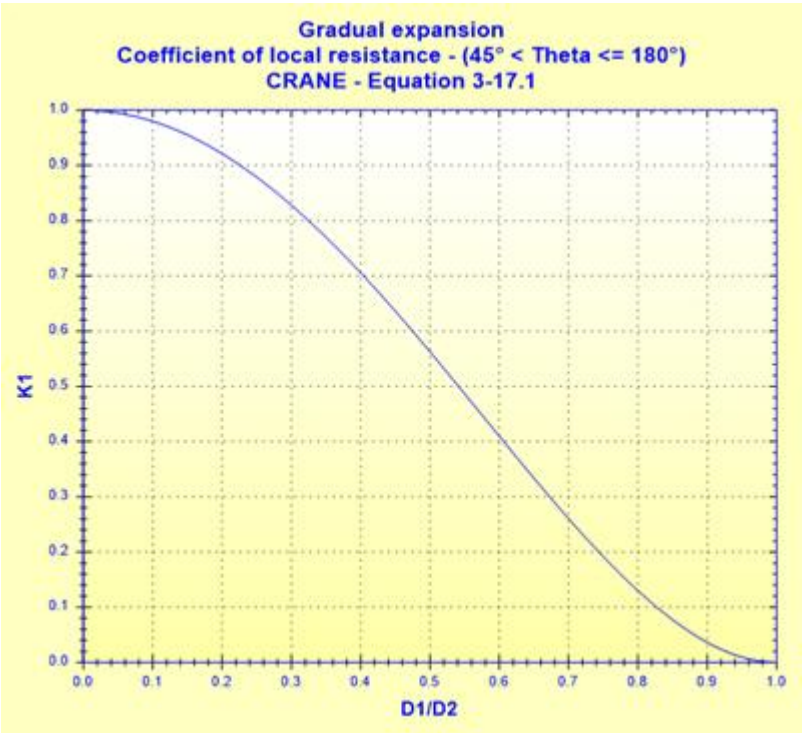
- $\theta \leq 45°$:

$$K_1 = 2.6 \sin\left(\frac{\theta}{2}\right)\left(1-\beta^2\right)^2$$ (Equation 3-17)



■ 45° < θ ≤ 180°:

$$K_1 = \left(1-\beta^2\right)^2$$ (Equation 3-17.1)



Total pressure loss coefficient (based on mean velocity in minor diameter):

$$K = K_1$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot v_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot q$$

Symbols, Definitions, SI Units:

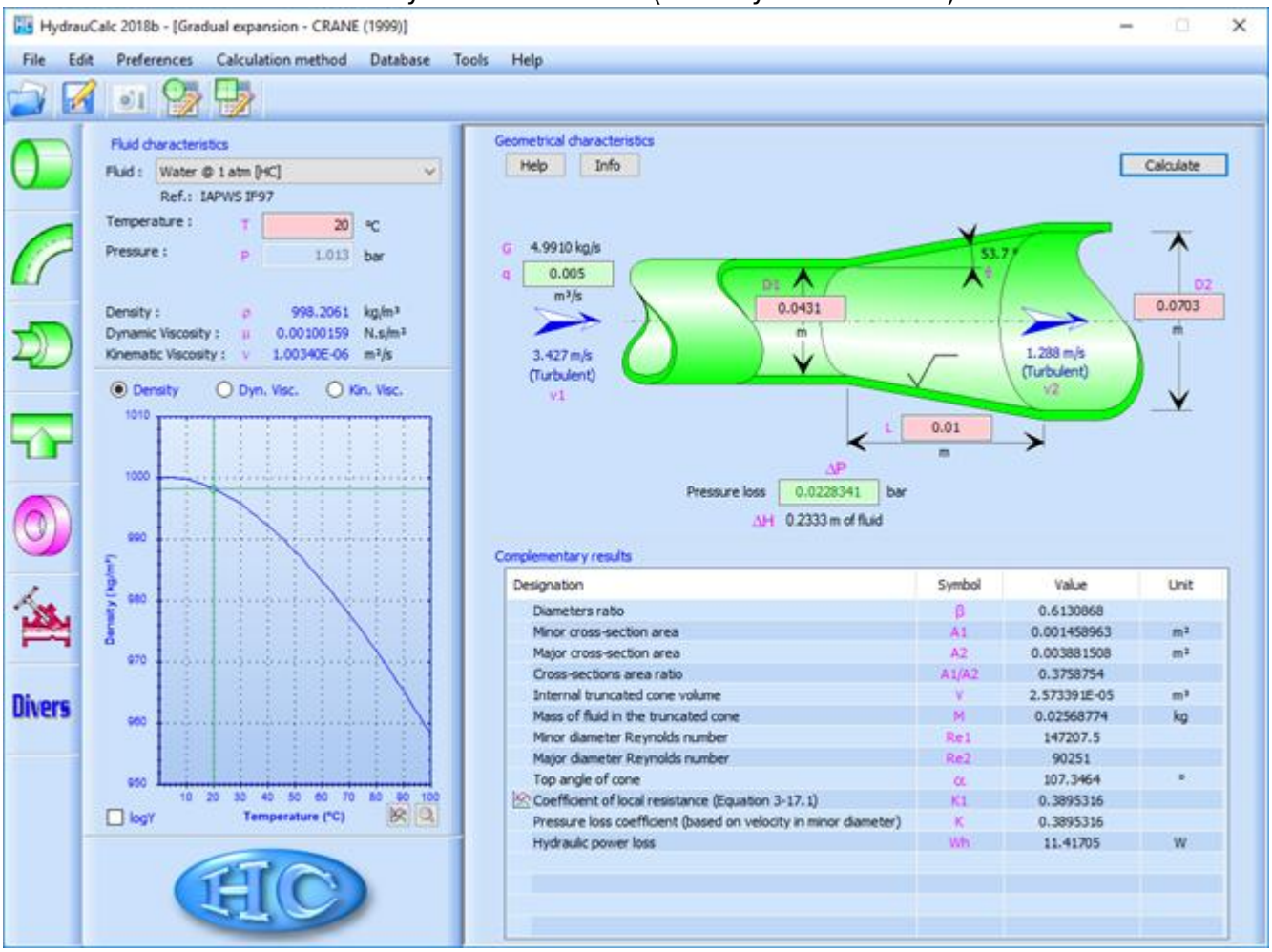
D_1	Minor diameter (m)
D_2	Major diameter (m)
β	Ratio of small to large diameter ()
θ	Half top angle of cone (°)
L	Contraction length (m)
A_1	Minor cross-sectional area (m^2)
A_2	Major cross-sectional area (m^2)
v_1	Mean velocity in minor diameter (m/s)
v_2	Mean velocity in major diameter (m/s)
q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V	Fluid volume in the truncated cone (m^3)

M	Fluid mass in the truncated cone (kg)
Re_1	Reynolds number in minor diameter ()
Re_2	Reynolds number in major diameter ()
K_1	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in minor diameter ($Re_1 \geq 10^4$)

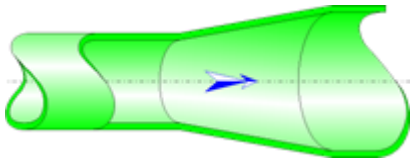
Example of application:



References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 – Edition 1999

2.3.5.4 Pipe Flow - Guide



Model description:

This model of component calculates the head loss (pressure drop) generated by the flow in a gradual expansion. The head loss by friction in the gradual expansion is taken into account for cone angles less than 60 °, beyond this angle the head loss by friction becomes negligible.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of small to large diameter:

$$\beta = \frac{d_1}{d_2}$$

Top angle of cone (°):

$$\alpha = 2 \cdot \tan^{-1}\left(\frac{d_2 - d_1}{2 \cdot l}\right)$$

Minor cross-sectional area (m²):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Major cross-sectional area (m²):

$$A_2 = \pi \cdot \frac{d_2^{\,2}}{4}$$

Mean velocity in minor diameter (m/s):

$$V_1 = \frac{Q}{A_1}$$

Mean velocity in major diameter (m/s):

$$V_2 = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Fluid volume in the truncated cone (m^3):

$$V = l \cdot \frac{\pi}{3} \cdot \left(\left(\frac{d_1}{2} \right)^2 + \left(\frac{d_2}{2} \right)^2 + \left(\frac{d_1}{2} \right) \cdot \left(\frac{d_2}{2} \right) \right)$$

Fluid mass in the truncated cone (kg):

$$M = V \cdot \rho_m$$

Reynolds number in minor diameter:

$$N_{Re_1} = \frac{V_1 \cdot d_1}{\nu}$$

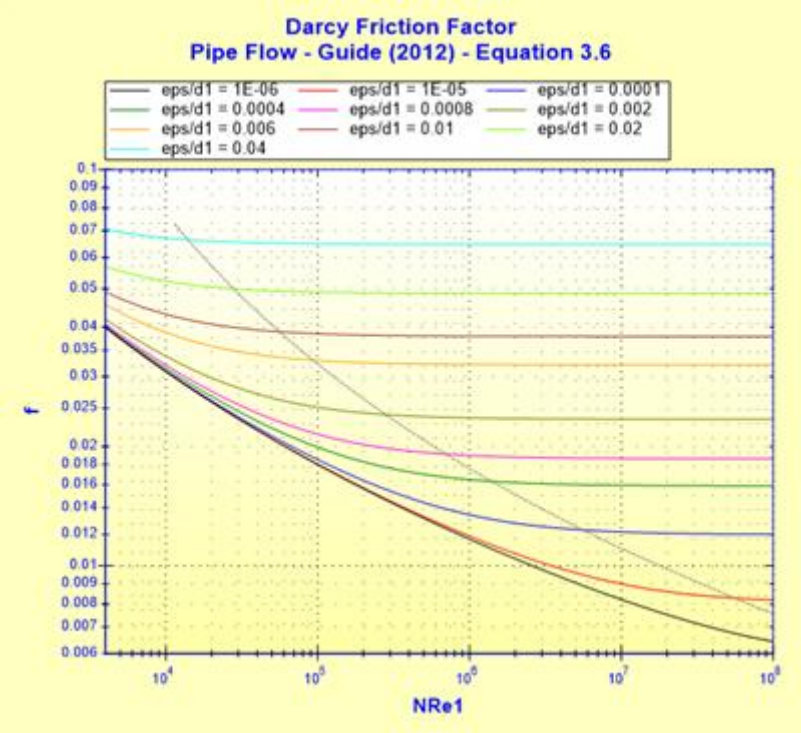
Reynolds number in major diameter:

$$N_{Re_2} = \frac{V_2 \cdot d_2}{\nu}$$

Darcy friction factor:

$$f = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d_1} + \frac{2.51}{NRe_1 \cdot \sqrt{f}}\right)\right]^2}$$

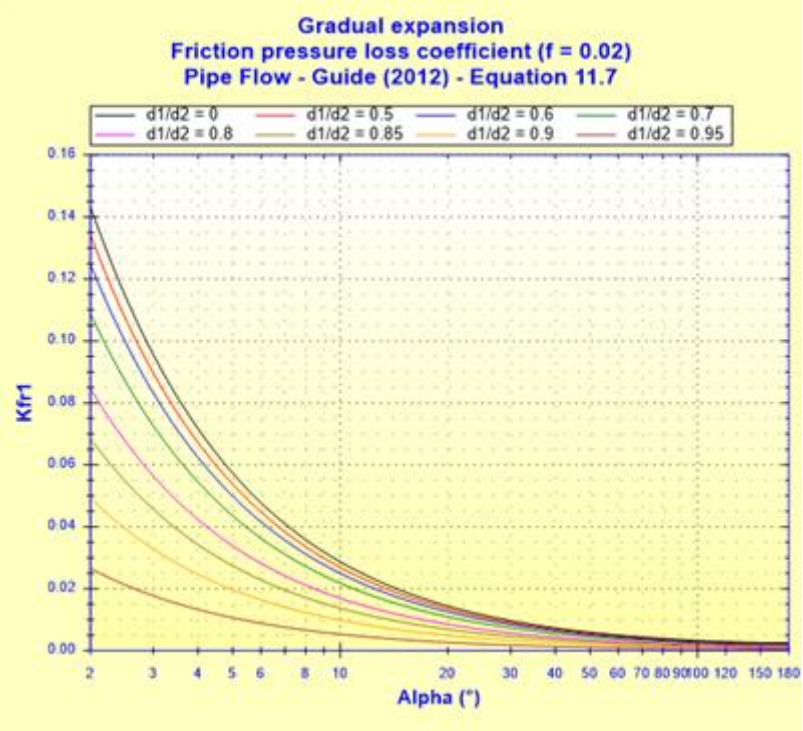
Colebrook-White equation ([1] equation 3.6)



Friction pressure loss coefficient:

$$K_{fr1} = \frac{f \cdot \left(1 - \beta^4\right)}{8 \cdot \sin\left(\frac{\alpha}{2}\right)}$$

([1] equation 11.7)



([1] equation 11.7 with f = 0.02)

Total pressure loss coefficient (based on mean velocity in minor diameter):

- $0° \le \alpha \le 20°$:

$$K_1 = 8.30 \cdot \left[\tan\left(\frac{\alpha}{2}\right)\right]^{1.75} \cdot \left(1-\beta^2\right)^2 + \frac{f \cdot \left(1-\beta^4\right)}{8 \cdot \sin\left(\frac{\alpha}{2}\right)}$$

([1] equation 11.8)

- $20° \le \alpha < 60°$:
  - $0 \le \beta < 0.5$

$$K_1 = \left\{1.366 \cdot \sin\left(2 \cdot (\alpha - 15)\right)^{1/2} - 0.170 - 3.28 \cdot \left(\left(0.0625 - \beta^4\right) \cdot \sqrt{\frac{\alpha - 20}{40}}\right)\right\} \cdot \left(1-\beta^2\right)^2 + \frac{f \cdot \left(1-\beta^4\right)}{8 \cdot \sin\left(\frac{\alpha}{2}\right)}$$

([1] equation 11.9a)

  - $0.5 \le \beta \le 1$

$$K_1 = \left\{1.366 \cdot \sin\left(2 \cdot (\alpha - 15)\right)^{1/2} - 0.170\right\} \cdot \left(1-\beta^2\right)^2 + \frac{f \cdot \left(1-\beta^4\right)}{8 \cdot \sin\left(\frac{\alpha}{2}\right)}$$

([1] equation 11.9b)

- $60° \le \alpha \le 180°$:
  - $0 \le \beta < 0.5$

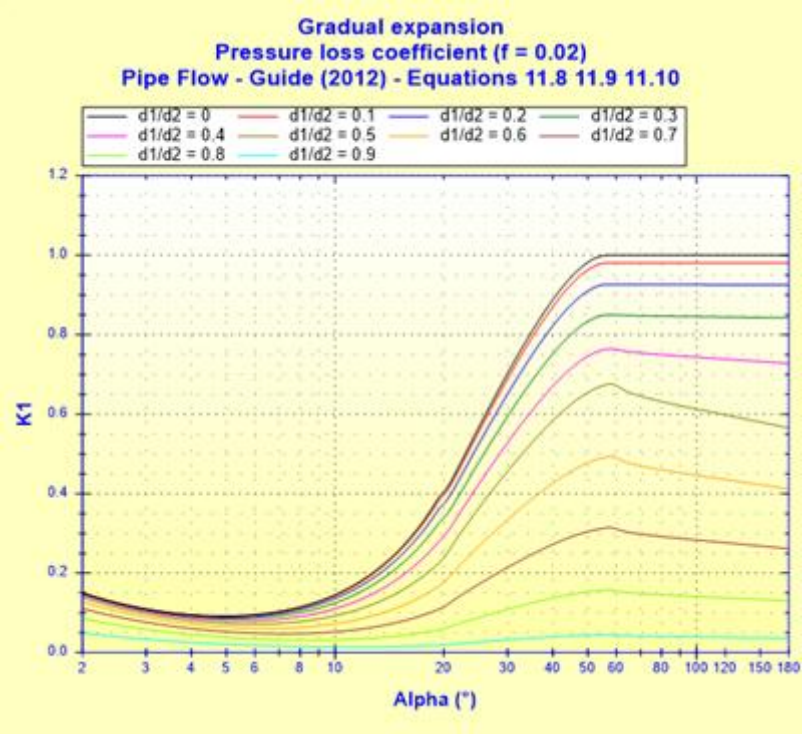
$$K_1 = \left[1.205 - 3.28 \cdot \left(0.0625 - \beta^4\right) - 12.8 \cdot \beta^6 \cdot \sqrt{\frac{\alpha - 60}{120}}\right] \cdot \left(1 - \beta^2\right)^2$$

([1] equation 11.10a)

- $0.5 \leq \beta \leq 1$

$$K_1 = \left[1.205 - 0.20 \cdot \sqrt{\frac{\alpha - 60}{120}}\right] \cdot \left(1 - \beta^2\right)^2$$

([1] equation 11.10b)



Local resistance coefficient:

- $0° \leq \alpha < 60°$:

$$K_{L1} = K_1 - K_{fr1}$$

- $60° \leq \alpha \leq 180°$:

$$K_{L1} = K_1$$

Total pressure loss (Pa):

$$\Delta P = K_1 \cdot \frac{\rho_m \cdot V_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K_1 \cdot \frac{V_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_1	Minor diameter (m)
d_2	Major diameter (m)
β	Ratio of small to large diameter ()
α	Top angle of cone (°)
l	Truncated cone length (m)
A_1	Minor cross-sectional area (m^2)
A_2	Major cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
V_1	Mean velocity in minor diameter (m/s)
V_2	Mean velocity in major diameter (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume in the truncated cone (m^3)
M	Fluid mass in the truncated cone (kg)
NRe_1	Reynolds number in minor diameter ()
NRe_2	Reynolds number in major diameter ()
f	Darcy friction factor ()
ε	Absolute roughness of the cone walls (m)
K_{fr1}	Friction pressure loss coefficient ()
K_{L1}	Local resistance coefficient ()
K_1	Total pressure loss coefficient (based on mean velocity in minor diameter) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m³)

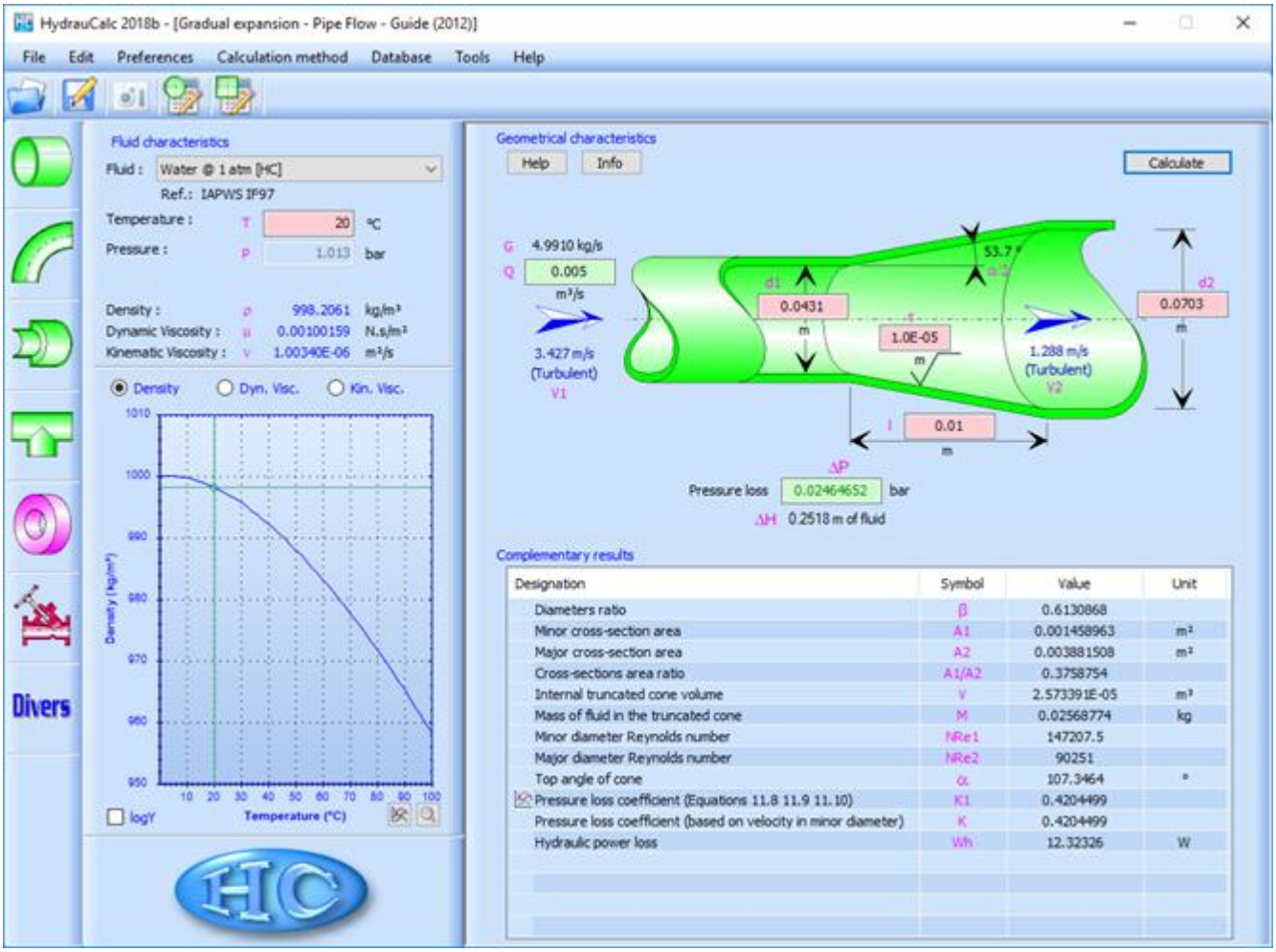
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime in minor diameter ($NRe_1 \geq 10^4$)

Example of application:



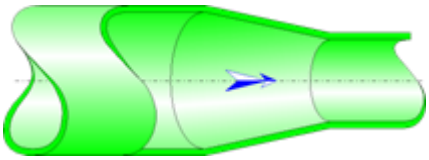
References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.3.6 Gradual contraction - Circular cross-section

Gradual Contraction

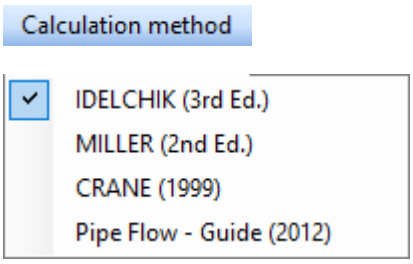
Circular Cross-section



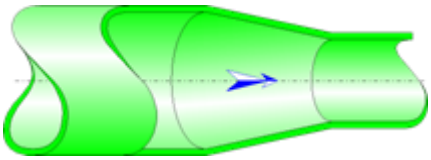
For the calculation of the pressure loss coefficient of gradual contractions, the user can choose from one of the methods described in the following four reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.3.6.1 IDELCHIK



Model description:

This model of component calculates the head loss (pressure drop) generated by the flow in a gradual contraction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Top angle of cone (°):

$$\alpha = 2 \cdot \tan^{-1}\left(\frac{D_1 - D_0}{2 \cdot l}\right)$$

Minor cross-sectional area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Major cross-sectional area (m²):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Cross-sections ratio:

$$n_0 = \frac{F_0}{F_1}$$

Mean velocity in minor diameter (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in major diameter (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the truncated cone (m^3):

$$V = N \cdot \frac{\pi}{3} \cdot \left(\left(\frac{D_0}{2} \right)^2 + \left(\frac{D_1}{2} \right)^2 + \left(\frac{D_0}{2} \right) \cdot \left(\frac{D_1}{2} \right) \right)$$

Fluid mass in the truncated cone (kg):

$$M = V \cdot \rho$$

Reynolds number in minor diameter:

$$Re_0 = \frac{w_0 \cdot D_0}{\nu}$$

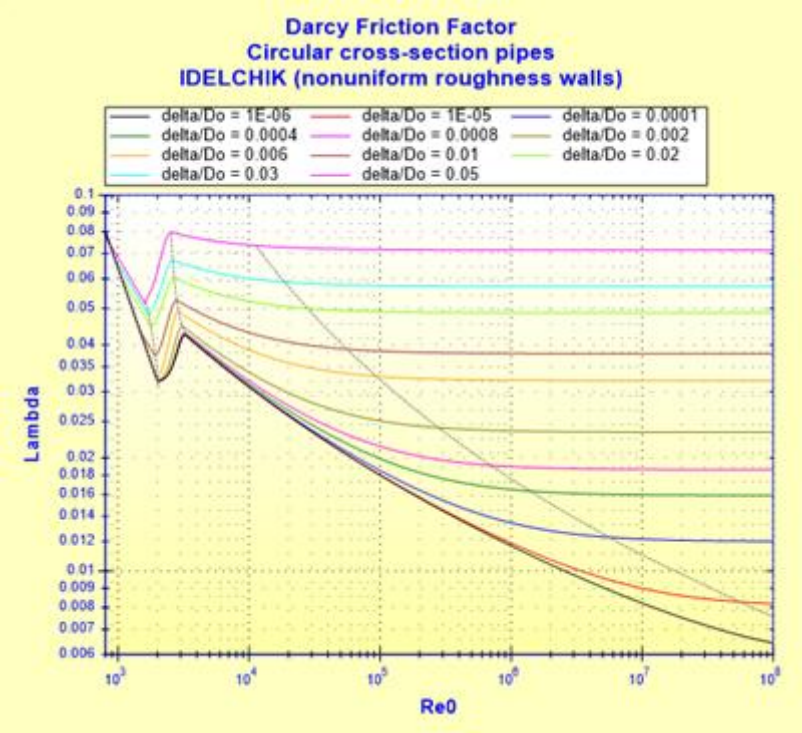
Reynolds number in major diameter:

$$Re_1 = \frac{w_1 \cdot D_1}{\nu}$$

Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}_0, \frac{\Delta}{D_0}\right)$$

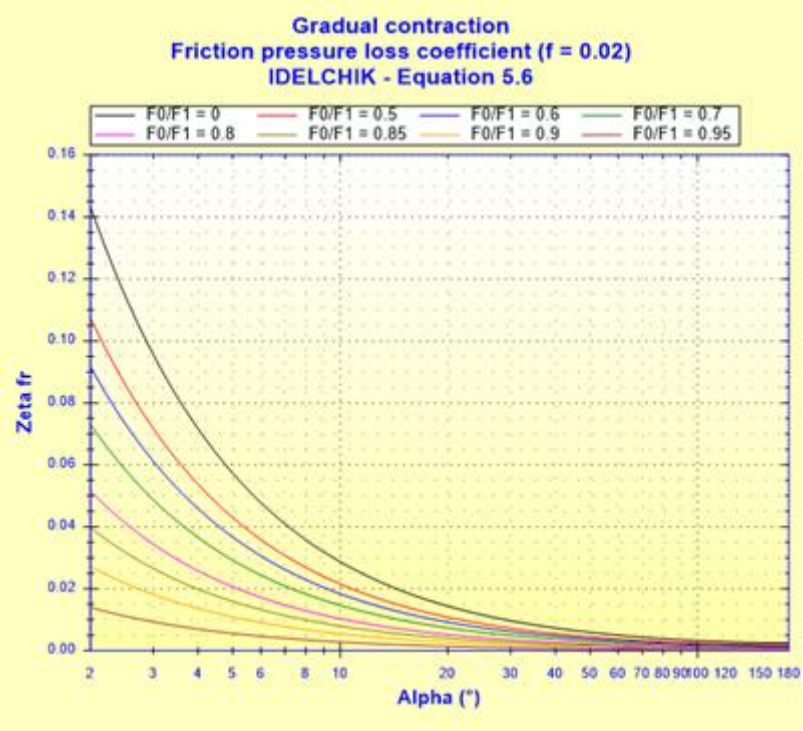
See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



Friction resistance coefficient:

$$\zeta_{fr} = \frac{\lambda}{8 \cdot \sin(\alpha/2)} \cdot \left[1 - \left(\frac{F_0}{F_1}\right)^2\right]$$

([1] equation 5.6)



([1] equation 5.6 with $\lambda = 0.02$)

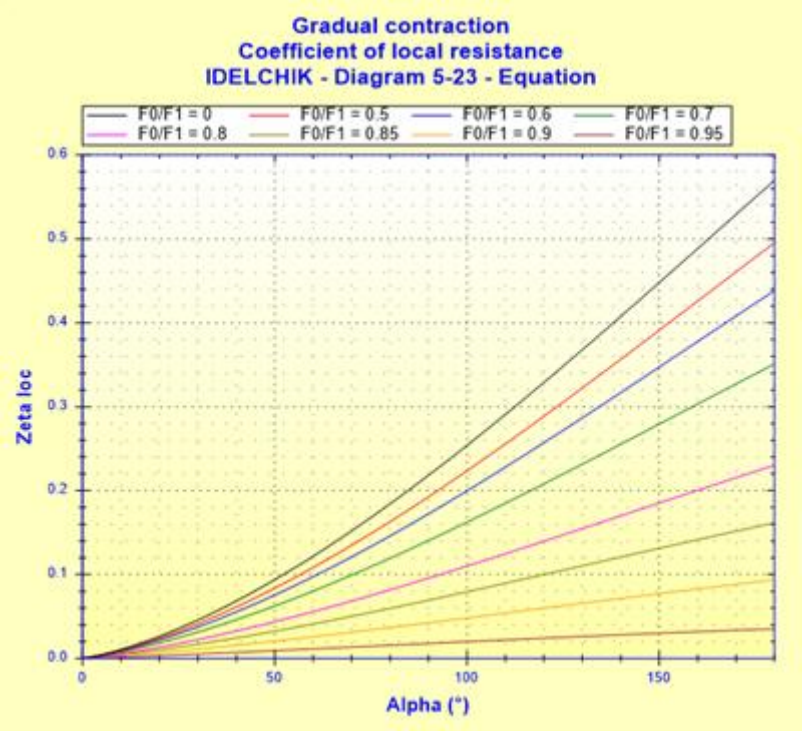
Local resistance coefficient:

$$\zeta_{loc} = (-0.0125 \cdot n_0^4 + 0.0224 \cdot n_0^3 - 0.00723 \cdot n_0^2 + 0.00444 \cdot n_0 - 0.00745) \cdot (\alpha_r^3 - 2 \cdot \pi \cdot \alpha_r^2 - 10 \cdot \alpha_r)$$

([1] diagram 5.23 (1))

with:

$$\alpha_r = 0.01745 \cdot \alpha$$



Total pressure loss coefficient (based on mean velocity in minor diameter):

$$\zeta = \zeta_{loc} + \zeta_{fr}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_0 Minor diameter (m)

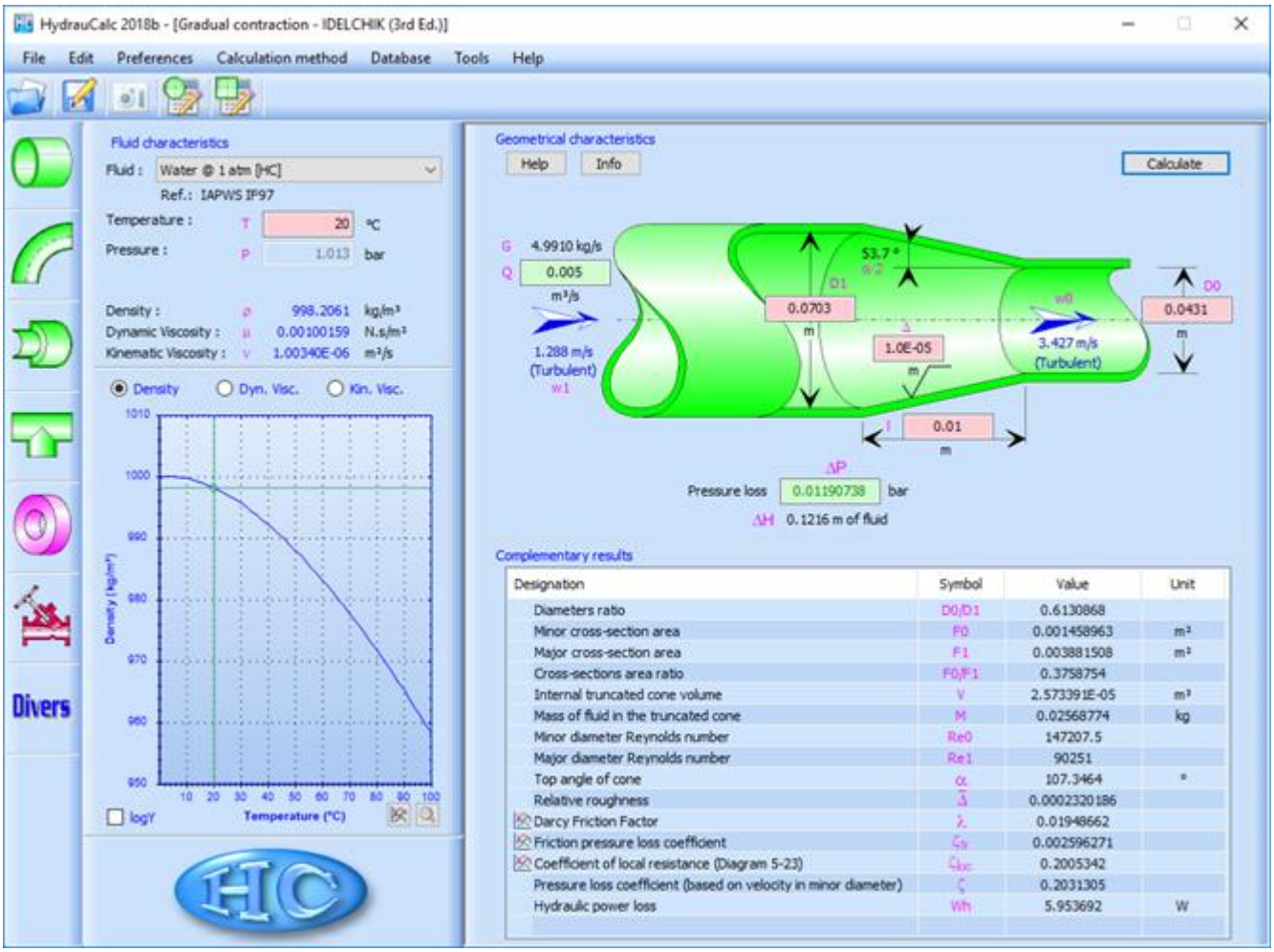
D_1 Major diameter (m)

α	Top angle of cone (°)
l	Truncated cone length (m)
F_0	Minor cross-sectional area (m^2)
F_1	Major cross-sectional area (m^2)
n_0	Cross-sections area ratio ()
w_0	Mean velocity in minor diameter (m/s)
w_1	Mean velocity in major diameter (m/s)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V	Fluid volume in the truncated cone (m^3)
M	Fluid mass in the truncated cone (kg)
Re_0	Reynolds number in minor diameter ()
Re_1	Reynolds number in major diameter ()
Δ	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ()
λ	Darcy friction factor ()
ζ_{loc}	Local resistance coefficient ()
ζ_{fr}	Friction resistance coefficient ()
ζ	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in minor diameter ($Re_0 \geq 10^5$)

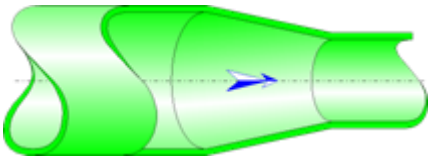
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.3.6.2 MILLER



Model description:

This model of component calculates the head loss (pressure drop) generated by the flow in a gradual contraction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Half top angle of cone (°):

$$\theta = \tan^{-1}\left(\frac{D_2 - D_1}{2 \cdot N}\right)$$

Major cross-sectional area (m²):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Minor cross-sectional area (m²):

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity in major diameter (m/s):

$$U_1 = \frac{Q}{A_1}$$

Mean velocity in minor diameter (m/s):

$$U_2 = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the truncated cone (m^3):

$$V = N \cdot \frac{\pi}{3} \cdot \left(\left(\frac{D_1}{2} \right)^2 + \left(\frac{D_2}{2} \right)^2 + \left(\frac{D_1}{2} \right) \cdot \left(\frac{D_2}{2} \right) \right)$$

Fluid mass in the truncated cone (kg):

$$M = V \cdot \rho$$

Reynolds number in major diameter:

$$Re_1 = \frac{U_1 \cdot D_1}{\nu}$$

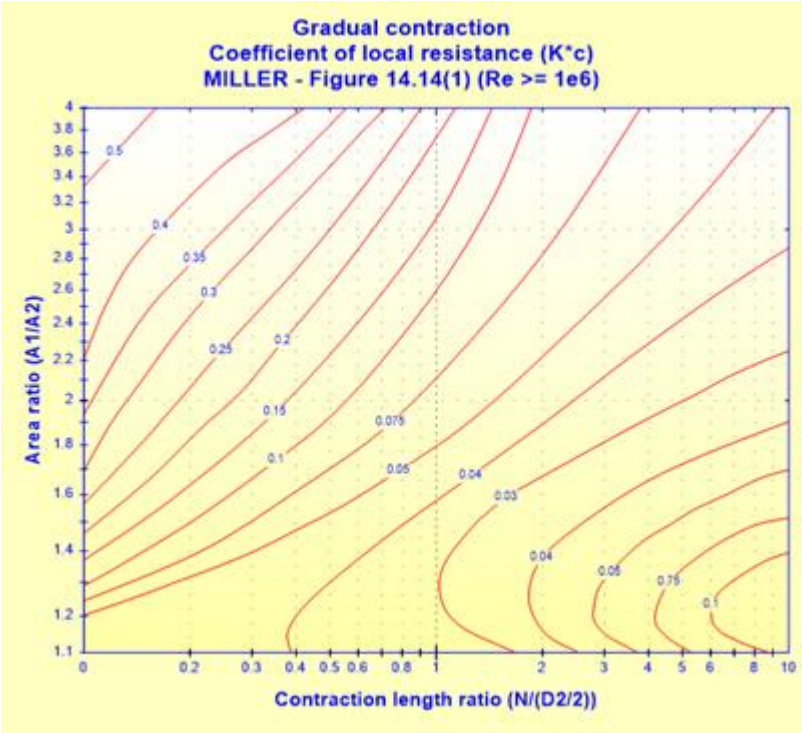
Reynolds number in minor diameter:

$$Re_2 = \frac{U_2 \cdot D_2}{\nu}$$

Local resistance coefficient:

- $Re_2 \geq 10^4$

$$K^*_c = f\left(\frac{N}{D_2/2}, \frac{A_1}{A_2} \right)$$ ([1] figure 14.14+)

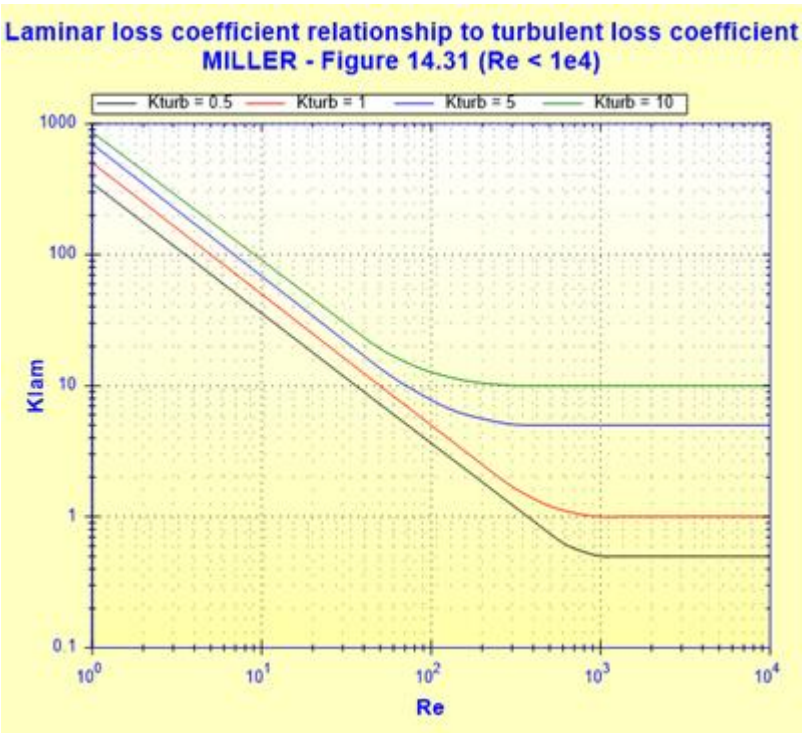


■ $Re_2 < 10^4$

$$K_{lam} = f(K_{turb}, Re_2)$$ ([1] figure 14.31)

where:

K_{turb} is the local resistance coefficient in turbulent regime (K_s for $Re_2 = 10^4$ - figure 14.14+)



Reynolds Number Correction ($Re_1 < 10^4$):

$$C_{Re} = \frac{K_{lam}}{K_{turb}}$$

Total pressure loss coefficient (based on mean velocity in minor diameter):

- turbulent flow ($Re_2 \geq 10^4$):

$$K = K^*_c$$

- laminar flow ($Re_2 < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U_2^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U_2^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_1	Major diameter (m)
D_2	Minor diameter (m)
N	Contraction length (m)
θ	Half top angle of cone (°)
A_1	Major cross-sectional area (m^2)
A_2	Minor cross-sectional area (m^2)

U_1 Mean velocity in major diameter (m/s)

U_2 Mean velocity in minor diameter (m/s)

Q Volume flow rate (m^3/s)

G Mass flow rate (kg/s)

V Fluid volume in the truncated cone (m^3)

M Fluid mass in the truncated cone (kg)

Re_1 Reynolds number in major diameter ()

Re_2 Reynolds number in minor diameter ()

K^*_c Local resistance coefficient for $Re_2 \geq 10^4$ ()

K_{turb} Local resistance coefficient for $Re_2 = 10^4$ ()

K_{lam} Local resistance coefficient for $Re_2 < 10^4$ ()

C_{Re} Reynolds number correction ()

K Total pressure loss coefficient (based on mean velocity in minor diameter) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

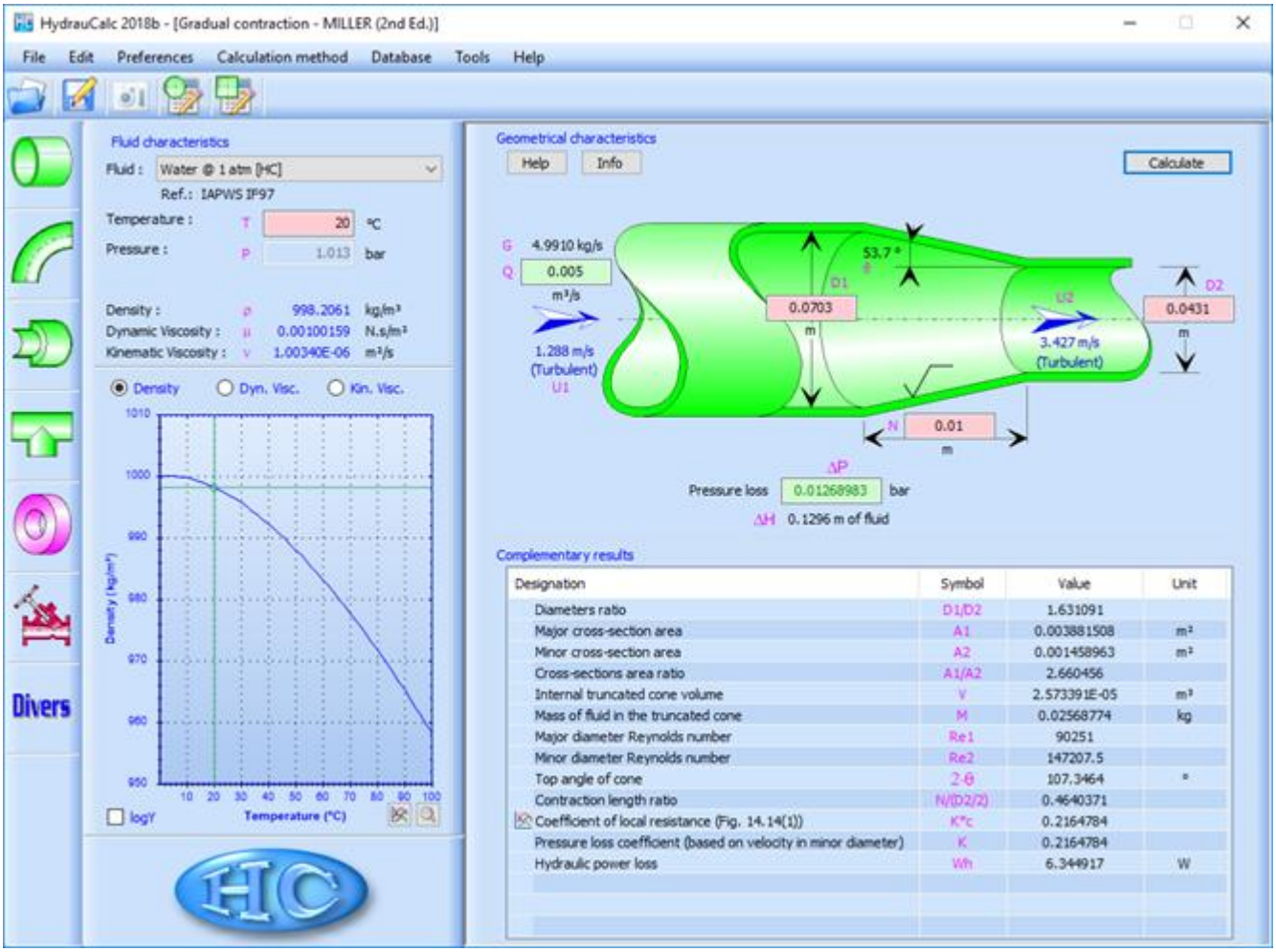
Validity range:

- any flow regime: laminar and turbulent
- area ratio (A1/A2) between 1.1 and 4
- contraction length ratio (N/(D2/2)) less than 10

note: for Reynolds number "Re_2" lower than 10^4, and coefficients "K_{turb}" lower than 0.5 or greater than 10, the laminar pressure loss coefficient is extrapolated

---

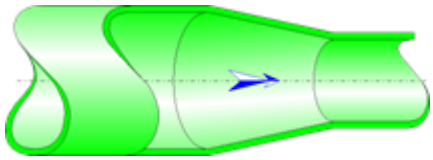
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.3.6.3 CRANE



Model description:

This model of component calculates the head loss (pressure drop) generated by the flow in a gradual contraction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of small to large diameter:

$$\beta = \frac{D_1}{D_2}$$

Half top angle of cone (°):

$$\theta = \tan^{-1}\left(\frac{D_2 - D_1}{2 \cdot L}\right)$$

Minor cross-sectional area (m²):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Major cross-sectional area (m²):

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity in minor diameter (m/s):

$$v_1 = \frac{q}{A_1}$$

Mean velocity in major diameter (m/s):

$$v_2 = \frac{q}{A_2}$$

Mass flow rate (kg/s):

$$G = q \cdot \rho$$

Fluid volume in the truncated cone (m^3):

$$V = L \cdot \frac{\pi}{3} \cdot \left(\left(\frac{D_1}{2} \right)^2 + \left(\frac{D_2}{2} \right)^2 + \left(\frac{D_1}{2} \right) \cdot \left(\frac{D_2}{2} \right) \right)$$

Fluid mass in the truncated cone (kg):

$$M = V \cdot \rho$$

Reynolds number in minor diameter:

$$Re_1 = \frac{v_1 \cdot D_1}{\nu}$$

Reynolds number in major diameter:

$$Re_2 = \frac{v_2 \cdot D_2}{\nu}$$

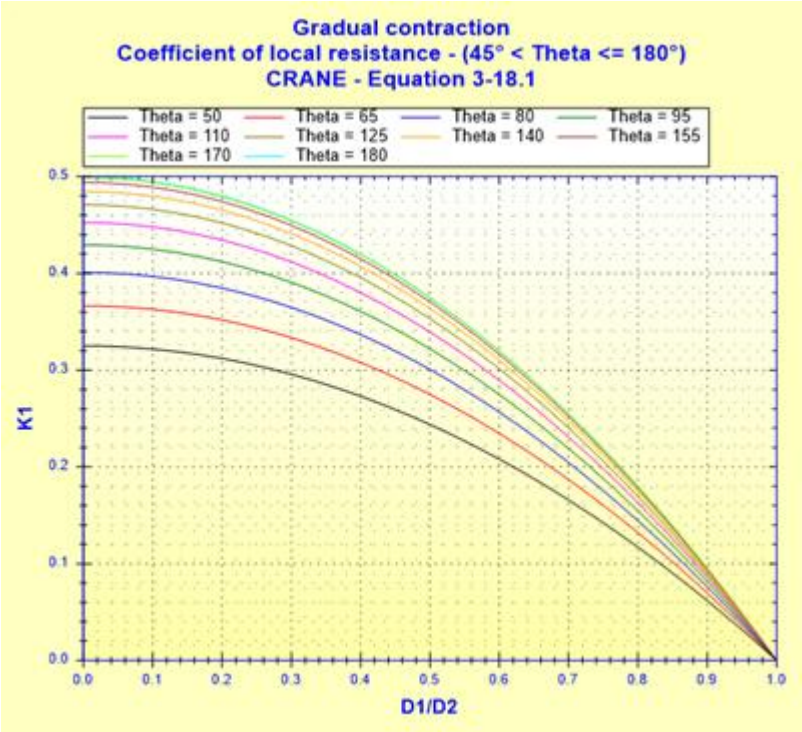
Local resistance coefficient:

- $\theta \leq 45°$:

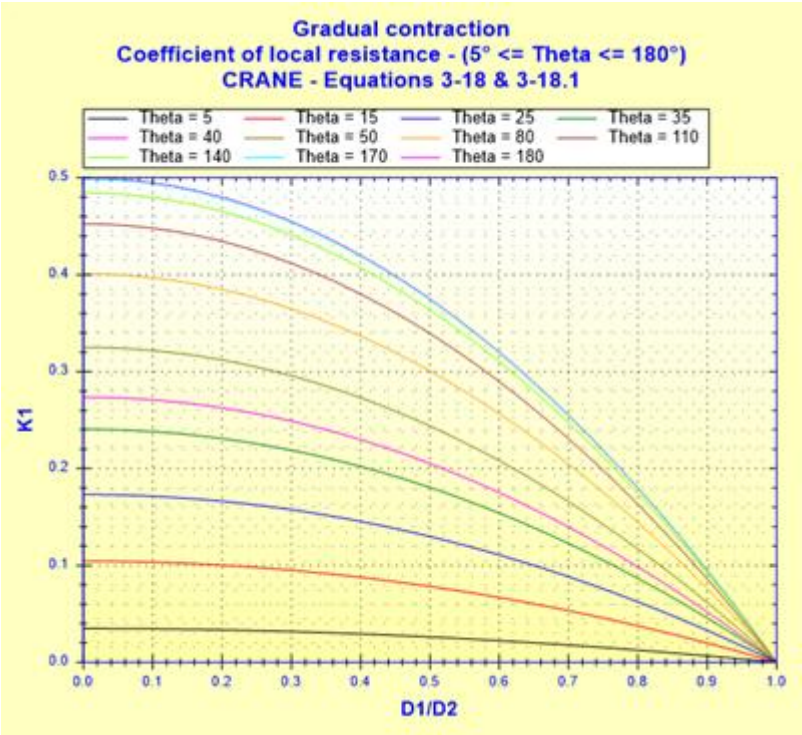
$$K_1 = 0.8 \sin\left(\frac{\theta}{2}\right)\left(1-\beta^2\right)$$ (Equation 3-18)

■ 45° < θ ≤ 180°:

$$K_1 = 0.5\sqrt{\sin\left(\frac{\theta}{2}\right)\left(1-\beta^2\right)}$$ (Equation 3-18.1)



■ $5° \leq \theta \leq 180°$:



Total pressure loss coefficient (based on mean velocity in minor diameter):

$$K = K_1$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot v_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot q$$

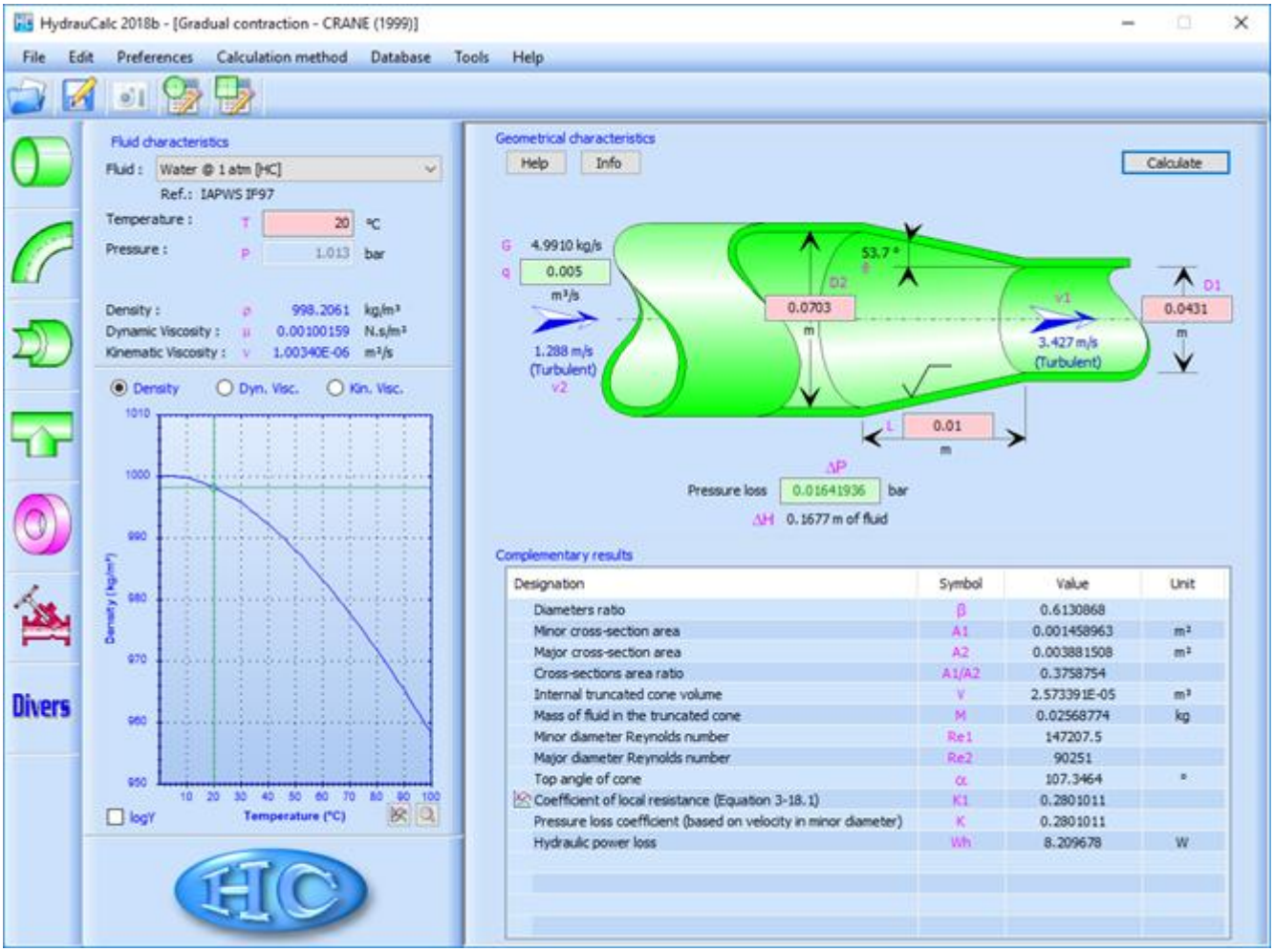
Symbols, Definitions, SI Units:

D_1	Minor diameter (m)
D_2	Major diameter (m)
β	Ratio of small to large diameter ()
L	Contraction length (m)
θ	Half top angle of cone (°)
A_1	Minor cross-sectional area (m^2)
A_2	Major cross-sectional area (m^2)
v_1	Mean velocity in minor diameter (m/s)
v_2	Mean velocity in major diameter (m/s)
q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V	Fluid volume in the truncated cone (m^3)
M	Fluid mass in the truncated cone (kg)
Re_1	Reynolds number in minor diameter ()
Re_2	Reynolds number in major diameter ()
K_1	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in minor diameter ($Re_1 \geq 10^4$)

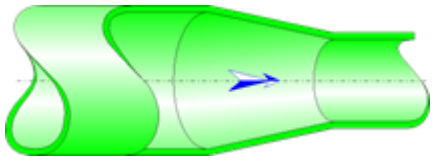
Example of application:



References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 – Edition 1999

2.3.6.4 Pipe Flow - Guide



Model description:

This model of component calculates the head loss (pressure drop) generated by the flow in a gradual contraction. The head loss by friction in the gradual contraction is also taken into account.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of small to large diameter:

$$\beta = \frac{d_2}{d_1}$$

Top cone angle (°):

$$\alpha = 2 \cdot \tan^{-1}\left(\frac{d_1 - d_2}{2 \cdot l}\right)$$

Major cross-sectional area (m²):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Minor cross-sectional area (m²):

$$A_2 = \pi \cdot \frac{d_2^{\,2}}{4}$$

Mean velocity in major diameter (m/s):

$$V_1 = \frac{Q}{A_1}$$

Mean velocity in minor diameter (m/s):

$$V_2 = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Fluid volume in the truncated cone (m^3):

$$V = l \cdot \frac{\pi}{3} \cdot \left(\left(\frac{d_1}{2} \right)^2 + \left(\frac{d_2}{2} \right)^2 + \left(\frac{d_1}{2} \right) \cdot \left(\frac{d_2}{2} \right) \right)$$

Fluid mass in the truncated cone (kg):

$$M = V \cdot \rho_m$$

Reynolds number in major diameter:

$$N_{Re_1} = \frac{V_1 \cdot d_1}{\nu}$$

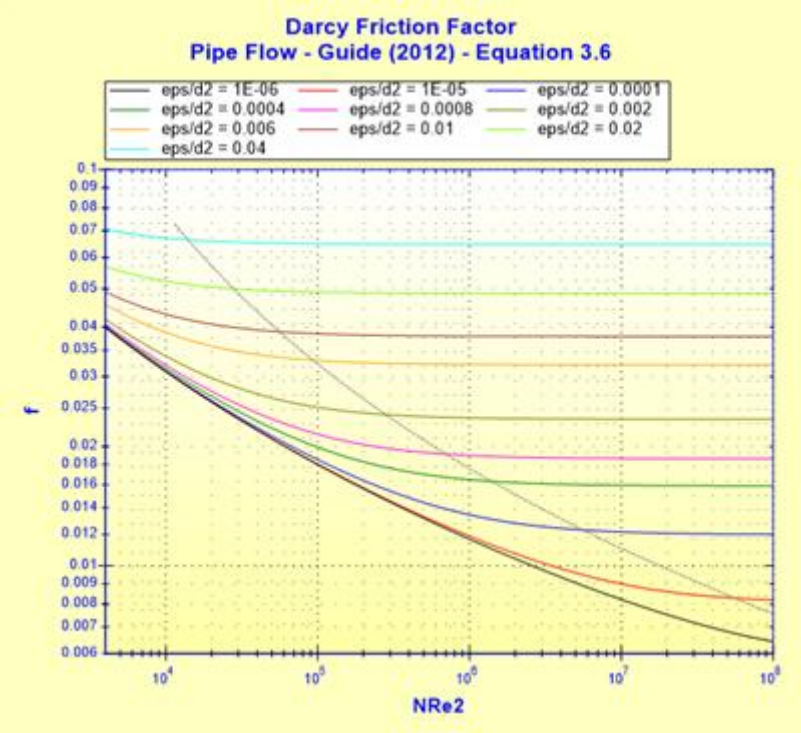
Reynolds number in minor diameter:

$$N_{Re_2} = \frac{V_2 \cdot d_2}{\nu}$$

Darcy friction factor:

$$f = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d_2} + \frac{2.51}{NRe_2 \cdot \sqrt{f}}\right)\right]^2}$$

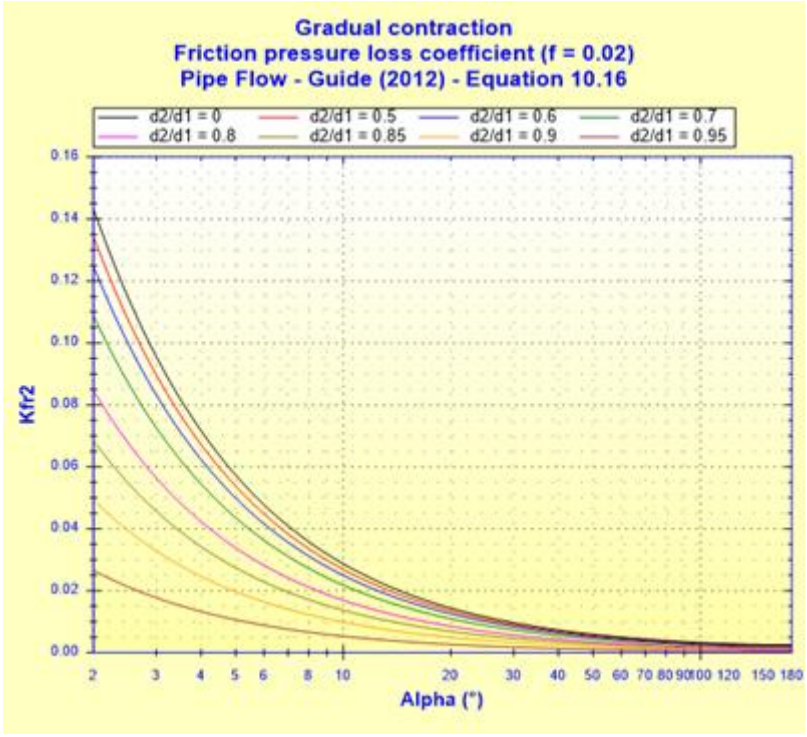
Colebrook-White equation ([1] equation 3.6)



Friction pressure loss coefficient:

$$K_{fr\,2} = \frac{f \cdot \left(1 - \beta^4\right)}{8 \cdot \sin\left(\frac{\alpha}{2}\right)}$$

([1] equation 10.16)

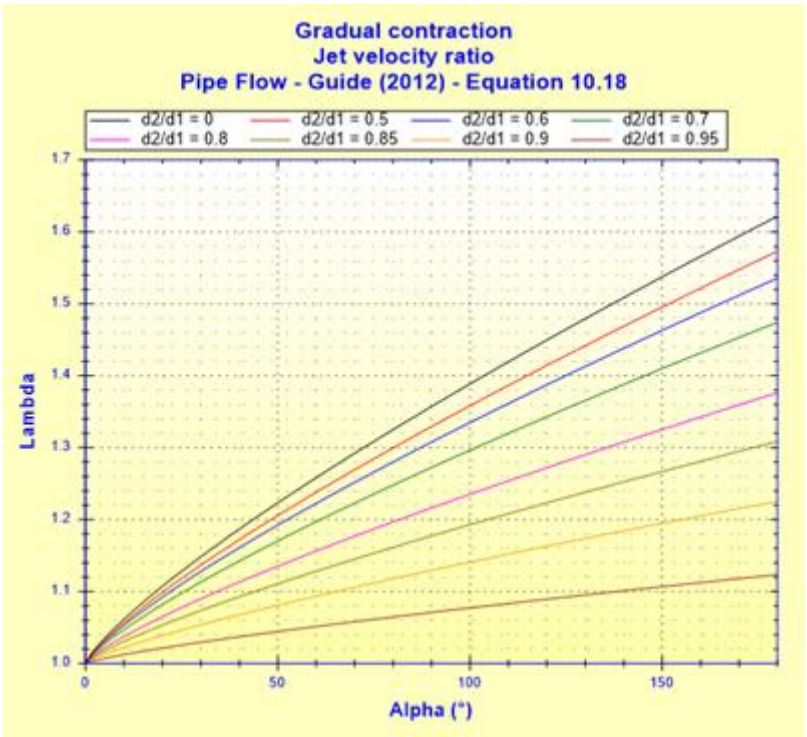


([1] equation 10.16 with f = 0.02)

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left(\frac{\alpha}{180}\right)^{\frac{4}{5}} \cdot \left(1 - 0.215\beta^2 - 0.785\beta^5\right)$$

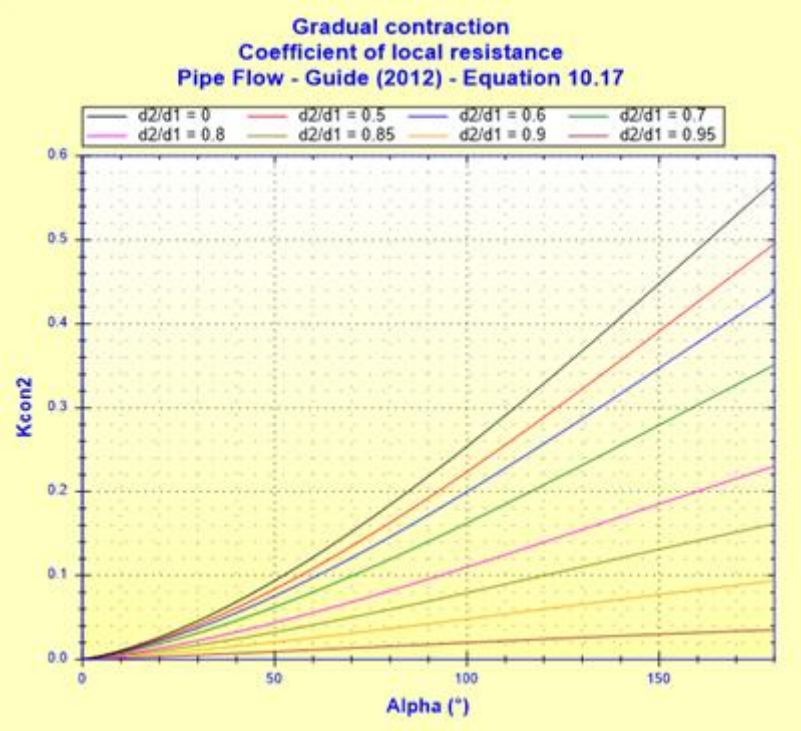
([1] equation 10.18)



Local resistance coefficient:

$$K_{con2} = 0.0696 \cdot \sin\left(\frac{\alpha}{2}\right) \cdot \left(1-\beta^5\right) \cdot \lambda^2 + (\lambda - 1)^2$$

([1] equation 10.17)



Total pressure loss coefficient (based on mean velocity in minor diameter):

$$K_2 = K_{fr2} + K_{con2}$$

([1] equation 10.11)

Total pressure loss (Pa):

$$\Delta P = K_2 \cdot \frac{\rho_m \cdot {v_2}^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K_2 \cdot \frac{{v_2}^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_1 Major diameter (m)

d_2 Minor diameter (m)

β Ratio of small to large diameter ()

l Contraction length (m)

α Top cone angle (°)

A_1 Major cross-sectional area (m^2)

A_2 Minor cross-sectional area (m^2)

V_1 Mean velocity in major diameter (m/s)

V_2 Mean velocity in minor diameter (m/s)

Q Volume flow rate (m^3/s)

G Mass flow rate (kg/s)

V Fluid volume in the truncated cone (m^3)

M Fluid mass in the truncated cone (kg)

NRe_1 Reynolds number in major diameter ()

NRe_2 Reynolds number in minor diameter ()

f Darcy friction factor ()

ε Absolute roughness of the cone walls (m)

Kfr_2 Friction pressure loss coefficient ()

λ Jet velocity ratio ()

$Kcon_2$ Local resistance coefficient ()

K_2 Total pressure loss coefficient (based on mean velocity in minor diameter) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m^3)

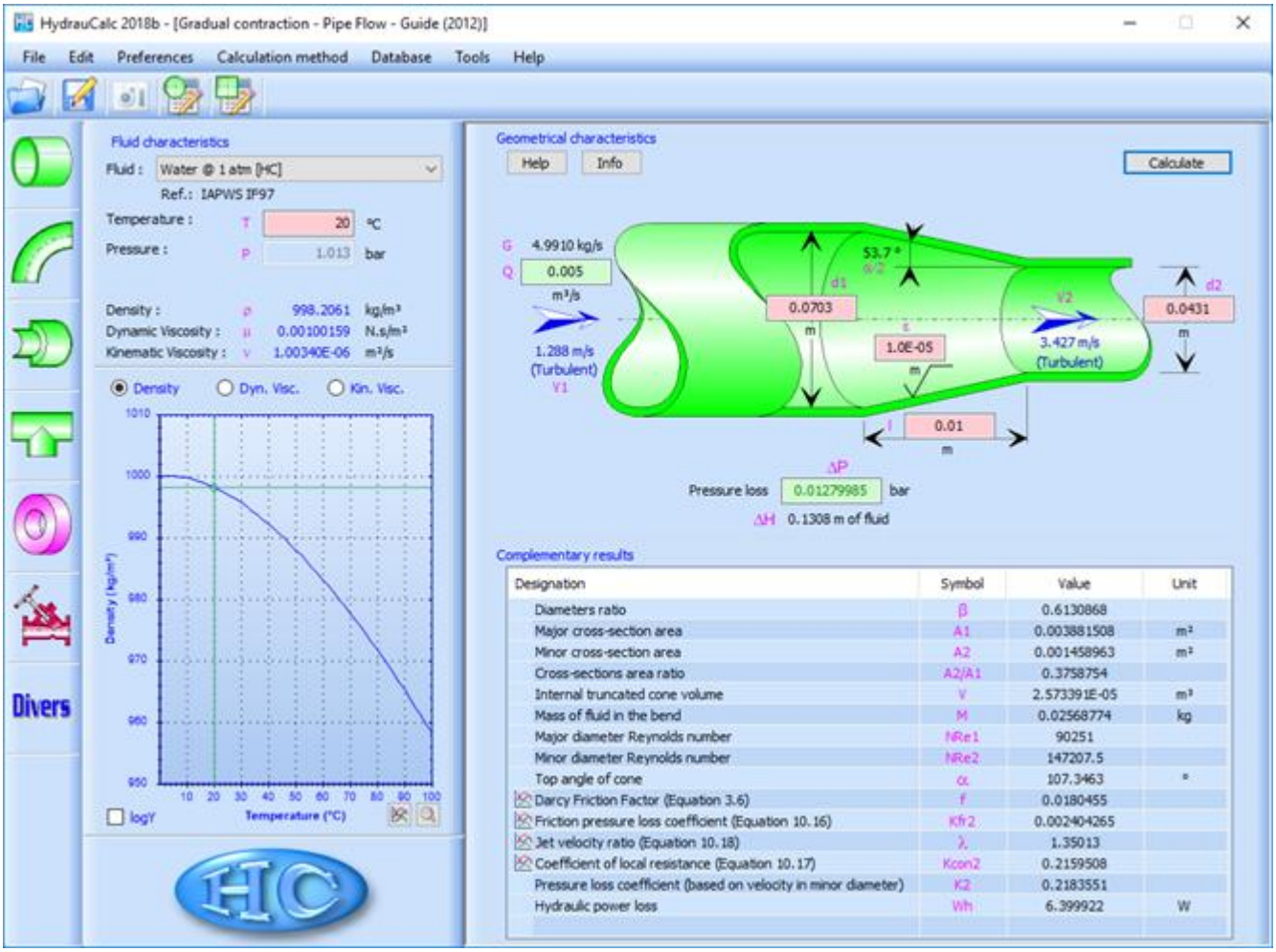
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in minor diameter ($NRe_2 \geq 10^4$)

Example of application:



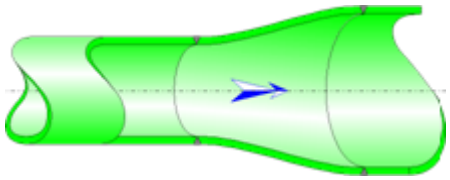
References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.3.7 Welded pipe expansion - Circular cross-section

Welded Pipe Expansion

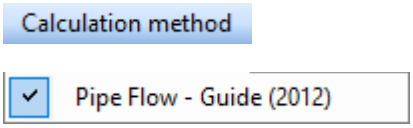
Circular Cross-section



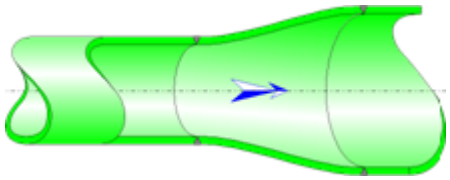
The calculation method used to calculate the pressure loss coefficient of a welded pipe expansion (ANSI standard pipe reducer) is described in the following reference document:

- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The only calculation method offered appears in the "Calculation method" menu and is activated by default.



2.3.7.1 Pipe Flow - Guide



Model description:

This model of component calculates the head loss (pressure drop) generated by the flow in a welded pipe expansion (ANSI standard pipe reducer).

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of small to large diameter:

$$\beta = \frac{d_1}{d_2}$$

Top angle of cone (°):

$$\alpha \approx 2 \cdot \tan^{-1}\left(\frac{d_1 - d_2}{1.2 \cdot l}\right)$$ ([1] §11.5)

Minor cross-sectional area (m²):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Major cross-sectional area (m²):

$$A_2 = \pi \cdot \frac{d_2^{\,2}}{4}$$

Mean velocity in minor diameter (m/s):

$$V_1 = \frac{Q}{A_1}$$

Mean velocity in major diameter (m/s):

$$V_2 = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Fluid volume in the truncated cone (m^3):

$$V \approx 0.2 \cdot l \cdot \pi \cdot \frac{d_1^2}{4} + 0.6 \cdot l \cdot \frac{\pi}{3} \cdot \left(\left(\frac{d_1}{2}\right)^2 + \left(\frac{d_2}{2}\right)^2 + \left(\frac{d_1}{2}\right) \cdot \left(\frac{d_2}{2}\right) \right) + 0.2 \cdot l \cdot \pi \cdot \frac{d_2^{\,2}}{4}$$

Fluid mass in the truncated cone (kg):

$$M = V \cdot \rho_m$$

Reynolds number in minor diameter:

$$N_{Re_1} = \frac{V_1 \cdot d_1}{\nu}$$

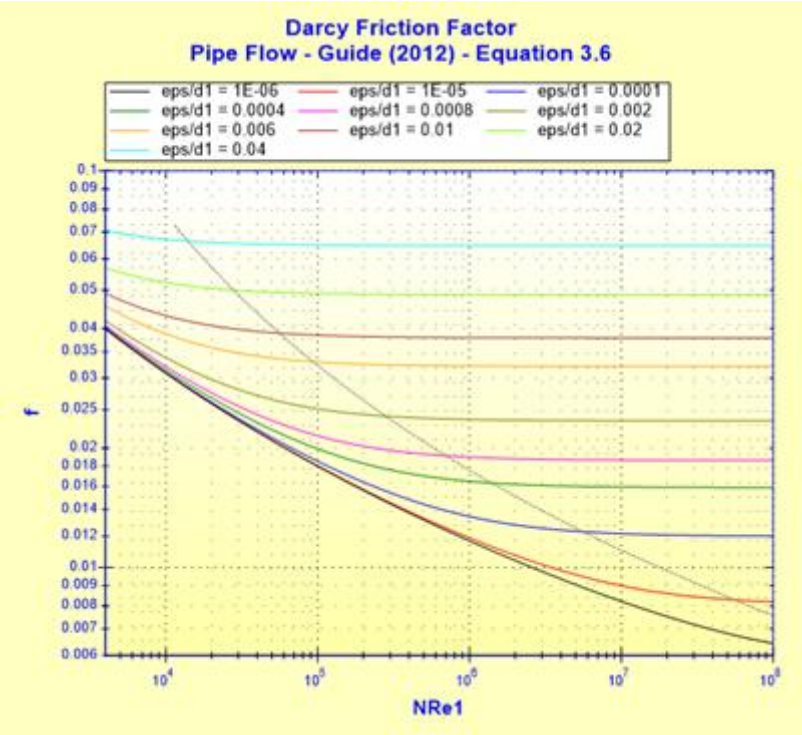
Reynolds number in major diameter:

$$N_{Re_2} = \frac{V_2 \cdot d_2}{\nu}$$

Darcy friction factor (Colebrook-White equation ([1] equation 3.6)):

$$f_1 = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d_1} + \frac{2.51}{NRe_1 \cdot \sqrt{f_1}}\right)\right]^2}$$

$$f_2 = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d_2} + \frac{2.51}{NRe_2 \cdot \sqrt{f_2}}\right)\right]^2}$$



Friction pressure loss coefficient:

$$K_f = f_1 \cdot \frac{0.2 \cdot l}{d_1} + \frac{f_1 \cdot (1 - \beta)}{8 \cdot \sin\left(\alpha/2\right)} + f_2 \cdot \frac{0.2 \cdot l}{d_2} \cdot \beta^4$$

([1] equation 11.13)

Total pressure loss coefficient (based on mean velocity in minor diameter):

$$K_1 = K_f$$

Total pressure loss (Pa):

$$\Delta P = K_1 \cdot \frac{\rho_m \cdot V_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K_1 \cdot \frac{V_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_1	Minor diameter (m)
d_2	Major diameter (m)
β	Ratio of small to large diameter ()
α	Top angle of cone (°)
l	Total reducer length (m)
A_1	Minor cross-sectional area (m^2)
A_2	Major cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
V_1	Mean velocity in minor diameter (m/s)
V_2	Mean velocity in major diameter (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume in the truncated cone (m^3)
M	Fluid mass in the truncated cone (kg)
NRe_1	Reynolds number in minor diameter ()
NRe_2	Reynolds number in major diameter ()
f_1	Darcy friction factor of the minor diameter ()
f_2	Darcy friction factor of the major diameter ()
ε	Absolute roughness of the cone walls (m)
K_f	Friction pressure loss coefficient ()
K_1	Total pressure loss coefficient (based on mean velocity in minor diameter) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m³)

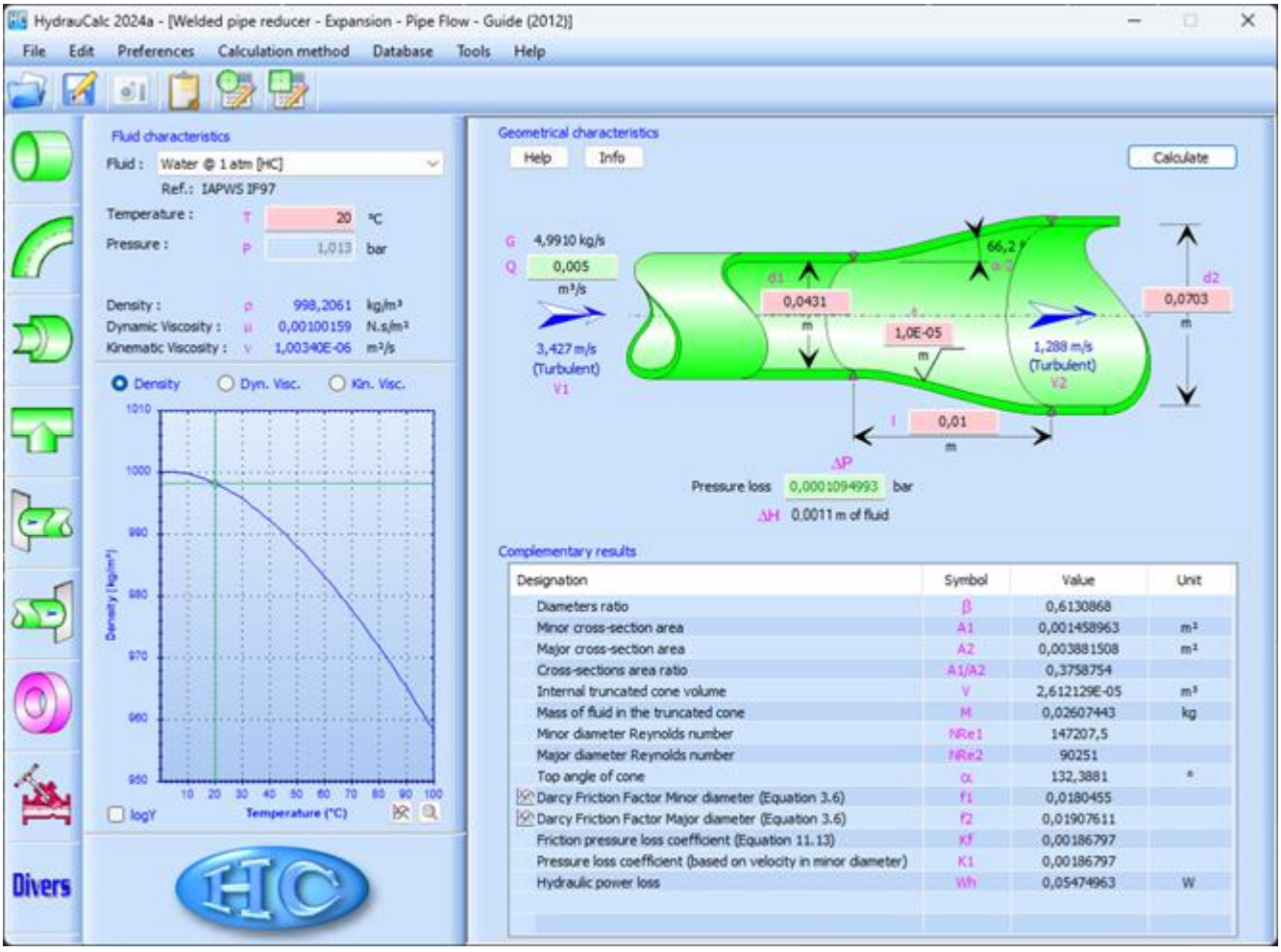
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime in minor diameter ($NRe_1 \geq 10^4$)

Example of application:



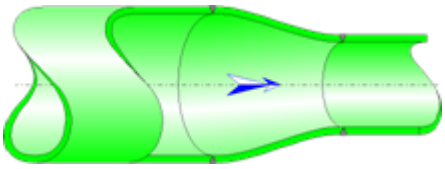
References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.3.8 Weldedp pipe contraction - Circular cross-section

Welded Pipe Contraction

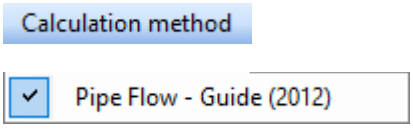
Circular Cross-section



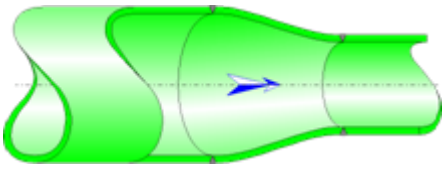
The calculation method used to calculate the pressure loss coefficient of a welded pipe contraction (ANSI standard pipe reducer) is described in the following reference document:

- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The only calculation method offered appears in the "Calculation method" menu and is activated by default.



2.3.8.1 Pipe Flow - Guide



Model description:

This model of component calculates the head loss (pressure drop) generated by the flow in a welded pipe contraction (ANSI standard pipe reducer).

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of small to large diameter:

$$\beta = \frac{d_2}{d_1}$$

Top cone angle (°):

$$\alpha \approx 2 \cdot \tan^{-1}\left(\frac{d_1 - d_2}{1.2 \cdot l}\right)$$ ([1] §11.5)

Major cross-sectional area (m²):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Minor cross-sectional area (m²):

$$A_2 = \pi \cdot \frac{d_2^{\,2}}{4}$$

Mean velocity in major diameter (m/s):

$$V_1 = \frac{Q}{A_1}$$

Mean velocity in minor diameter (m/s):

$$V_2 = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Fluid volume in the truncated cone (m^3):

$$V \approx 0.2 \cdot l \cdot \pi \cdot \frac{d_1^{\,2}}{4} + 0.6 \cdot l \cdot \frac{\pi}{3} \cdot \left(\left(\frac{d_1}{2}\right)^2 + \left(\frac{d_2}{2}\right)^2 + \left(\frac{d_1}{2}\right) \cdot \left(\frac{d_2}{2}\right) \right) + 0.2 \cdot l \cdot \pi \cdot \frac{d_2^{\,2}}{4}$$

Fluid mass in the truncated cone (kg):

$$M = V \cdot \rho_m$$

Reynolds number in major diameter:

$$N_{Re_1} = \frac{V_1 \cdot d_1}{\nu}$$

Reynolds number in minor diameter:

$$N_{Re_2} = \frac{V_2 \cdot d_2}{\nu}$$

Darcy friction factor (Colebrook-White equation):

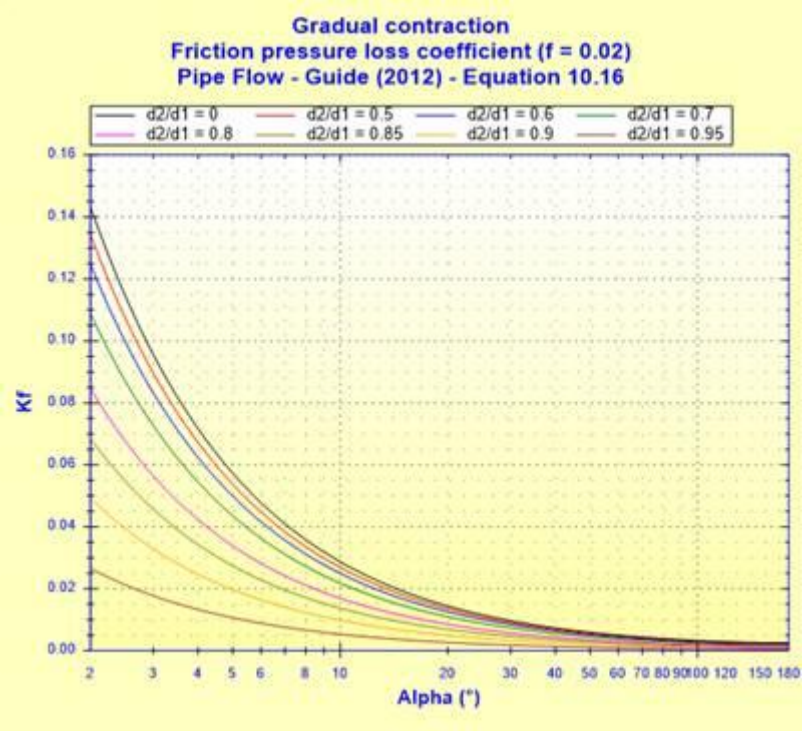
$$f = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d_2} + \frac{2.51}{NRe_2 \cdot \sqrt{f}}\right)\right]^2}$$

([1] equation 3.6)

Friction pressure loss coefficient:

$$K_f = \frac{f \cdot \left(1 - \beta^4\right)}{8 \cdot \sin\left(\alpha/2\right)}$$

([1] equation 10.16)



([1] equation 10.16 with f = 0.02)

Total pressure loss coefficient (based on mean velocity in minor diameter):

$$K_2 = K_f$$

Total pressure loss (Pa):

$$\Delta P = K_2 \cdot \frac{\rho_m \cdot v_2^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K_2 \cdot \frac{v_2^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_1 Major diameter (m)

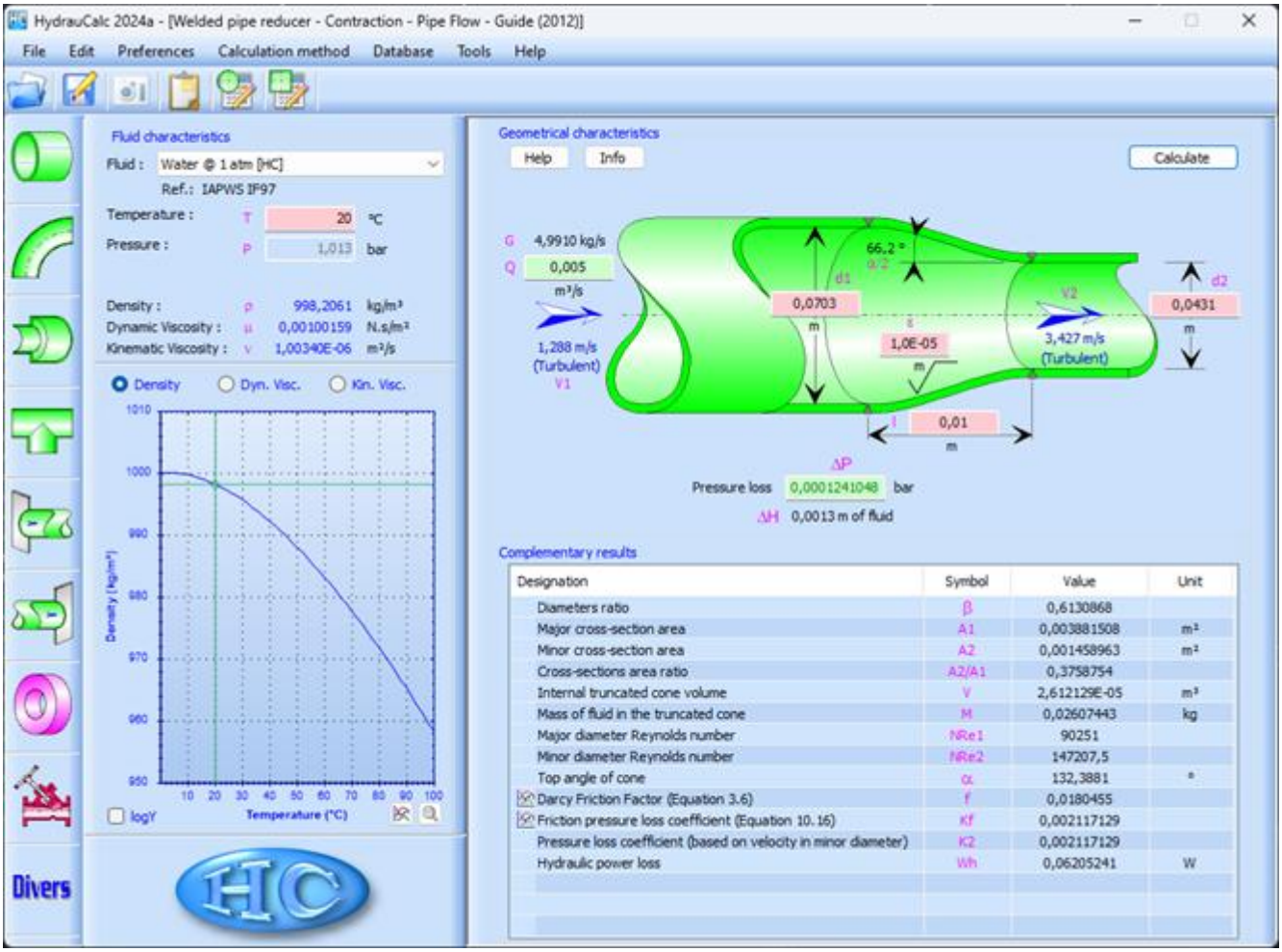
d_2 Minor diameter (m)

β	Ratio of small to large diameter ()
l	Contraction length (m)
α	Top cone angle (°)
A_1	Major cross-sectional area (m^2)
A_2	Minor cross-sectional area (m^2)
V_1	Mean velocity in major diameter (m/s)
V_2	Mean velocity in minor diameter (m/s)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V	Fluid volume in the truncated cone (m^3)
M	Fluid mass in the truncated cone (kg)
NRe_1	Reynolds number in major diameter ()
NRe_2	Reynolds number in minor diameter ()
f	Darcy friction factor of the minor diameter ()
ε	Absolute roughness of the cone walls (m)
Kf	Friction pressure loss coefficient ()
K_2	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in minor diameter ($NRe_2 \geq 10^4$)

Example of application:

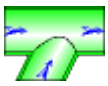
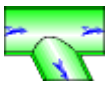
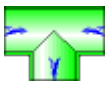
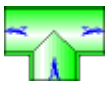
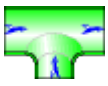
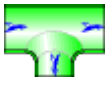
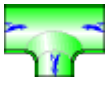
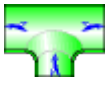


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.4 Junctions

This subsection regroups the set of junctions that can be modeled and calculated. The types of junction available are:

- Combining sharp-edged junction

- Dividing sharp-edged junction

- Symmetric combining sharp-edged T-junction

- Symmetric dividing sharp-edged T-junction

- Combining radiused-edged T-junction

- Dividing radiused-edged T-junction

- Symmetric combining radiused-edged T-junction

- Symmetric dividing radiused-edged T-junction

- Symmetric combining T-junction with smooth turn through 90°

- Symmetric dividing T-junction with Smooth turn through 90°

- Symmetrical combining Y-junction with branches of unequal sections

- Symmetrical dividing Y-junction with branches of unequal sections

- Symmetrical combining Y-junction with branches of equal sections

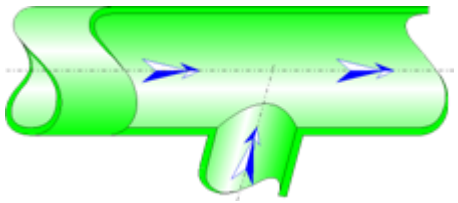
- Symmetrical dividing Y-junction with branches of equal sections

- Four-way combining junction with branches of unequal sections

- Four-way dividing junction with branches of unequal sections

2.4.1 Combining sharp-edged junction

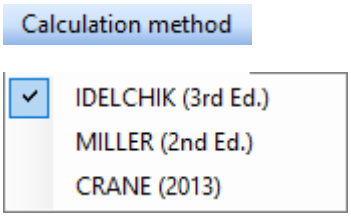
Circular Cross-Section



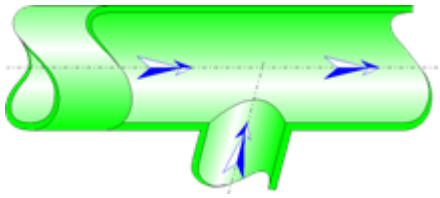
For the calculation of the pressure loss coefficient of combining sharp-edged junctions, the user can choose from one of the methods described in the following three reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 2013

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.4.1.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a combining sharp-edged junction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the lateral branch (m^2):

$$F_s = \pi \cdot \frac{D_s^2}{4}$$

Cross-sectional area of the common branch and the straight branch (m^2):

$$F_c = \pi \cdot \frac{D_c^2}{4}$$

Volume flow rate in the common branch (m^3/s):

$$Q_c = Q_s + Q_{st}$$

Mean velocity in the lateral branch (m/s):

$$w_s = \frac{Q_s}{F_s}$$

Mean velocity in the straight branch (m/s):

$$w_{st} = \frac{Q_{st}}{F_c}$$

Mean velocity in the common branch (m/s):

$$w_c = \frac{Q_c}{F_c}$$

Mass flow rate in the lateral branch (kg/s):

$$G_s = Q_s \cdot \rho$$

Mass flow rate in the straight branch (kg/s):

$$G_{st} = Q_{st} \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_c = Q_c \cdot \rho$$

Reynolds number in the lateral branch:

$$\mathrm{Re}_s = \frac{w_s \cdot D_s}{\nu}$$

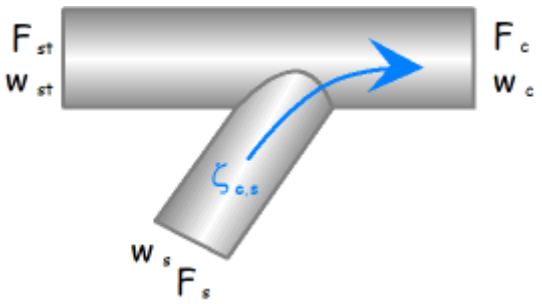
Reynolds number in the straight branch:

$$\mathrm{Re}_{st} = \frac{w_{st} \cdot D_c}{\nu}$$

Reynolds number in the common branch:

$$Re_c = \frac{w_c \cdot D_c}{\nu}$$

Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch):



■ $Re_c \geq 4000$

$$\zeta_{c,s} = A \cdot \zeta'_{c,s}$$ ([1] diagram 7.1 7.2 7.3 7.4)

with:

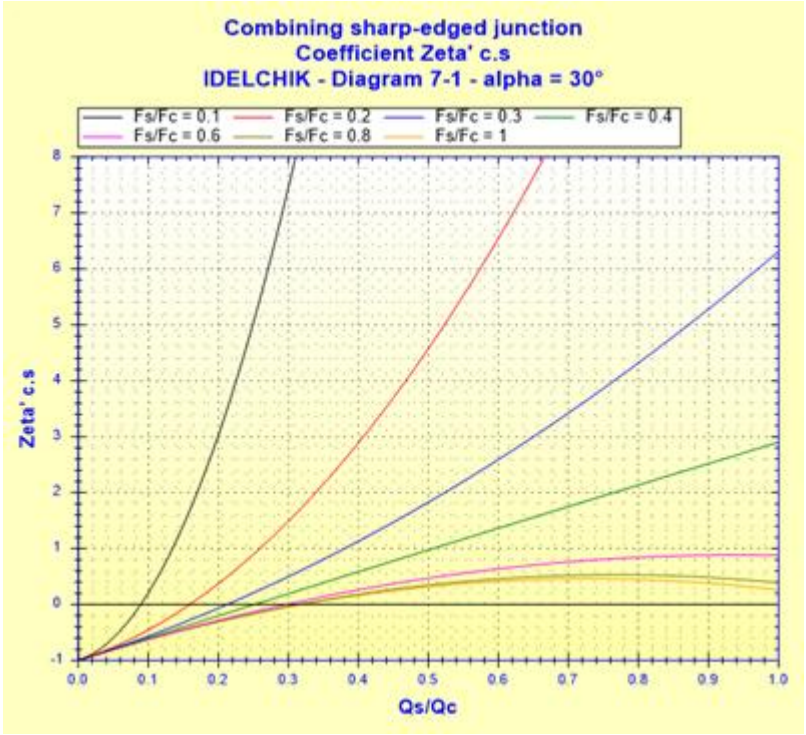
Values of *A*

F_s / F_c	≤ 0.35	> 0.35	
Q_s / Q_c	≤ 1	≤ 0.4	> 0.4
A	1	$0.9 \cdot \left(1 - \frac{Q_s}{Q_c}\right)$	0.55

([1] table 7-1)

● Angle $\alpha = 30°$

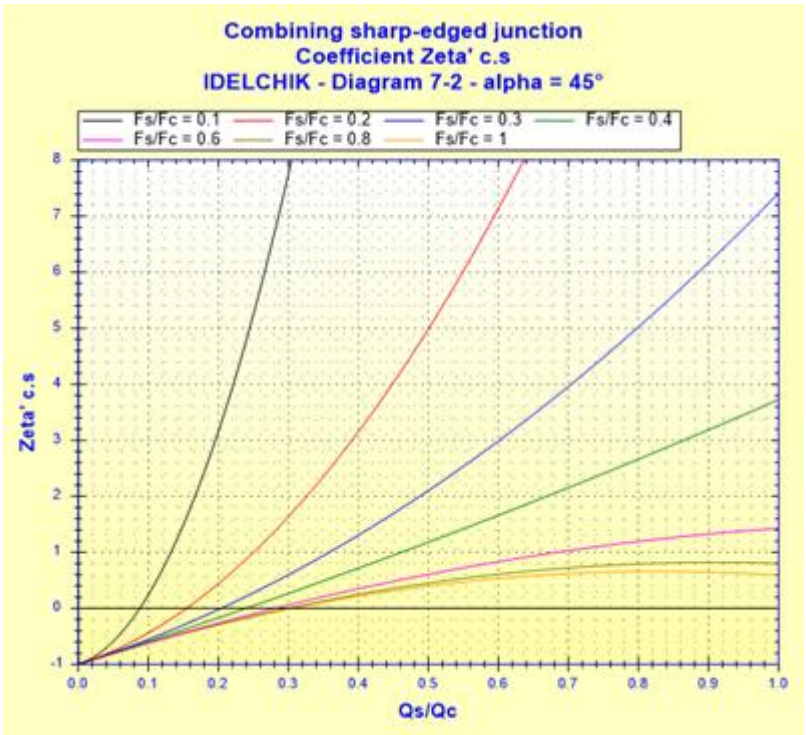
$$\zeta'_{c,s} = 1 + \left(\frac{Q_s}{Q_c} \cdot \frac{F_c}{F_s}\right)^2 - 2 \cdot \left(1 - \frac{Q_s}{Q_c}\right)^2 - 1.74 \cdot \frac{F_c}{F_s} \cdot \left(\frac{Q_s}{Q_c}\right)^2$$ ([1] diagram 7.1)



- Angle $\alpha = 45°$

$$\zeta'_{c.s} = 1 + \left(\frac{Q_s}{Q_c} \cdot \frac{F_c}{F_s}\right)^2 - 2 \cdot \left(1 - \frac{Q_s}{Q_c}\right)^2 - 1.41 \cdot \frac{F_c}{F_s} \cdot \left(\frac{Q_s}{Q_c}\right)^2$$

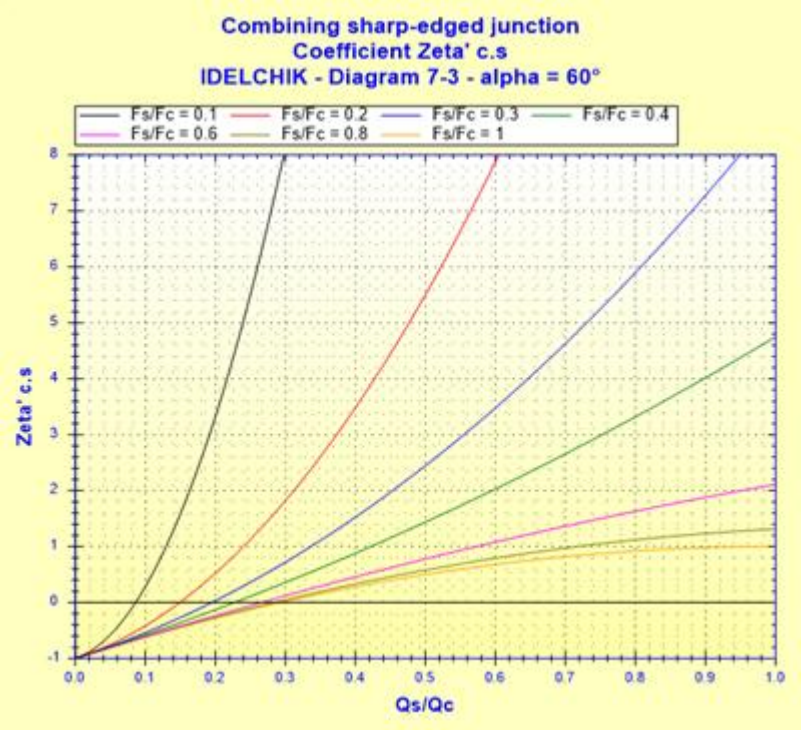
([1] diagram 7.2)



- Angle $\alpha = 60°$

$$\zeta'_{c.s} = 1 + \left(\frac{Q_s}{Q_c} \cdot \frac{F_c}{F_s}\right)^2 - 2 \cdot \left(1 - \frac{Q_s}{Q_c}\right)^2 - \frac{F_c}{F_s} \cdot \left(\frac{Q_s}{Q_c}\right)^2$$

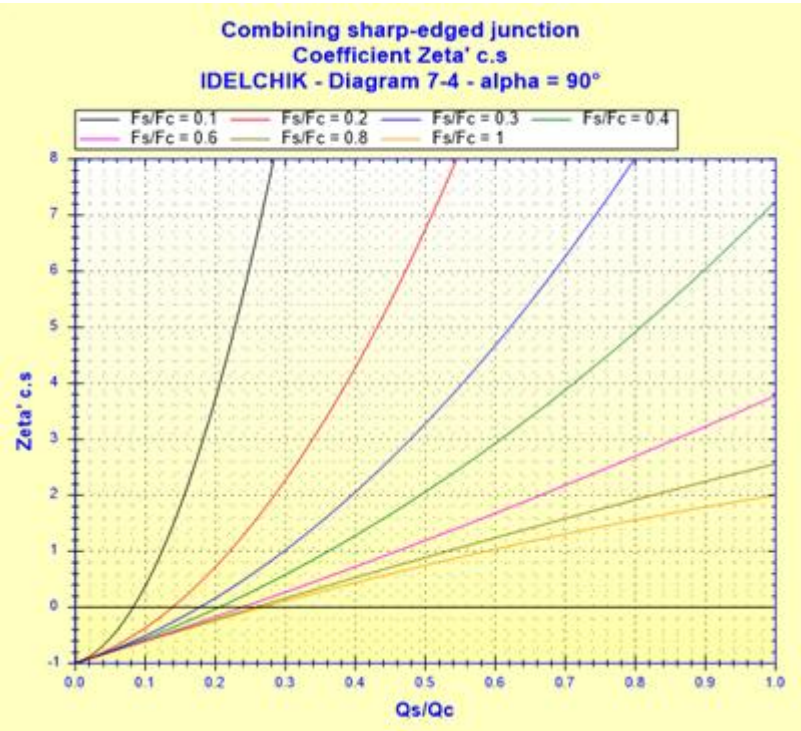
([1] diagram 7.3)



- Angle $\alpha = 90°$

$$\zeta'_{c.s} = 1 + \left(\frac{Q_s}{Q_c} \cdot \frac{F_c}{F_s}\right)^2 - 2 \cdot \left(1 - \frac{Q_s}{Q_c}\right)^2$$

([1] diagram 7.4)



For any angles α between 30 ° and 90 °, the coefficient $\zeta'_{c.s}$ is obtained by linear interpolation between the values of $\zeta'_{c.s}$ calculated at 30 °, 45 °, 60 ° and 90 °.

■ $Re_c \leq 2000$

$$\zeta_{c.s} = 2 \cdot \zeta^t_{c.s} + \frac{150}{Re_c}$$

([1] equation §30)

with

$$\zeta^t_{c.s} = A \cdot \left[1 + \left(\frac{Q_s}{Q_c} \cdot \frac{F_c}{F_s} \right)^2 - 2 \cdot \frac{F_c}{F_{st}} \cdot \left(1 - \frac{Q_s}{Q_c} \right)^2 - 2 \cdot \frac{F_c}{F_s} \cdot \left(\frac{Q_s}{Q_c} \right)^2 \cdot \cos(\alpha) \right] + K_s$$

([1] equation 7.1)

with :

Values of *A*

F_s / F_c	≤ 0.35	> 0.35	
Q_s / Q_c	≤ 1	≤ 0.4	> 0.4
A	**1**	$0.9 \cdot \left(1 - \frac{Q_s}{Q_c} \right)$	**0.55**

([1] table 7-1)

$$K_S = 0$$

■ $2000 < Re_c < 4000$

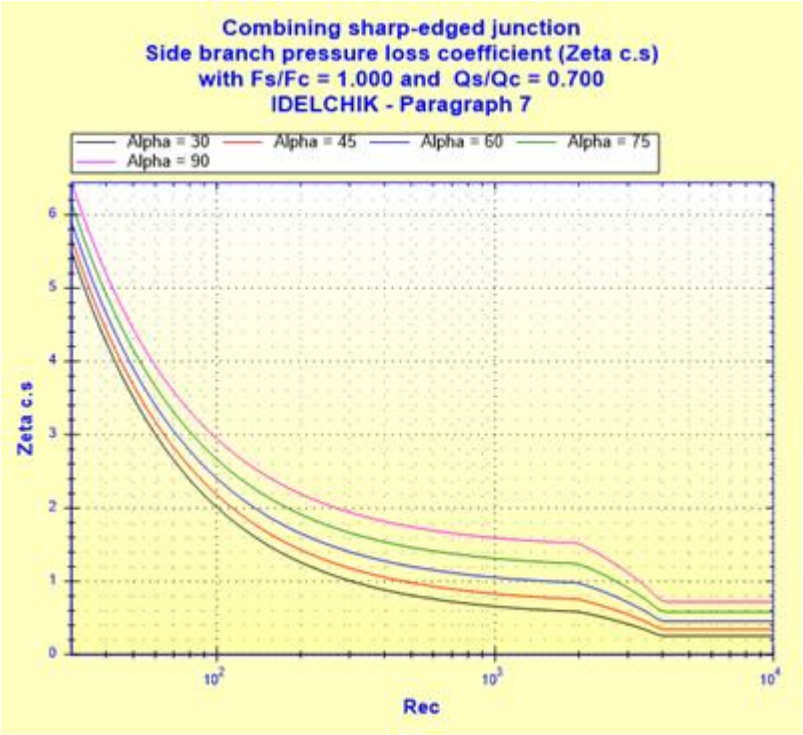
linear interpolation

$$\zeta_{c.s} = \zeta^l_{c.s} \cdot \left(1 - \frac{Re_c - 2000}{2000} \right) + \zeta^t_{c.s} \cdot \left(\frac{Re_c - 2000}{2000} \right)$$

with:

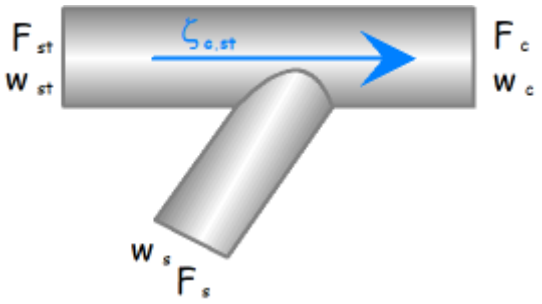
$\zeta^l_{c.s}$ = laminar coefficient obtained with $Re_c = 2000$

$\zeta^t_{c.s}$ = turbulent coefficient obtained with $Re_c = 4000$



$\zeta_{c.s}$ for Re_c < 4000 and with F_s/F_c = 1 and Q_s/Q_c = 0.7

Pressure loss coefficient of the straight branch (based on mean velocity in the common branch):

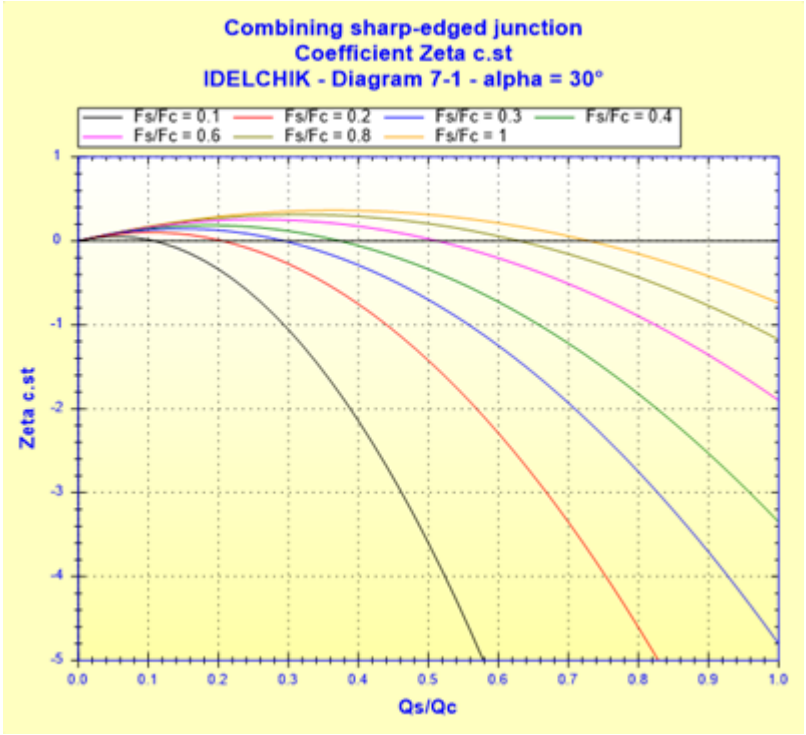


■ $Re_c \geq 4000$

● Angle $\alpha = 30°$

$$\zeta_{c.st} = 1 - \left(1 - \frac{Q_s}{Q_c}\right)^2 - 1.74 \cdot \frac{F_c}{F_s} \cdot \left(\frac{Q_s}{Q_c}\right)^2$$

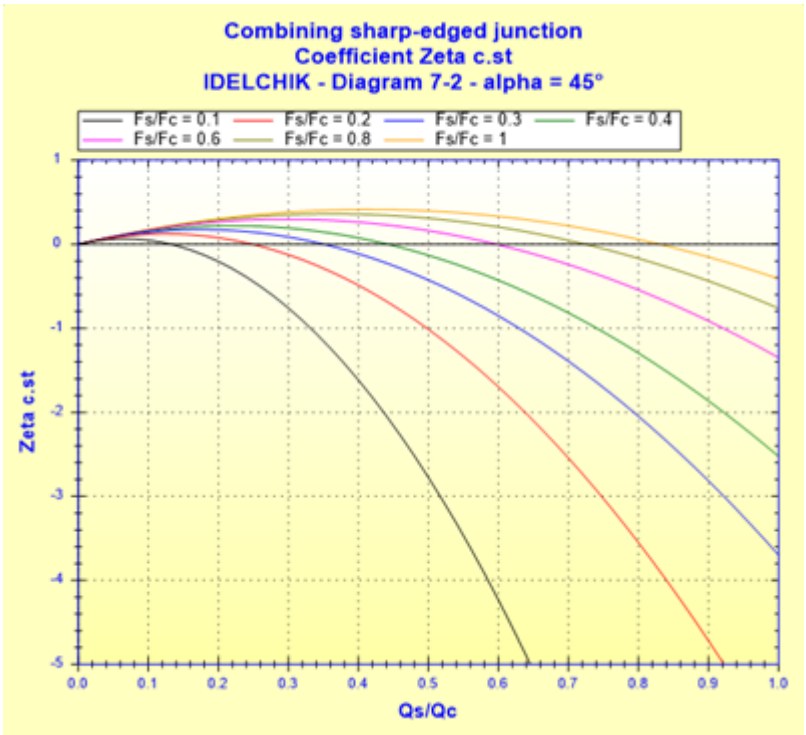
([1] diagram 7.1)



- Angle $\alpha = 45°$

$$\zeta_{c.st} = 1 - \left(1 - \frac{Q_s}{Q_c}\right)^2 - 1.41 \cdot \frac{F_c}{F_s} \cdot \left(\frac{Q_s}{Q_c}\right)^2$$

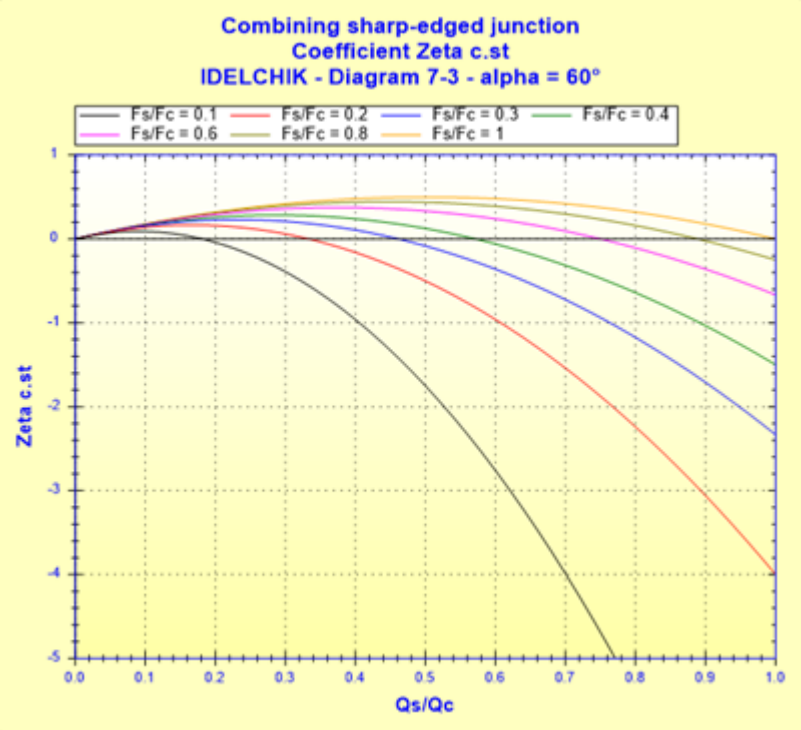
([1] diagram 7.2)



- Angle $\alpha = 60°$

$$\zeta_{c.st} = 1 - \left(1 - \frac{Q_s}{Q_c}\right)^2 - \frac{F_c}{F_s} \cdot \left(\frac{Q_s}{Q_c}\right)^2$$

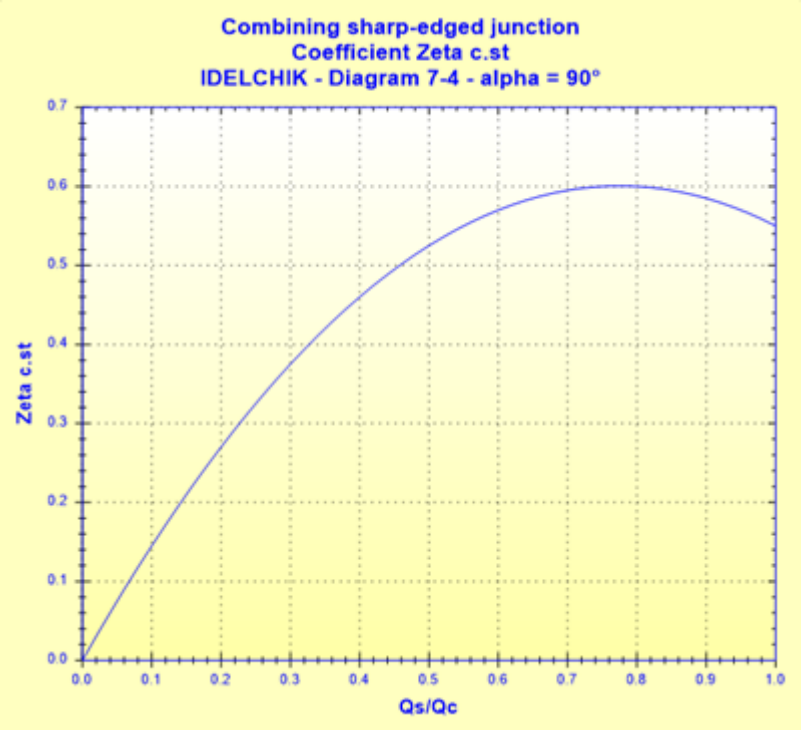
([1] diagram 7.3)



- Angle $\alpha = 90°$

$$\zeta_{c.st} = 1.55 \cdot \frac{Q_s}{Q_c} - \left(\frac{Q_s}{Q_c}\right)^2$$

([1] diagram 7.4)



For any angles α between 30 ° and 90 °, the coefficient $\zeta_{c.st}$ is obtained by linear interpolation between the values of $\zeta_{c.st}$ calculated at 30 °, 45 °, 60 ° and 90 °.

■ $Re_c \leq 2000$

$$\zeta_{c.st} = 2 \cdot \zeta^{l}_{c.s} + a_0 \cdot \left(1 - \frac{Q_s}{Q_c}\right)^2 - \left(1.6 - 0.3 \cdot \frac{F_s}{F_c}\right) \cdot \left(\frac{F_c}{F_s} \cdot \frac{Q_s}{Q_c}\right)^2$$

([1] equation §30)

with:

Values of a_0

F_s / F_c	≤ 0.35	> 0.35	
Q_s / Q_c	≤ 1	≤ 0.2	> 0.2
a_0	$1.8 - \frac{Q_s}{Q_c}$	$1.8 - 4 \cdot \frac{Q_s}{Q_c}$	$1.2 - \frac{Q_s}{Q_c}$

([1] table 7-6)

$$\zeta^{l}_{c.s} = 2 \cdot \zeta^{t}_{c.s} + \frac{150}{Re_c}$$

([1] équation 7.6)

with:

$$\zeta^{t}_{c.s} = A \cdot \left[1 + \left(\frac{Q_s}{Q_c} \cdot \frac{F_c}{F_s}\right)^2 - 2 \cdot \frac{F_c}{F_{st}} \cdot \left(1 - \frac{Q_s}{Q_c}\right)^2 - 2 \cdot \frac{F_c}{F_s} \cdot \left(\frac{Q_s}{Q_c}\right)^2 \cdot \cos(\alpha)\right] + K_s$$

([1] équation 7.1)

with:

Values of A

F_s / F_c	≤ 0.35	> 0.35	
Q_s / Q_c	≤ 1	≤ 0.4	> 0.4
A	1	$0.9 \cdot \left(1 - \frac{Q_s}{Q_c}\right)$	0.55

([1] table 7-1)

$$K_s = 0$$

■ $2000 < Re_c < 4000$

linear interpolation

$$\zeta_{c.s} = \zeta^{l}_{c.s} \cdot \left(1 - \frac{Re_c - 2000}{2000}\right) + \zeta^{t}_{c.s} \cdot \left(\frac{Re_c - 2000}{2000}\right)$$

with:

$\zeta^{l}_{c.s}$ = laminar coefficient obtained with Re_c = 2000

$\zeta^{t}_{c.s}$ = turbulent coefficient obtained with Re_c = 4000

$\zeta_{c.s}$ for Re_c < 4000 and with F_s/F_c = 1 and Q_s/Q_c = 0.7

Pressure loss in the lateral branch (Pa):

$$\Delta P_{c.s} = \zeta_{c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Pressure loss in the straight branch (Pa):

$$\Delta P_{c.st} = \zeta_{c.st} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Head loss of fluid in the lateral branch (m):

$$\Delta H_{c.s} = \zeta_{c.s} \cdot \frac{W_c^{\,2}}{2 \cdot g}$$

Head loss of fluid in the straight branch (m):

$$\Delta H_{c.st} = \zeta_{c.st} \cdot \frac{W_c^{\,2}}{2 \cdot g}$$

Hydraulic power loss in the lateral branch (W):

$$Wh_s = \Delta P_{c.s} \cdot Q_s$$

Hydraulic power loss in the straight branch (W):

$$Wh_{st} = \Delta P_{c.st} \cdot Q_{st}$$

Symbols, Definitions, SI Units:

D_s	Diameter of the lateral branch (m)
D_c	Diameter of the common branch and the straight branch (m)
F_s	Cross-sectional area of the lateral branch (m^2)
F_c	Cross-sectional area of the common branch and the straight branch (m^2)
Q_s	Volume flow rate in the lateral branch (m^3/s)
w_s	Mean velocity in the lateral branch (m/s)
Q_{st}	Volume flow rate in the straight branch (m^3/s)
w_{st}	Mean velocity in the straight branch (m/s)
Q_c	Volume flow rate in the common branch (m^3/s)
w_c	Mean velocity in the common branch (m/s)
G_s	Mass flow rate in the lateral branch (kg/s)
G_{st}	Mass flow rate in the straight branch (kg/s)
G_c	Mass flow rate in the common branch (kg/s)
Re_s	Reynolds number in the lateral branch ()
Re_{st}	Reynolds number in the straight branch ()
Re_c	Reynolds number in the common branch ()
α	Angle of the lateral branch (°)
$\zeta_{c.s}$	Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch) ()
$\zeta_{c.st}$	Pressure loss coefficient of the straight branch (based on mean velocity in the common branch) ()

ΔP_s Pressure loss in the lateral branch (Pa)

ΔP_{st} Pressure loss in the straight branch (Pa)

ΔH_s Head loss of fluid in the lateral branch (m)

ΔH_{st} Head loss of fluid in the straight branch (m)

Wh_s Hydraulic power loss in the lateral branch (W)

Wh_{st} Hydraulic power loss in the straight branch (W)

ρ Fluid density (kg/m³)

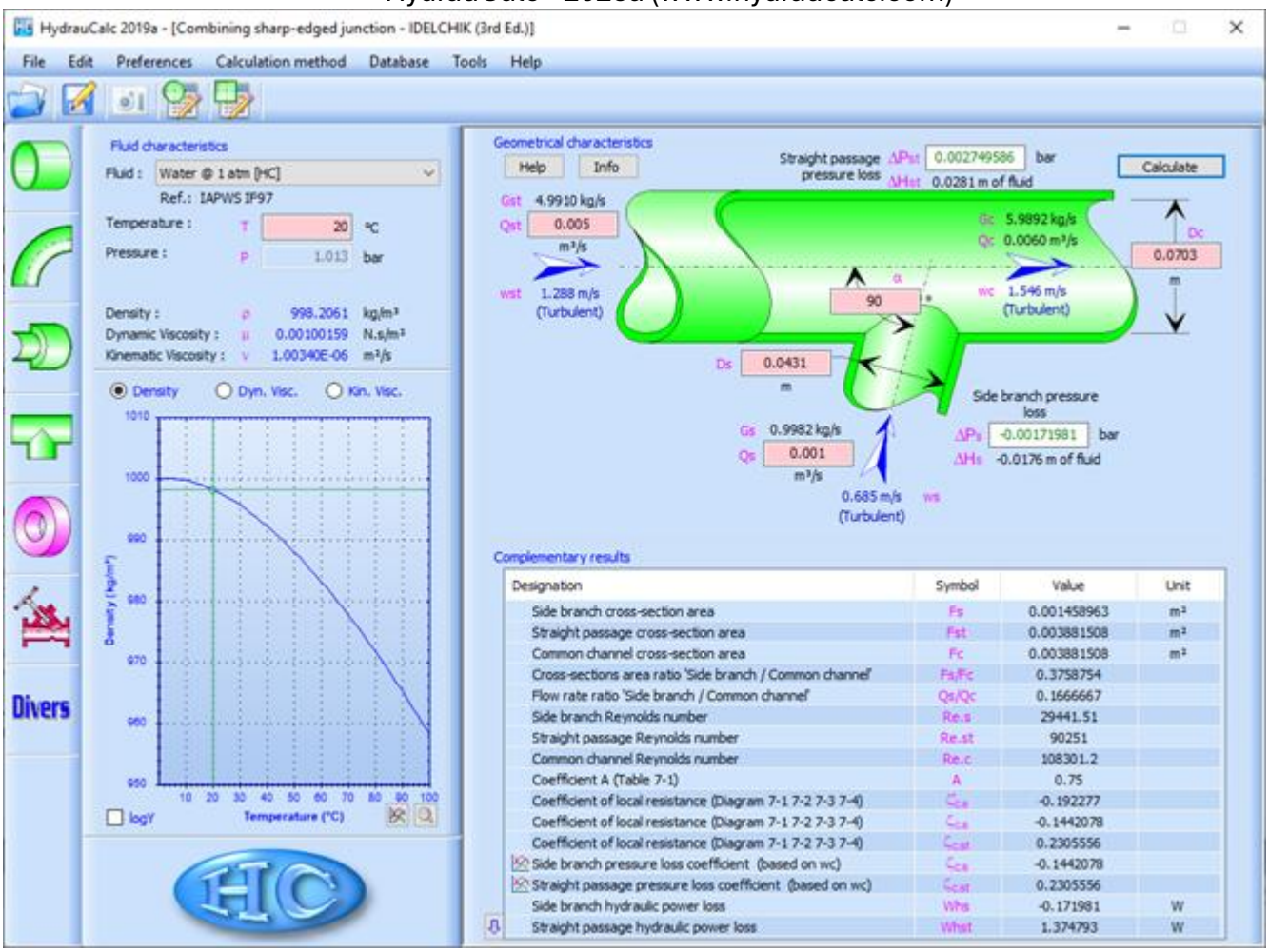
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- angle of the lateral branch: between 30° and 90°

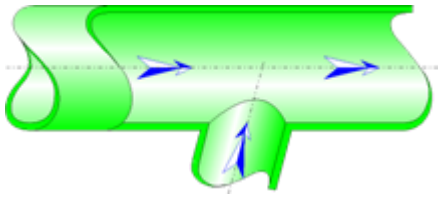
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.4.1.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a combining sharp-edged junction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the lateral branch (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Cross-sectional area of the common branch and the straight branch (m^2):

$$A_3 = \pi \cdot \frac{D_3^2}{4}$$

Volume flow rate in the common branch (m^3/s):

$$Q_3 = Q_1 + Q_2$$

Mean velocity in the lateral branch (m/s):

$$U_1 = \frac{Q_1}{A_1}$$

Mean velocity in the straight branch (m/s):

$$U_2 = \frac{Q_2}{A_3}$$

Mean velocity in the common branch (m/s):

$$U_3 = \frac{Q_3}{A_3}$$

Mass flow rate in the lateral branch (kg/s):

$$G_1 = Q_1 \cdot \rho$$

Mass flow rate in the straight branch (kg/s):

$$G_2 = Q_2 \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_3 = Q_3 \cdot \rho$$

Reynolds number in the lateral branch:

$$\mathrm{Re}_1 = \frac{U_1 \cdot D_1}{\nu}$$

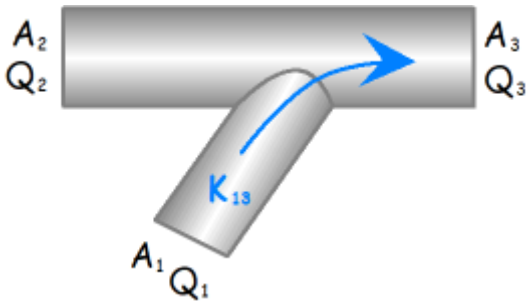
Reynolds number in the straight branch:

$$\mathrm{Re}_2 = \frac{U_2 \cdot D_3}{\nu}$$

Reynolds number in the common branch:

$$\mathrm{Re}_3 = \frac{U_3 \cdot D_3}{\nu}$$

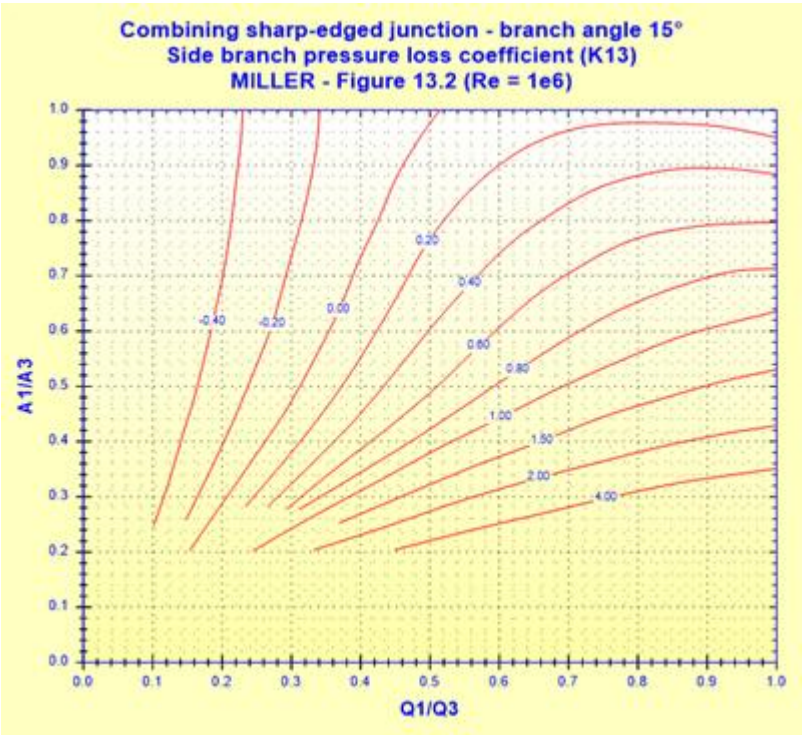
Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch):



■ Angle $\theta = 15°$

$$K_{13} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

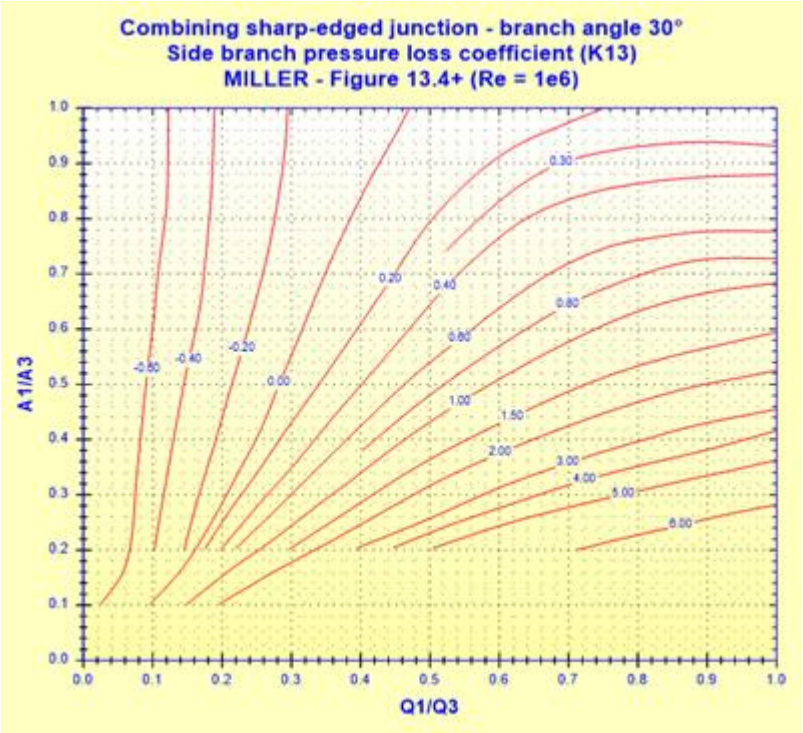
([1] figure 13.2)



■ Angle $\theta = 30°$

$$K_{13} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

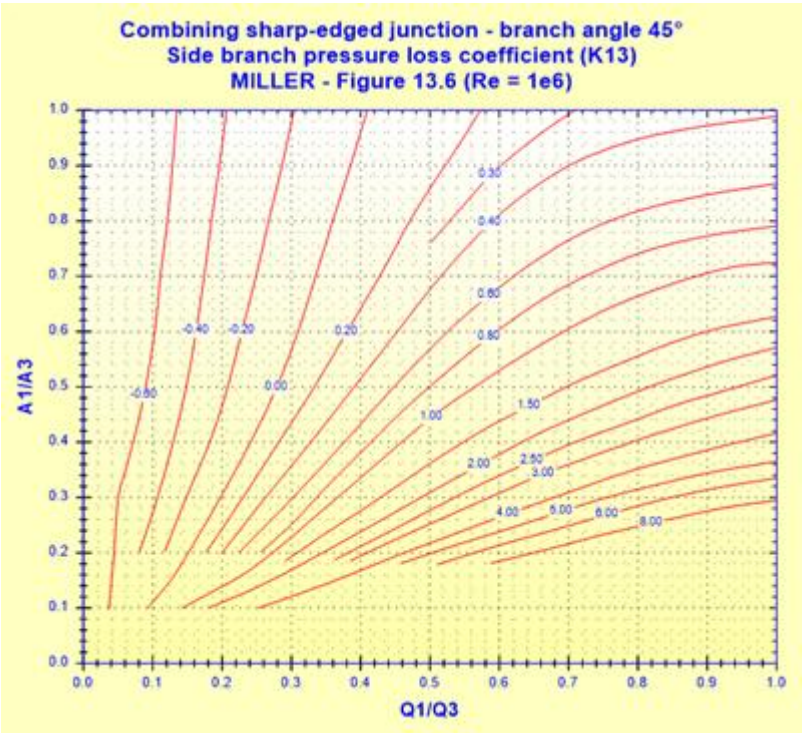
([1] figure 13.4+)



■ Angle $\theta = 45°$

$$K_{13} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.6)



■ Angle $\theta = 60°$

$$K_{13} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.8)

■ Angle $\theta = 90°$

$$K_{13} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.10+)

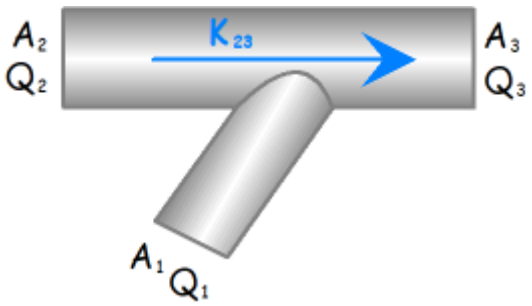
■ Angle $\theta = 120°$

$$K_{13} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.12)

For any angles between 15 ° and 120 °, the coefficient K_{13} is obtained by linear interpolation between the values of K_{13} calculated at 15 °, 30 °, 45 °, 60 °, 90 ° and 120 °.

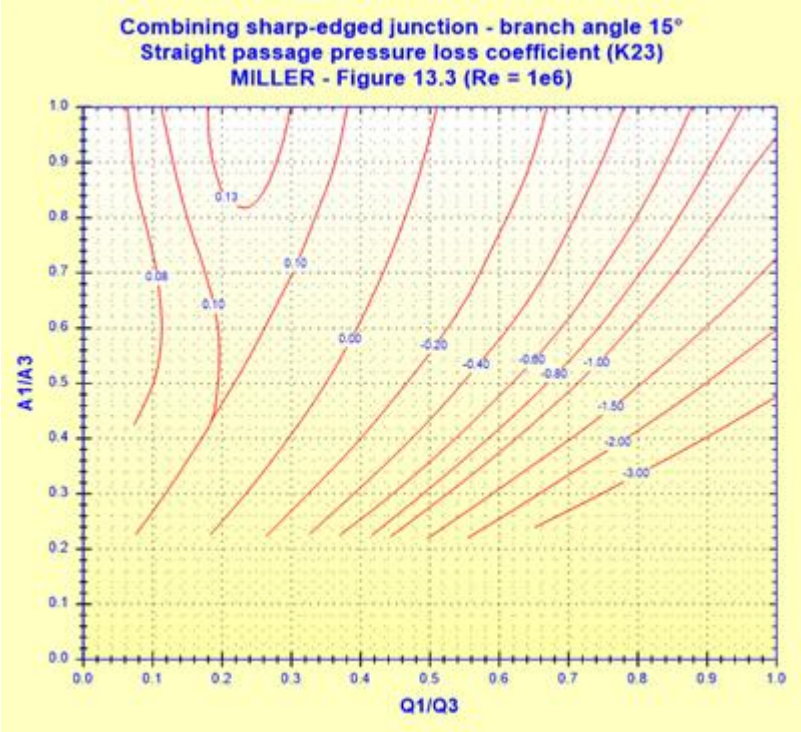
Pressure loss coefficient of the straight branch (based on mean velocity in the common branch):



■ Angle $\theta = 15°$

$$K_{23} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.3)



■ Angle $\theta = 30°$

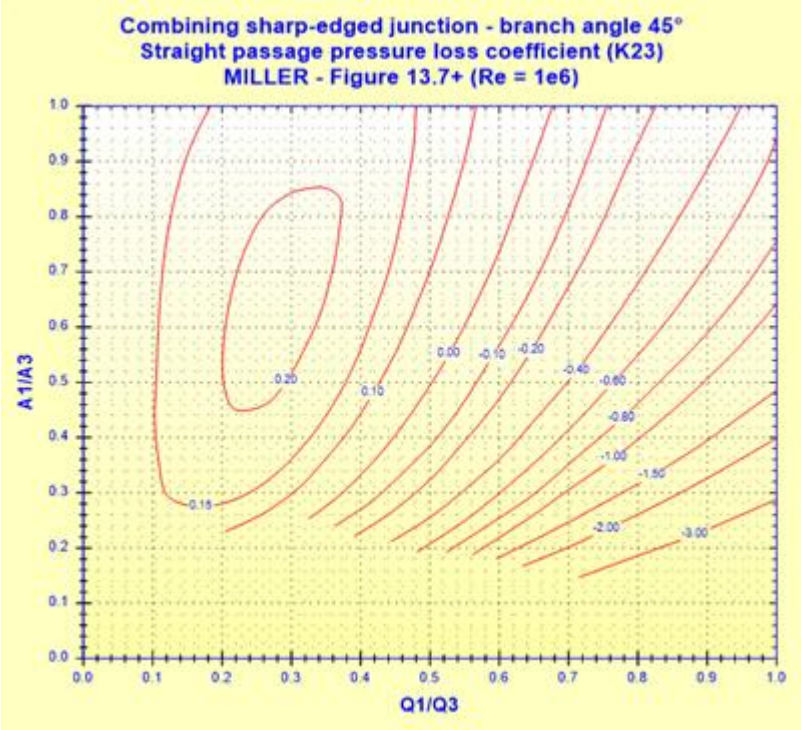
$$K_{23} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.5)

■ Angle $\theta = 45°$

$$K_{23} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.7+)



■ Angle $\theta = 60°$

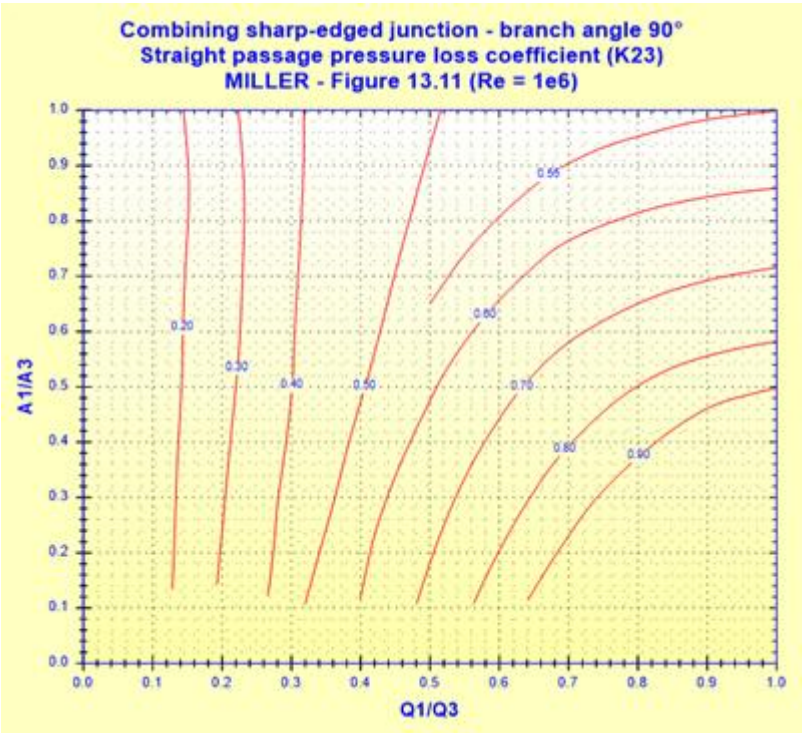
$$K_{23} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.9)

■ *Angle* $\theta = 90°$

$$K_{23} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.11)



■ *Angle* $\theta = 120°$

$$K_{23} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.13)

For any angles θ between 15 ° and 120 °, the coefficient K_{23} is obtained by linear interpolation between the values of K_{23} calculated at 15 °, 30 °, 45 °, 60 °, 90 ° and 120 °.

Pressure loss in the lateral branch (Pa):

$$\Delta P_{13} = K_{13} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.1)

Pressure loss in the straight branch (Pa):

$$\Delta P_{23} = K_{23} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.2)

Head loss of fluid in the lateral branch (m):

$$\Delta H_{13} = K_{13} \cdot \frac{U_3^2}{2 \cdot g}$$

Head loss of fluid in the straight branch (m):

$$\Delta H_{23} = K_{23} \cdot \frac{U_3^2}{2 \cdot g}$$

Hydraulic power loss in the lateral branch (W):

$$Wh_{13} = \Delta P_{13} \cdot Q_1$$

Hydraulic power loss in the straight branch (W):

$$Wh_{23} = \Delta P_{23} \cdot Q_2$$

Symbols, Definitions, SI Units:

D_1	Diameter of the lateral branch (m)
D_3	Diameter of the common branch and the straight branch (m)
A_1	Cross-sectional area of the lateral branch (m^2)
A_3	Cross-sectional area of the common branch and the straight branch (m^2)
Q_1	Volume flow rate in the lateral branch (m^3/s)
U_1	Mean velocity in the lateral branch (m/s)
Q_2	Volume flow rate in the straight branch (m^3/s)
U_2	Mean velocity in the straight branch (m/s)
Q_3	Volume flow rate in the common branch (m^3/s)
U_3	Mean velocity in the common branch (m/s)
G_1	Mass flow rate in the lateral branch (kg/s)
G_2	Mass flow rate in the straight branch (kg/s)
G_3	Mass flow rate in the common branch (kg/s)
Re_1	Reynolds number in the lateral branch ()
Re_2	Reynolds number in the straight branch ()
Re_3	Reynolds number in the common branch ()
θ	Angle of the lateral branch (°)

K_{13} Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch) ()

K_{23} Pressure loss coefficient of the straight branch (based on mean velocity in the common branch) ()

ΔP_{13} Pressure loss in the lateral branch (Pa)

ΔP_{23} Pressure loss in the straight branch (Pa)

ΔH_{13} Head loss of fluid in the lateral branch (m)

ΔH_{23} Head loss of fluid in the straight branch (m)

Wh_{13} Hydraulic power loss in the lateral branch (W)

Wh_{23} Hydraulic power loss in the straight branch (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($Re_3 \geq 10^5$)
- angle of the lateral branch: between 15 ° and 120 °
- cross-sections area ratio $A_1/A_3 \geq 0.2$

  note: for cross-sections area ratios A_1/A_3 lower than 0.2 the pressure loss coefficients "K_{13}" and "K_{23}" are extrapolated

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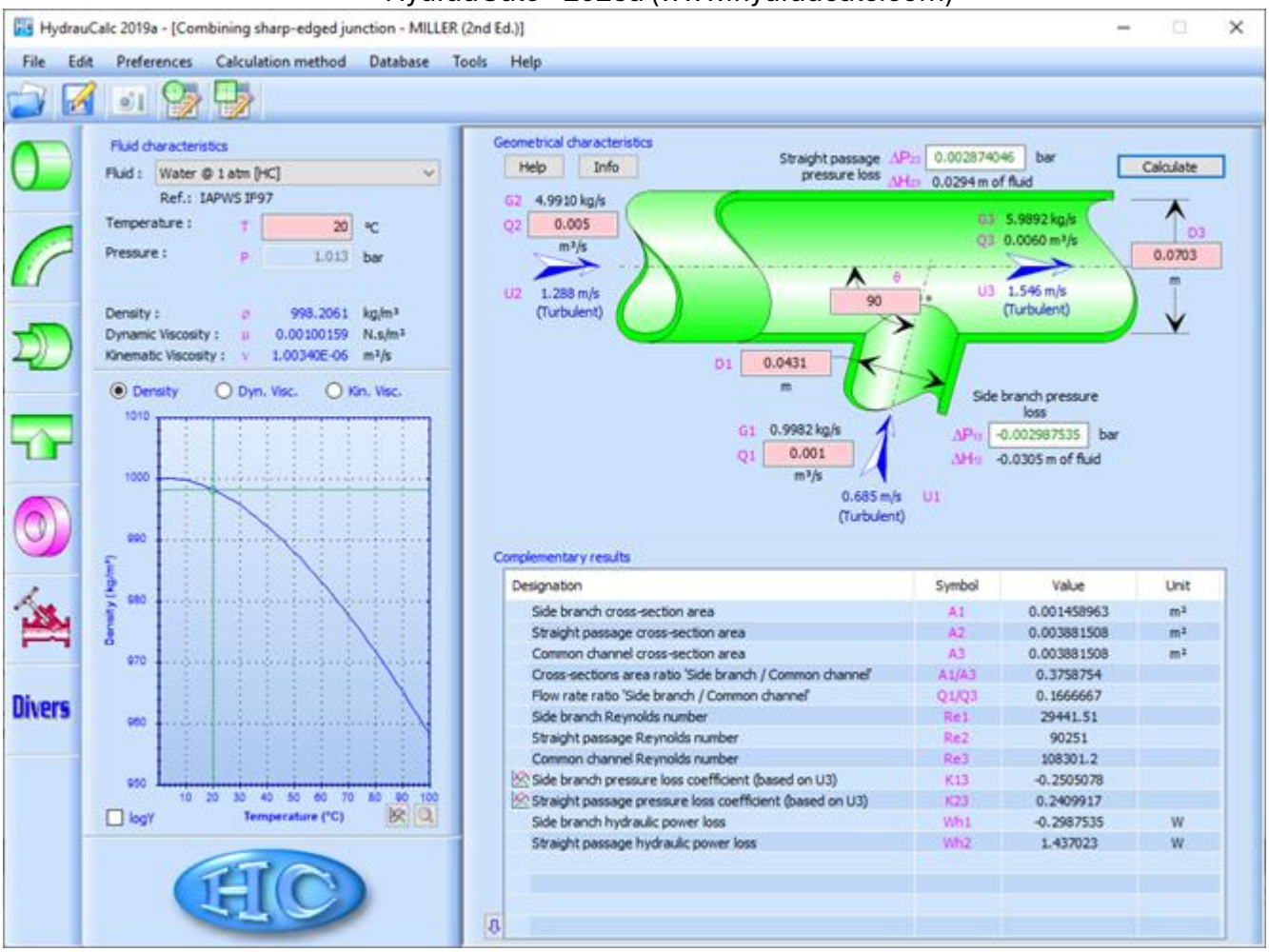
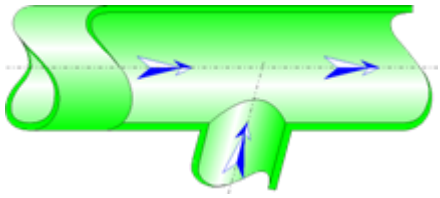
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

2.4.1.3 CRANE



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a combining sharp-edged junction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio between the diameter of the lateral branch and that of the common branch:

$$\beta_b = \frac{d_b}{d_c}$$

Cross-sectional area of the lateral branch (m^2):

$$A_b = \pi \cdot \frac{d_b^2}{4}$$

Cross-sectional area of the common branch and the straight branch (m^2):

$$A_c = \pi \cdot \frac{d_c^2}{4}$$

Volume flow rate in the common branch (m^3/s):

$$Q_c = Q_b + Q_r$$

Mean velocity in the lateral branch (m/s):

$$v_b = \frac{Q_b}{A_b}$$

Mean velocity in the straight branch (m/s):

$$v_r = \frac{Q_r}{A_c}$$

Mean velocity in the common branch (m/s):

$$v_c = \frac{Q_c}{A_c}$$

Mass flow rate in the lateral branch (kg/s):

$$G_b = Q_b \cdot \rho$$

Mass flow rate in the straight branch (kg/s):

$$G_r = Q_r \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_c = Q_c \cdot \rho$$

Reynolds number in the lateral branch:

$$\mathrm{Re}_b = \frac{v_b \cdot d_b}{\nu}$$

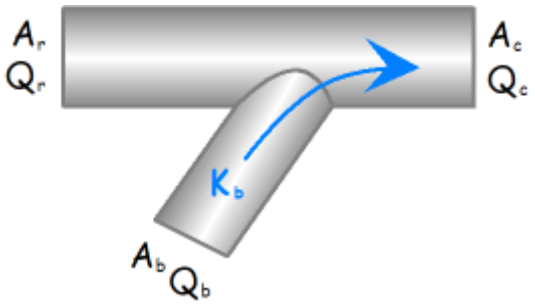
Reynolds number in the straight branch:

$$Re_r = \frac{v_r \cdot d_c}{\nu}$$

Reynolds number in the common branch:

$$Re_c = \frac{v_c \cdot d_c}{\nu}$$

Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch):



$$K_b = C_b \cdot \left[1 + D_b \cdot \left(\frac{Q_b}{Q_c} \cdot \frac{1}{\beta_b^2} \right)^2 - E_b \cdot \left(1 - \frac{Q_b}{Q_c} \right)^2 - F_b \cdot \frac{1}{\beta_b^2} \cdot \left(\frac{Q_b}{Q_c} \right)^2 \right]$$

([1] equation 2-35)

with:

Values of D_b, E_b, F_b

Angle	D_b	E_b	F_b
30°	1	2	1.74
45°	1	2	1.41
60°	1	2	1
90°	1	2	0

([1] table 2-1)

For any angles between 30 ° and 90 °, the coefficients D_b, E_b, F_b are obtained by linear interpolation of the coefficients of the table 2-1.

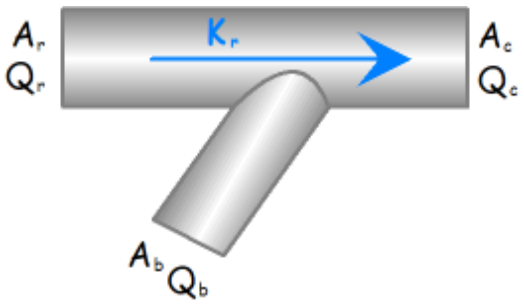
Values of C_b

Q_b / Q_c	≤ 0.4		> 0.4	
β^2_b	≤ 0.35	> 0.35	≤ 0.35	> 0.35
C_b	1	$0.9 \cdot \left(1 - \frac{Q_b}{Q_c} \right)$	1	0.55

([1] table 2-2)

([1] equation 2-35 with Ab/Ac = 1)

Pressure loss coefficient of the straight branch (based on mean velocity in the common branch):



■ Angle ≤ 60°

$$K_r = C_r \cdot \left[1 + D_r \cdot \left(\frac{Q_b}{Q_c} \cdot \frac{1}{\beta_b^2} \right)^2 - E_r \cdot \left(1 - \frac{Q_b}{Q_c} \right)^2 - F_r \cdot \frac{1}{\beta_b^2} \cdot \left(\frac{Q_b}{Q_c} \right)^2 \right]$$

([1] equation 2-35)

with:

Values of C_r , D_r, E_r ,F_r

Angle	C_r	D_r	E_r	F_r
30°	1	0	1	1.74
45°	1	0	1	1.41
60°	1	0	1	1

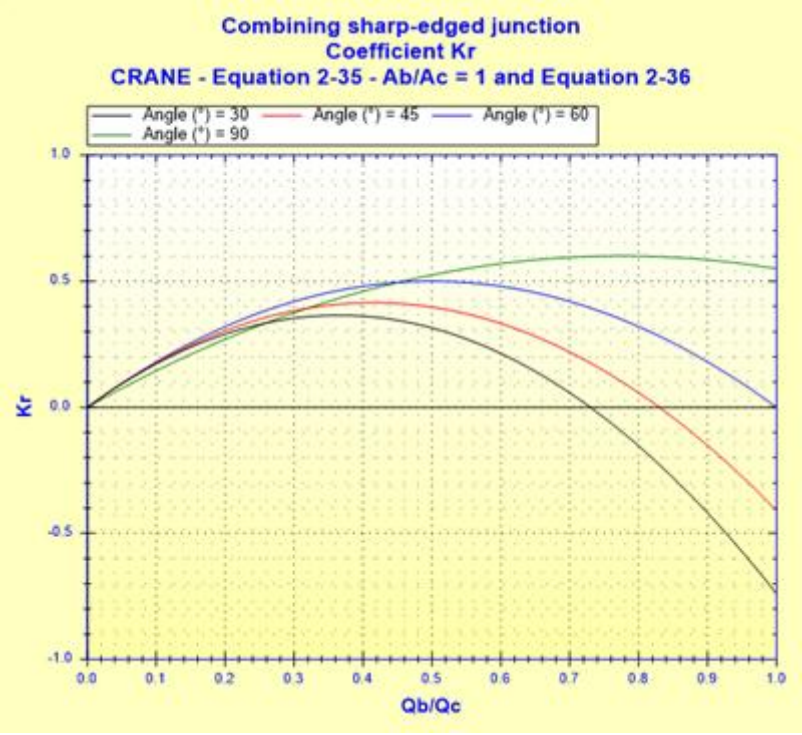
([1] table 2-1)

For arbitrary angles between 30 ° and 60 °, the coefficients C_r , D_r, E_r ,F_r are obtained by linear interpolation of the coefficients of table 2-1.

■ Angle = 90°

$$K_r = 1.55 \cdot \left(\frac{Q_b}{Q_c}\right) - \left(\frac{Q_b}{Q_c}\right)^2$$

([1] equation 2-36)



([1] equations 2-35 with Ab/Ac = 1 and 2-36)

For any angles between 60 ° and 90 °, the coefficient Kr is obtained by linear interpolation between the value of Kr calculated at 60 ° and that calculated at 90 °.

Pressure loss in the lateral branch (Pa):

$$\Delta P_b = K_b \cdot \frac{\rho \cdot V_c^2}{2}$$

Pressure loss in the straight branch (Pa):

$$\Delta P_r = K_r \cdot \frac{\rho \cdot v_c^2}{2}$$

Head loss of fluid in the lateral branch (m):

$$\Delta H_b = K_b \cdot \frac{v_c^2}{2 \cdot g}$$

Head loss of fluid in the straight branch (m):

$$\Delta H_r = K_r \cdot \frac{v_c^2}{2 \cdot g}$$

Hydraulic power loss in the lateral branch (W):

$$Wh_b = \Delta P_b \cdot Q_b$$

Hydraulic power loss in the straight branch (W):

$$Wh_r = \Delta P_r \cdot Q_r$$

Symbols, Definitions, SI Units:

d_b	Diameter of the lateral branch (m)
d_c	Diameter of the common branch and the straight branch (m)
β_b	Ratio between the diameter of the lateral branch and that of the common branch ()
A_b	Cross-sectional area of the lateral branch (m^2)
A_c	Cross-sectional area of the common branch and the straight branch (m^2)
Q_b	Volume flow rate in the lateral branch (m^3/s)
v_b	Mean velocity in the lateral branch (m/s)
Q_r	Volume flow rate in the straight branch (m^3/s)
v_r	Mean velocity in the straight branch (m/s)
Q_c	Volume flow rate in the common branch (m^3/s)

v_c Mean velocity in the common branch (m/s)

G_b Mass flow rate in the lateral branch (kg/s)

G_r Mass flow rate in the straight branch (kg/s)

G_c Mass flow rate in the common branch (kg/s)

Re_b Reynolds number in the lateral branch ()

Re_r Reynolds number in the straight branch ()

Re_c Reynolds number in the common branch ()

α Angle of the lateral branch (°)

K_b Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch) ()

K_r Pressure loss coefficient of the straight branch (based on mean velocity in the common branch) ()

ΔP_b Pressure loss in the lateral branch (Pa)

ΔP_r Pressure loss in the straight branch (Pa)

ΔH_b Head loss of fluid in the lateral branch (m)

ΔH_r Head loss of fluid in the straight branch (m)

Wh_b Hydraulic power loss in the lateral branch (W)

Wh_r Hydraulic power loss in the straight branch (W)

ρ Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

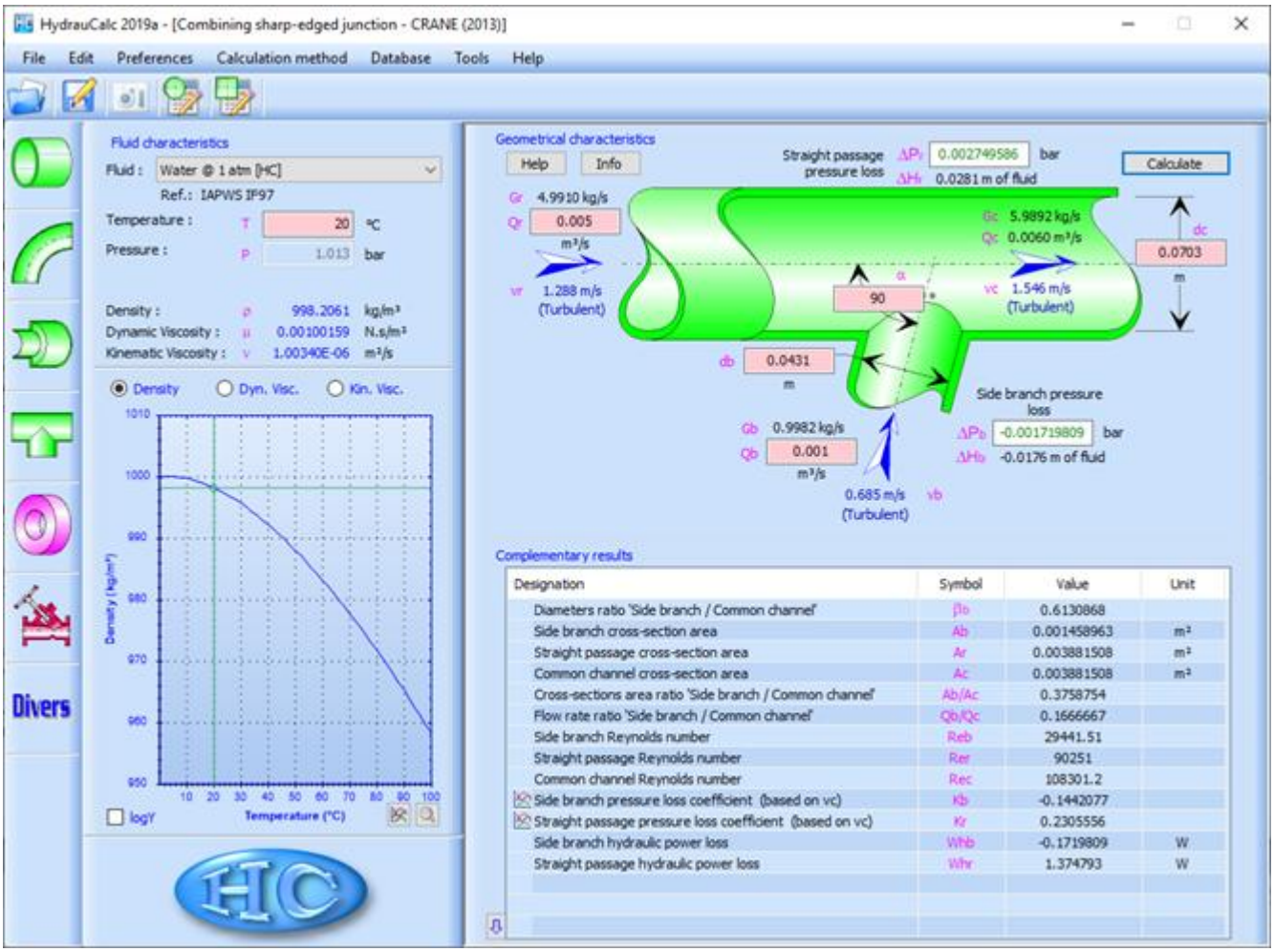
note: the indices $_b$, $_r$ and $_c$ correspond respectively to the indices $_{branch}$, $_{run}$ and $_{combined}$ of the reference document.

Validity range:

- turbulent flow regime ($Re_c \geq 10^4$)

- angle of the lateral branch: between 30° and 90°

Example of application:

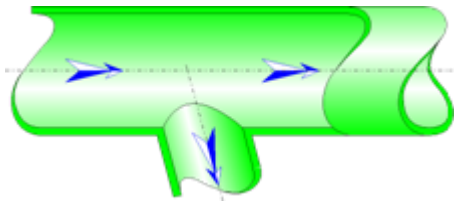


References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 2013

2.4.2 Dividing sharp-edged junction

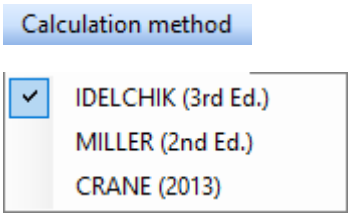
Circular Cross-Section



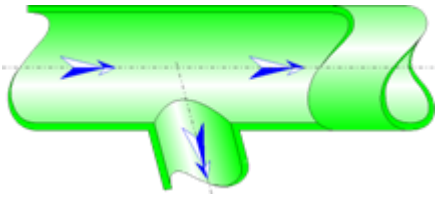
For the calculation of the pressure loss coefficient of dividing sharp-edged junctions, the user can choose from one of the methods described in the following three reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 2013

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.4.2.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a dividing sharp-edged junction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the lateral branch (m^2):

$$F_s = \pi \cdot \frac{D_s^2}{4}$$

Cross-sectional area of the common branch and the straight branch (m^2):

$$F_c = \pi \cdot \frac{D_c^2}{4}$$

Volume flow rate in the common branch (m^3/s):

$$Q_c = Q_s + Q_{st}$$

Mean velocity in the lateral branch (m/s):

$$w_s = \frac{Q_s}{F_s}$$

Mean velocity in the straight branch (m/s):

$$w_{st} = \frac{Q_{st}}{F_c}$$

Mean velocity in the common branch (m/s):

$$w_c = \frac{Q_c}{F_c}$$

Mass flow rate in the lateral branch (kg/s):

$$G_s = Q_s \cdot \rho$$

Mass flow rate in the straight branch (kg/s):

$$G_{st} = Q_{st} \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_c = Q_c \cdot \rho$$

Reynolds number in the lateral branch:

$$\mathrm{Re}_s = \frac{w_s \cdot D_s}{\nu}$$

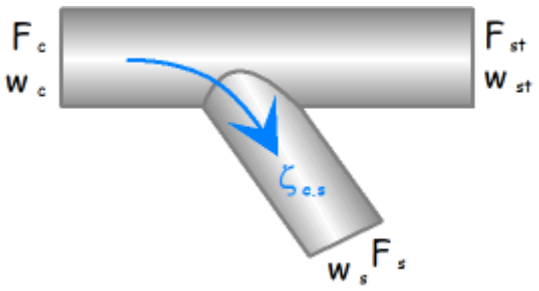
Reynolds number in the straight branch:

$$\mathrm{Re}_{st} = \frac{w_{st} \cdot D_c}{\nu}$$

Reynolds number in the common branch:

$$Re_c = \frac{w_c \cdot D_c}{\nu}$$

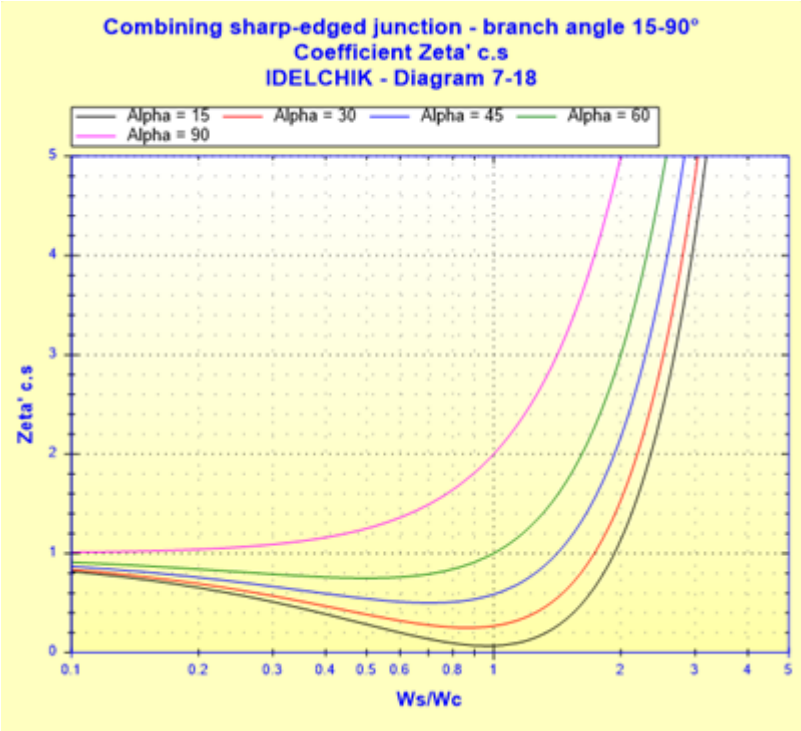
Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch):



■ $Re_c \geq 4000$

$$\zeta'_{c.s} = 1 + \left(\frac{w_s}{w_c}\right)^2 - 2 \cdot \left(\frac{w_s}{w_c}\right) \cdot \cos(\alpha)$$

([1] diagram 7-18)



● $\alpha < 60°$

$$\zeta_{c.s} = A' \cdot \zeta'_{c.s}$$

([1] diagram 7-18)

with:

Values of *A'*

F_s / F_c	≤ 0.35		> 0.35	
Q_s / Q_c	≤ 0.4	> 0.4	≤ 0.6	> 0.6
A'	$1.1-0.7\cdot\frac{Q_s}{Q_c}$	0.85	$1.0-0.6\cdot\frac{Q_s}{Q_c}$	0.6

([1] table 7-4)

- α = 90°
  - ♦ $D_s/D_c \le 2/3$

$$\zeta_{c.s} = \zeta'_{c.s}$$

([1] diagram 7-18)

  - ♦ $D_s/D_c = 1$

$$\zeta_{c.s} = \zeta'_{c.s}\cdot\left[1+0.3\cdot\left(\frac{w_s}{w_c}\right)^2\right]$$

([1] diagram 7-18)

  - ♦ $2/3 < D_s/D_c < 1$

For diameters ratios 'D_s/D_c' included between 2/3 and 1, the pressure loss coefficient '$\zeta_{c.s}$' at 90° is estimated by interpolation.

- 60° ≤ α < 90°

For angles 'α' between 60° and 90° the value of the pressure loss coefficient '$\zeta_{c.s}$' is estimated by interpolation between the values calculated at 60° and those calculated at 90°.

■ $Re_c \le 2000$

$$\zeta_{c.s} = (k_1+1)\cdot\zeta^t_{c.s} + \frac{150}{Re_c}$$

([1] equation §31)

with:

Values of k_1

Q_s/Q_c	Alpha			
	30°	45°	60°	90°
0	0.9	0.9	0.9	0.9
0.2	1.8	1.8	1.5	1.1
0.4	3.4	2.9	2.2	1.3
0.6	6.1	4.3	3	1.5
0.8	7.2	4.3	2.7	1.4
1	6	3.6	2.3	1.3

([1] table 7-7)

$$\zeta^t_{c.s} = A' \cdot \left[1 + \left(\frac{w_s}{w_c} \right)^2 - 2 \cdot \frac{w_s}{w_c} \cdot \cos(\alpha) \right] - K'_{st} \cdot \left(\frac{w_s}{w_c} \right)^2$$

([1] equation 7.3)

with:

Values of A'

F_s / F_c	≤ 0.35		> 0.35	
Q_s / Q_c	≤ 0.4	> 0.4	≤ 0.6	> 0.6
A'	$1.1 - 0.7 \cdot \frac{Q_s}{Q_c}$	0.85	$1.0 - 0.6 \cdot \frac{Q_s}{Q_c}$	0.6

([1] table 7-4)

$$K'_{st} = 0$$

■ $2000 < Re_c < 4000$

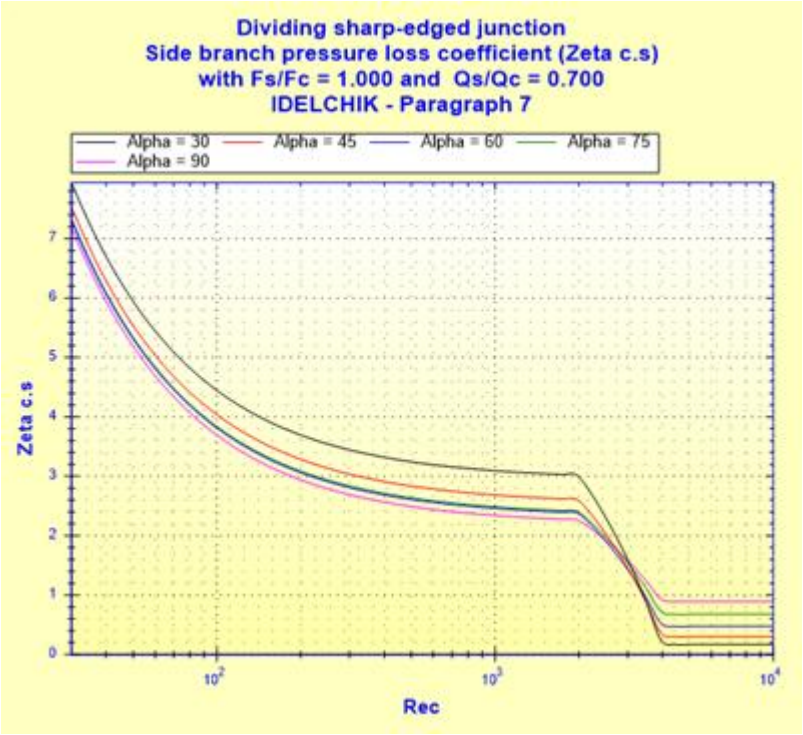
linear interpolation

$$\zeta_{c.s} = \zeta^l_{c.s} \cdot \left(1 - \frac{Re_c - 2000}{2000} \right) + \zeta^t_{c.s} \cdot \left(\frac{Re_c - 2000}{2000} \right)$$

with:

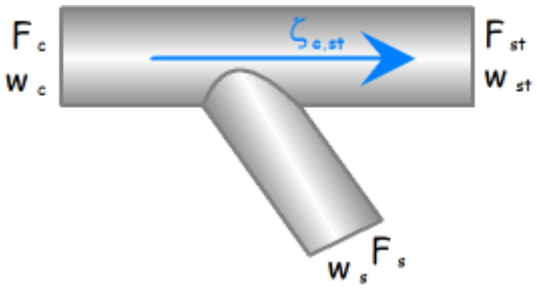
$\zeta^l_{c.s}$ = laminar coefficient obtained with Re_c = 2000

$\zeta^t_{c.s}$ = turbulent coefficient obtained with Re_c = 4000



$\zeta_{c.s}$ for Re_c < 4000 and with F_s/F_c = 1 and Q_s/Q_c = 0.7

Pressure loss coefficient of the straight branch (based on mean velocity in the common branch):



■ $Re_c \geq 4000$

$$\zeta_{c.st} = \tau_{st} \cdot \left(\frac{Q_s}{Q_c}\right)^2$$

([1] diagram 7-20)

with:

Values of τ_{st}

F_s / F_c	≤ 0.4	> 0.4	
Q_s / Q_c	0 - 1.0	≤ 0.5	> 0.5
τ_{st}	0.4	$2 \cdot \left(2 \cdot \frac{Q_s}{Q_c} - 1\right)$	$0.3 \cdot \left(2 \cdot \frac{Q_s}{Q_c} - 1\right)$

([1] diagram 7-20)

■ $Re_c \leq 2000$

$$\zeta_{c.st} = 3 \cdot \zeta^t_{c.st} + \frac{33}{Re_c}$$

([1] equation §31)

with:

$$\zeta^t_{c.st} = \tau_{st} \cdot \left(\frac{Q_s}{Q_c}\right)^2$$

([1] equation 7-4)

with:

Values of τ_{st}

F_s / F_c	≤ 0.4	> 0.4	
Q_s / Q_c	0 - 1.0	≤ 0.5	> 0.5
τ_{st}	0.4	$2 \cdot \left(2 \cdot \frac{Q_s}{Q_c} - 1\right)$	$0.3 \cdot \left(2 \cdot \frac{Q_s}{Q_c} - 1\right)$

([1] diagram 7-20)

■ $2000 < Re_c < 4000$

linear interpolation

$$\zeta_{c.st} = \zeta^{l}_{c.st} \cdot \left(1 - \frac{Re_c - 2000}{2000}\right) + \zeta^{t}_{c.st} \cdot \left(\frac{Re_c - 2000}{2000}\right)$$

with:

$\zeta^{l}_{c.st}$ = laminar coefficient obtained with $Re_c = 2000$

$\zeta^{t}_{c.st}$ = turbulent coefficient obtained with $Re_c = 4000$

$\zeta_{c.st}$ for $Re_c < 4000$ and with $F_s/F_c = 1$ and $Q_s/Q_c = 0.7$

Pressure loss in the lateral branch (Pa):

$$\Delta P_{c.s} = \zeta_{c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Pressure loss in the straight branch (Pa):

$$\Delta P_{c.st} = \zeta_{c.st} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Head loss of fluid in the lateral branch (m):

$$\Delta H_{c.s} = \zeta_{c.s} \cdot \frac{w_c^2}{2 \cdot g}$$

Head loss of fluid in the straight branch (m):

$$\Delta H_{c.st} = \zeta_{c.st} \cdot \frac{w_c^2}{2 \cdot g}$$

Hydraulic power loss in the lateral branch (W):

$$Wh_s = \Delta P_{c.s} \cdot Q_s$$

Hydraulic power loss in the straight branch (W):

$$Wh_{st} = \Delta P_{c.st} \cdot Q_{st}$$

Symbols, Definitions, SI Units:

D_s	Diameter of the lateral branch (m)
D_c	Diameter of the common branch and the straight branch (m)
F_s	Cross-sectional area of the lateral branch (m^2)
F_c	Cross-sectional area of the common branch and the straight branch (m^2)
Q_s	Volume flow rate in the lateral branch (m^3/s)
w_s	Mean velocity in the lateral branch (m/s)
Q_{st}	Volume flow rate in the straight branch (m^3/s)
w_{st}	Mean velocity in the straight branch (m/s)
Q_c	Volume flow rate in the common branch (m^3/s)
w_c	Mean velocity in the common branch (m/s)
G_s	Mass flow rate in the lateral branch (kg/s)
G_{st}	Mass flow rate in the straight branch (kg/s)
G_c	Mass flow rate in the common branch (kg/s)
Re_s	Reynolds number in the lateral branch ()
Re_{st}	Reynolds number in the straight branch ()

Re_c Reynolds number in the common branch ()

α Angle of the lateral branch (°)

$\zeta^l_{c.s}$ Pressure loss coefficient of the lateral branch in laminar flow ()

$\zeta^t_{c.st}$ Pressure loss coefficient of the lateral branch in turbulent flow ()

$\zeta^t_{c.st}$ Pressure loss coefficient of the straight branch in turbulent flow ()

$\zeta'_{c.s}$ Coefficient of the lateral branch ()

$\zeta_{c.s}$ Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch) ()

$\zeta_{c.st}$ Pressure loss coefficient of the straight branch (based on mean velocity in the common branch) ()

ΔP_s Pressure loss in the lateral branch (Pa)

ΔP_{st} Pressure loss in the straight branch (Pa)

ΔH_s Head loss of fluid in the lateral branch (m)

ΔH_{st} Head loss of fluid in the straight branch (m)

Wh_s Hydraulic power loss in the lateral branch (W)

Wh_{st} Hydraulic power loss in the straight branch (W)

ρ Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

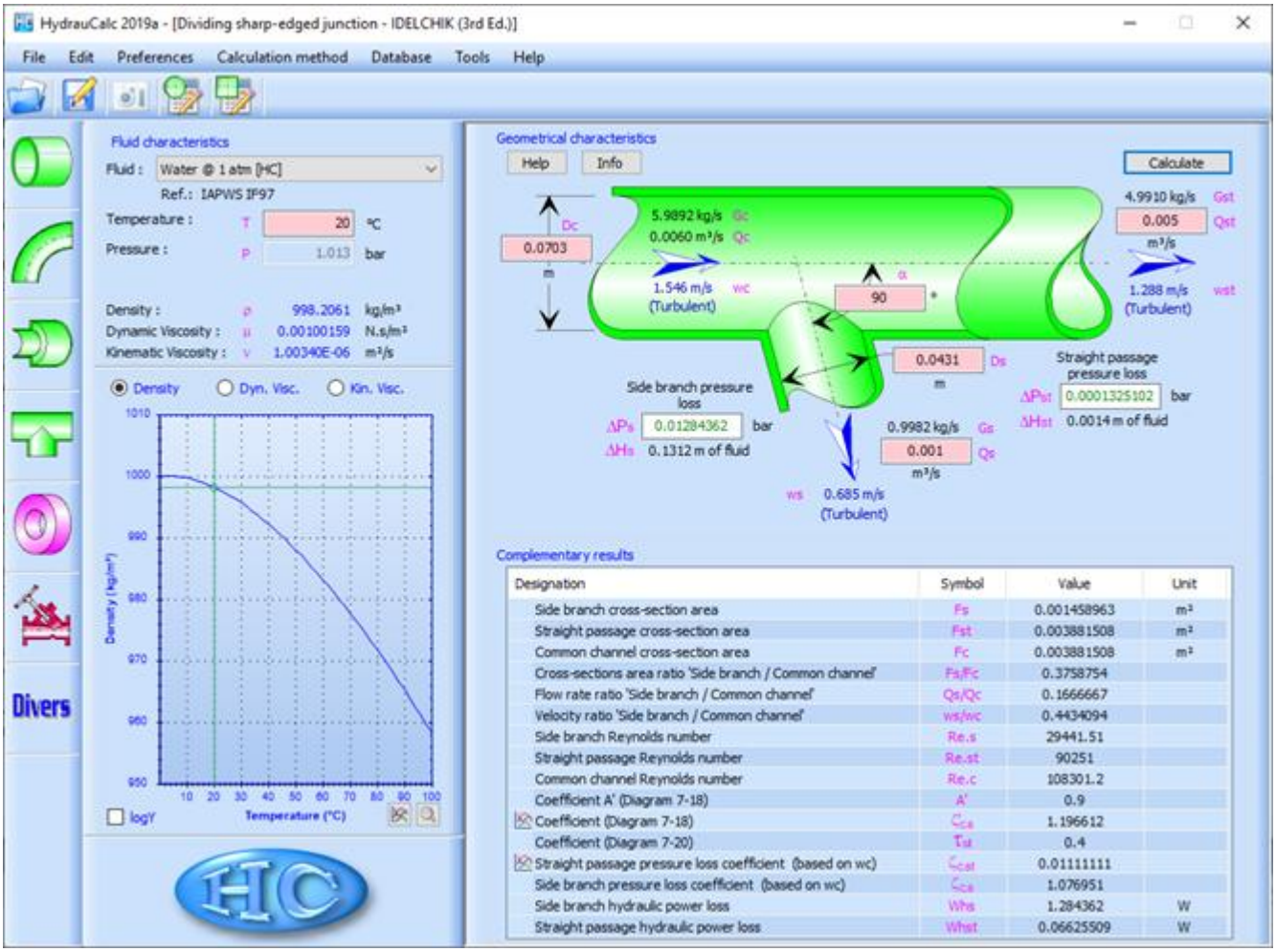
g Gravitational acceleration (m/s^2)

Validity range:

- angle of the lateral branch: between 30° and 90°

note: for angles 'α' between 60° and 90° the value of the pressure loss coefficient '$\zeta_{c.s}$' is estimated by interpolation between the values calculated at 60° and those calculated at 90°,
for diameters ratios 'D_s/D_c' included between 2/3 and 1, the pressure loss coefficient '$\zeta_{c.s}$' at 90° is estimated by interpolation.

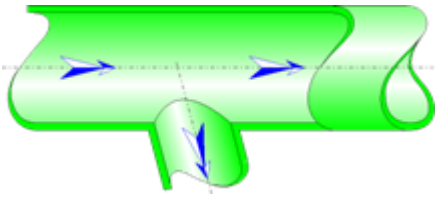
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.4.2.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a dividing sharp-edged junction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the lateral branch (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Cross-sectional area of the common branch and the straight branch (m^2):

$$A_3 = \pi \cdot \frac{D_3^2}{4}$$

Volume flow rate in the common branch (m^3/s):

$$Q_3 = Q_1 + Q_2$$

Mean velocity in the lateral branch (m/s):

$$U_1 = \frac{Q_1}{A_1}$$

Mean velocity in the straight branch (m/s):

$$U_2 = \frac{Q_2}{A_3}$$

Mean velocity in the common branch (m/s):

$$U_3 = \frac{Q_3}{A_3}$$

Mass flow rate in the lateral branch (kg/s):

$$G_1 = Q_1 \cdot \rho$$

Mass flow rate in the straight branch (kg/s):

$$G_2 = Q_2 \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_3 = Q_3 \cdot \rho$$

Reynolds number in the lateral branch:

$$\mathrm{Re}_1 = \frac{U_1 \cdot D_1}{\nu}$$

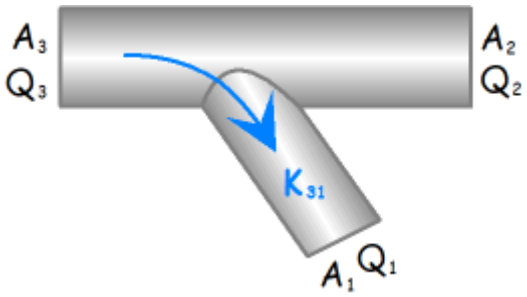
Reynolds number in the straight branch:

$$\mathrm{Re}_2 = \frac{U_2 \cdot D_3}{\nu}$$

Reynolds number in the common branch:

$$\mathrm{Re}_3 = \frac{U_3 \cdot D_3}{\nu}$$

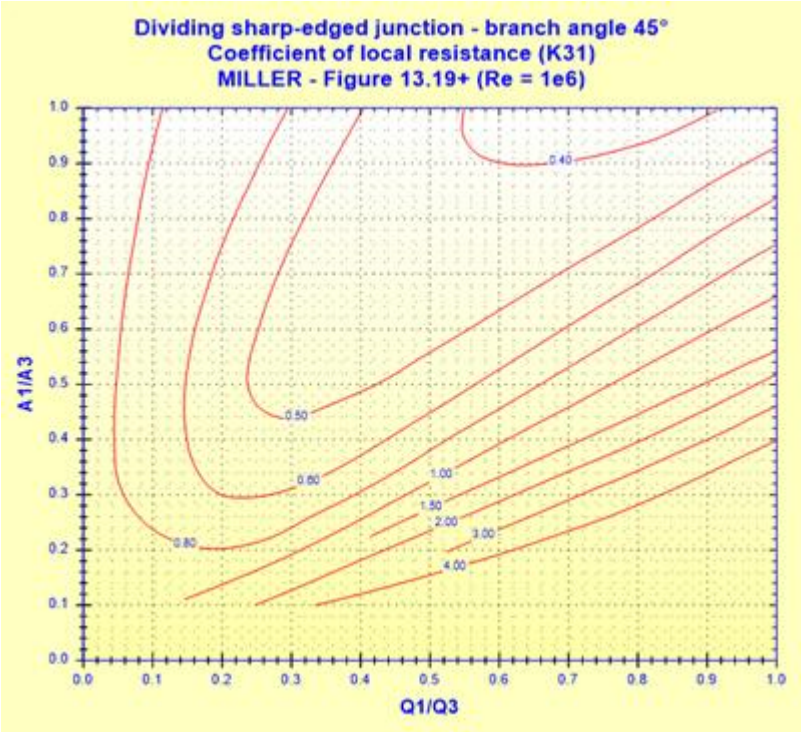
Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch):



■ Angle $\theta = 45°$

$$K_{31} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.19+)



■ Angle $\theta = 60°$

$$K_{31} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.20+)

■ *Angle* $\theta = 90°$

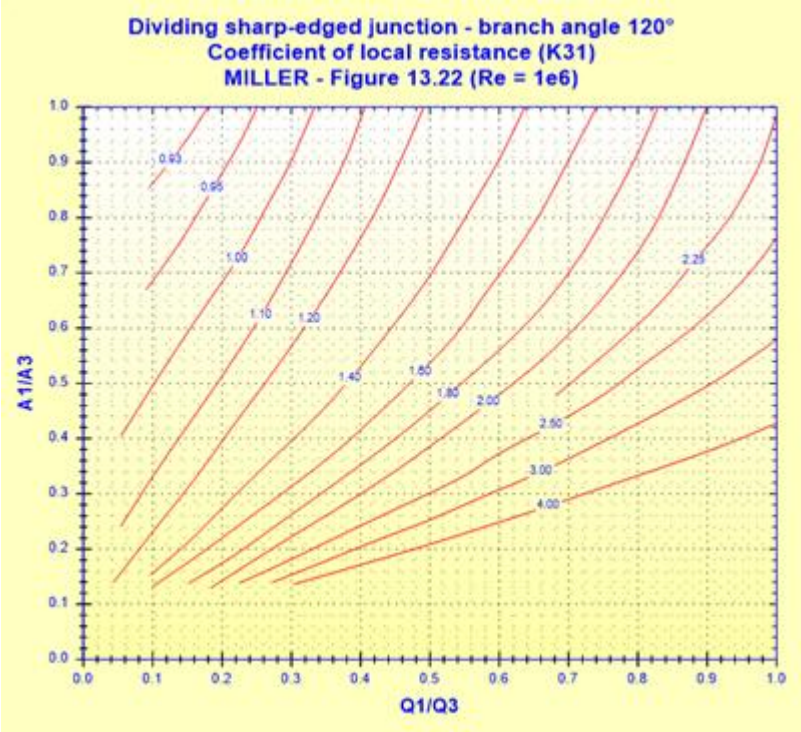
$$K_{31} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.21+)

■ *Angle* $\theta = 120°$

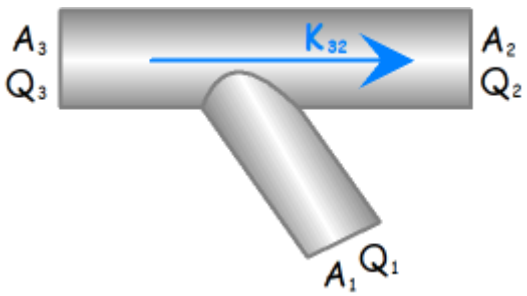
$$K_{31} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.22)



For any angles between 45 ° and 120 °, the coefficient K_{31} is obtained by linear interpolation between the values of K_{31} calculated at 45 °, 60 °, 90 ° and 120 °.

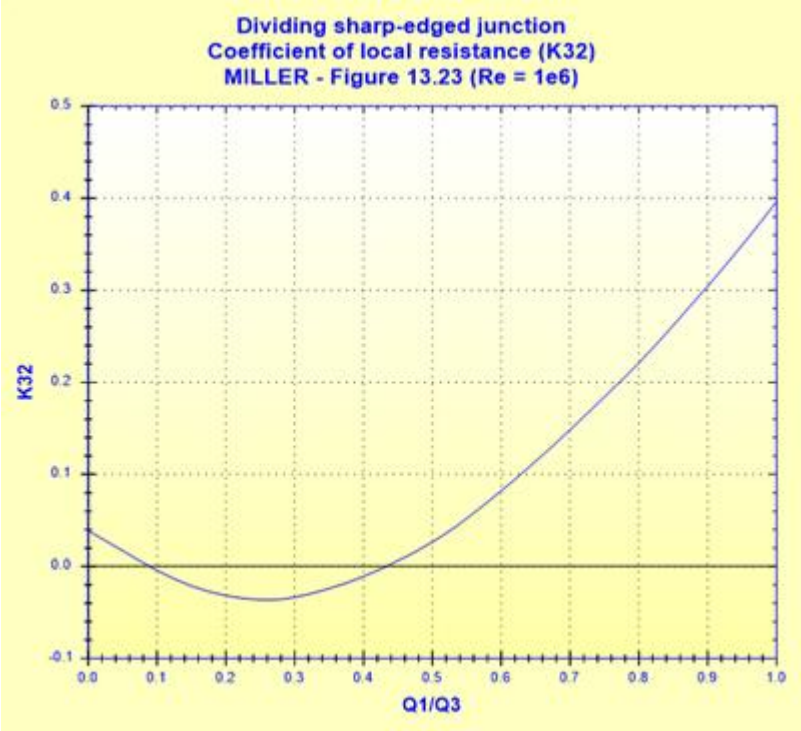
Pressure loss coefficient of the straight branch (based on mean velocity in the common branch):



■ Angle θ = 45° - 90°

$$K_{32} = f\left(\frac{Q_1}{Q_3}\right)$$

([1] figure 13.23)



Pressure loss in the lateral branch (Pa):

$$\Delta P_{31} = K_{31} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.3)

Pressure loss in the straight branch (Pa):

$$\Delta P_{32} = K_{32} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.4)

Head loss of fluid in the lateral branch (m):

$$\Delta H_{31} = K_{31} \cdot \frac{U_3^2}{2 \cdot g}$$

Head loss of fluid in the straight branch (m):

$$\Delta H_{32} = K_{32} \cdot \frac{U_3^2}{2 \cdot g}$$

Hydraulic power loss in the lateral branch (W):

$$Wh_{31} = \Delta P_{31} \cdot Q_1$$

Hydraulic power loss in the straight branch (W):

$$Wh_{32} = \Delta P_{32} \cdot Q_2$$

Symbols, Definitions, SI Units:

D_1	Diameter of the lateral branch (m)
D_3	Diameter of the common branch and the straight branch (m)
A_1	Cross-sectional area of the lateral branch (m^2)
A_3	Cross-sectional area of the common branch and the straight branch (m^2)
Q_1	Volume flow rate in the lateral branch (m^3/s)
U_1	Mean velocity in the lateral branch (m/s)
Q_2	Volume flow rate in the straight branch (m^3/s)
U_2	Mean velocity in the straight branch (m/s)
Q_3	Volume flow rate in the common branch (m^3/s)
U_3	Mean velocity in the common branch (m/s)
G_1	Mass flow rate in the lateral branch (kg/s)
G_2	Mass flow rate in the straight branch (kg/s)
G_3	Mass flow rate in the common branch (kg/s)
Re_1	Reynolds number in the lateral branch ()
Re_2	Reynolds number in the straight branch ()
Re_3	Reynolds number in the common branch ()
θ	Angle of the lateral branch (°)
K_{31}	Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch) ()
K_{32}	Pressure loss coefficient of the straight branch (based on mean velocity in the common branch) ()
ΔP_{31}	Pressure loss in the lateral branch (Pa)
ΔP_{32}	Pressure loss in the straight branch (Pa)

ΔH_{31} Head loss of fluid in the lateral branch (m)

ΔH_{32} Head loss of fluid in the straight branch (m)

Wh_{31} Hydraulic power loss in the lateral branch (W)

Wh_{32} Hydraulic power loss in the straight branch (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($Re_3 \geq 10^5$)
- angle of the lateral branch:

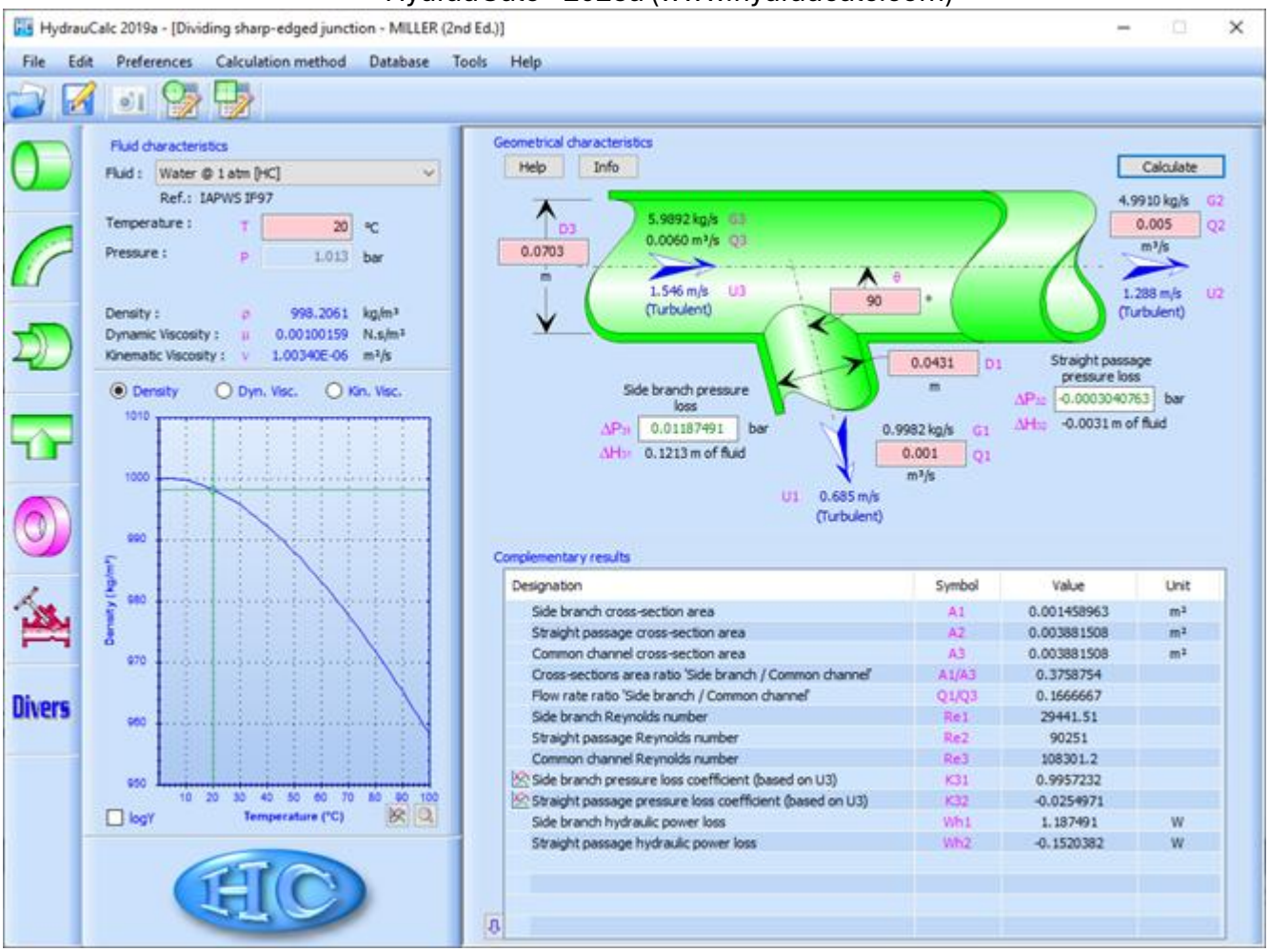
  between 45° and 120° for the pressure loss coefficient "K_{31}"

  between 45° and 90° for the pressure loss coefficient "K_{32}"
- cross-sections area ratio $A_1/A_3 \geq 0.1$

  note: for cross-sections area ratios A_1/A_3 lower than 0.1 the pressure loss coefficients "K_{31}" and "K_{32}" are extrapolated

---

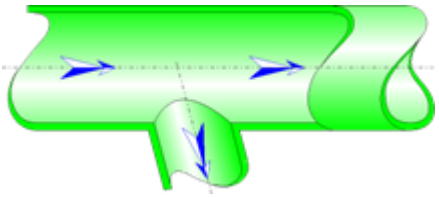
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

2.4.2.3 CRANE



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a dividing sharp-edged junction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio between the diameter of the lateral branch and that of the common branch:

$$\beta_b = \frac{d_b}{d_c}$$

Cross-sectional area of the lateral branch (m^2):

$$A_b = \pi \cdot \frac{d_b^2}{4}$$

Cross-sectional area of the common branch and the straight branch (m^2):

$$A_c = \pi \cdot \frac{d_c^2}{4}$$

Volume flow rate in the common branch (m^3/s):

$$Q_c = Q_b + Q_r$$

Mean velocity in the lateral branch (m/s):

$$v_b = \frac{Q_b}{A_b}$$

Mean velocity in the straight branch (m/s):

$$v_r = \frac{Q_r}{A_c}$$

Mean velocity in the common branch (m/s):

$$v_c = \frac{Q_c}{A_c}$$

Mass flow rate in the lateral branch (kg/s):

$$G_b = Q_b \cdot \rho$$

Mass flow rate in the straight branch (kg/s):

$$G_r = Q_r \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_c = Q_c \cdot \rho$$

Reynolds number in the lateral branch:

$$\mathrm{Re}_b = \frac{v_b \cdot d_b}{\nu}$$

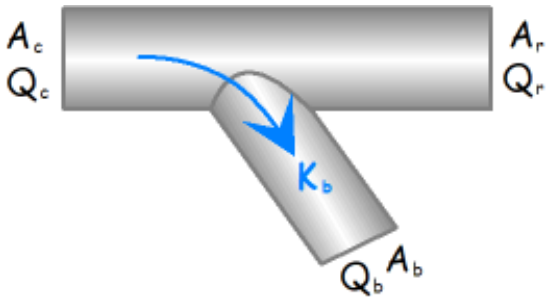
Reynolds number in the straight branch:

$$Re_r = \frac{v_r \cdot d_c}{\nu}$$

Reynolds number in the common branch:

$$Re_c = \frac{v_c \cdot d_c}{\nu}$$

Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch):



$$K_b = G \cdot \left[1 + H \cdot \left(\frac{Q_b}{Q_c} \cdot \frac{1}{\beta_b^2} \right)^2 - J \cdot \left(\frac{Q_b}{Q_c} \cdot \frac{1}{\beta_b^2} \right) \cdot \cos(\alpha) \right]$$

([1] equation 2-37)

with:

Values of G, H, J

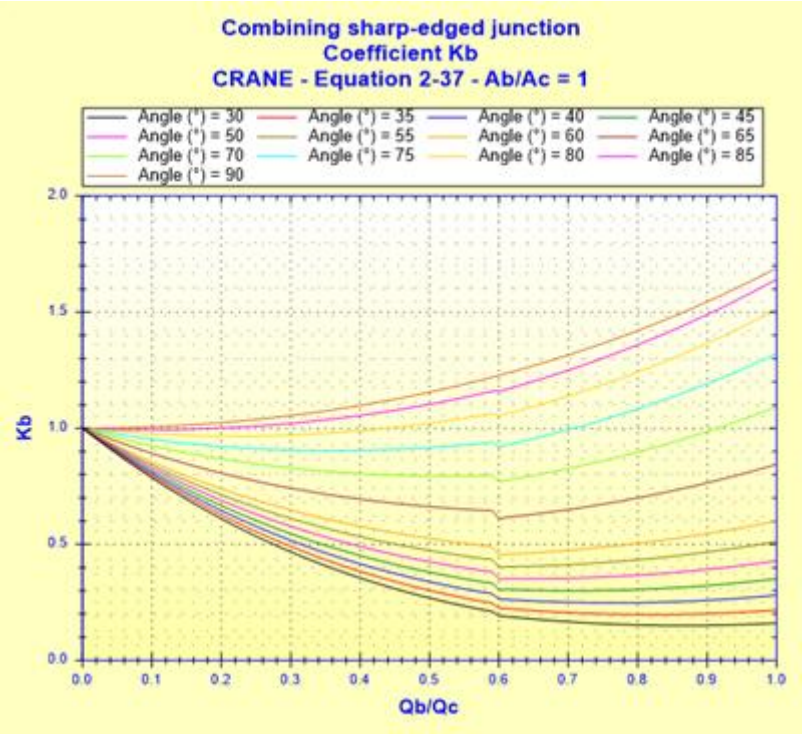
Angle	β	G	H	J
30° - 60°		Table 2-4	1	2
90°	≤ 2/3	1	1	2
	1	$1 + 0.3 \cdot \left(\frac{Q_b}{Q_c} \right)^2$	0.3	0

([1] table 2-3)

Values of G for angle ≤ 60°

β^2_b	≤ 0.35		> 0.35	
Q_b / Q_c	≤ 0.4	> 0.4	≤ 0.6	> 0.6
G	$1.1 - 0.7 \cdot \frac{Q_b}{Q_c}$	0.85	$1.0 - 0.6 \cdot \frac{Q_b}{Q_c}$	0.6

([1] table 2-4)

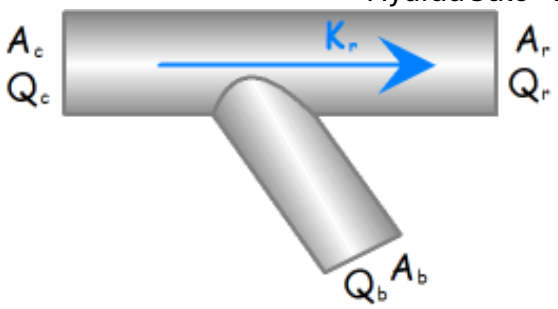


([1] equation 2-37 with Ab/Ac = 1)

For angles 'α' between 60° and 90° the values of the coefficients 'G', 'H' and 'J' are estimated by interpolation between the values calculated at 60° and those calculated at 90°.

For diameters ratios 'β' included between 2/3 and 1, the coefficients values 'G', 'H' et 'J' at 90° are estimated by interpolation.

Pressure loss coefficient of the straight branch (based on mean velocity in the common branch):



$$K_r = M \cdot \left(\frac{Q_b}{Q_c}\right)^2$$

([1] equation 2-38)

with:

Values of M

Q_b / Q_c	≤ 0.5		> 0.5	
β^2_b	≤ 0.4	> 0.4	≤ 0.4	> 0.4
M	0.4	$2 \cdot \left(2 \cdot \frac{Q_b}{Q_c} - 1\right)$	0.4	$0.3 \cdot \left(2 \cdot \frac{Q_b}{Q_c} - 1\right)$

([1] table 2-5)

([1] equation 2-38)

Pressure loss in the lateral branch (Pa):

$$\Delta P_b = K_b \cdot \frac{\rho \cdot v_c^2}{2}$$

Pressure loss in the straight branch (Pa):

$$\Delta P_r = K_r \cdot \frac{\rho \cdot v_c^2}{2}$$

Head loss of fluid in the lateral branch (m):

$$\Delta H_b = K_b \cdot \frac{v_c^2}{2 \cdot g}$$

Head loss of fluid in the straight branch (m):

$$\Delta H_r = K_r \cdot \frac{v_c^2}{2 \cdot g}$$

Hydraulic power loss in the lateral branch (W):

$$Wh_b = \Delta P_b \cdot Q_b$$

Hydraulic power loss in the straight branch (W):

$$Wh_r = \Delta P_r \cdot Q_r$$

Symbols, Definitions, SI Units:

d_b	Diameter of the lateral branch (m)
d_c	Diameter of the common branch and the straight branch (m)
β_b	Ratio between the diameter of the lateral branch and that of the common branch ()
A_b	Cross-sectional area of the lateral branch (m^2)
A_c	Cross-sectional area of the common branch and the straight branch (m^2)
Q_b	Volume flow rate in the lateral branch (m^3/s)
v_b	Mean velocity in the lateral branch (m/s)

Q_r Volume flow rate in the straight branch (m^3/s)

v_r Mean velocity in the straight branch (m/s)

Q_c Volume flow rate in the common branch (m^3/s)

v_c Mean velocity in the common branch (m/s)

G_b Mass flow rate in the lateral branch (kg/s)

G_r Mass flow rate in the straight branch (kg/s)

G_c Mass flow rate in the common branch (kg/s)

Re_b Reynolds number in the lateral branch ()

Re_r Reynolds number in the straight branch ()

Re_c Reynolds number in the common branch ()

α Angle of the lateral branch (°)

K_b Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch) ()

K_r Pressure loss coefficient of the straight branch (based on mean velocity in the common branch) ()

ΔP_b Pressure loss in the lateral branch (Pa)

ΔP_r Pressure loss in the straight branch (Pa)

ΔH_b Head loss of fluid in the lateral branch (m)

ΔH_r Head loss of fluid in the straight branch (m)

Wh_b Hydraulic power loss in the lateral branch (W)

Wh_r Hydraulic power loss in the straight branch (W)

ρ Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

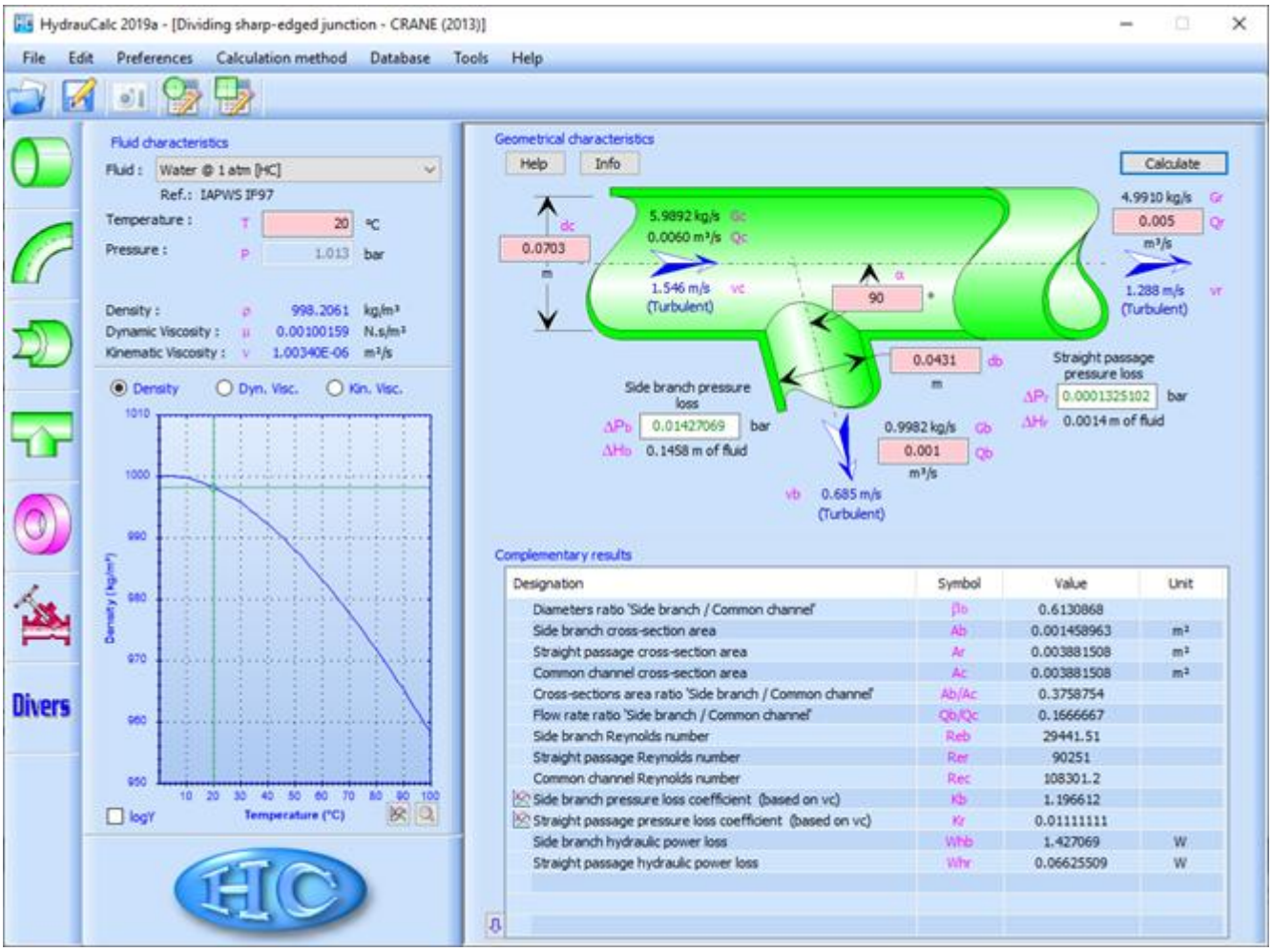
note: the indices $_b$, $_r$ and $_c$ correspond respectively to the indices $_{branch}$, $_{run}$ and $_{combined}$ of the reference document.

Validity range:

- flow regime: turbulent ($Re_c \geq 10^4$)
- angle of the lateral branch: between 30° and 90°

  note: for angles 'α' between 60° and 90° the values of the coefficients 'G', 'H' and 'J' are estimated by interpolation between the values calculated at 60° and those calculated at 90°,
  for diameters ratios 'β' included between 2/3 and 1, the coefficients values 'G', 'H' et 'J' at 90° are estimated by interpolation.

Example of application:

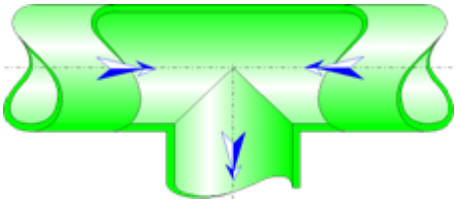


References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 2013

2.4.3 Symmetric combining sharp-edged T-junction

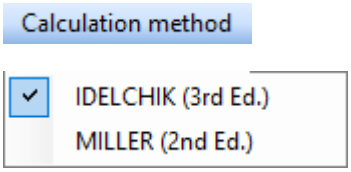
Circular Cross-Section



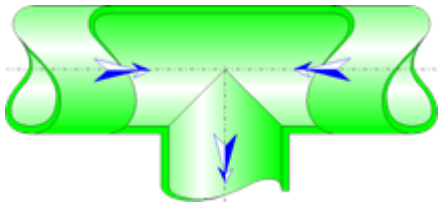
For the calculation of the pressure loss coefficient of symmetric combining sharp-edged T-junctions, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.4.3.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric combining sharp-edged T-junction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the right branch (m^2):

$$F_{1s} = \pi \cdot \frac{D_s^2}{4}$$

Cross-sectional area of the left branch (m^2):

$$F_{2s} = \pi \cdot \frac{D_s^2}{4}$$

Cross-sectional area of the common branch (m^2):

$$F_c = \pi \cdot \frac{D_c^2}{4}$$

Volume flow rate in the common branch (m^3/s):

$$Q_c = Q_{1s} + Q_{2s}$$

Mean velocity in the right branch (m/s):

$$w_{1s} = \frac{Q_{1s}}{F_{1s}}$$

Mean velocity in the left branch (m/s):

$$w_{2s} = \frac{Q_{2s}}{F_{2s}}$$

Mean velocity in the common branch (m/s):

$$w_c = \frac{Q_c}{F_c}$$

Mass flow rate in the right branch (kg/s):

$$G_{1s} = Q_{1s} \cdot \rho$$

Mass flow rate in the left branch (kg/s):

$$G_{2s} = Q_{2s} \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_c = Q_c \cdot \rho$$

Reynolds number in the right branch:

$$\mathrm{Re}_{1s} = \frac{w_{1s} \cdot D_s}{\nu}$$

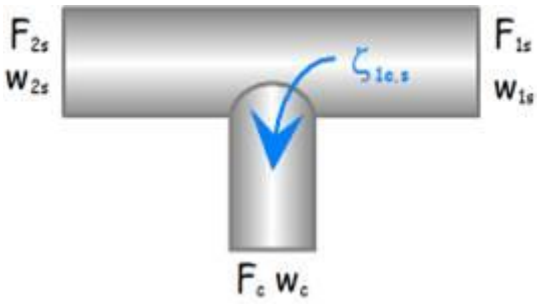
Reynolds number in the left branch:

$$Re_{2s} = \frac{w_{2s} \cdot D_s}{\nu}$$

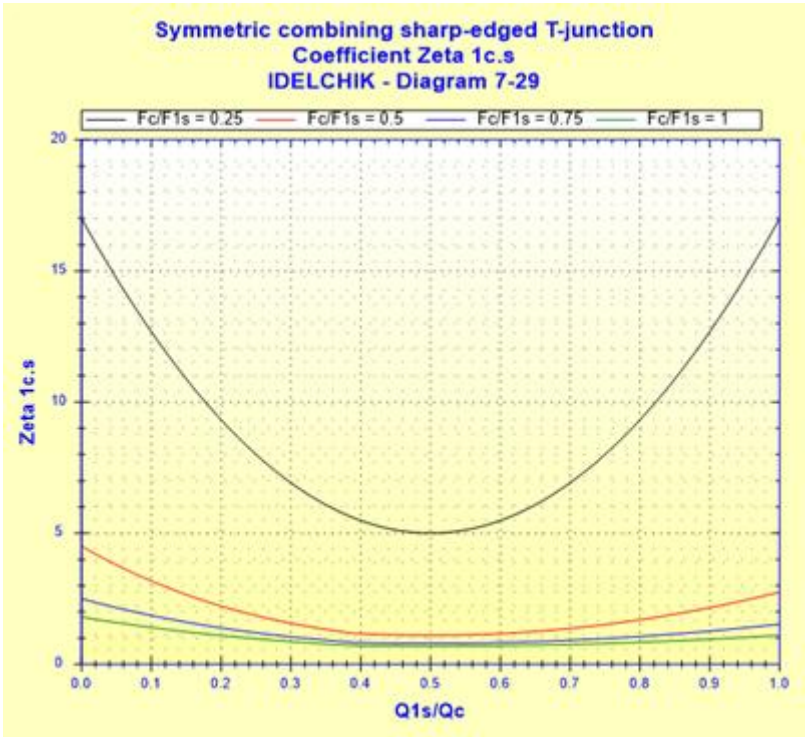
Reynolds number in the common branch:

$$Re_c = \frac{w_c \cdot D_c}{\nu}$$

Pressure loss coefficient of the right branch (based on mean velocity in the common branch):



$$\zeta_{1c.s} = A_{1s} \cdot \zeta'_{1c.s}$$ ([1] diagram 7.29 – Merging of streams without partition)



with:

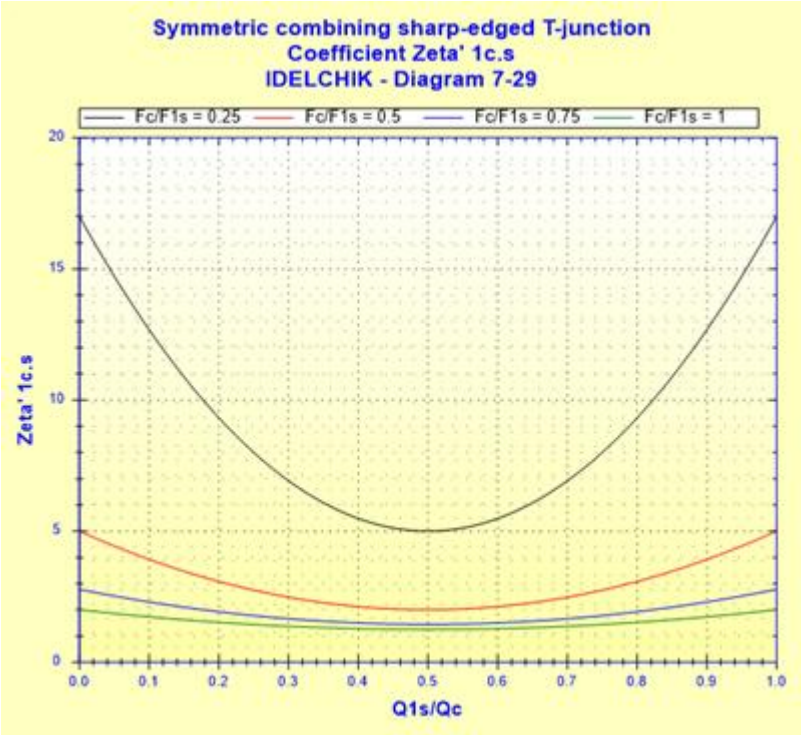
Values of A_{1s}

F_c / F_{1s}	≤ 0.35	> 0.35	
Q_{1s} / Q_c	≤ 1	≤ 0.4	> 0.4
A_{1s}	1	$0.9 \cdot \left(1 - \frac{Q_{1s}}{Q_c}\right)$	0.55

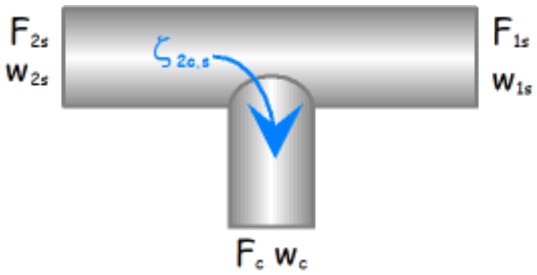
([1] table 7-1)

$$\zeta'_{1c.s} = 1 + \left(\frac{F_{1s}}{F_c}\right)^2 + 3 \cdot \left(\frac{F_{1s}}{F_c}\right)^2 \cdot \left[\left(\frac{Q_{1s}}{Q_c}\right)^2 - \left(\frac{Q_{1s}}{Q_c}\right)\right]$$

([1] diagram 7.29)



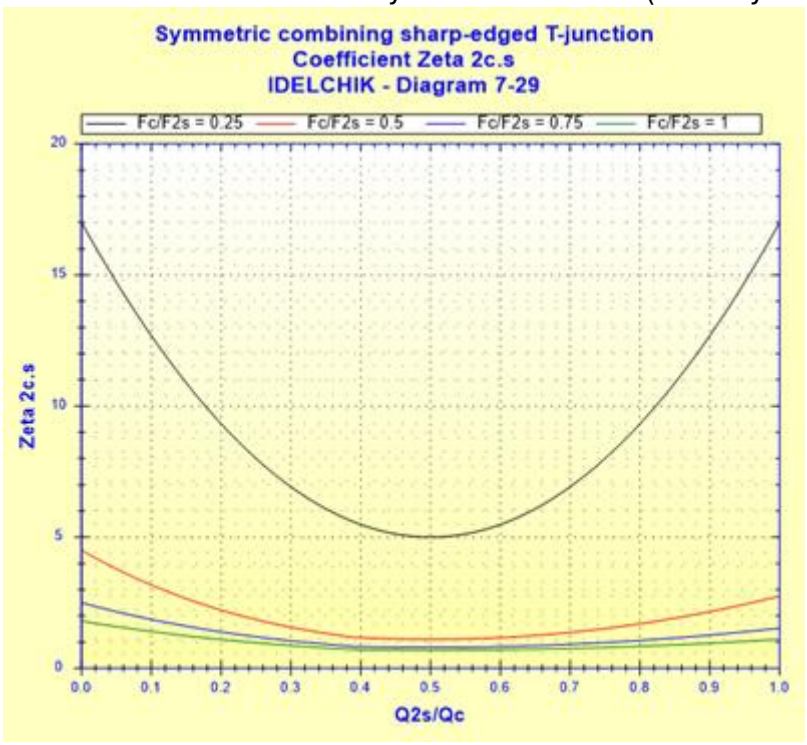
Pressure loss coefficient of the left branch (based on mean velocity in the common branch):



Note: for the left branch, the formulas are the same as those of the right branch, with subscript 2 instead of subscript 1.

$$\zeta_{2c.s} = A_{2s} \cdot \zeta'_{2c.s}$$

([1] diagram 7.29 – Merging of streams without partition)



with:

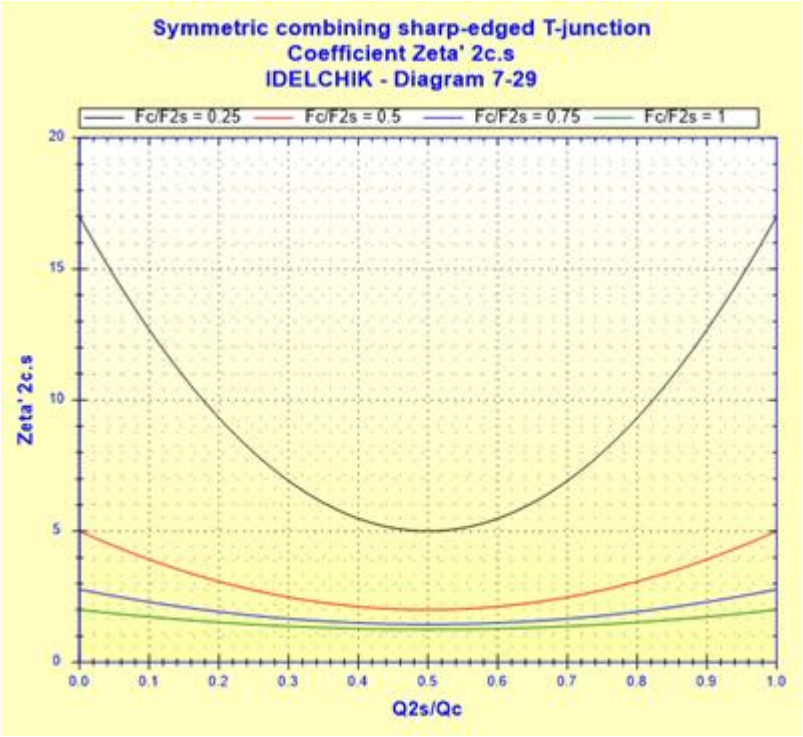
Values of A_{2s}

F_c / F_{2s}	≤ 0.35	> 0.35	
Q_{2s} / Q_c	≤ 1	≤ 0.4	> 0.4
A_{2s}	1	$0.9 \cdot \left(1 - \frac{Q_{2s}}{Q_c}\right)$	0.55

([1] table 7-1)

$$\zeta'_{2c.s} = 1 + \left(\frac{F_{2s}}{F_c}\right)^2 + 3 \cdot \left(\frac{F_{2s}}{F_c}\right)^2 \cdot \left[\left(\frac{Q_{2s}}{Q_c}\right)^2 - \left(\frac{Q_{2s}}{Q_c}\right)\right]$$

([1] diagram 7.29)



Pressure loss in the right branch (Pa):

$$\Delta P_{1c.s} = \zeta_{1c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Pressure loss in the left branch (Pa):

$$\Delta P_{2c.s} = \zeta_{2c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{1c.s} = \zeta_{1c.s} \cdot \frac{W_c^{\,2}}{2 \cdot g}$$

Head loss of fluid in the left branch (m):

$$\Delta H_{2c.s} = \zeta_{2c.s} \cdot \frac{W_c^{\,2}}{2 \cdot g}$$

Hydraulic power loss in the right branch (W):

$$Wh_{1s} = \Delta P_{1c.s} \cdot Q_{1s}$$

Hydraulic power loss in the left branch (W):

$$Wh_{2s} = \Delta P_{2c.s} \cdot Q_{2s}$$

Symbols, Definitions, SI Units:

D_s	Diameter of the right and left branches (m)
D_c	Diameter of the common branch (m)
F_{1s}	Cross-sectional area of the right branch (m^2)
F_{2s}	Cross-sectional area of the left branch (m^2)
F_c	Cross-sectional area of the common branch (m^2)
Q_{1s}	Volume flow rate in the right branch (m^3/s)
w_{1s}	Mean velocity in the right branch (m/s)
Q_{2s}	Volume flow rate in the left branch (m^3/s)
w_{2s}	Mean velocity in the left branch (m/s)
Q_c	Volume flow rate in the common branch (m^3/s)
w_c	Mean velocity in the common branch (m/s)
G_{1s}	Mass flow rate in the right branch (kg/s)
G_{2s}	Mass flow rate in the left branch (kg/s)
G_c	Mass flow rate in the common branch (kg/s)
Re_{1s}	Reynolds number in the right branch ()
Re_{2s}	Reynolds number in the left branch ()
Re_c	Reynolds number in the common branch ()
$\zeta_{1c.s}$	Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()
$\zeta_{2c.s}$	Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()
ΔP_{1s}	Pressure loss in the right branch (Pa)
ΔP_{2s}	Pressure loss in the left branch (Pa)

ΔH_{1s} Head loss of fluid in the right branch (m)

ΔH_{2s} Head loss of fluid in the left branch (m)

Wh_{1s} Hydraulic power loss in the right branch (W)

Wh_{2s} Hydraulic power loss in the left branch (W)

ρ Fluid density (kg/m³)

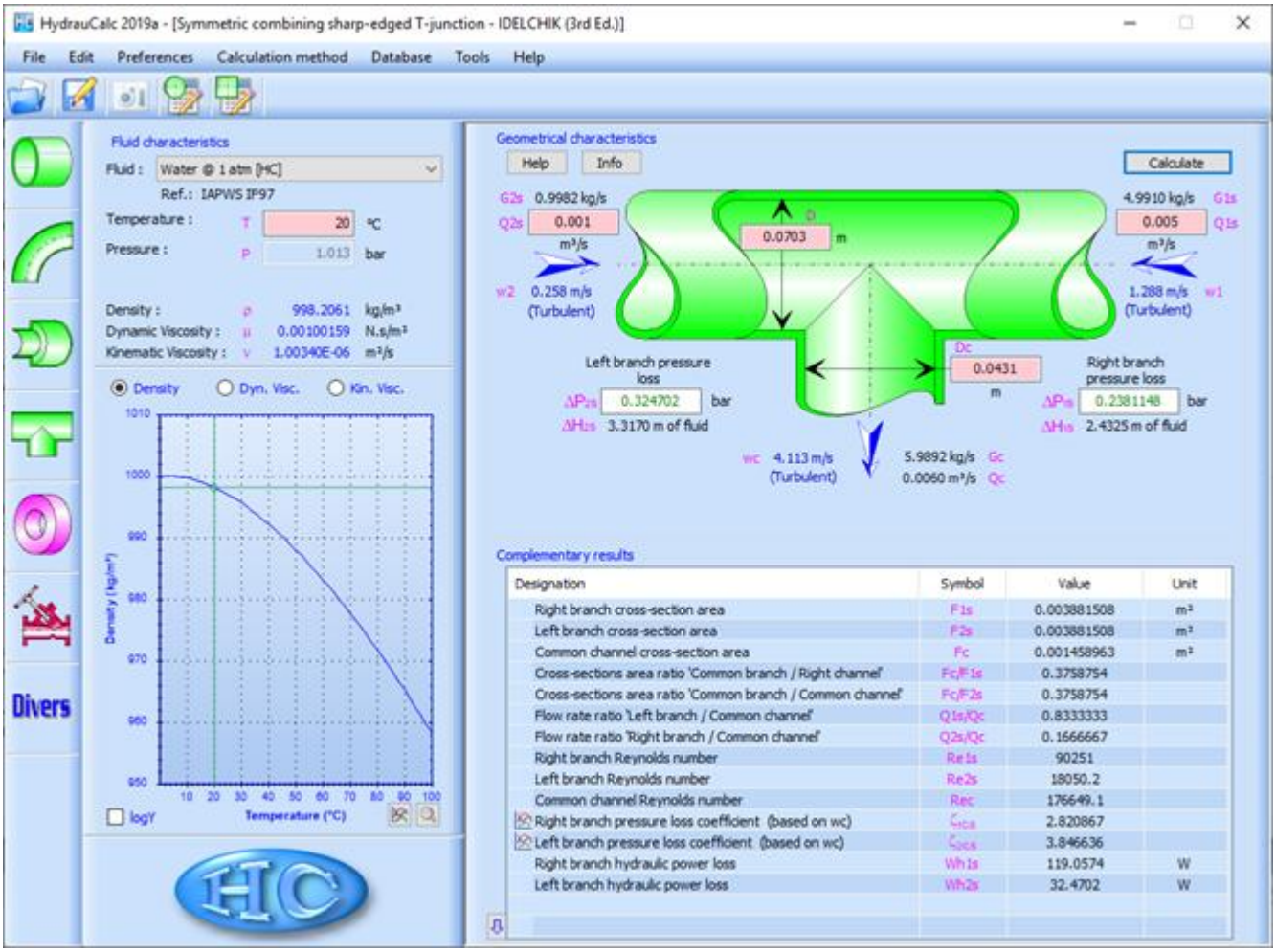
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($Re_c \geq 10^4$)
- diameter of common branch (D_c) ≤ diameter of right and left branches (D_s)

Example of application:

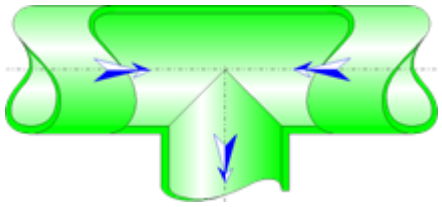


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

Note: Diagram 7-29 of the reference document contains anomalies:
In the formula for the coefficient $\zeta_{1c.s}$ the ratio of the sections (F_c/F_{1s}) must be replaced by the ratio (F_{1s}/F_c).
In the table presenting the values of $\zeta_{1c.s}$ the ratio of the sections (F_{1s}/F_c) must be replaced by the ratio (F_c/F_{1s}).
In the graph of the values of ζ_{cs} the ratio of the sections (F_s/F_c) must be replaced by the ratio (F_c/F_s).

2.4.3.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric combining sharp-edged T-junction with three legs of equal area.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the three branches (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

$$A_3 = \pi \cdot \frac{D_3^2}{4}$$

with $D_1 = D_2 = D_3 = D$

Volume flow rate in the common branch (m^3/s):

$$Q_3 = Q_1 + Q_2$$

Mean velocity in the left branch (m/s):

$$U_1 = \frac{Q_1}{A_1}$$

Mean velocity in the right branch (m/s):

$$U_2 = \frac{Q_2}{A_2}$$

Mean velocity in the common branch (m/s):

$$U_3 = \frac{Q_3}{A_3}$$

Mass flow rate in the left branch (kg/s):

$$G_1 = Q_1 \cdot \rho$$

Mass flow rate in the right branch (kg/s):

$$G_2 = Q_2 \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_3 = Q_3 \cdot \rho$$

Reynolds number in the left branch:

$$\mathrm{Re}_1 = \frac{U_1 \cdot D_1}{\nu}$$

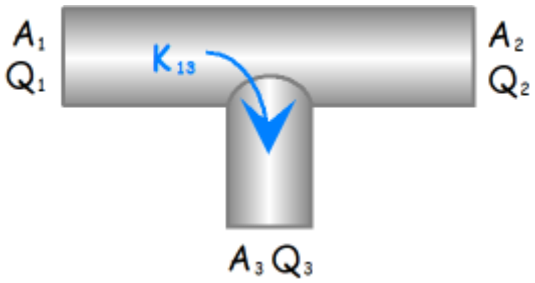
Reynolds number in the right branch:

$$\mathrm{Re}_2 = \frac{U_2 \cdot D_2}{\nu}$$

Reynolds number in the common branch:

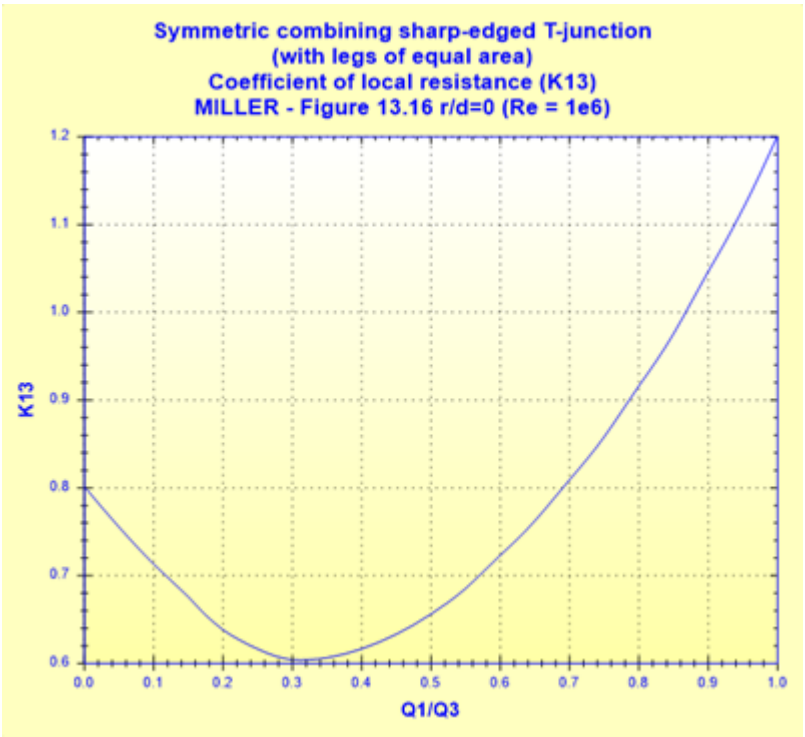
$$Re_3 = \frac{U_3 \cdot D_3}{\nu}$$

Pressure loss coefficient of the left branch (based on mean velocity in the common branch):

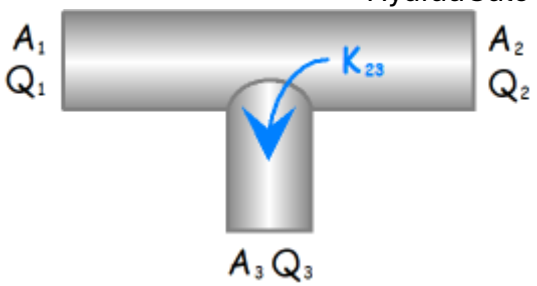


$$K_{13} = f\left(\frac{Q_1}{Q_3}\right)$$

([1] figure 13.16 with r/d = 0)

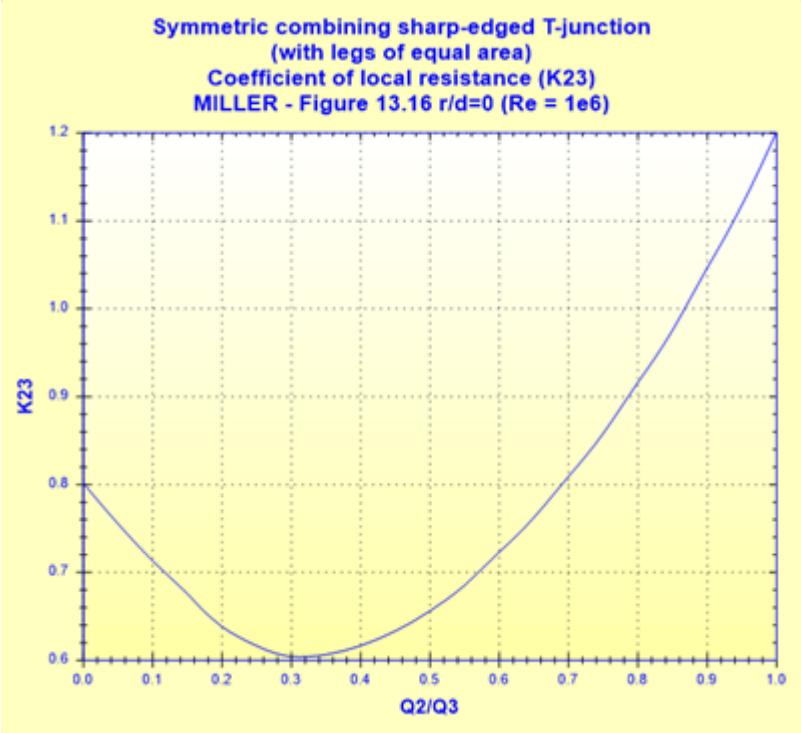


Pressure loss coefficient of the right branch (based on mean velocity in the common branch):



$$K_{23} = f\left(\frac{Q_2}{Q_3}\right)$$

([1] figure 13.16 with r/d = 0)



Pressure loss in the left branch (Pa):

$$\Delta P_{13} = K_{13} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.1)

Pressure loss in the right branch (Pa):

$$\Delta P_{23} = K_{23} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.2)

Head loss of fluid in the left branch (m):

$$\Delta H_{13} = K_{13} \cdot \frac{U_3^2}{2 \cdot g}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{23} = K_{23} \cdot \frac{U_3^2}{2 \cdot g}$$

Hydraulic power loss in the left branch (W):

$$Wh_{13} = \Delta P_{13} \cdot Q_1$$

Hydraulic power loss in the right branch (W):

$$Wh_{23} = \Delta P_{23} \cdot Q_2$$

Symbols, Definitions, SI Units:

D	Inside diameter of the three branches (m)
D_1	Diameter of the left branch (m)
D_2	Diameter of the right branch (m)
D_3	Diameter of the common branch (m)
A_1	Cross-sectional area of the left branch (m^2)
A_2	Cross-sectional area of the right branch (m^2)
A_3	Cross-sectional area of the common branch (m^2)
Q_1	Volume flow rate in the left branch (m^3/s)
U_1	Mean velocity in the left branch (m/s)
Q_2	Volume flow rate in the right branch (m^3/s)
U_2	Mean velocity in the right branch (m/s)
Q_3	Volume flow rate in the common branch (m^3/s)
U_3	Mean velocity in the common branch (m/s)
G_1	Mass flow rate in the left branch (kg/s)
G_2	Mass flow rate in the right branch (kg/s)
G_3	Mass flow rate in the common branch (kg/s)

Re_1 Reynolds number in the left branch ()

Re_2 Reynolds number in the right branch ()

Re_3 Reynolds number in the common branch ()

K_{13} Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

K_{23} Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

ΔP_{13} Pressure loss in the left branch (Pa)

ΔP_{23} Pressure loss in the right branch (Pa)

ΔH_{13} Head loss of fluid in the left branch (m)

ΔH_{23} Head loss of fluid in the right branch (m)

Wh_{13} Hydraulic power loss in the left branch (W)

Wh_{23} Hydraulic power loss in the right branch (W)

ρ Fluid density (kg/m^3)

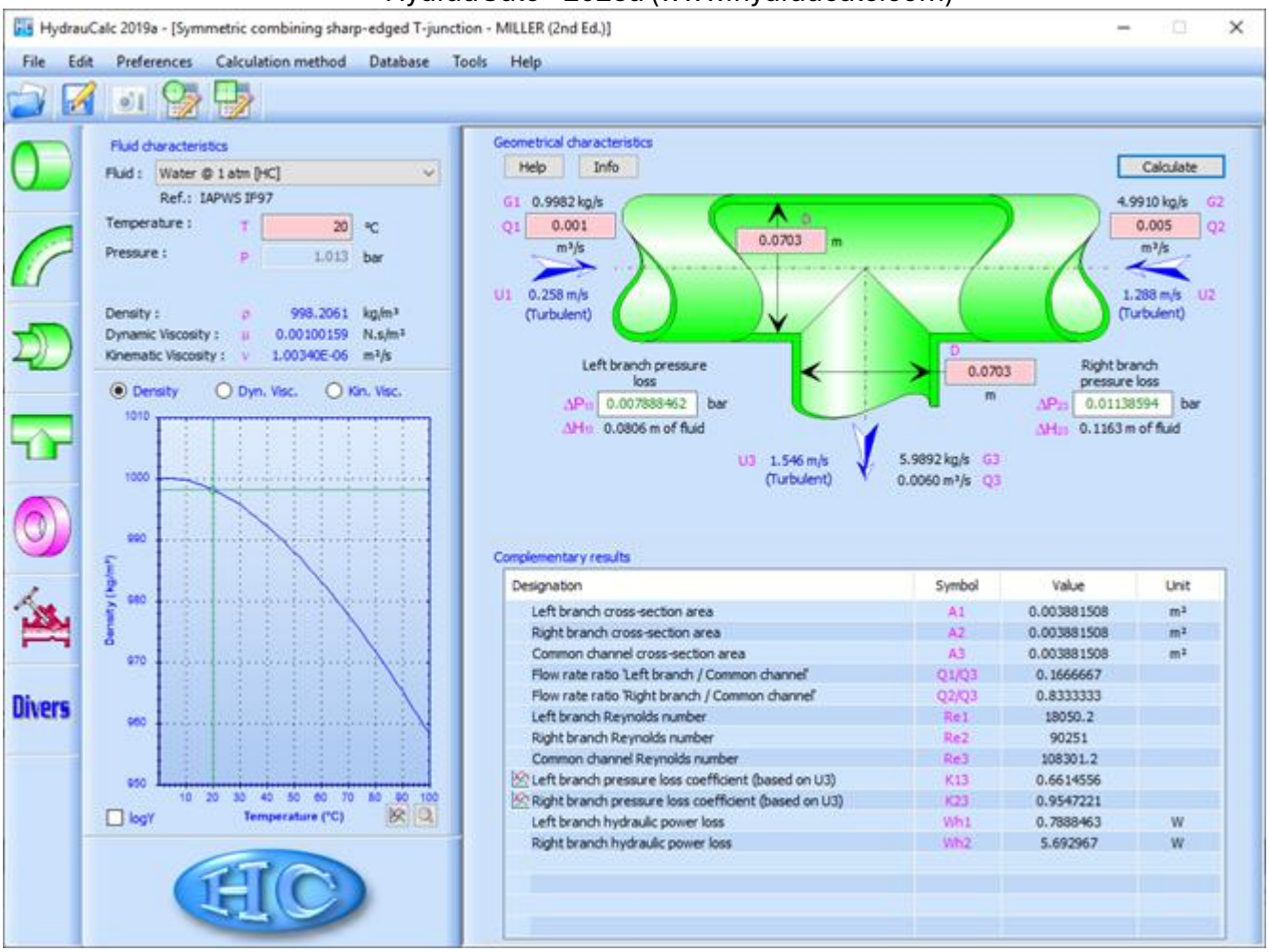
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re_3 \geq 10^5$)
- three legs of equal area ($D_1 = D_2 = D_3$)

Example of application:

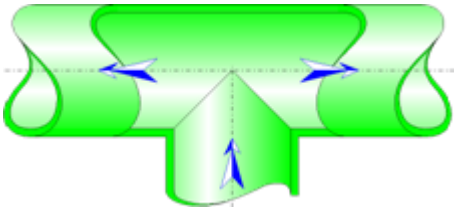


References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

2.4.4 Symmetric dividing sharp-edged T-junction

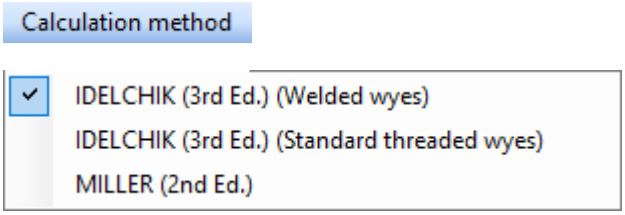
Circular Cross-Section



For the calculation of the pressure loss coefficient of symmetric dividing sharp-edged T-junctions, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.) (Welded wyes)"



Note: The reference document "Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik" proposes formulations for two types of junction:

- Welded wyes
- Standard threaded wyes

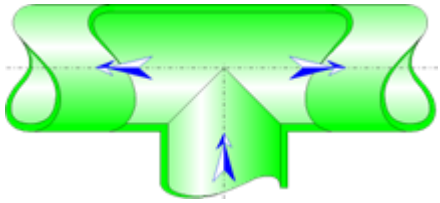
2.4.4.1 IDELCHIK (welded)

Symmetric dividing sharp-edged T-junction

(welded type)

Circular Cross-Section

(IDELCHIK)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric dividing sharp-edged T-junction welded type.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the right branch (m^2):

$$F_{1s} = \pi \cdot \frac{D_s^2}{4}$$

Cross-sectional area of the left branch (m^2):

$$F_{2s} = \pi \cdot \frac{D_s^2}{4}$$

Cross-sectional area of the common branch (m^2):

$$F_c = \pi \cdot \frac{D_c^2}{4}$$

Volume flow rate in the common branch (m^3/s):

$$Q_c = Q_{1s} + Q_{2s}$$

Mean velocity in the right branch (m/s):

$$w_{1s} = \frac{Q_{1s}}{F_{1s}}$$

Mean velocity in the left branch (m/s):

$$w_{2s} = \frac{Q_{2s}}{F_{2s}}$$

Mean velocity in the common branch (m/s):

$$w_c = \frac{Q_c}{F_c}$$

Mass flow rate in the right branch (kg/s):

$$G_{1s} = Q_{1s} \cdot \rho$$

Mass flow rate in the left branch (kg/s):

$$G_{2s} = Q_{2s} \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_c = Q_c \cdot \rho$$

Reynolds number in the right branch:

$$Re_{1s} = \frac{w_{1s} \cdot D_s}{\nu}$$

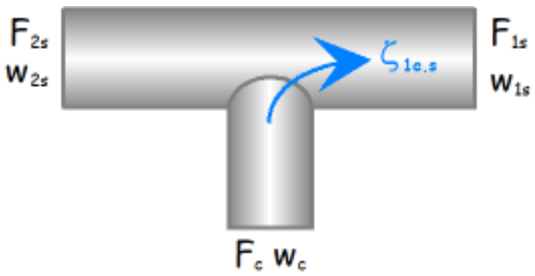
Reynolds number in the left branch:

$$Re_{2s} = \frac{w_{2s} \cdot D_s}{\nu}$$

Reynolds number in the common branch:

$$Re_c = \frac{w_c \cdot D_c}{\nu}$$

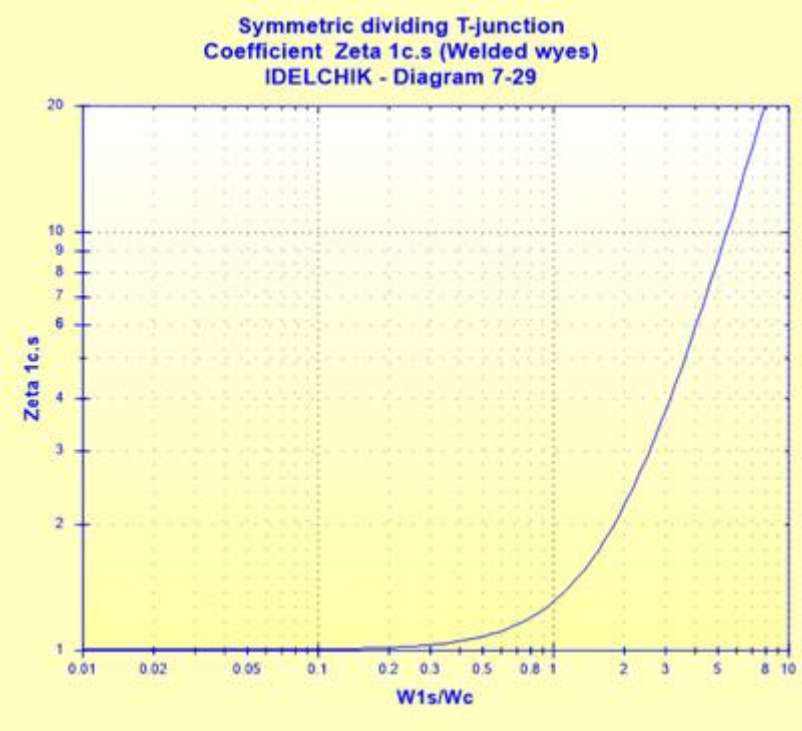
Pressure loss coefficient of the right branch (based on mean velocity in the common branch):



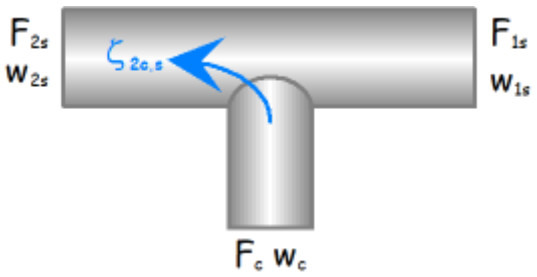
$$\zeta_{1c.s} = 1 + k_1 \cdot \left(\frac{w_{1s}}{w_c}\right)^2$$

([1] diagram 7.29 – Division of flow)

with: $k_1 = 0.3$



Pressure loss coefficient of the left branch (based on mean velocity in the common branch):

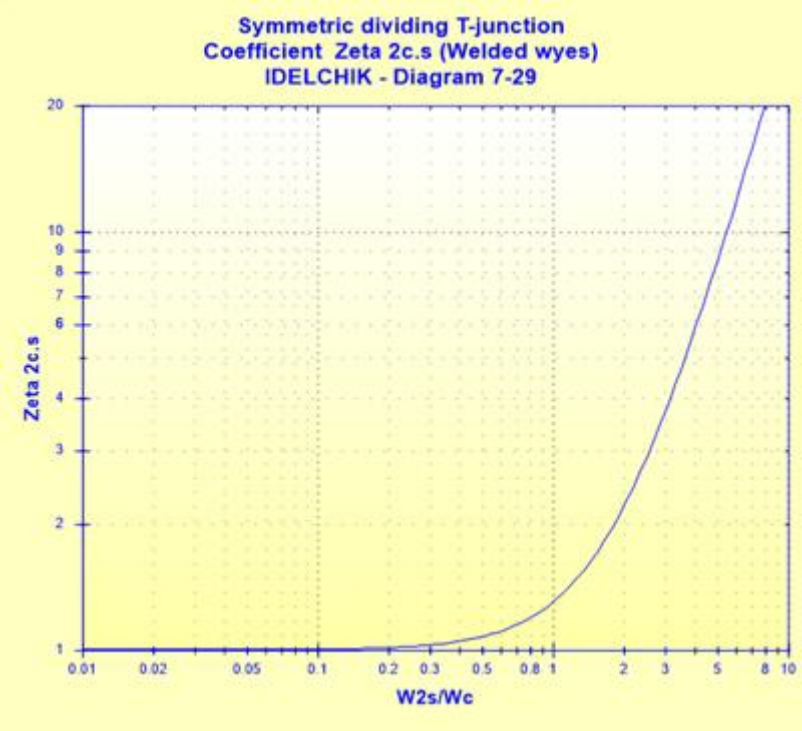


Note: for the left branch, the formulas are the same as those of the right branch, with subscript 2 instead of subscript 1.

$$\zeta_{2c.s} = 1 + k_2 \cdot \left(\frac{W_{2s}}{W_c} \right)^2$$

([1] diagram 7.29 – Division of flow)

with: $k_2 = 0.3$



Pressure loss in the right branch (Pa):

$$\Delta P_{1c.s} = \zeta_{1c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Pressure loss in the left branch (Pa):

$$\Delta P_{2c.s} = \zeta_{2c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{1c.s} = \zeta_{1c.s} \cdot \frac{W_c^{\,2}}{2 \cdot g}$$

Head loss of fluid in the left branch (m):

$$\Delta H_{2c.s} = \zeta_{2c.s} \cdot \frac{W_c^{\,2}}{2 \cdot g}$$

Hydraulic power loss in the right branch (W):

$$Wh_{1s} = \Delta P_{1c.s} \cdot Q_{1s}$$

Hydraulic power loss in the left branch (W):

$$Wh_{2s} = \Delta P_{2c.s} \cdot Q_{2s}$$

Symbols, Definitions, SI Units:

D_s	Diameter of the right and left branches (m)
D_c	Diameter of the common branch (m)
F_{1s}	Cross-sectional area of the right branch (m^2)
F_{2s}	Cross-sectional area of the left branch (m^2)
F_c	Cross-sectional area of the common branch (m^2)
Q_{1s}	Volume flow rate in the right branch (m^3/s)
w_{1s}	Mean velocity in the right branch (m/s)
Q_{2s}	Volume flow rate in the left branch (m^3/s)
w_{2s}	Mean velocity in the left branch (m/s)
Q_c	Volume flow rate in the common branch (m^3/s)
w_c	Mean velocity in the common branch (m/s)
G_{1s}	Mass flow rate in the right branch (kg/s)
G_{2s}	Mass flow rate in the left branch (kg/s)
G_c	Mass flow rate in the common branch (kg/s)
Re_{1s}	Reynolds number in the right branch ()
Re_{2s}	Reynolds number in the left branch ()
Re_c	Reynolds number in the common branch ()
$\zeta_{1c.s}$	Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()
$\zeta_{2c.s}$	Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()
ΔP_{1s}	Pressure loss in the right branch (Pa)
ΔP_{2s}	Pressure loss in the left branch (Pa)
ΔH_{1s}	Head loss of fluid in the right branch (m)

ΔH_{2s} Head loss of fluid in the left branch (m)

Wh_{1s} Hydraulic power loss in the right branch (W)

Wh_{2s} Hydraulic power loss in the left branch (W)

ρ Fluid density (kg/m³)

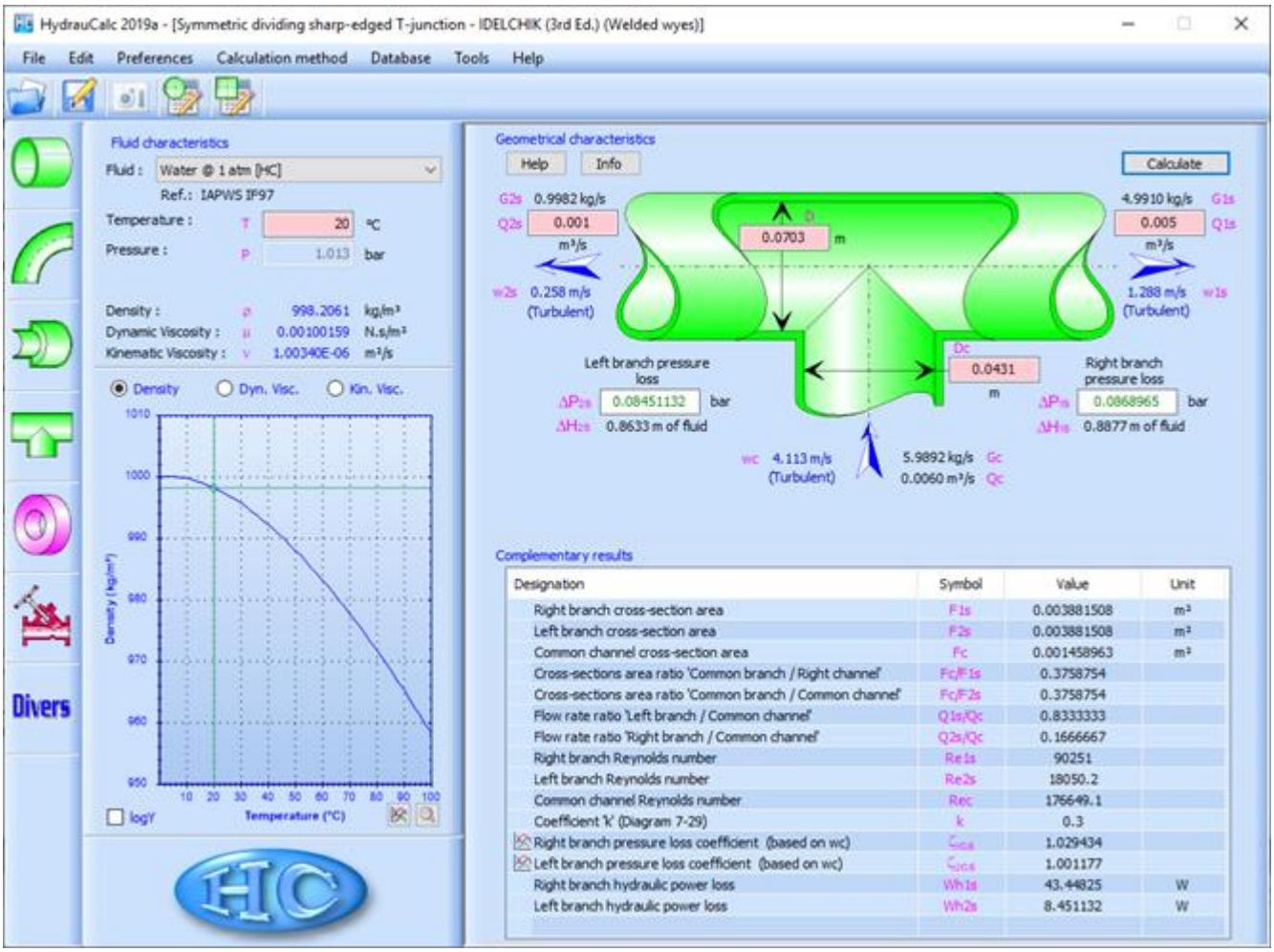
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($Re_c \geq 10^4$)
- diameter of common branch (D_c) ≤ diameter of right and left branches (D_s)

Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

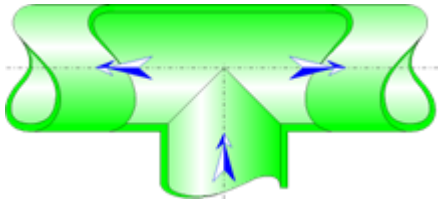
2.4.4.2 IDELCHIK (standard threaded)

Symmetric dividing sharp-edged T-junction

(standard threaded type)

Circular Cross-Section

(IDELCHIK)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric dividing sharp-edged T-junction standard threaded type.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the right branch (m^2):

$$F_{1s} = \pi \cdot \frac{D_s^2}{4}$$

Cross-sectional area of the left branch (m^2):

$$F_{2s} = \pi \cdot \frac{D_s^2}{4}$$

Cross-sectional area of the common branch (m^2):

$$F_c = \pi \cdot \frac{D_c^2}{4}$$

Volume flow rate in the common branch (m^3/s):

$$Q_c = Q_{1s} + Q_{2s}$$

Mean velocity in the right branch (m/s):

$$w_{1s} = \frac{Q_{1s}}{F_{1s}}$$

Mean velocity in the left branch (m/s):

$$w_{2s} = \frac{Q_{2s}}{F_{2s}}$$

Mean velocity in the common branch (m/s):

$$w_c = \frac{Q_c}{F_c}$$

Mass flow rate in the right branch (kg/s):

$$G_{1s} = Q_{1s} \cdot \rho$$

Mass flow rate in the left branch (kg/s):

$$G_{2s} = Q_{2s} \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_c = Q_c \cdot \rho$$

Reynolds number in the right branch:

$$Re_{1s} = \frac{w_{1s} \cdot D_s}{\nu}$$

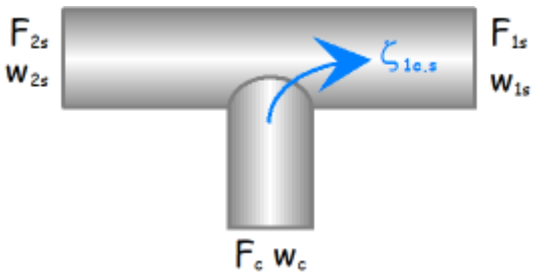
Reynolds number in the left branch:

$$Re_{2s} = \frac{w_{2s} \cdot D_s}{\nu}$$

Reynolds number in the common branch:

$$Re_c = \frac{w_c \cdot D_c}{\nu}$$

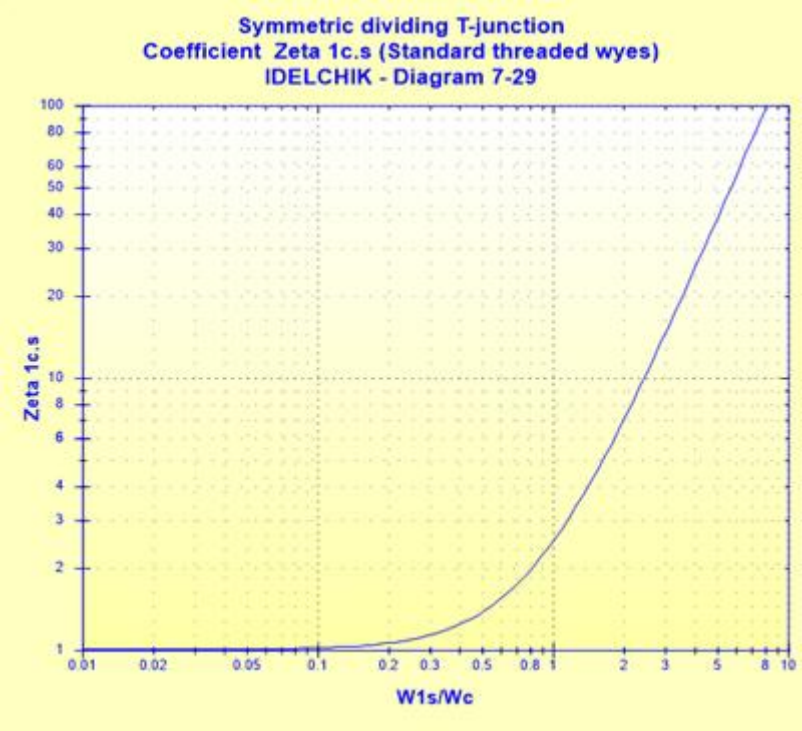
Pressure loss coefficient of the right branch (based on mean velocity in the common branch):



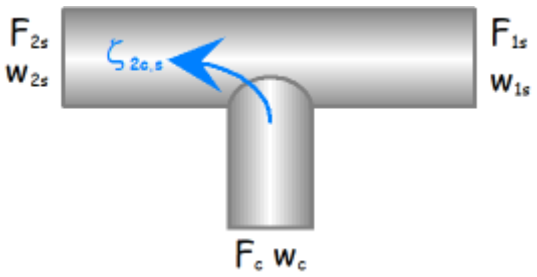
$$\zeta_{1c.s} = 1 + k_1 \cdot \left(\frac{w_{1s}}{w_c}\right)^2$$

([1] diagram 7.29 – Division of flow)

with: $k_1 = 1.5$



Pressure loss coefficient of the left branch (based on mean velocity in the common branch):

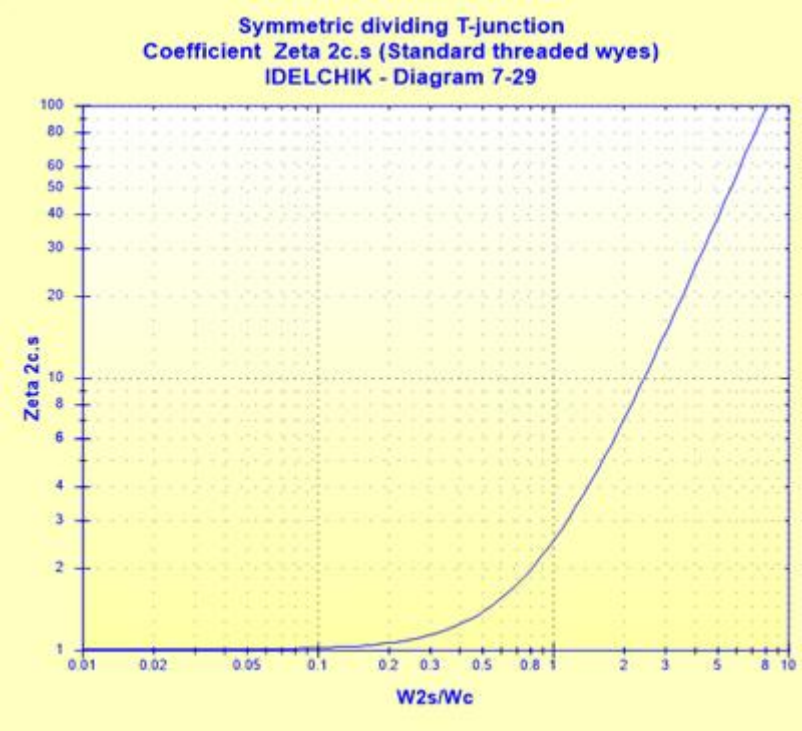


Note: for the left branch, the formulas are the same as those of the right branch, with subscript 2 instead of subscript 1.

$$\zeta_{2c.s} = 1 + k_2 \cdot \left(\frac{W_{2s}}{W_c} \right)^2$$

([1] diagram 7.29 – Division of flow)

with: $k_2 = 1.5$



Pressure loss in the right branch (Pa):

$$\Delta P_{1c.s} = \zeta_{1c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Pressure loss in the left branch (Pa):

$$\Delta P_{2c.s} = \zeta_{2c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{1c.s} = \zeta_{1c.s} \cdot \frac{W_c^{\,2}}{2 \cdot g}$$

Head loss of fluid in the left branch (m):

$$\Delta H_{2c.s} = \zeta_{2c.s} \cdot \frac{W_c^{\,2}}{2 \cdot g}$$

Hydraulic power loss in the right branch (W):

$$Wh_{1s} = \Delta P_{1c.s} \cdot Q_{1s}$$

Hydraulic power loss in the left branch (W):

$$Wh_{2s} = \Delta P_{2c.s} \cdot Q_{2s}$$

Symbols, Definitions, SI Units:

D_s	Diameter of the right and left branches (m)
D_c	Diameter of the common branch (m)
F_{1s}	Cross-sectional area of the right branch (m^2)
F_{2s}	Cross-sectional area of the left branch (m^2)
F_c	Cross-sectional area of the common branch (m^2)
Q_{1s}	Volume flow rate in the right branch (m^3/s)
w_{1s}	Mean velocity in the right branch (m/s)
Q_{2s}	Volume flow rate in the left branch (m^3/s)
w_{2s}	Mean velocity in the left branch (m/s)
Q_c	Volume flow rate in the common branch (m^3/s)
w_c	Mean velocity in the common branch (m/s)
G_{1s}	Mass flow rate in the right branch (kg/s)
G_{2s}	Mass flow rate in the left branch (kg/s)
G_c	Mass flow rate in the common branch (kg/s)
Re_{1s}	Reynolds number in the right branch ()
Re_{2s}	Reynolds number in the left branch ()
Re_c	Reynolds number in the common branch ()
$\zeta_{1c.s}$	Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()
$\zeta_{2c.s}$	Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()
ΔP_{1s}	Pressure loss in the right branch (Pa)
ΔP_{2s}	Pressure loss in the left branch (Pa)
ΔH_{1s}	Head loss of fluid in the right branch (m)

ΔH_{2s} Head loss of fluid in the left branch (m)

Wh_{1s} Hydraulic power loss in the right branch (W)

Wh_{2s} Hydraulic power loss in the left branch (W)

ρ Fluid density (kg/m³)

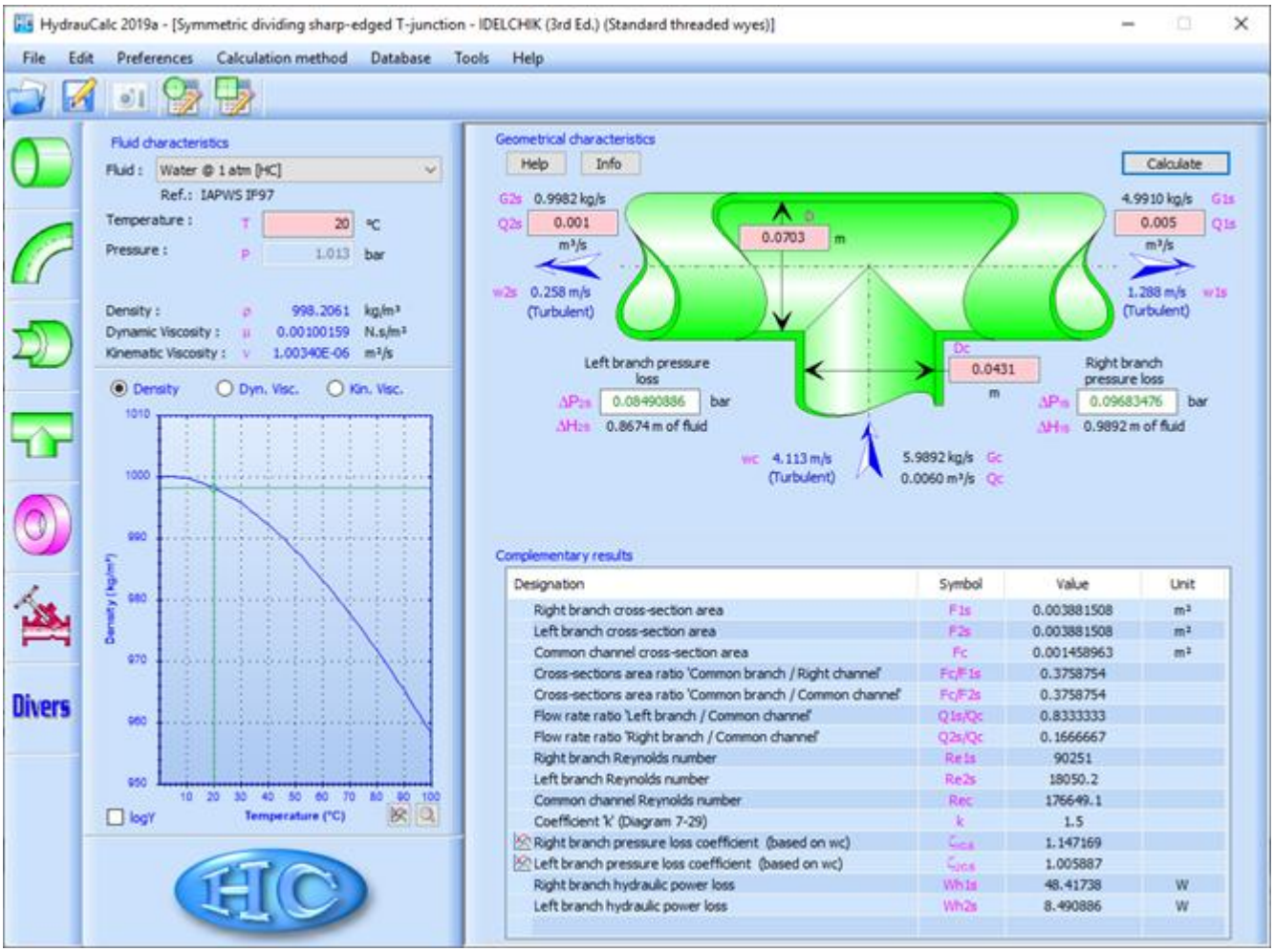
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($Re_c \geq 10^4$)
- diameter of common branch (D_c) ≤ diameter of right and left branches (D_s)

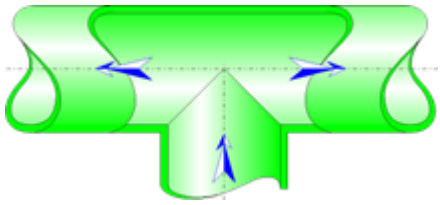
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.4.4.3 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric dividing sharp-edged T-junction with three legs of equal area.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the three branches (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

$$A_3 = \pi \cdot \frac{D_3^2}{4}$$

with $D_1 = D_2 = D_3 = D$

Volume flow rate in the common branch (m^3/s):

$$Q_3 = Q_1 + Q_2$$

Mean velocity in the left branch (m/s):

$$U_1 = \frac{Q_1}{A_1}$$

Mean velocity in the right branch (m/s):

$$U_2 = \frac{Q_2}{A_2}$$

Mean velocity in the common branch (m/s):

$$U_3 = \frac{Q_3}{A_3}$$

Mass flow rate in the left branch (kg/s):

$$G_1 = Q_1 \cdot \rho$$

Mass flow rate in the right branch (kg/s):

$$G_2 = Q_2 \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_3 = Q_3 \cdot \rho$$

Reynolds number in the left branch:

$$\mathrm{Re}_1 = \frac{U_1 \cdot D_1}{\nu}$$

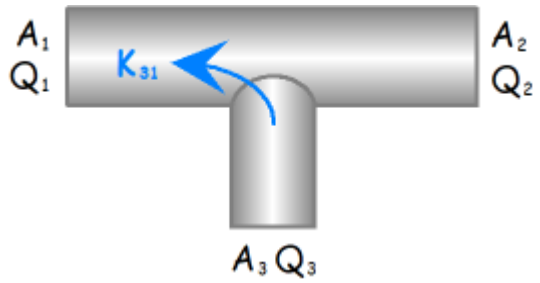
Reynolds number in the right branch:

$$\mathrm{Re}_2 = \frac{U_2 \cdot D_2}{\nu}$$

Reynolds number in the common branch:

$$Re_3 = \frac{U_3 \cdot D_3}{\nu}$$

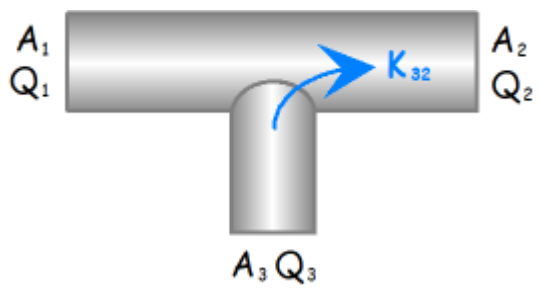
Pressure loss coefficient of the left branch (based on mean velocity in the common branch):



$$K_{31} = f\left(\frac{Q_1}{Q_3}\right)$$

([1] figure 13.27 with r/d = 0)

Pressure loss coefficient of the right branch (based on mean velocity in the common branch):



$$K_{32} = f\left(\frac{Q_2}{Q_3}\right)$$

([1] figure 13.27 with r/d = 0)

Pressure loss in the left branch (Pa):

$$\Delta P_{31} = K_{31} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.3)

Pressure loss in the right branch (Pa):

$$\Delta P_{32} = K_{32} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.4)

Head loss of fluid in the left branch (m):

$$\Delta H_{31} = K_{31} \cdot \frac{U_3^2}{2 \cdot g}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{32} = K_{32} \cdot \frac{U_3^2}{2 \cdot g}$$

Hydraulic power loss in the left branch (W):

$$Wh_{31} = \Delta P_{31} \cdot Q_1$$

Hydraulic power loss in the right branch (W):

$$Wh_{32} = \Delta P_{32} \cdot Q_2$$

Symbols, Definitions, SI Units:

D	Inside diameter of the three branches (m)
D_1	Diameter of the left branch (m)
D_2	Diameter of the right branch (m)
D_3	Diameter of the common branch
A_1	Cross-sectional area of the left branch (m^2)
A_2	Cross-sectional area of the right branch (m^2)
A_3	Cross-sectional area of the common branch (m^2)
Q_1	Volume flow rate in the left branch (m^3/s)
U_1	Mean velocity in the left branch (m/s)
Q_2	Volume flow rate in the right branch (m^3/s)
U_2	Mean velocity in the right branch (m/s)
Q_3	Volume flow rate in the common branch (m^3/s)
U_3	Mean velocity in the common branch (m/s)
G_1	Mass flow rate in the left branch (kg/s)
G_2	Mass flow rate in the right branch (kg/s)
G_3	Mass flow rate in the common branch (kg/s)
Re_1	Reynolds number in the left branch ()
Re_2	Reynolds number in the right branch ()
Re_3	Reynolds number in the common branch ()

K_{31} Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

K_{32} Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

ΔP_{31} Pressure loss in the left branch (Pa)

ΔP_{32} Pressure loss in the right branch (Pa)

ΔH_{31} Head loss of fluid in the left branch (m)

ΔH_{32} Head loss of fluid in the right branch (m)

Wh_{31} Hydraulic power loss in the left branch (W)

Wh_{32} Hydraulic power loss in the right branch (W)

ρ Fluid density (kg/m^3)

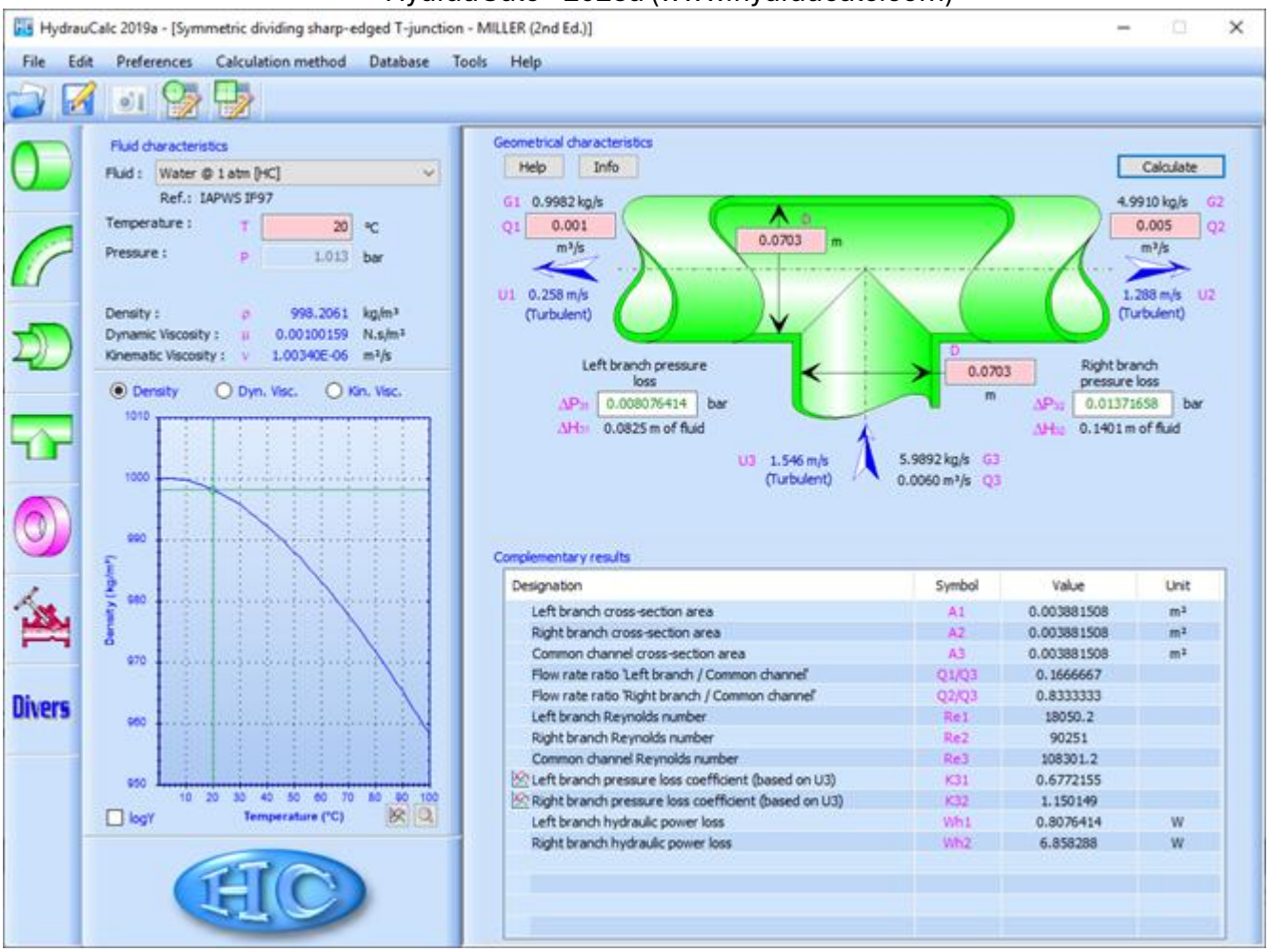
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re_3 \geq 10^5$)
- three legs of equal area ($D_1 = D_2 = D_3$)

Example of application:

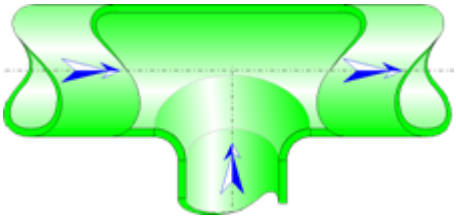


References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

2.4.5 Combining radiused-edged T-junction

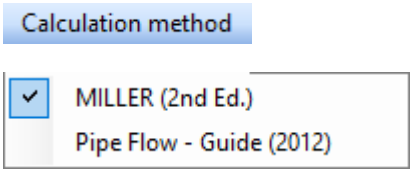
Circular Cross-Section



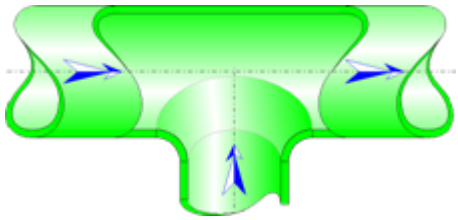
For the calculation of the pressure loss coefficient of combining radiused-edged T-junctions, the user can choose from one of the methods described in the following two reference documents:

- Internal Flow System, 2nd Edition, D.S. Miller
- Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "MILLER (2nd Ed.)"



2.4.5.1 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a combining radiused-edged T-junction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the lateral branch (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Cross-sectional area of the common branch and the straight branch (m^2):

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Volume flow rate in the common branch (m^3/s):

$$Q_3 = Q_1 + Q_2$$

Mean velocity in the lateral branch (m/s):

$$U_1 = \frac{Q_1}{A_1}$$

Mean velocity in the straight branch (m/s):

$$U_2 = \frac{Q_2}{A_2}$$

Mean velocity in the common branch (m/s):

$$U_3 = \frac{Q_3}{A_2}$$

Mass flow rate in the lateral branch (kg/s):

$$G_1 = Q_1 \cdot \rho$$

Mass flow rate in the straight branch (kg/s):

$$G_2 = Q_2 \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_3 = Q_3 \cdot \rho$$

Reynolds number in the lateral branch:

$$\mathrm{Re}_1 = \frac{U_1 \cdot D_1}{\nu}$$

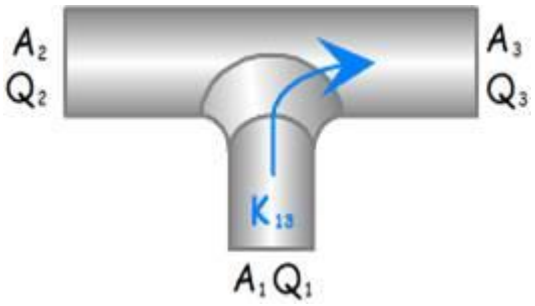
Reynolds number in the straight branch:

$$\mathrm{Re}_2 = \frac{U_2 \cdot D_2}{\nu}$$

Reynolds number in the common branch:

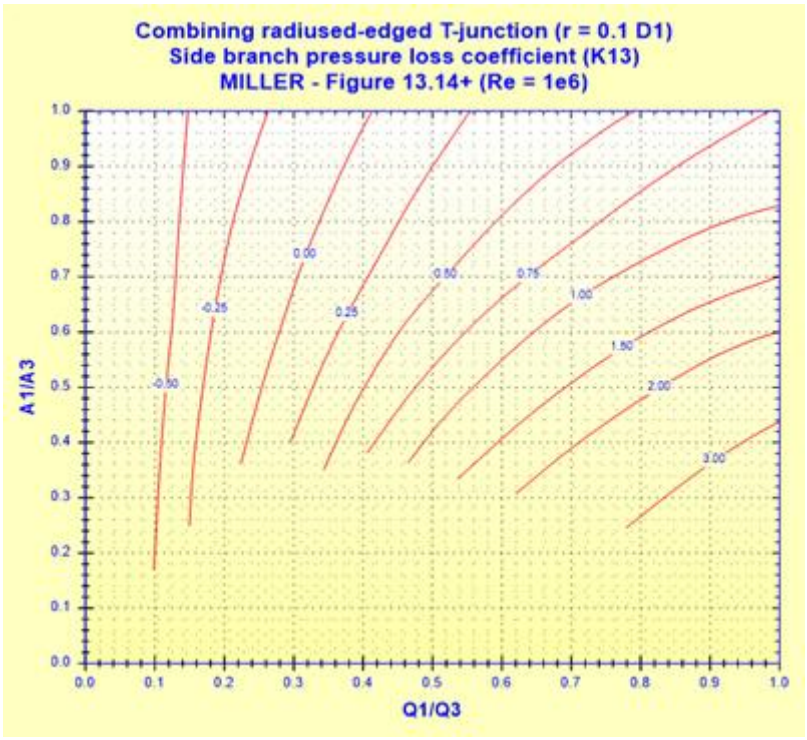
$$\mathrm{Re}_3 = \frac{U_3 \cdot D_2}{\nu}$$

Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch):

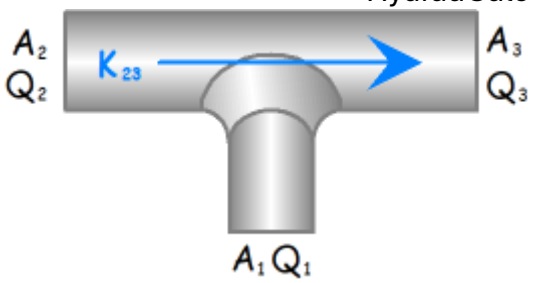


$$K_{13} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.14+)



Pressure loss coefficient of the straight branch (based on mean velocity in the common branch):



$$K_{23} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$ ([1] figure 13.15+)

Pressure loss in the lateral branch (Pa):

$$\Delta P_{13} = K_{13} \cdot \frac{\rho \cdot U_3^2}{2}$$ ([1] equation 13.1)

Pressure loss in the straight branch (Pa):

$$\Delta P_{23} = K_{23} \cdot \frac{\rho \cdot U_3^2}{2}$$ ([1] equation 13.2)

Head loss of fluid in the lateral branch (m):

$$\Delta H_{13} = K_{13} \cdot \frac{U_3^2}{2 \cdot g}$$

Head loss of fluid in the straight branch (m):

$$\Delta H_{23} = K_{23} \cdot \frac{U_3^2}{2 \cdot g}$$

Hydraulic power loss in the lateral branch (W):

$$Wh_{13} = \Delta P_{13} \cdot Q_1$$

Hydraulic power loss in the straight branch (W):

$$Wh_{23} = \Delta P_{23} \cdot Q_2$$

Symbols, Definitions, SI Units:

D_1	Diameter of the lateral branch (m)
D_2	Diameter of the common branch and the straight branch (m)
A_1	Cross-sectional area of the lateral branch (m^2)
A_2	Cross-sectional area of the common branch and the straight branch (m^2)
Q_1	Volume flow rate in the lateral branch (m^3/s)
U_1	Mean velocity in the lateral branch (m/s)
Q_2	Volume flow rate in the straight branch (m^3/s)
U_2	Mean velocity in the straight branch (m/s)
Q_3	Volume flow rate in the common branch (m^3/s)
U_3	Mean velocity in the common branch (m/s)
G_1	Mass flow rate in the lateral branch (kg/s)
G_2	Mass flow rate in the straight branch (kg/s)
G_3	Mass flow rate in the common branch (kg/s)
Re_1	Reynolds number in the lateral branch ()
Re_2	Reynolds number in the straight branch ()

Re_3 Reynolds number in the common branch ()

r Rounded radius (m)

K_{13} Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch) ()

K_{23} Pressure loss coefficient of the straight branch (based on mean velocity in the common branch) ()

ΔP_{13} Pressure loss in the lateral branch (Pa)

ΔP_{23} Pressure loss in the straight branch (Pa)

ΔH_{13} Head loss of fluid in the lateral branch (m)

ΔH_{23} Head loss of fluid in the straight branch (m)

Wh_{13} Hydraulic power loss in the lateral branch (W)

Wh_{23} Hydraulic power loss in the straight branch (W)

ρ Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re_3 \geq 10^5$)
- rounded radius equal to 0.1 diameter of the lateral branch ($r = 0.1\ D_1$)
- cross-sections area ratio equal to or greater than 0.3 ($A_1/A_2 \geq 0.3$)

  note: for cross-sections area ratios lower than 0.3 the pressure loss coefficients "K_{13}" and "K_{23}" are extrapolated

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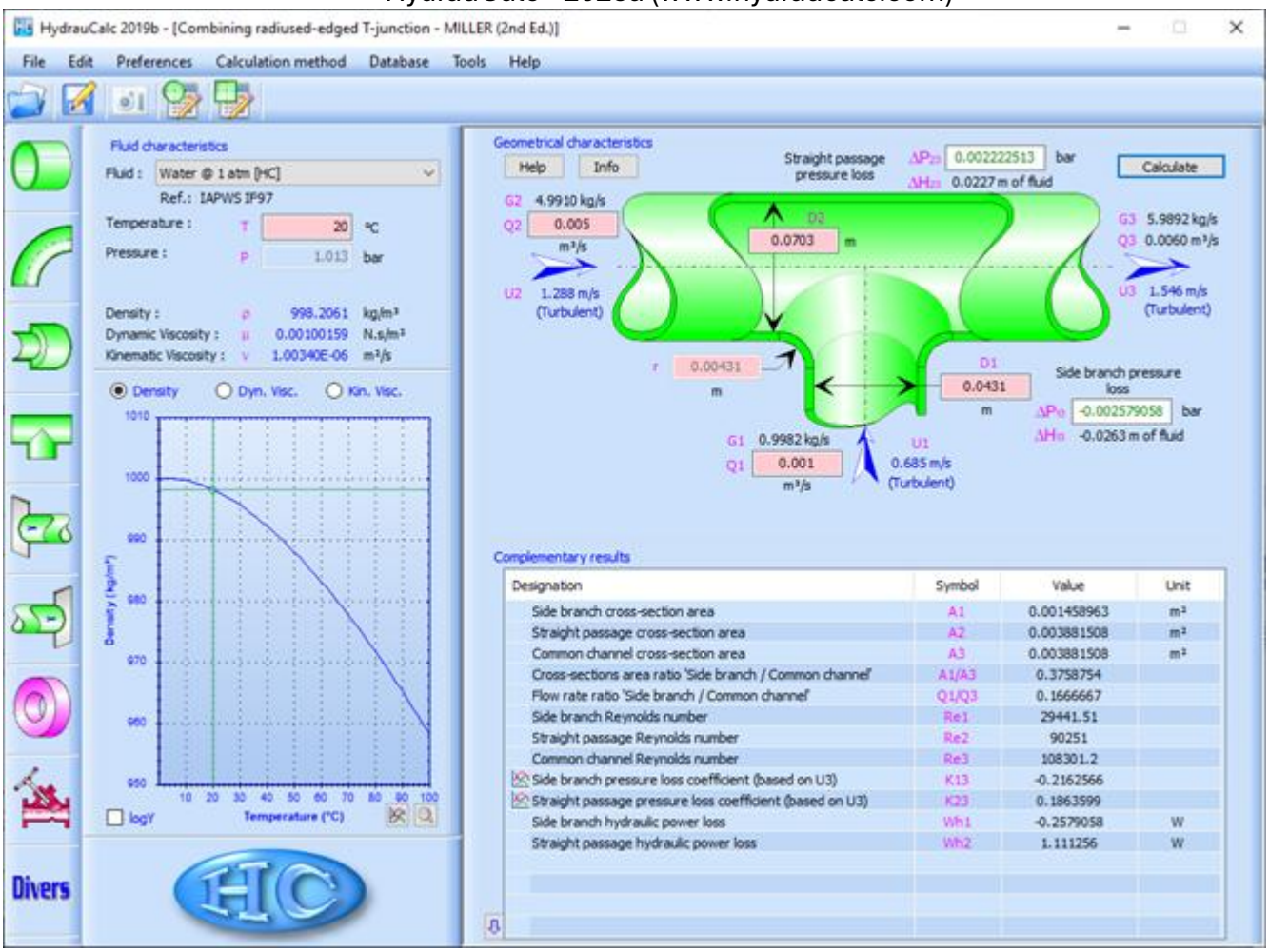
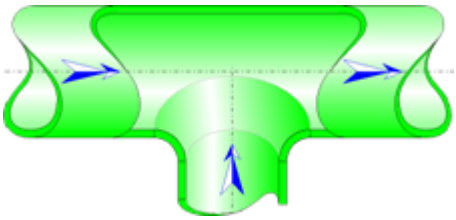
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

2.4.5.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a combining radiused-edged T-junction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the common branch (m^2):

$$A_1 = \pi \cdot \frac{d_2^2}{4}$$

Cross-sectional area of the straight branch (m^2):

$$A_2 = \pi \cdot \frac{d_2^2}{4}$$

Cross-sectional area of the side branch (m^2):

$$A_3 = \pi \cdot \frac{d_3^2}{4}$$

Volume flow rate in the common branch (m^3/s):

$$Q_1 = Q_2 + Q_3$$

Mean velocity in the common branch (m/s):

$$V_1 = \frac{Q_1}{A_1}$$

Mean velocity in the straight branch (m/s):

$$V_2 = \frac{Q_2}{A_2}$$

Mean velocity in the side branch (m/s):

$$V_3 = \frac{Q_3}{A_3}$$

Mass flow rate in the common branch (kg/s):

$$W_1 = Q_1 \cdot \rho_m$$

Mass flow rate in the straight branch (kg/s):

$$W_2 = Q_2 \cdot \rho_m$$

Mass flow rate in the side branch (kg/s):

$$W_3 = Q_3 \cdot \rho_m$$

Reynolds number in the common branch:

$$N\mathrm{Re}_1 = \frac{V_1 \cdot d_2}{\nu}$$

Reynolds number in the straight branch:

$$N\mathrm{Re}_2 = \frac{V_2 \cdot d_2}{\nu}$$

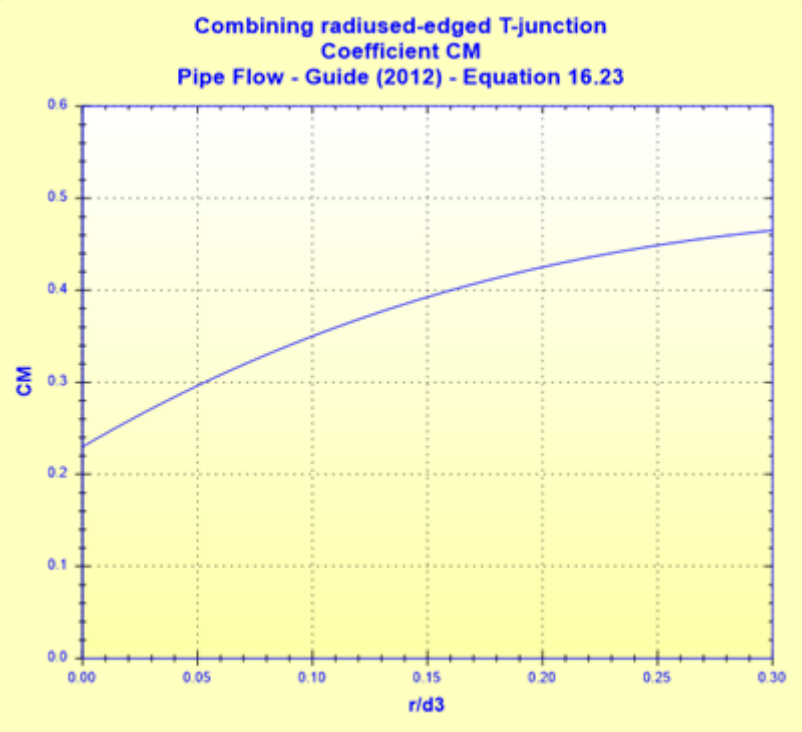
Reynolds number in the side branch:

$$N\mathrm{Re}_3 = \frac{V_3 \cdot d_3}{\nu}$$

Coefficient C_M:

$$C_M = 0.23 + 1.46 \cdot \left(\frac{r}{d_3}\right) - 2.75 \cdot \left(\frac{r}{d_3}\right)^2 + 1.65 \cdot \left(\frac{r}{d_3}\right)^3$$

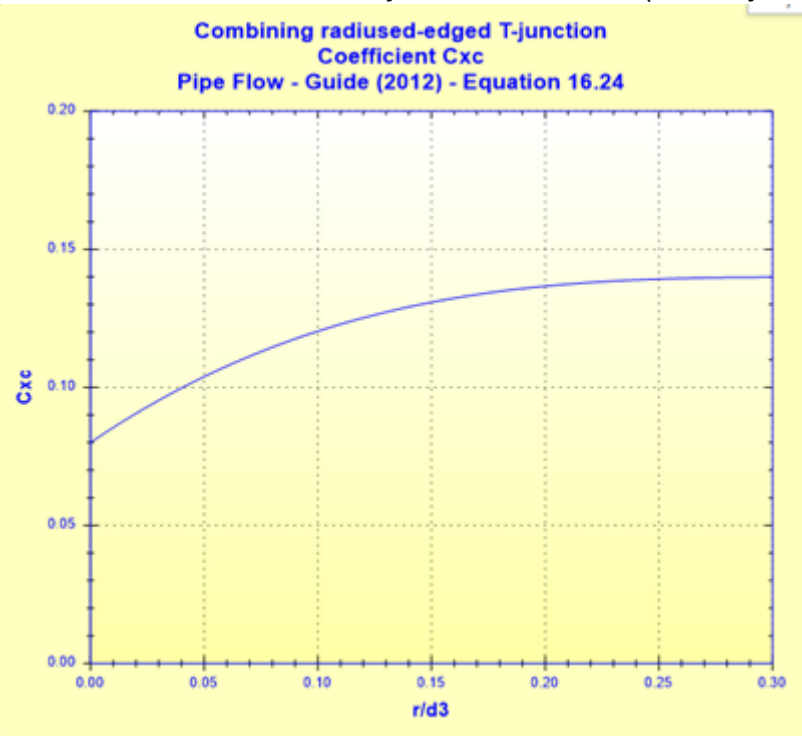
([1] equation 16.23)



Coefficient C_{xC}:

$$C_{xC} = 0.08 + 0.56 \cdot \left(\frac{r}{d_3}\right) - 1.75 \cdot \left(\frac{r}{d_3}\right)^2 + 1.83 \cdot \left(\frac{r}{d_3}\right)^3$$

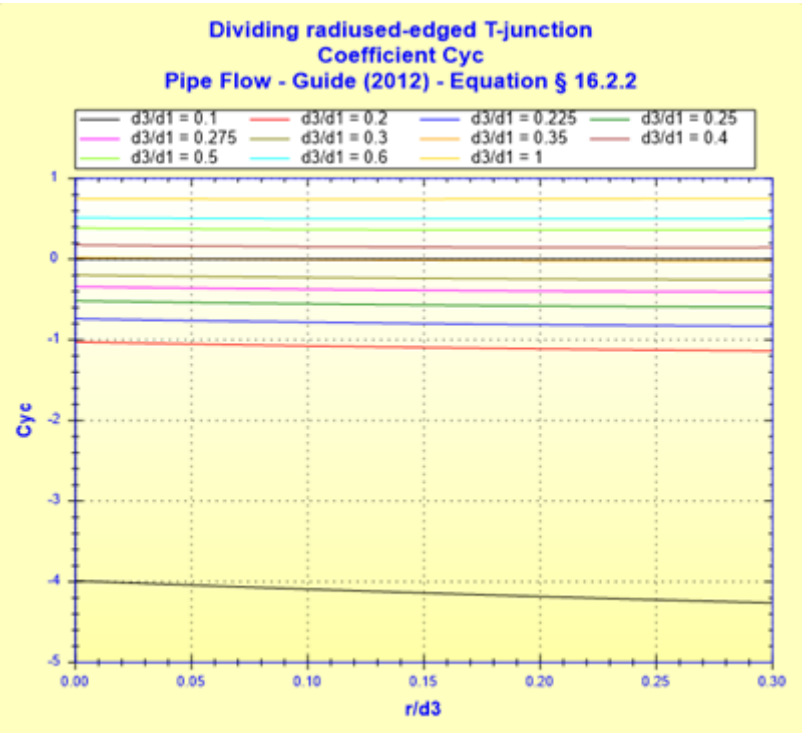
([1] equation 16.24)



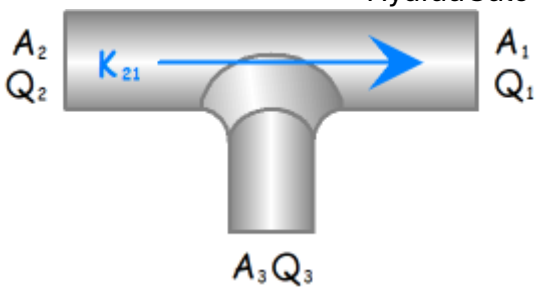
Coefficient C_{yC}:

$$C_{yC} = 1 - 0.25 \cdot \left(\frac{d_3}{d_1}\right)^{1.3} - \left(0.11 \cdot \frac{r}{d_3} - 0.65 \cdot \frac{r^2}{d_3^2} + 0.83 \cdot \frac{r^3}{d_3^3}\right) \cdot \frac{d_3^2}{d_1^2}$$

([1] equation §16.2.2)



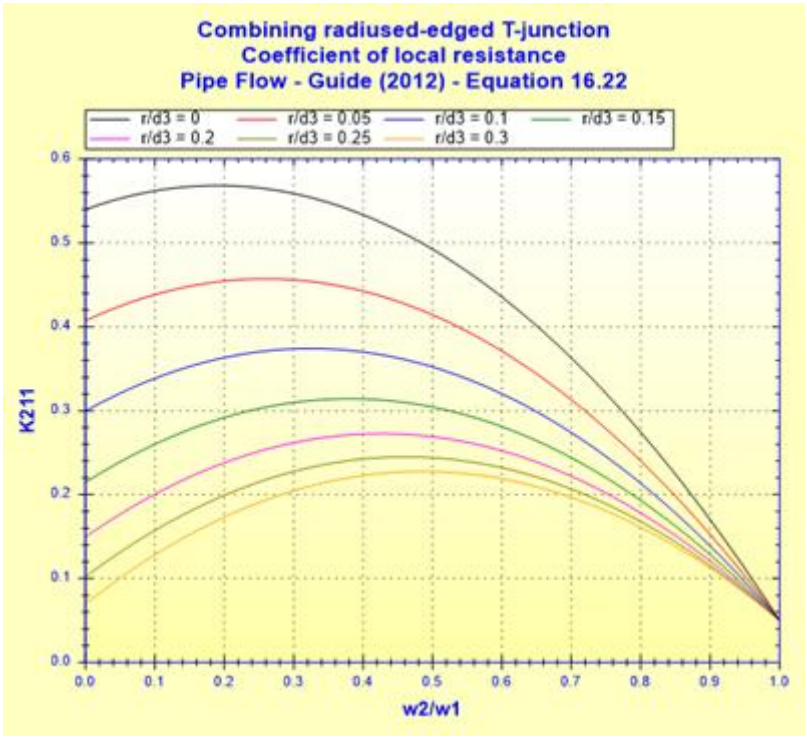
Pressure loss coefficient of the straight branch:



Coefficient based on mean velocity in the common branch:

$$K_{21_1} = 1 - 0.95 \cdot \frac{W_2^2}{W_1^2} - 2 \cdot C_{xC} \cdot \left(\frac{W_2}{W_1} - \frac{W_2^2}{W_1^2} \right) - 2 \cdot C_M \cdot \left(1 - \frac{W_2}{W_1} \right)$$

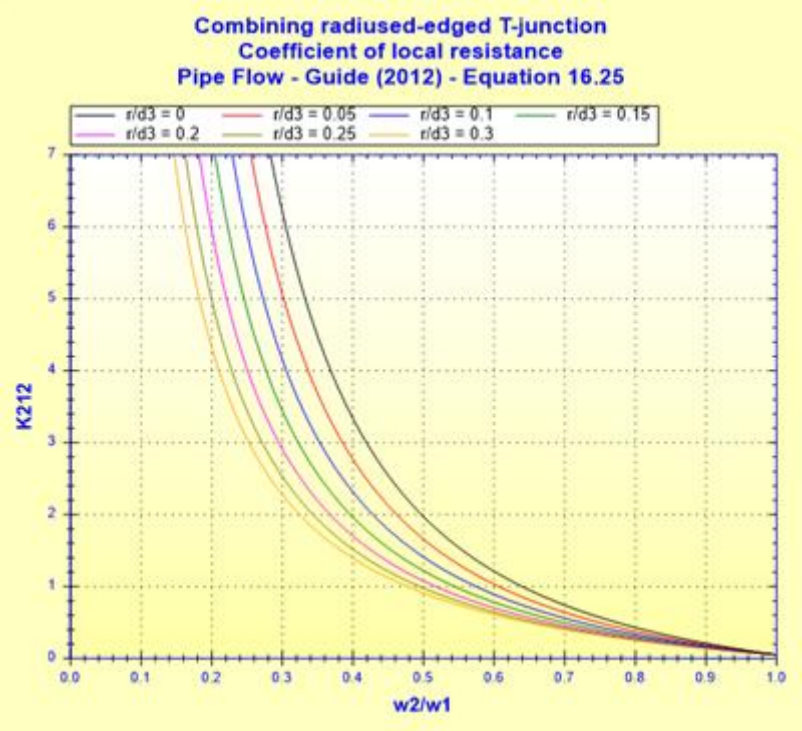
([1] equation 16.22)



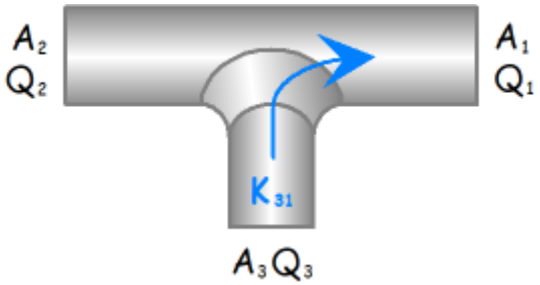
Coefficient based on mean velocity in the straight branch:

$$K_{21_2} = \frac{W_1^2}{W_2^2} - 0.95 - 2 \cdot C_{xC} \cdot \left(\frac{W_1}{W_2} - 1 \right) - 2 \cdot C_M \cdot \left(\frac{W_1^2}{W_2^2} - \frac{W_1}{W_2} \right)$$

([1] equation 16.25)



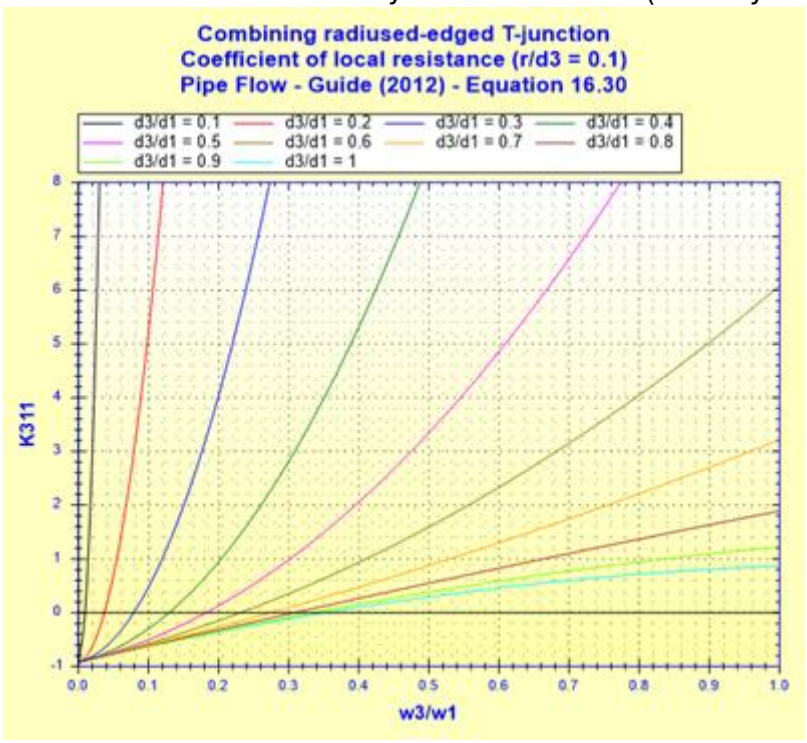
Pressure loss coefficient of the side branch:



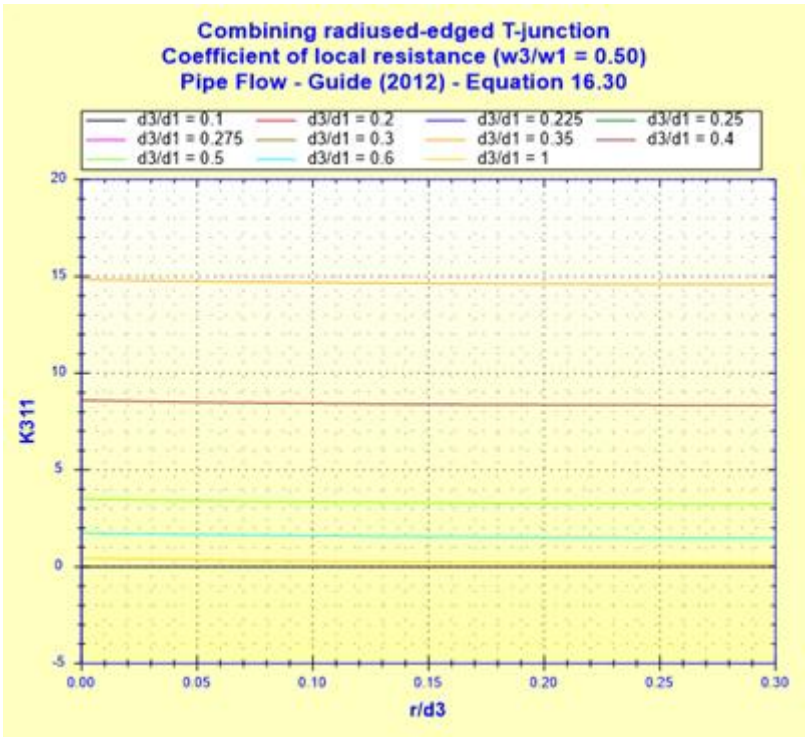
Coefficient based on mean velocity in the common branch:

$$K_{31_1} = -0.92 + 2 \cdot (2 - C_{xC} - C_M) \cdot \frac{W_3}{W_1} + \left[(2 \cdot C_{yC} - 1) \cdot \frac{d_1^4}{d_3^4} + 2 \cdot (C_{xC} - 1) \right] \cdot \frac{W_3^2}{W_1^2}$$

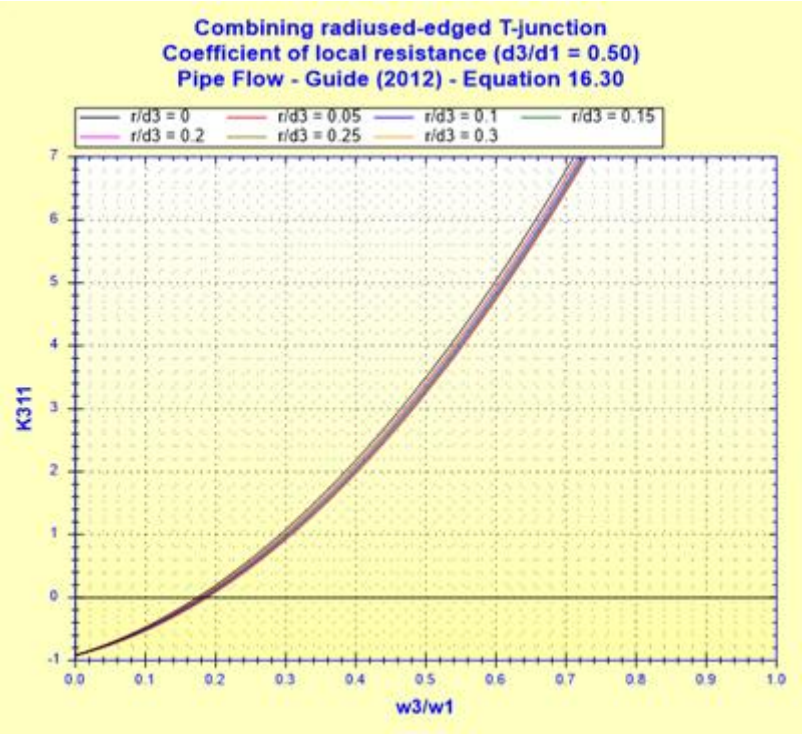
([1] equation 16.30)



([1] Equation 16.30 with r/d3 = 0.1)



([1] Equation 16.30 with w3/w1 = 0.5)

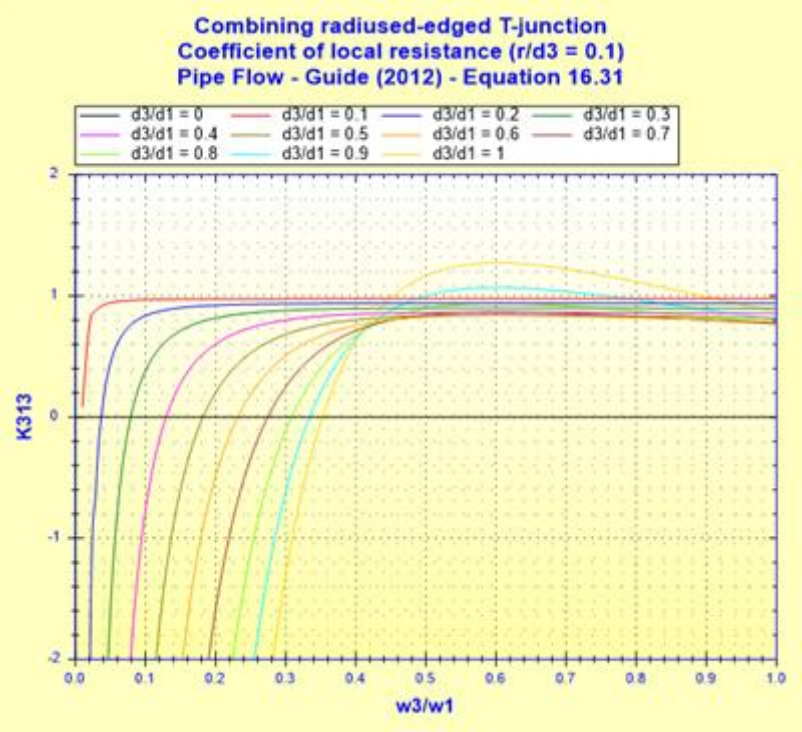


([1] Equation 16.30 with d3/d1 = 0.5)

Coefficient based on mean velocity in the straight branch:

$$K_{31_3} = 2 \cdot C_{yC} - 1 + \frac{d_3^{\,4}}{d_1^{\,4}} \cdot \left[2 \cdot (C_{xC} - 1) + 2 \cdot (2 - C_{xC} - C_M) \cdot \frac{W_1}{W_3} - 0.92 \cdot \frac{W_1^{\,2}}{W_3^{\,2}} \right]$$

([1] equation 16.31)



Pressure loss in the straight branch (Pa):

$$\Delta P_{21} = K_{21_1} \cdot \frac{\rho_m \cdot W_1^2}{2}$$

Pressure loss in the side branch (Pa):

$$\Delta P_{31} = K_{31_1} \cdot \frac{\rho_m \cdot W_1^2}{2}$$

Head loss of fluid in the straight branch (m):

$$\Delta H_{21} = K_{21_1} \cdot \frac{W_1^2}{2 \cdot g}$$

Head loss of fluid in the side branch (m):

$$\Delta H_{31} = K_{31_1} \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss in the straight branch (W):

$$Wh_{21} = \Delta P_{21} \cdot Q_2$$

Hydraulic power loss in the side branch (W):

$$Wh_{31} = \Delta P_{31} \cdot Q_3$$

Symbols, Definitions, SI Units:

d_2	Diameter of the straight and side branches (m)
d_3	Diameter of the side branch (m)
A_1	Cross-sectional area of the common branch (m^2)
A_2	Cross-sectional area of the straight branch (m^2)
A_3	Cross-sectional area of the side branch (m^2)
Q_1	Volume flow rate in the common branch (m^3/s)
V_1	Mean velocity in the common branch (m/s)
Q_2	Volume flow rate in the straight branch (m^3/s)

V_2 Mean velocity in the straight branch (m/s)

Q_3 Volume flow rate in the side branch (m^3/s)

V_3 Mean velocity in the side branch (m/s)

w_1 Mass flow rate in the common branch (kg/s)

w_2 Mass flow rate in the straight branch (kg/s)

w_3 Mass flow rate in the side branch (kg/s)

NRe_1 Reynolds number in the common branch ()

NRe_2 Reynolds number in the straight branch ()

NRe_3 Reynolds number in the side branch ()

r Rounded radius (m)

C_M Coefficient ()

C_{xC} Coefficient ()

C_{yC} Coefficient ()

K_{211} Pressure loss coefficient of the straight branch (based on mean velocity in the common branch) ()

K_{311} Pressure loss coefficient of the side branch (based on mean velocity in the common branch) ()

K_{212} Pressure loss coefficient of the straight branch (based on mean velocity in the straight branch) ()

K_{313} Pressure loss coefficient of the side branch (based on mean velocity in the side branch) ()

ΔP_{21} Pressure loss in the straight branch (Pa)

ΔP_{31} Pressure loss in the side branch (Pa)

ΔH_{21} Head loss of fluid in the straight branch (m)

ΔH_{31} Head loss of fluid in the side branch (m)

Wh_{21} Hydraulic power loss in the straight branch (W)

Wh_{31} Hydraulic power loss in the side branch (W)

ρ_m Fluid density (kg/m³)

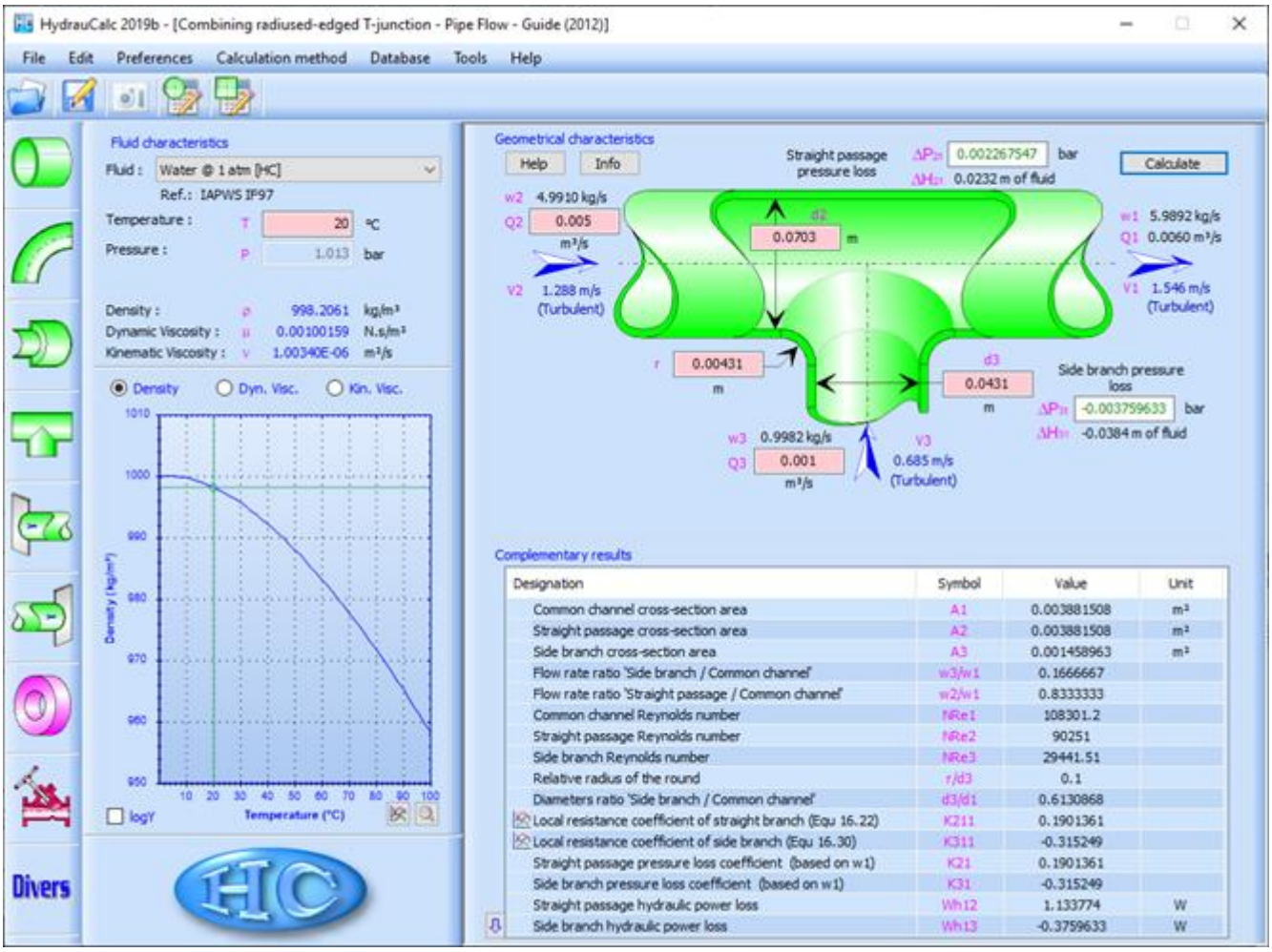
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($NRe_1 \geq 10^4$)
- diameter of common branch lower than or equal to diameter of right and straight branches ($d_3 \leq d_2$)
- rounding ratio lower than or equal to 0.4 ($r/d_3 \leq 0.4$)

Example of application:

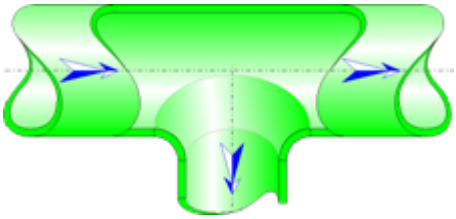


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.4.6 Dividing radiused-edged T-junction

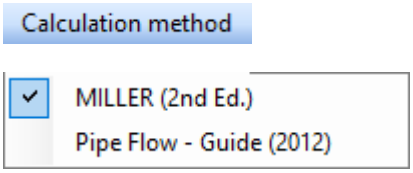
Circular Cross-Section



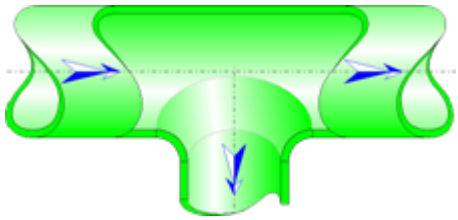
For the calculation of the pressure loss coefficient of dividing radiused-edged T-junctions, the user can choose from one of the methods described in the following two reference documents:

- Internal Flow System, 2nd Edition, D.S. Miller
- Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "MILLER (2nd Ed.)"



2.4.6.1 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a dividing radiused-edged T-junction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the lateral branch (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Cross-sectional area of the common branch and the straight branch (m^2):

$$A_3 = \pi \cdot \frac{D_3^2}{4}$$

Volume flow rate in the common branch (m^3/s):

$$Q_3 = Q_1 + Q_2$$

Mean velocity in the lateral branch (m/s):

$$U_1 = \frac{Q_1}{A_1}$$

Mean velocity in the straight branch (m/s):

$$U_2 = \frac{Q_2}{A_3}$$

Mean velocity in the common branch (m/s):

$$U_3 = \frac{Q_3}{A_3}$$

Mass flow rate in the lateral branch (kg/s):

$$G_1 = Q_1 \cdot \rho$$

Mass flow rate in the straight branch (kg/s):

$$G_2 = Q_2 \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_3 = Q_3 \cdot \rho$$

Reynolds number in the lateral branch:

$$\mathrm{Re}_1 = \frac{U_1 \cdot D_1}{\nu}$$

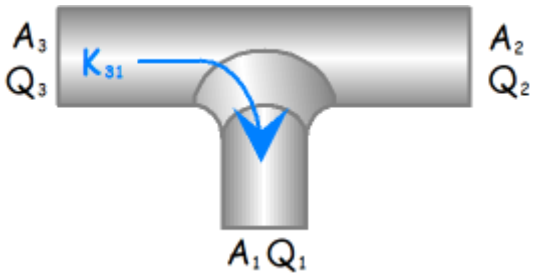
Reynolds number in the straight branch:

$$\mathrm{Re}_2 = \frac{U_2 \cdot D_3}{\nu}$$

Reynolds number in the common branch:

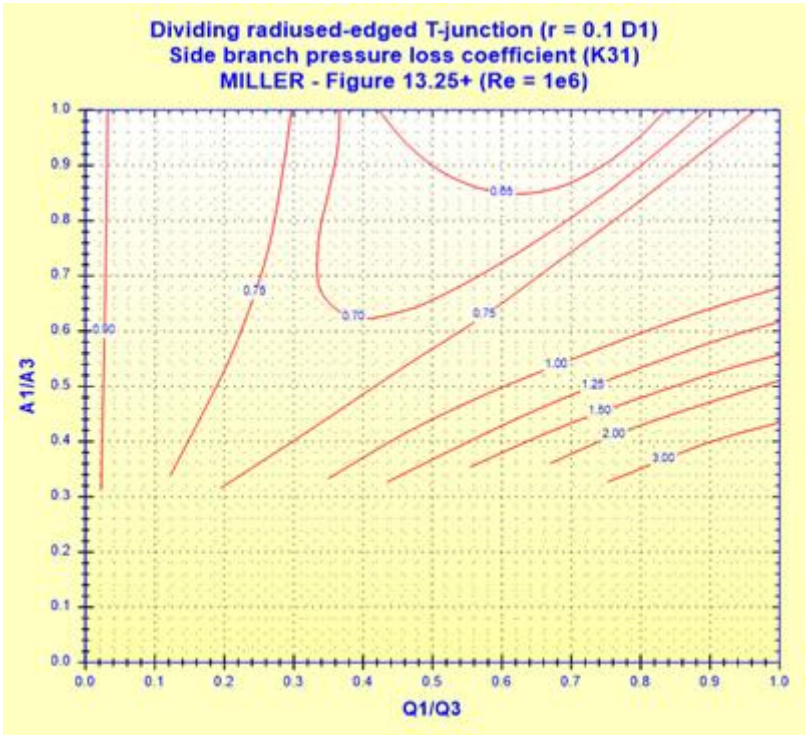
$$\mathrm{Re}_3 = \frac{U_3 \cdot D_3}{\nu}$$

Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch):

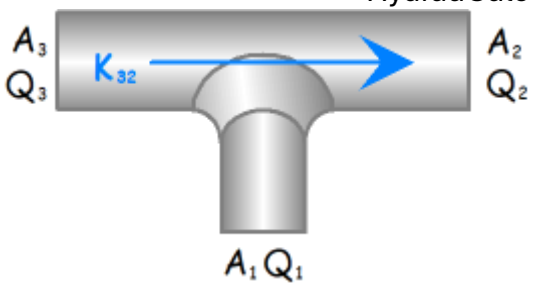


$$K_{31} = f\left(\frac{Q_1}{Q_3}, \frac{A_1}{A_3}\right)$$

([1] figure 13.25+)

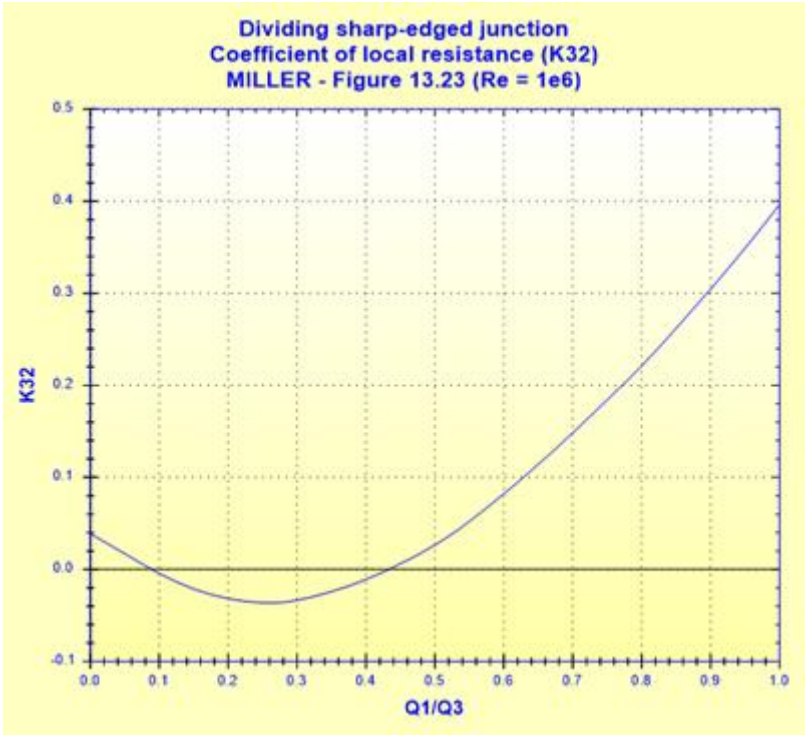


Pressure loss coefficient of the straight branch (based on mean velocity in the common branch):



$$K_{32} = f\left(\frac{Q_1}{Q_3}\right)$$

([1] figure 13.23)



Pressure loss in the lateral branch (Pa):

$$\Delta P_{31} = K_{31} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.3)

Pressure loss in the straight branch (Pa):

$$\Delta P_{32} = K_{32} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.4)

Head loss of fluid in the lateral branch (m):

$$\Delta H_{31} = K_{31} \cdot \frac{U_3^2}{2 \cdot g}$$

Head loss of fluid in the straight branch (m):

$$\Delta H_{32} = K_{32} \cdot \frac{U_3^2}{2 \cdot g}$$

Hydraulic power loss in the lateral branch (W):

$$Wh_{31} = \Delta P_{31} \cdot Q_1$$

Hydraulic power loss in the straight branch (W):

$$Wh_{32} = \Delta P_{32} \cdot Q_2$$

Symbols, Definitions, SI Units:

D_1	Diameter of the lateral branch (m)
D_3	Diameter of the common branch and the straight branch (m)
A_1	Cross-sectional area of the lateral branch (m^2)
A_3	Cross-sectional area of the common branch and the straight branch (m^2)
Q_1	Volume flow rate in the lateral branch (m^3/s)
U_1	Mean velocity in the lateral branch (m/s)
Q_2	Volume flow rate in the straight branch (m^3/s)
U_2	Mean velocity in the straight branch (m/s)
Q_3	Volume flow rate in the common branch (m^3/s)
U_3	Mean velocity in the common branch (m/s)
G_1	Mass flow rate in the lateral branch (kg/s)
G_2	Mass flow rate in the straight branch (kg/s)
G_3	Mass flow rate in the common branch (kg/s)
Re_1	Reynolds number in the lateral branch ()
Re_2	Reynolds number in the straight branch ()

Re_3 Reynolds number in the common branch ()

r Rounded radius (m)

K_{31} Pressure loss coefficient of the lateral branch (based on mean velocity in the common branch) ()

K_{32} Pressure loss coefficient of the straight branch (based on mean velocity in the common branch) ()

ΔP_{31} Pressure loss in the lateral branch (Pa)

ΔP_{32} Pressure loss in the straight branch (Pa)

ΔH_{31} Head loss of fluid in the lateral branch (m)

ΔH_{32} Head loss of fluid in the straight branch (m)

Wh_{31} Hydraulic power loss in the lateral branch (W)

Wh_{32} Hydraulic power loss in the straight branch (W)

ρ Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re_3 \geq 10^5$)
- rounded radius equal to 0.1 diameter of the lateral branch ($r = 0.1\ D_1$)
- cross-sections area ratio equal to or greater than 0.3 ($A_1/A_3 \geq 0.3$)

  note: for cross-sections area ratios lower than 0.3 the pressure loss coefficients "K_{31}" is extrapolated

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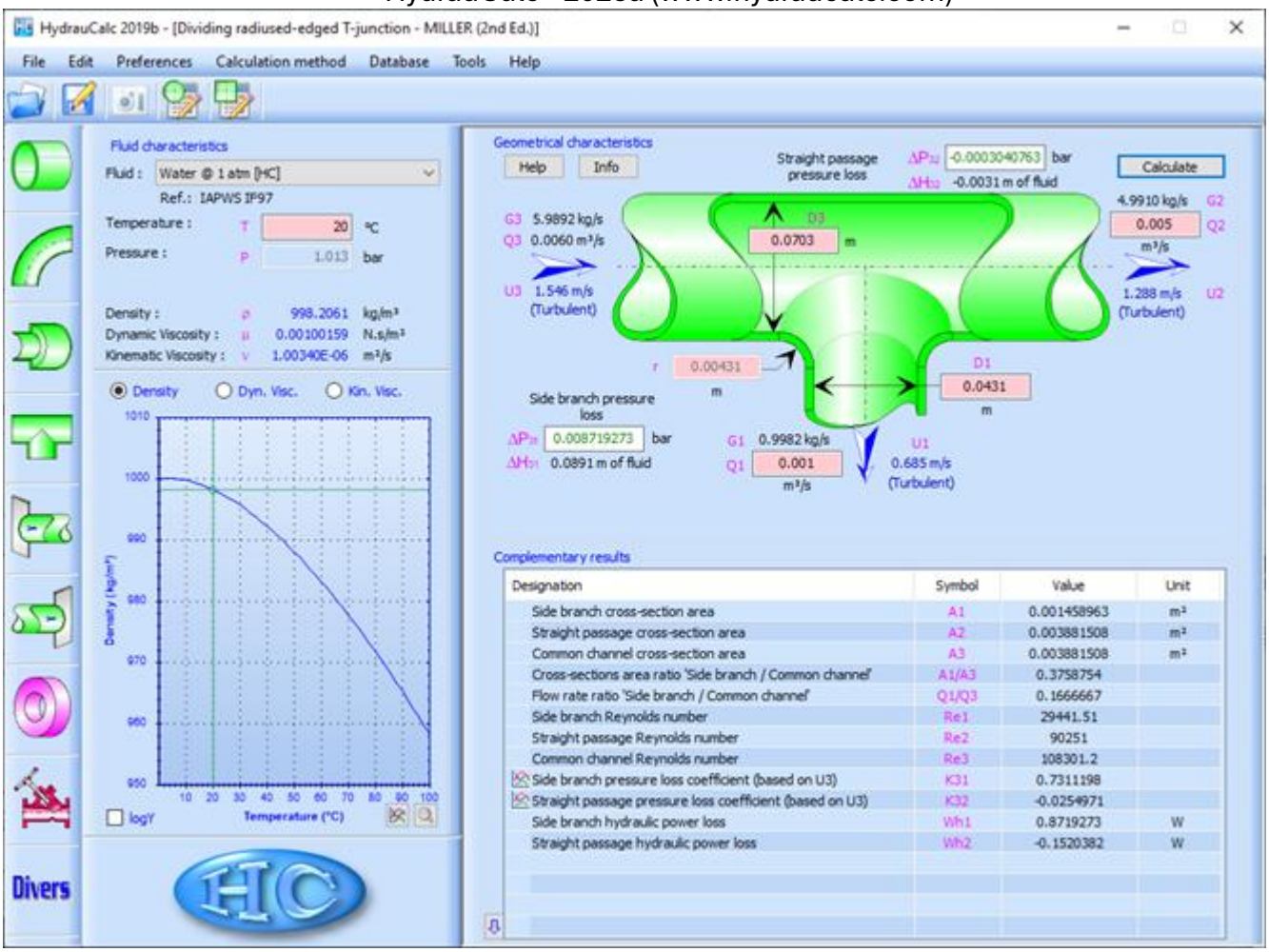
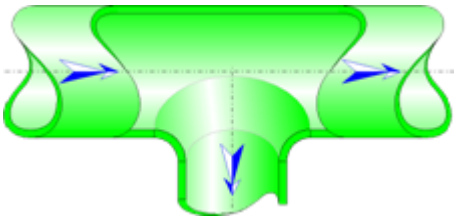
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

2.4.6.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a dividing radiused-edged T-junction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the common branch (m^2):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Cross-sectional area of the straight branch (m^2):

$$A_2 = \pi \cdot \frac{d_1^2}{4}$$

Cross-sectional area of the side branch (m^2):

$$A_3 = \pi \cdot \frac{d_3^2}{4}$$

Volume flow rate in the common branch (m^3/s):

$$Q_1 = Q_2 + Q_3$$

Mean velocity in the common branch (m/s):

$$V_1 = \frac{Q_1}{A_1}$$

Mean velocity in the straight branch (m/s):

$$V_2 = \frac{Q_2}{A_2}$$

Mean velocity in the side branch (m/s):

$$V_3 = \frac{Q_3}{A_3}$$

Mass flow rate in the common branch (kg/s):

$$W_1 = Q_1 \cdot \rho_m$$

Mass flow rate in the straight branch (kg/s):

$$W_2 = Q_2 \cdot \rho_m$$

Mass flow rate in the side branch (kg/s):

$$W_3 = Q_3 \cdot \rho_m$$

Reynolds number in the common branch:

$$N\mathrm{Re}_1 = \frac{V_1 \cdot d_1}{\nu}$$

Reynolds number in the straight branch:

$$NRe_2 = \frac{V_2 \cdot d_1}{\nu}$$

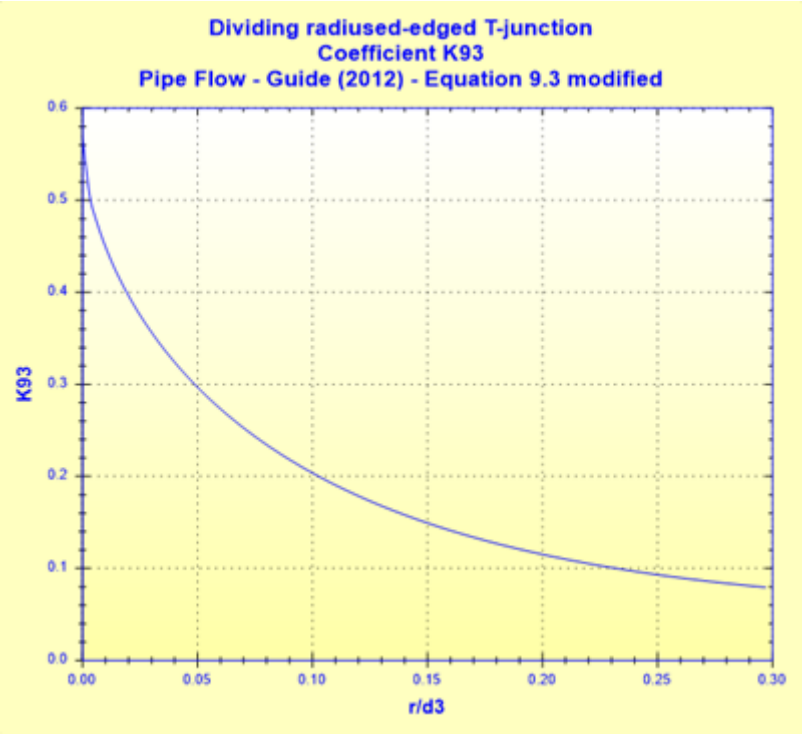
Reynolds number in the side branch:

$$NRe_3 = \frac{V_3 \cdot d_3}{\nu}$$

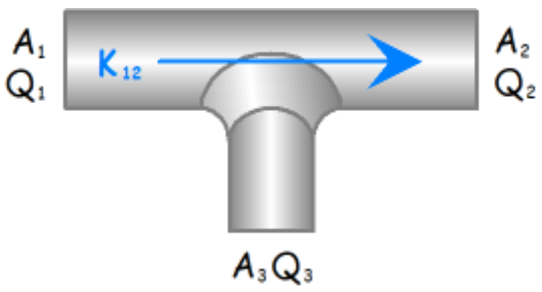
Coefficient K93:

$$K_{93} = 0.57 - 1.07 \cdot \left(\frac{r}{d_3}\right)^{1/2} - 2.13 \cdot \left(\frac{r}{d_3}\right) + 8.24 \cdot \left(\frac{r}{d_3}\right)^{3/2} - 8.48 \cdot \left(\frac{r}{d_3}\right)^{2} + 2.9 \cdot \left(\frac{r}{d_3}\right)^{5/2}$$

([1] equation §16.1.2)



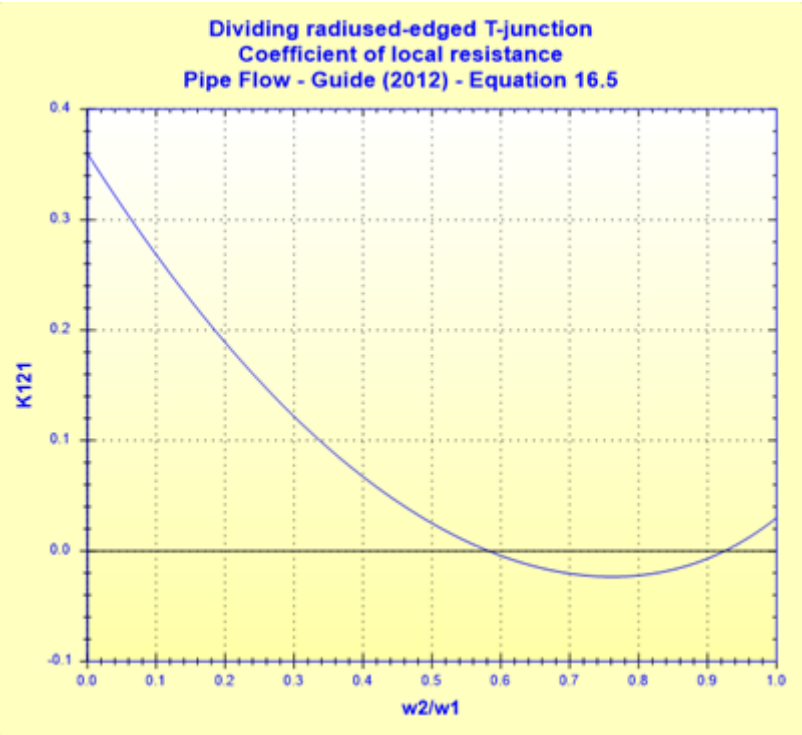
Pressure loss coefficient of the straight branch:



Coefficient based on mean velocity in the common branch:

$$K_{12_1} = 0.36 - 0.98 \cdot \frac{W_2}{W_1} + 0.62 \cdot \frac{W_2^2}{W_1^2} + 0.03 \cdot \frac{W_2^8}{W_1^8}$$

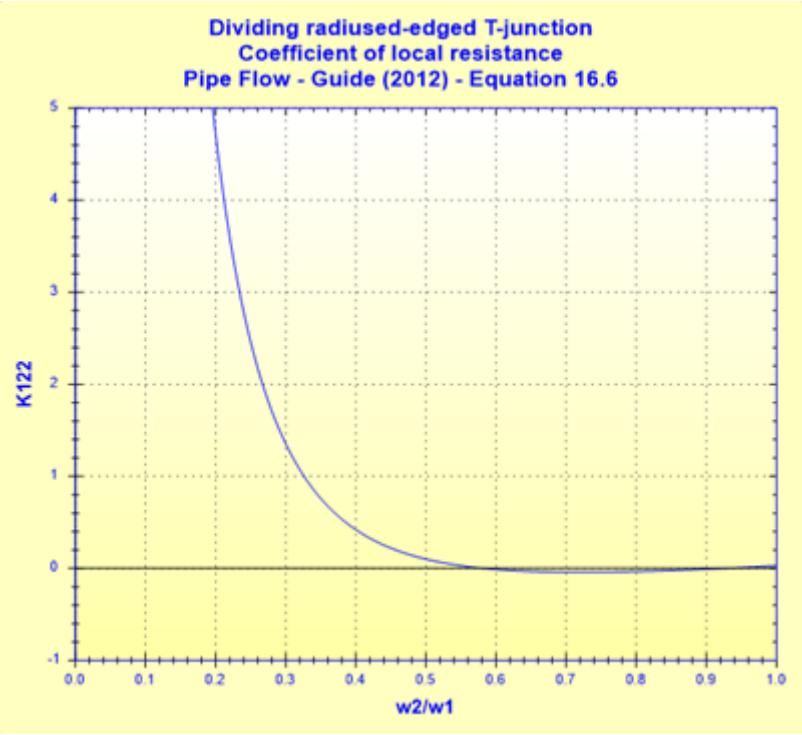
([1] equation 16.5)



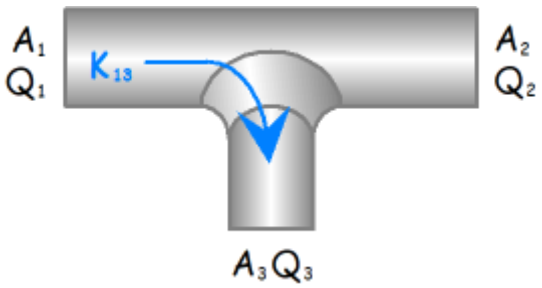
Coefficient based on mean velocity in the straight branch:

$$K_{12_2} = 0.62 - 0.98 \cdot \frac{W_1}{W_2} + 0.36 \cdot \frac{W_1^2}{W_2^2} + 0.03 \cdot \frac{W_2^6}{W_1^6}$$

([1] equation 16.6)



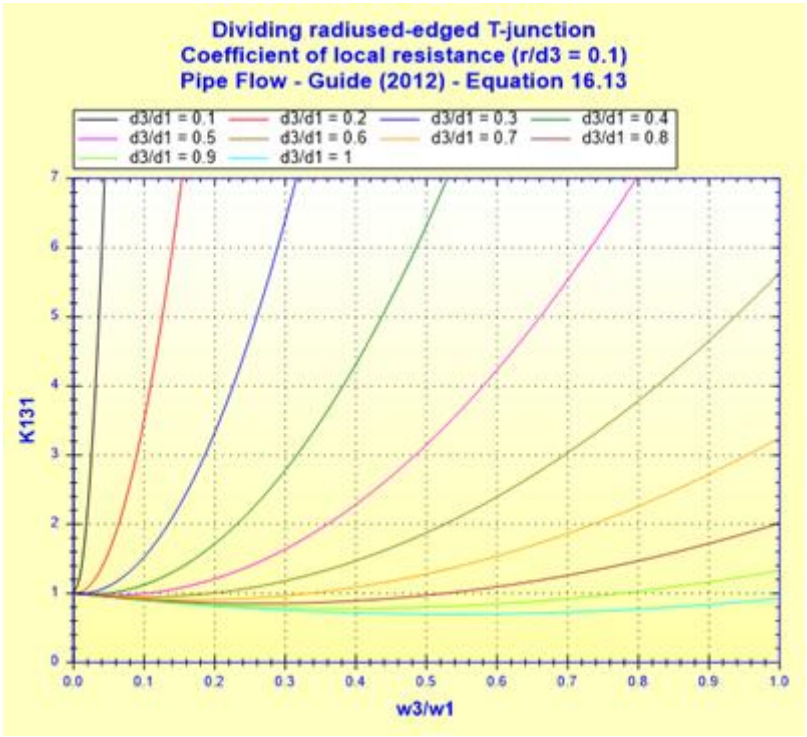
Pressure loss coefficient of the side branch:



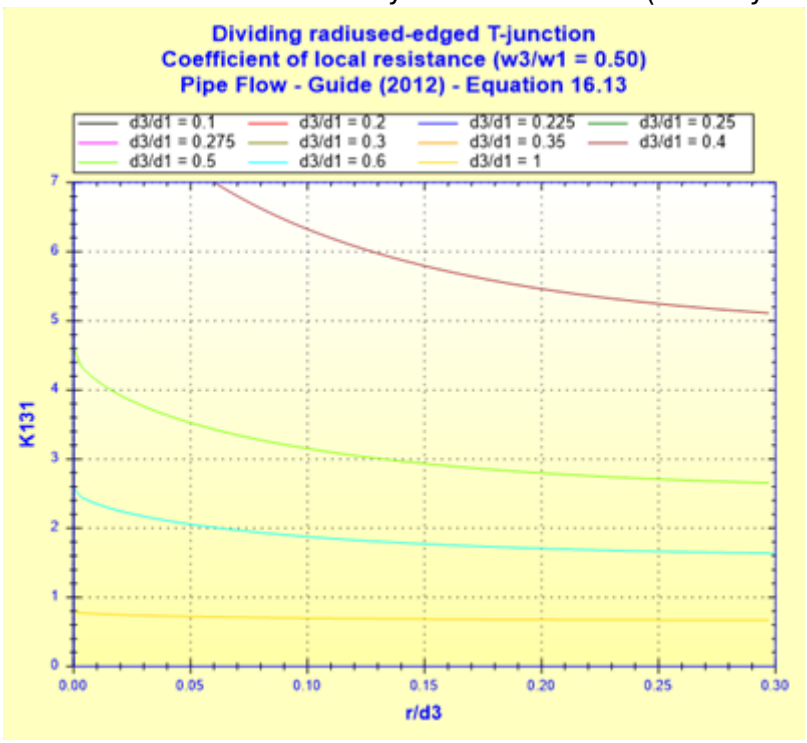
Coefficient based on mean velocity in the common branch:

$$K_{13_1} = 1 - 1.13 \cdot \frac{W_3}{W_1} + \left[0.81 + \left(1.12 \cdot \frac{d_3}{d_1} - 1.08 \cdot \frac{d_3^3}{d_1^3} + K_{93} \right) \cdot \frac{d_1^4}{d_3^4} \right] \cdot \frac{W_3^2}{W_1^2}$$

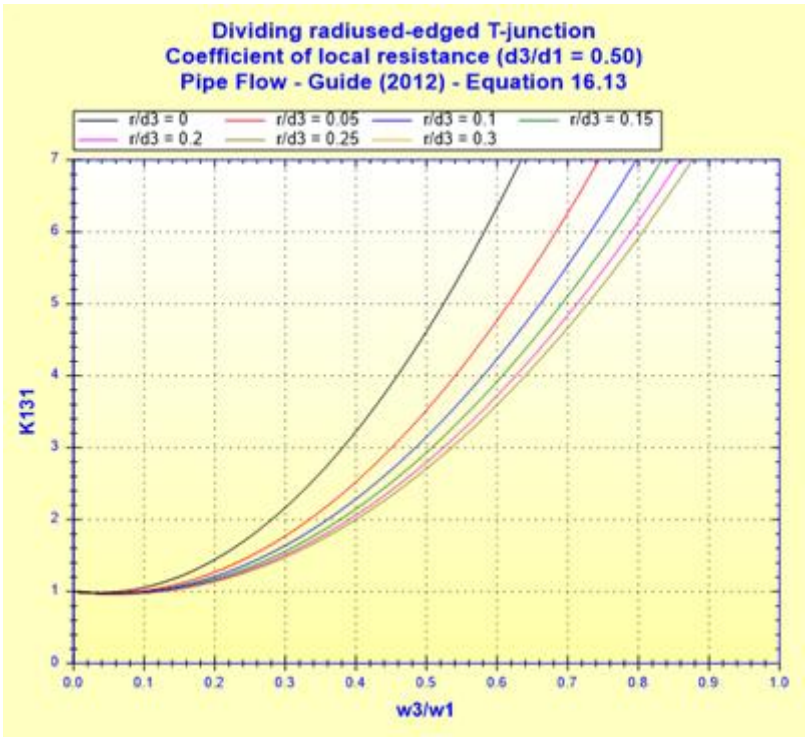
([1] equation 16.13)



([1] equation 16.13 with $r/d_3 = 0.1$)



([1] equation 16.13 with w_3/w_1 = 0.5)

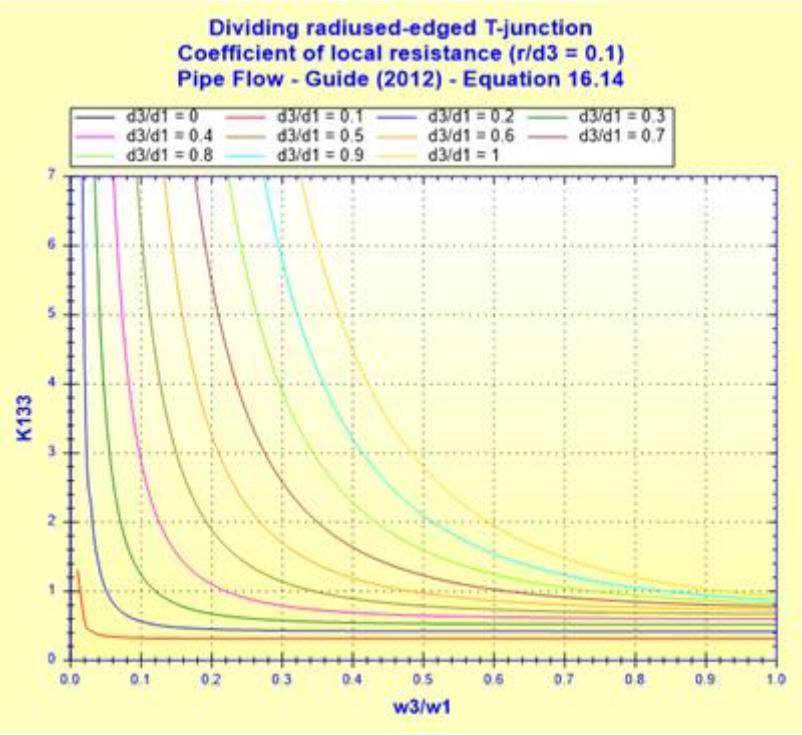


([1] equation 16.13 with d_3/d_1 = 0.5)

Coefficient based on mean velocity in the straight branch:

$$K_{13_3} = \left(0.81 - 1.13 \cdot \frac{W_1}{W_3} + \frac{W_1^2}{W_3^2}\right) \cdot \frac{d_3^4}{d_1^4} + 1.12 \cdot \frac{d_3}{d_1} - 1.08 \cdot \frac{d_3^3}{d_1^3} + K_{93}$$

([1] equation 16.14)



([1] equation 16.14 with $r/d_3 = 0.1$)

Pressure loss in the straight branch (Pa):

$$\Delta P_{12} = K_{12_1} \cdot \frac{\rho_m \cdot W_1^2}{2}$$

Pressure loss in the side branch (Pa):

$$\Delta P_{13} = K_{13_1} \cdot \frac{\rho_m \cdot W_1^2}{2}$$

Head loss of fluid in the straight branch (m):

$$\Delta H_{12} = K_{12_1} \cdot \frac{W_1^2}{2 \cdot g}$$

Head loss of fluid in the side branch (m):

$$\Delta H_{13} = K_{13_1} \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss in the straight branch (W):

$$Wh_{12} = \Delta P_{12} \cdot Q_2$$

Hydraulic power loss in the side branch (W):

$$Wh_{13} = \Delta P_{13} \cdot Q_3$$

Symbols, Definitions, SI Units:

d_1	Diameter of the straight and common branches (m)
d_3	Diameter of the side branch (m)
A_1	Cross-sectional area of the common branch (m^2)
A_2	Cross-sectional area of the straight branch (m^2)
A_3	Cross-sectional area of the side branch (m^2)
Q_1	Volume flow rate in the common branch (m^3/s)
V_1	Mean velocity in the common branch (m/s)
Q_2	Volume flow rate in the straight branch (m^3/s)
V_2	Mean velocity in the straight branch (m/s)
Q_3	Volume flow rate in the side branch (m^3/s)
V_3	Mean velocity in the side branch (m/s)
w_1	Mass flow rate in the common branch (kg/s)
w_2	Mass flow rate in the straight branch (kg/s)
w_3	Mass flow rate in the side branch (kg/s)
NRe_1	Reynolds number in the common branch ()
NRe_2	Reynolds number in the straight branch ()
NRe_3	Reynolds number in the side branch ()
r	Rounded radius (m)
K_{93}	Coefficient ()
K_{121}	Pressure loss coefficient of the straight branch (based on mean velocity in the common branch) ()
K_{131}	Pressure loss coefficient of the side branch (based on mean velocity in the common branch) ()

K_{122} Pressure loss coefficient of the straight branch (based on mean velocity in the straight branch) ()

K_{133} Pressure loss coefficient of the side branch (based on mean velocity in the side branch) ()

ΔP_{12} Pressure loss in the straight branch (Pa)

ΔP_{13} Pressure loss in the side branch (Pa)

ΔH_{12} Head loss of fluid in the straight branch (m)

ΔH_{13} Head loss of fluid in the side branch (m)

Wh_{12} Hydraulic power loss in the straight branch (W)

Wh_{13} Hydraulic power loss in the side branch (W)

ρ_m Fluid density (kg/m³)

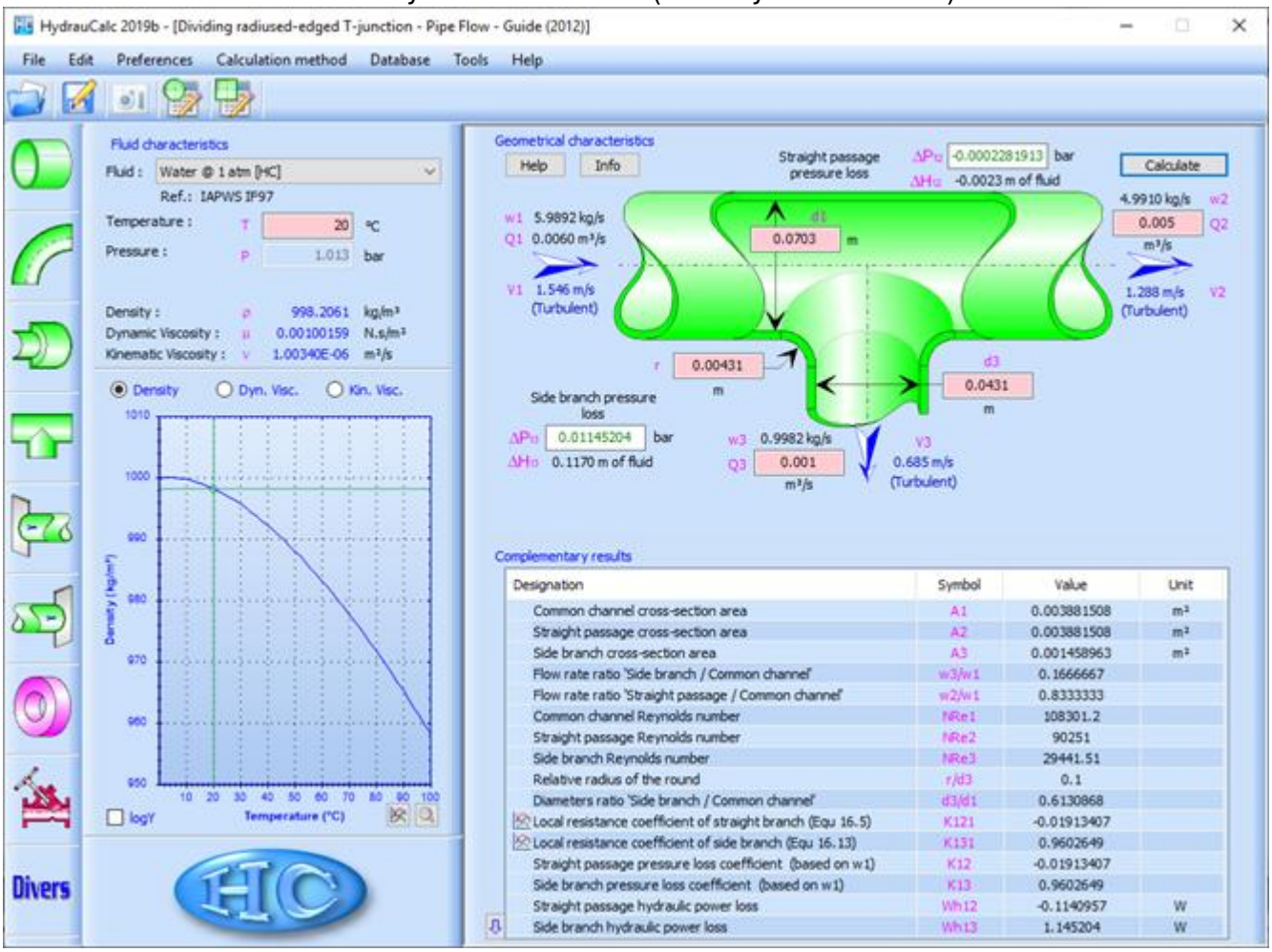
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($NRe_1 \geq 10^4$)
- diameter of side branch lower than or equal to diameter of straight and common branches ($d_3 \leq d_1$)
- rounding ratio lower than or equal to 1 ($r/d_3 \leq 1$)

Example of application:

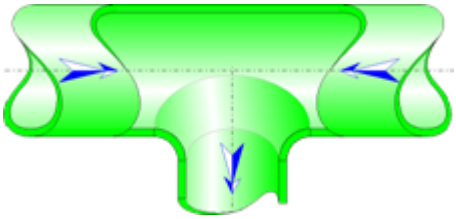


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.4.7 Symmetric combining radiused-edged T-junction

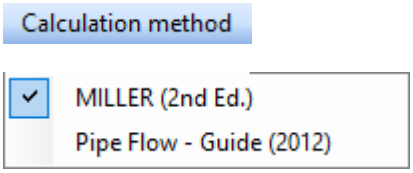
Circular Cross-Section



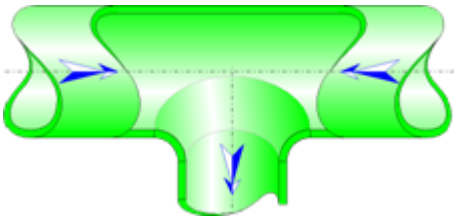
For the calculation of the pressure loss coefficient of symmetric combining radiused-edged T-junctions, the user can choose from one of the methods described in the following two reference documents:

- Internal Flow System, 2nd Edition, D.S. Miller
- Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "MILLER (2nd Ed.)"



2.4.7.1 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric combining radiused-edged T-junction with three legs of equal area.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the three branches (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

$$A_3 = \pi \cdot \frac{D_3^2}{4}$$

with $D_1 = D_2 = D_3 = D$

Volume flow rate in the common branch (m^3/s):

$$Q_3 = Q_1 + Q_2$$

Mean velocity in the left branch (m/s):

$$U_1 = \frac{Q_1}{A_1}$$

Mean velocity in the right branch (m/s):

$$U_2 = \frac{Q_2}{A_2}$$

Mean velocity in the common branch (m/s):

$$U_3 = \frac{Q_3}{A_3}$$

Mass flow rate in the left branch (kg/s):

$$G_1 = Q_1 \cdot \rho$$

Mass flow rate in the right branch (kg/s):

$$G_2 = Q_2 \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_3 = Q_3 \cdot \rho$$

Reynolds number in the left branch:

$$\mathrm{Re}_1 = \frac{U_1 \cdot D_1}{\nu}$$

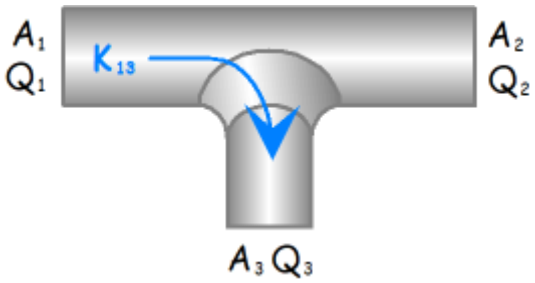
Reynolds number in the right branch:

$$\mathrm{Re}_2 = \frac{U_2 \cdot D_2}{\nu}$$

Reynolds number in the common branch:

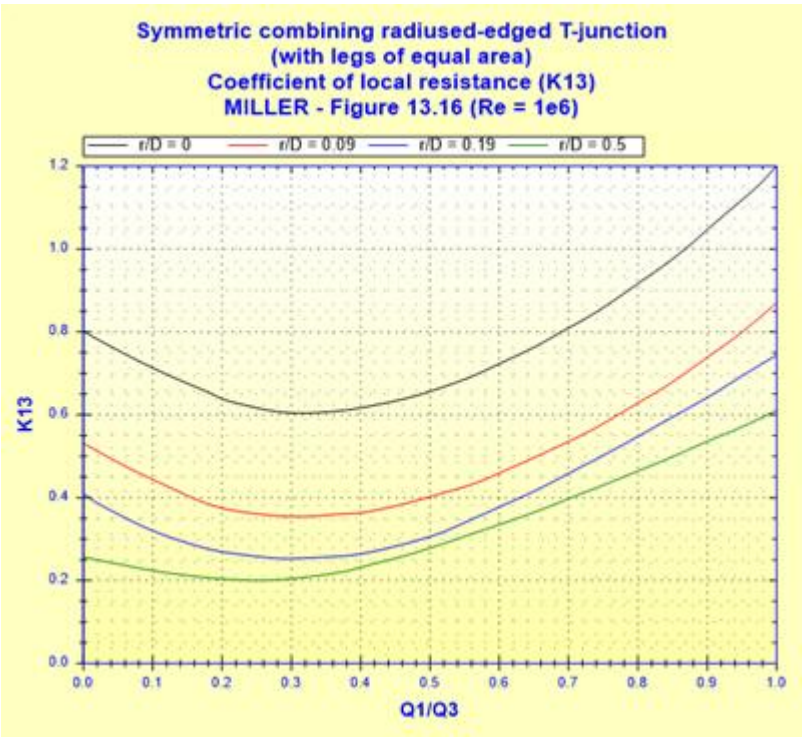
$$Re_3 = \frac{U_3 \cdot D_3}{\nu}$$

Pressure loss coefficient of the left branch (based on mean velocity in the common branch):

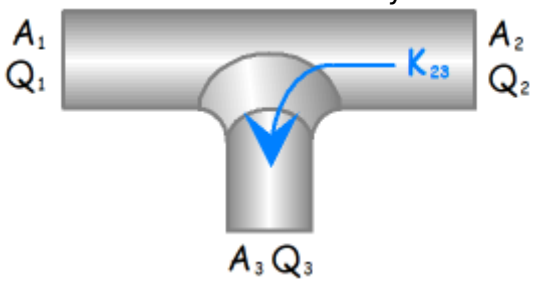


$$K_{13} = f\left(\frac{Q_1}{Q_3}, \frac{r}{D}\right)$$

([1] figure 13.16)

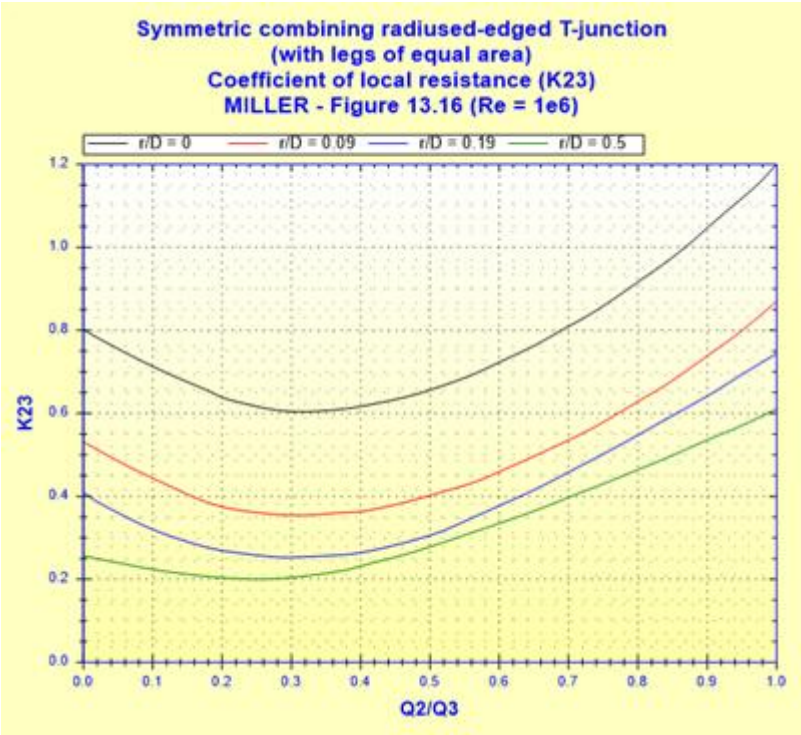


Pressure loss coefficient of the right branch (based on mean velocity in the common branch):



$$K_{23} = f\left(\frac{Q_2}{Q_3}, \frac{r}{D}\right)$$

([1] figure 13.16)



Pressure loss in the left branch (Pa):

$$\Delta P_{13} = K_{13} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.1)

Pressure loss in the right branch (Pa):

$$\Delta P_{23} = K_{23} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.2)

Head loss of fluid in the left branch (m):

$$\Delta H_{13} = K_{13} \cdot \frac{U_3^2}{2 \cdot g}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{23} = K_{23} \cdot \frac{U_3^2}{2 \cdot g}$$

Hydraulic power loss in the left branch (W):

$$Wh_{13} = \Delta P_{13} \cdot Q_1$$

Hydraulic power loss in the right branch (W):

$$Wh_{23} = \Delta P_{23} \cdot Q_2$$

Symbols, Definitions, SI Units:

D	Inside diameter of the three branches (m)
D_1	Diameter of the left branch (m)
D_2	Diameter of the right branch (m)
D_3	Diameter of the common branch (m)
A_1	Cross-sectional area of the left branch (m^2)
A_2	Cross-sectional area of the right branch (m^2)
A_3	Cross-sectional area of the common branch (m^2)
Q_1	Volume flow rate in the left branch (m^3/s)
U_1	Mean velocity in the left branch (m/s)
Q_2	Volume flow rate in the right branch (m^3/s)
U_2	Mean velocity in the right branch (m/s)
Q_3	Volume flow rate in the common branch (m^3/s)
U_3	Mean velocity in the common branch (m/s)
G_1	Mass flow rate in the left branch (kg/s)
G_2	Mass flow rate in the right branch (kg/s)
G_3	Mass flow rate in the common branch (kg/s)

Re_1 Reynolds number in the left branch ()

Re_2 Reynolds number in the right branch ()

Re_3 Reynolds number in the common branch ()

r Rounded radius (m)

K_{13} Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

K_{23} Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

ΔP_{13} Pressure loss in the left branch (Pa)

ΔP_{23} Pressure loss in the right branch (Pa)

ΔH_{13} Head loss of fluid in the left branch (m)

ΔH_{23} Head loss of fluid in the right branch (m)

Wh_{13} Hydraulic power loss in the left branch (W)

Wh_{23} Hydraulic power loss in the right branch (W)

ρ Fluid density (kg/m^3)

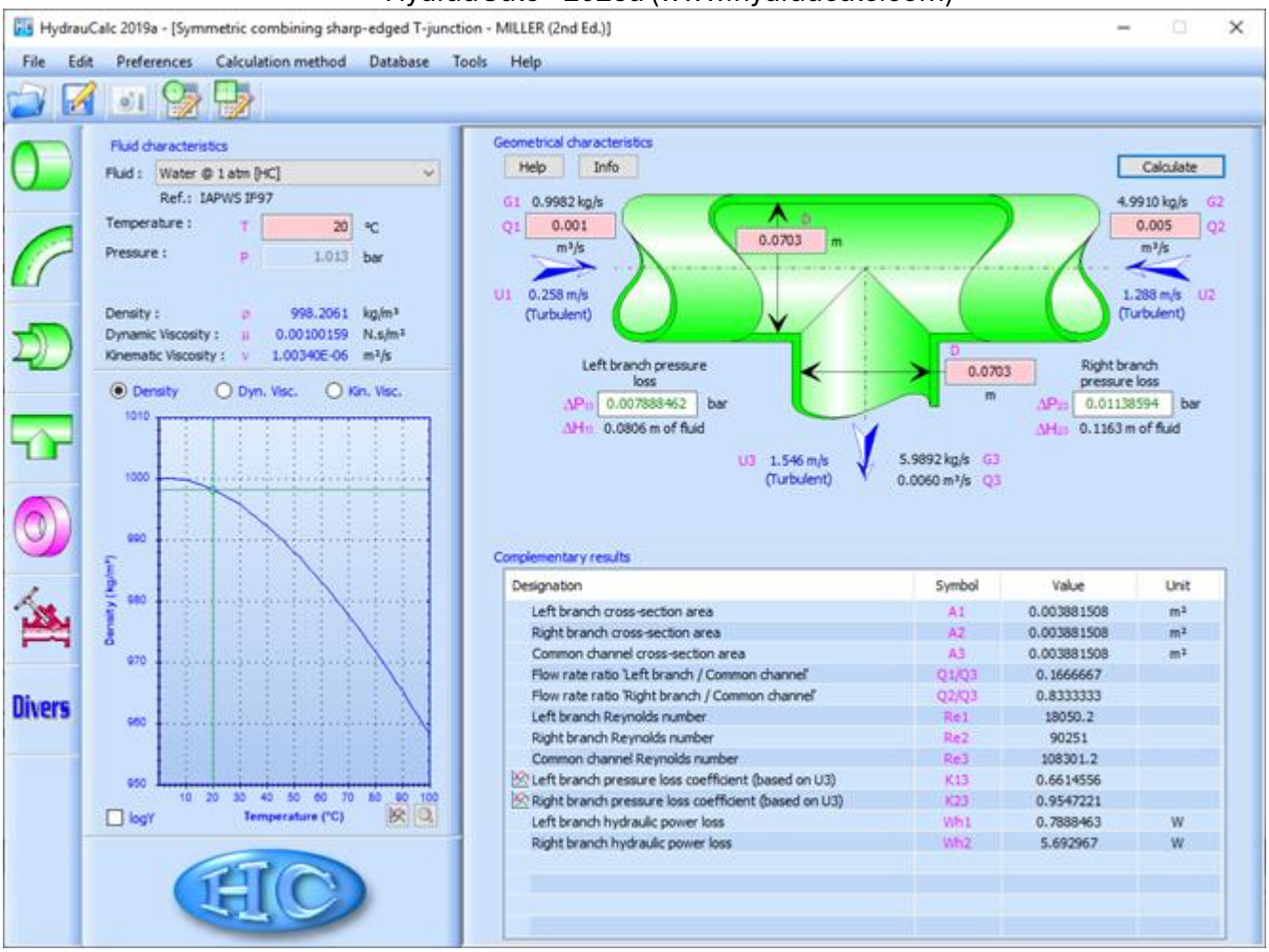
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re_3 \geq 10^5$)
- three legs of equal area ($D_1 = D_2 = D_3$)
- relative radius of the round (r/D) lower than or equal to 0.5D

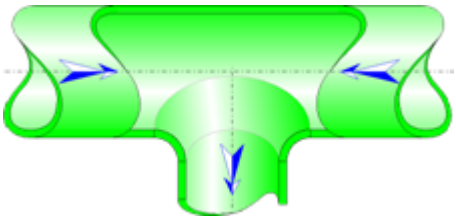
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

2.4.7.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric combining radiused-edged T-junction with three legs of equal area.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the three branches (m^2):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

$$A_2 = \pi \cdot \frac{d_2^2}{4}$$

$$A_3 = \pi \cdot \frac{d_3^2}{4}$$

with $d_1 = d_2 = d_3 = d$

Volume flow rate in the common branch (m^3/s):

$$Q_1 = Q_2 + Q_3$$

Mean velocity in the common branch (m/s):

$$V_1 = \frac{Q_1}{A_1}$$

Mean velocity in the left branch (m/s):

$$V_2 = \frac{Q_2}{A_2}$$

Mean velocity in the right branch (m/s):

$$V_3 = \frac{Q_3}{A_3}$$

Mass flow rate in the common branch (kg/s):

$$W_1 = Q_1 \cdot \rho_m$$

Mass flow rate in the left branch (kg/s):

$$W_2 = Q_2 \cdot \rho_m$$

Mass flow rate in the right branch (kg/s):

$$W_3 = Q_3 \cdot \rho_m$$

Reynolds number in the common branch:

$$N\mathrm{Re}_1 = \frac{V_1 \cdot d_1}{\nu}$$

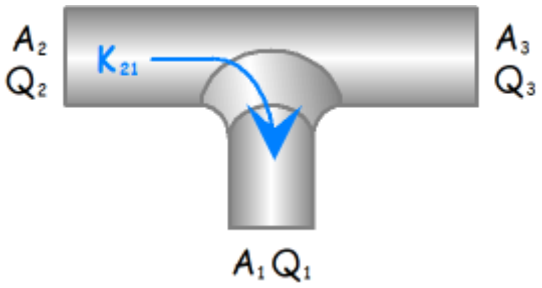
Reynolds number in the left branch:

$$NRe_2 = \frac{V_2 \cdot d_2}{\nu}$$

Reynolds number in the right branch:

$$NRe_3 = \frac{V_3 \cdot d_2}{\nu}$$

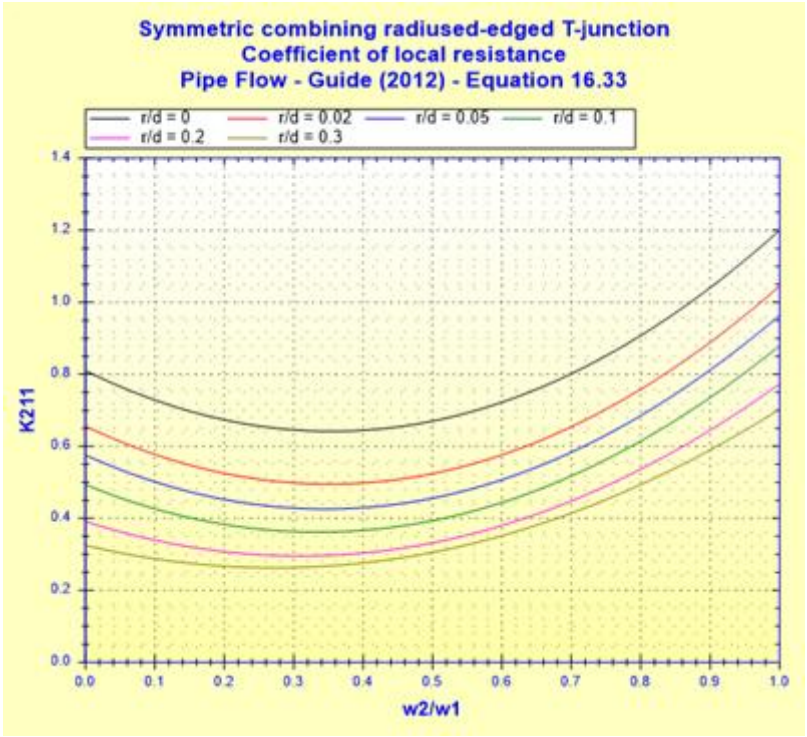
Pressure loss coefficient of the left branch:



Coefficient based on mean velocity in the common branch:

$$K_{21_1} = 0.81 - 1.16 \cdot \sqrt{\frac{r}{d}} + 0.5 \cdot \frac{r}{d} - \left(0.95 - 1.65 \cdot \frac{r}{d}\right) \cdot \frac{w_2}{w_1} + \left(1.34 - 1.69 \cdot \frac{r}{d}\right) \cdot \frac{{w_2}^2}{{w_1}^2}$$

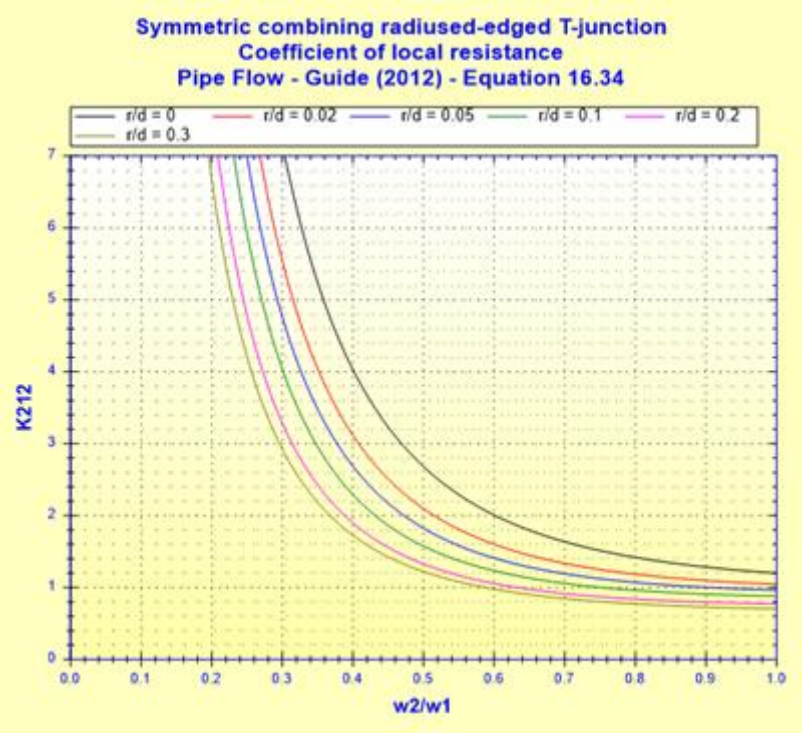
([1] equation 16.33)



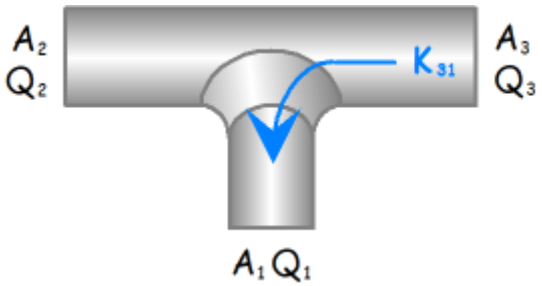
Coefficient based on mean velocity in the left branch:

$$K_{21_2} = \left(0.81 - 1.16 \cdot \sqrt{\frac{r}{d}} + 0.5 \cdot \frac{r}{d}\right) \cdot \frac{W_1^{\,2}}{W_2^{\,2}} - \left(0.95 - 1.65 \cdot \frac{r}{d}\right) \cdot \frac{W_1}{W_2} + 1.34 - 1.69 \cdot \frac{r}{d}$$

([1] equation 16.34)



Pressure loss coefficient of the right branch:

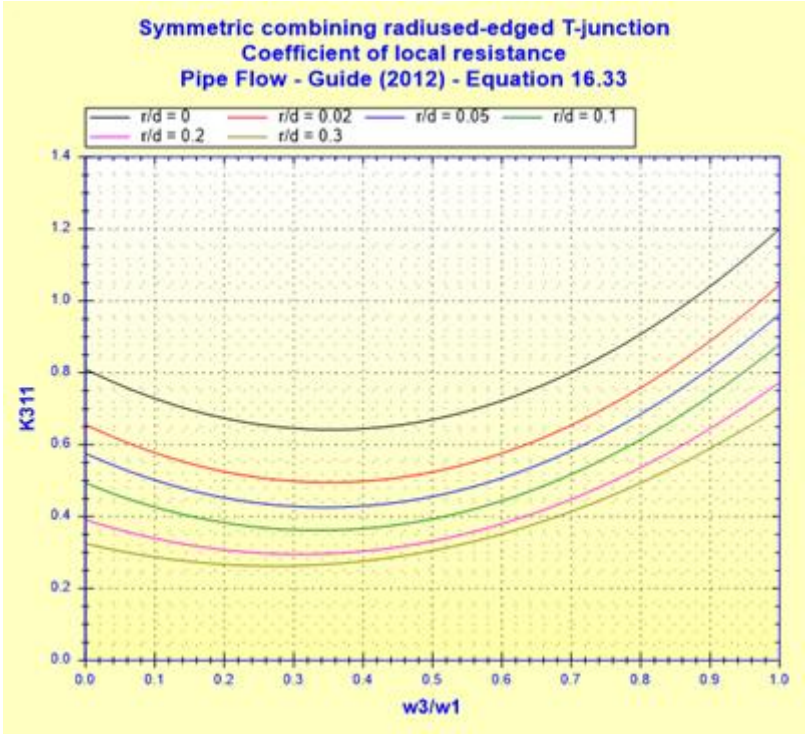


Note: for the right branch, the formulas are the same as those of the left branch, with subscript 3 instead of subscript 2.

Coefficient based on mean velocity in the common branch:

$$K_{31_1} = 0.81 - 1.16 \cdot \sqrt{\frac{r}{d}} + 0.5 \cdot \frac{r}{d} - \left(0.95 - 1.65 \cdot \frac{r}{d}\right) \cdot \frac{W_3}{W_1} + \left(1.34 - 1.69 \cdot \frac{r}{d}\right) \cdot \frac{W_3^{\,2}}{W_1^{\,2}}$$

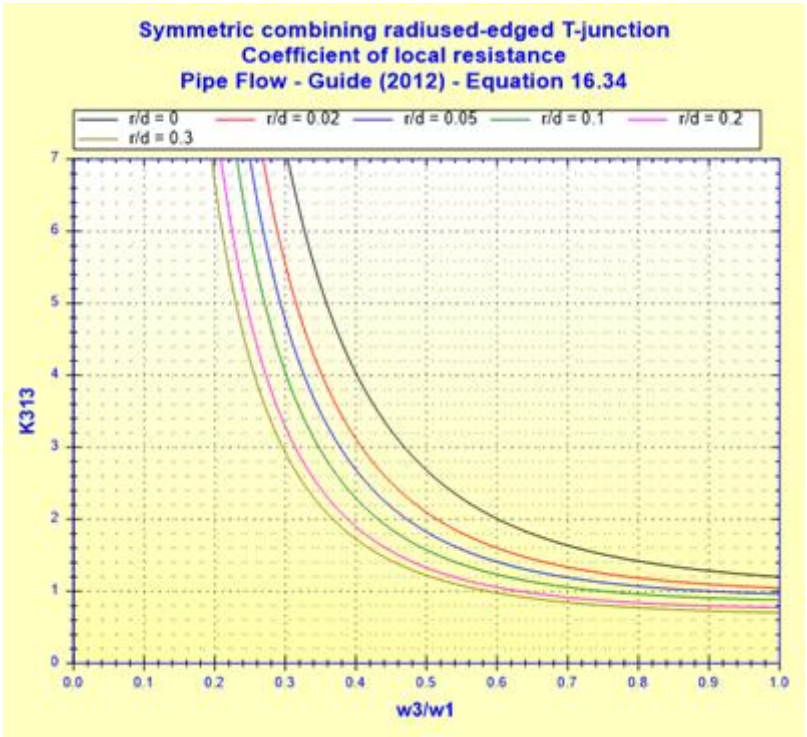
([1] equation 16.33)



Coefficient based on mean velocity in the right branch:

$$K_{31_3} = \left(0.81 - 1.16 \cdot \sqrt{\frac{r}{d}} + 0.5 \cdot \frac{r}{d}\right) \cdot \frac{W_1^{\,2}}{W_3^{\,2}} - \left(0.95 - 1.65 \cdot \frac{r}{d}\right) \cdot \frac{W_1}{W_3} + 1.34 - 1.69 \cdot \frac{r}{d}$$

([1] equation 16.34)



Pressure loss in the left branch (Pa):

$$\Delta P_{21} = K_{21_1} \cdot \frac{\rho_m \cdot W_1^2}{2}$$

Pressure loss in the right branch (Pa):

$$\Delta P_{31} = K_{31_1} \cdot \frac{\rho_m \cdot W_1^2}{2}$$

Head loss of fluid in the left branch (m):

$$\Delta H_{21} = K_{21_1} \cdot \frac{W_1^2}{2 \cdot g}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{31} = K_{31_1} \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss in the left branch (W):

$$Wh_{21} = \Delta P_{21} \cdot Q_2$$

Hydraulic power loss in the right branch (W):

$$Wh_{31} = \Delta P_{31} \cdot Q_3$$

Symbols, Definitions, SI Units:

d	Inside diameter of the three branches (m)
d_1	Diameter of the common branch (m)
d_2	Diameter of the left branch (m)
d_3	Diameter of the right branch
A_1	Cross-sectional area of the common branch (m^2)
A_2	Cross-sectional area of the left branch (m^2)
A_3	Cross-sectional area of the right branch (m^2)
Q_1	Volume flow rate in the common branch (m^3/s)

V_1 Mean velocity in the common branch (m/s)

Q_2 Volume flow rate in the left branch (m^3/s)

V_2 Mean velocity in the left branch (m/s)

Q_3 Volume flow rate in the right branch (m^3/s)

V_3 Mean velocity in the right branch (m/s)

w_1 Mass flow rate in the common branch (kg/s)

w_2 Mass flow rate in the left branch (kg/s)

w_3 Mass flow rate in the right branch (kg/s)

NRe_1 Reynolds number in the common branch ()

NRe_2 Reynolds number in the left branch ()

NRe_3 Reynolds number in the right branch ()

r Rounded radius (m)

K_{211} Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

K_{311} Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

K_{212} Pressure loss coefficient of the left branch (based on mean velocity in the left branch) ()

K_{313} Pressure loss coefficient of the right branch (based on mean velocity in the right branch) ()

ΔP_{21} Pressure loss in the left branch (Pa)

ΔP_{31} Pressure loss in the right branch (Pa)

ΔH_{21} Head loss of fluid in the left branch (m)

ΔH_{31} Head loss of fluid in the right branch (m)

Wh_{21} Hydraulic power loss in the left branch (W)

Wh_{31} Hydraulic power loss in the right branch (W)

ρ_m Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($NRe_1 \geq 10^4$)
- three legs of equal area ($d_1 = d_2 = d_3$)
- relative radius of the round (r/d) lower than or equal to 0.3d

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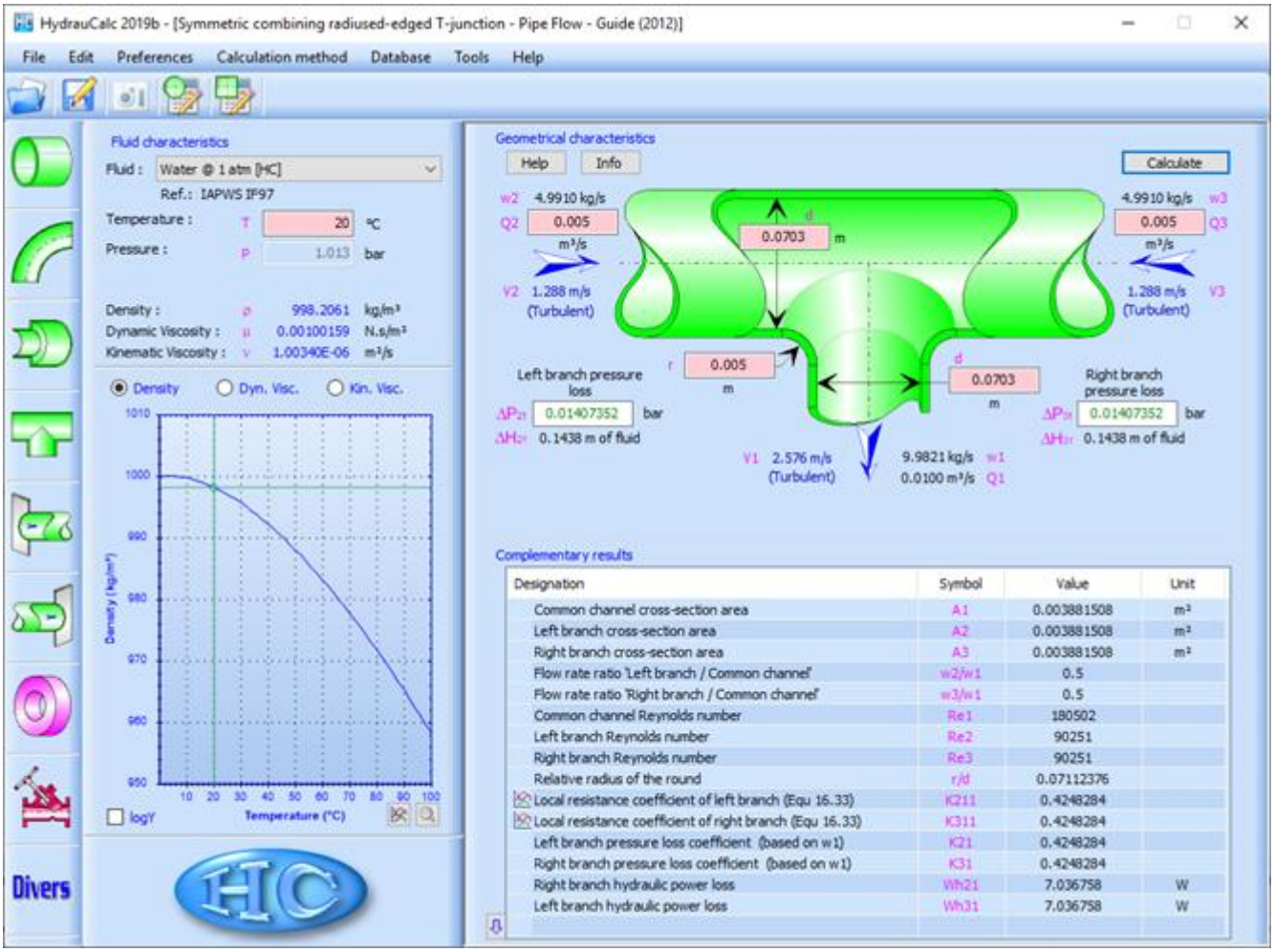
Example of application:

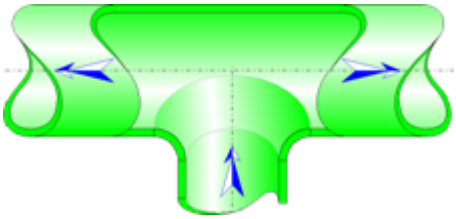


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.4.8 Symmetric dividing radiused-edged T-junction

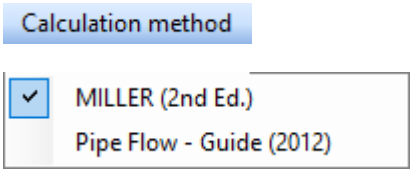
Circular Cross-Section



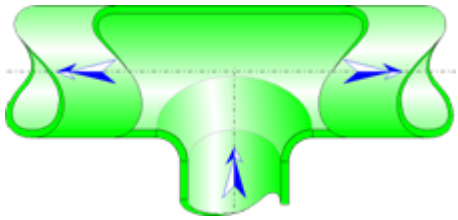
For the calculation of the pressure loss coefficient of symmetric dividing radiused-edged T-junctions, the user can choose from one of the methods described in the following two reference documents:

- Internal Flow System, 2nd Edition, D.S. Miller
- Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "MILLER (2nd Ed.)"



2.4.8.1 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric dividing radiused-edged T-junction with three legs of equal area.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the three branches (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

$$A_3 = \pi \cdot \frac{D_3^2}{4}$$

with $D_1 = D_2 = D_3 = D$

Volume flow rate in the common branch (m^3/s):

$$Q_3 = Q_1 + Q_2$$

Mean velocity in the left branch (m/s):

$$U_1 = \frac{Q_1}{A_1}$$

Mean velocity in the right branch (m/s):

$$U_2 = \frac{Q_2}{A_2}$$

Mean velocity in the common branch (m/s):

$$U_3 = \frac{Q_3}{A_3}$$

Mass flow rate in the left branch (kg/s):

$$G_1 = Q_1 \cdot \rho$$

Mass flow rate in the right branch (kg/s):

$$G_2 = Q_2 \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_3 = Q_3 \cdot \rho$$

Reynolds number in the left branch:

$$\mathrm{Re}_1 = \frac{U_1 \cdot D_1}{\nu}$$

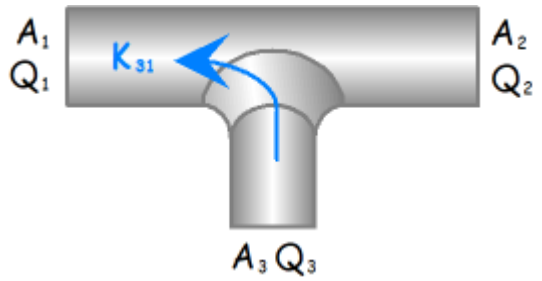
Reynolds number in the right branch:

$$\mathrm{Re}_2 = \frac{U_2 \cdot D_2}{\nu}$$

Reynolds number in the common branch:

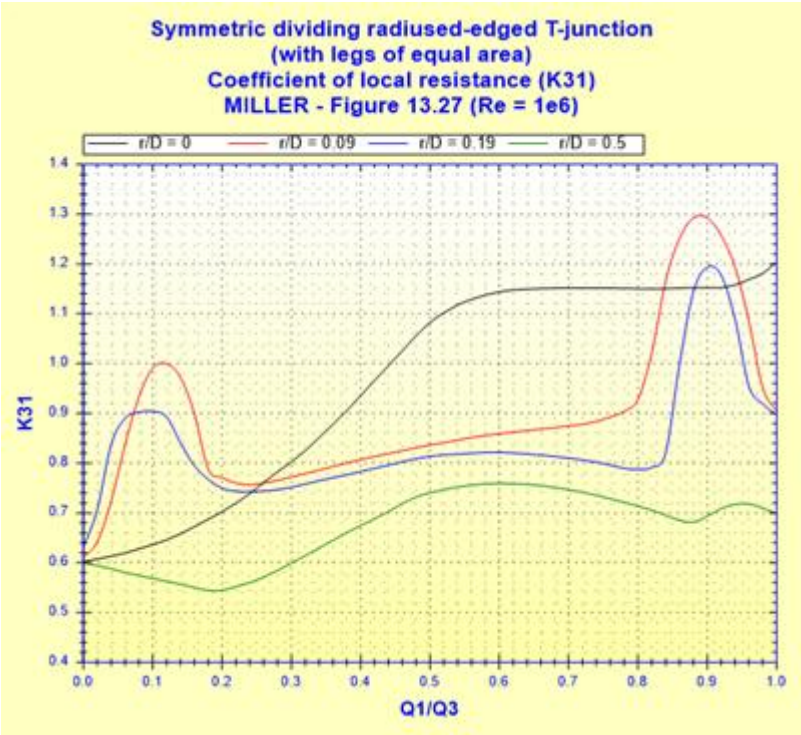
$$Re_3 = \frac{U_3 \cdot D_3}{\nu}$$

Pressure loss coefficient of the left branch (based on mean velocity in the common branch):

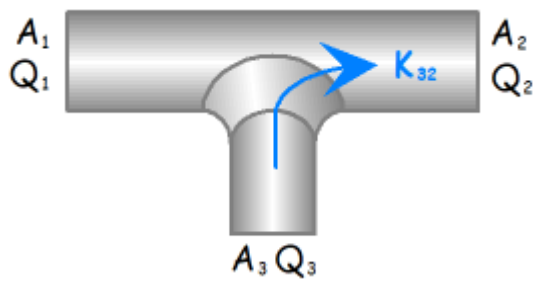


$$K_{31} = f\left(\frac{Q_1}{Q_3}, \frac{r}{D}\right)$$

([1] figure 13.27)

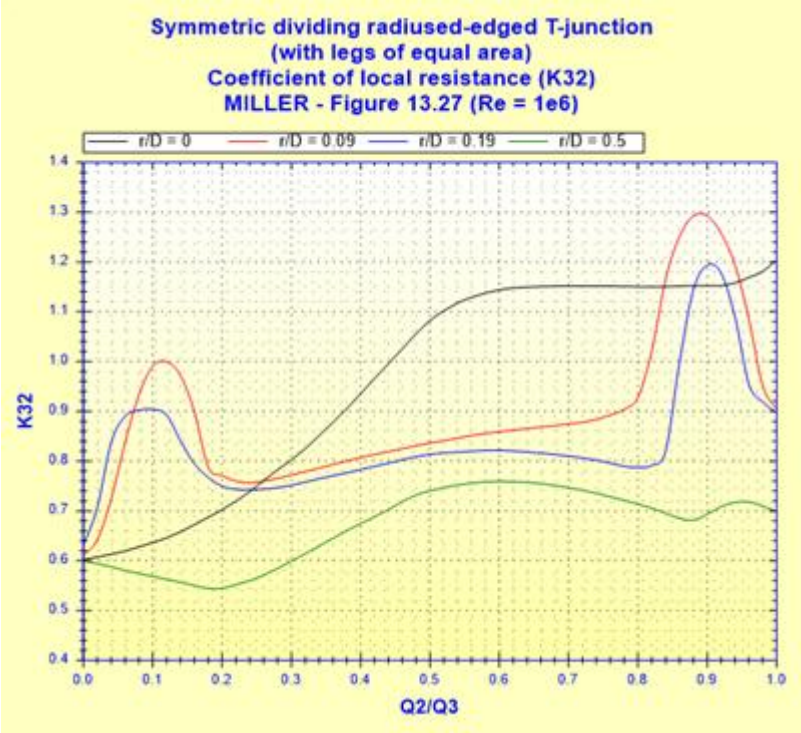


Pressure loss coefficient of the right branch (based on mean velocity in the common branch):



$$K_{32} = f\left(\frac{Q_2}{Q_3}, \frac{r}{D}\right)$$

([1] figure 13.27)



Pressure loss in the left branch (Pa):

$$\Delta P_{31} = K_{31} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.3)

Pressure loss in the right branch (Pa):

$$\Delta P_{32} = K_{32} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.4)

Head loss of fluid in the left branch (m):

$$\Delta H_{31} = K_{31} \cdot \frac{U_3^2}{2 \cdot g}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{32} = K_{32} \cdot \frac{U_3^2}{2 \cdot g}$$

Hydraulic power loss in the left branch (W):

$$Wh_{31} = \Delta P_{31} \cdot Q_1$$

Hydraulic power loss in the right branch (W):

$$Wh_{32} = \Delta P_{32} \cdot Q_2$$

Symbols, Definitions, SI Units:

D	Inside diameter of the three branches (m)
D_1	Diameter of the left branch (m)
D_2	Diameter of the right branch (m)
D_3	Diameter of the common branch
A_1	Cross-sectional area of the left branch (m^2)
A_2	Cross-sectional area of the right branch (m^2)
A_3	Cross-sectional area of the common branch (m^2)
Q_1	Volume flow rate in the left branch (m^3/s)
U_1	Mean velocity in the left branch (m/s)
Q_2	Volume flow rate in the right branch (m^3/s)
U_2	Mean velocity in the right branch (m/s)
Q_3	Volume flow rate in the common branch (m^3/s)
U_3	Mean velocity in the common branch (m/s)
G_1	Mass flow rate in the left branch (kg/s)
G_2	Mass flow rate in the right branch (kg/s)
G_3	Mass flow rate in the common branch (kg/s)
Re_1	Reynolds number in the left branch ()
Re_2	Reynolds number in the right branch ()
Re_3	Reynolds number in the common branch ()
r	Rounded radius (m)

K_{31} Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

K_{32} Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

ΔP_{31} Pressure loss in the left branch (Pa)

ΔP_{32} Pressure loss in the right branch (Pa)

ΔH_{31} Head loss of fluid in the left branch (m)

ΔH_{32} Head loss of fluid in the right branch (m)

Wh_{31} Hydraulic power loss in the left branch (W)

Wh_{32} Hydraulic power loss in the right branch (W)

ρ Fluid density (kg/m^3)

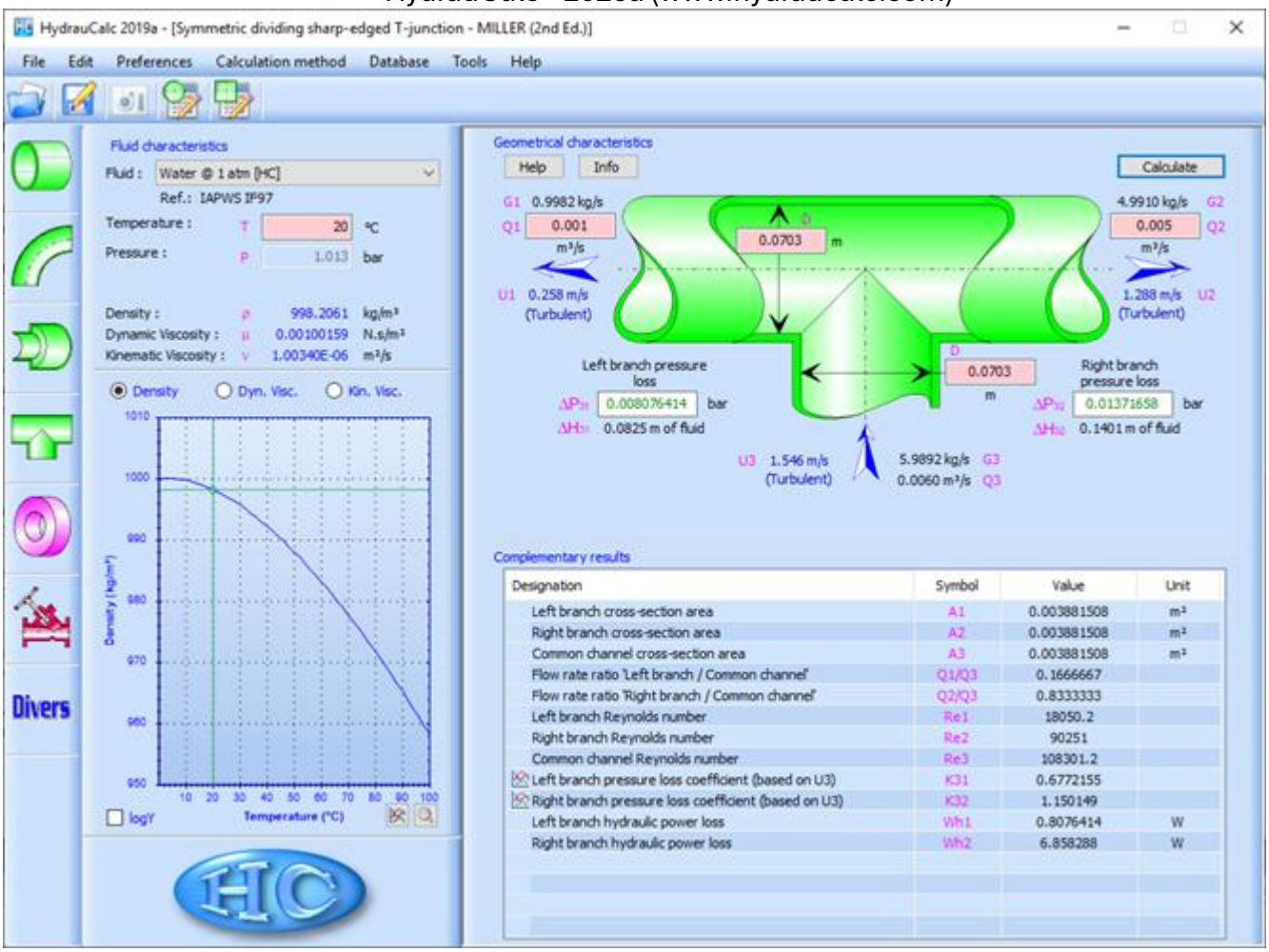
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re_3 \geq 10^5$)
- three legs of equal area ($D_1 = D_2 = D_3$)
- relative radius of the round (r/D) lower than or equal to 0.5D

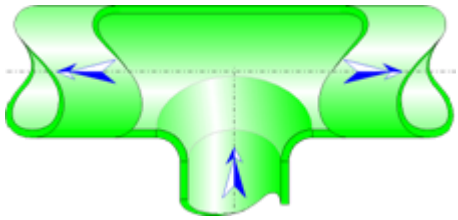
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

2.4.8.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric dividing radiused-edged T-junction with three legs of equal area.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the three branches (m^2):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

$$A_2 = \pi \cdot \frac{d_2^2}{4}$$

$$A_3 = \pi \cdot \frac{d_3^2}{4}$$

with $d_1 = d_2 = d_3 = d$

Volume flow rate in the common branch (m^3/s):

$$Q_1 = Q_2 + Q_3$$

Mean velocity in the common branch (m/s):

$$V_1 = \frac{Q_1}{A_1}$$

Mean velocity in the left branch (m/s):

$$V_2 = \frac{Q_2}{A_2}$$

Mean velocity in the right branch (m/s):

$$V_3 = \frac{Q_3}{A_3}$$

Mass flow rate in the common branch (kg/s):

$$W_1 = Q_1 \cdot \rho_m$$

Mass flow rate in the left branch (kg/s):

$$W_2 = Q_2 \cdot \rho_m$$

Mass flow rate in the right branch (kg/s):

$$W_3 = Q_3 \cdot \rho_m$$

Reynolds number in the common branch:

$$N\mathrm{Re}_1 = \frac{V_1 \cdot d_1}{\nu}$$

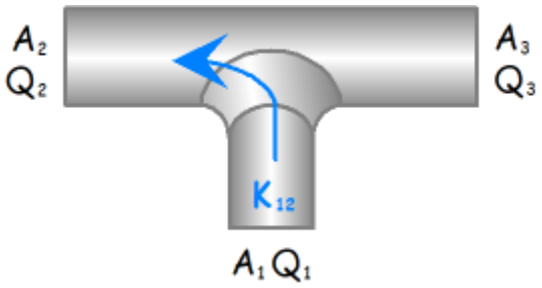
Reynolds number in the left branch:

$$N\mathrm{Re}_2 = \frac{V_2 \cdot d_2}{\nu}$$

Reynolds number in the right branch:

$$N\mathrm{Re}_3 = \frac{V_3 \cdot d_3}{\nu}$$

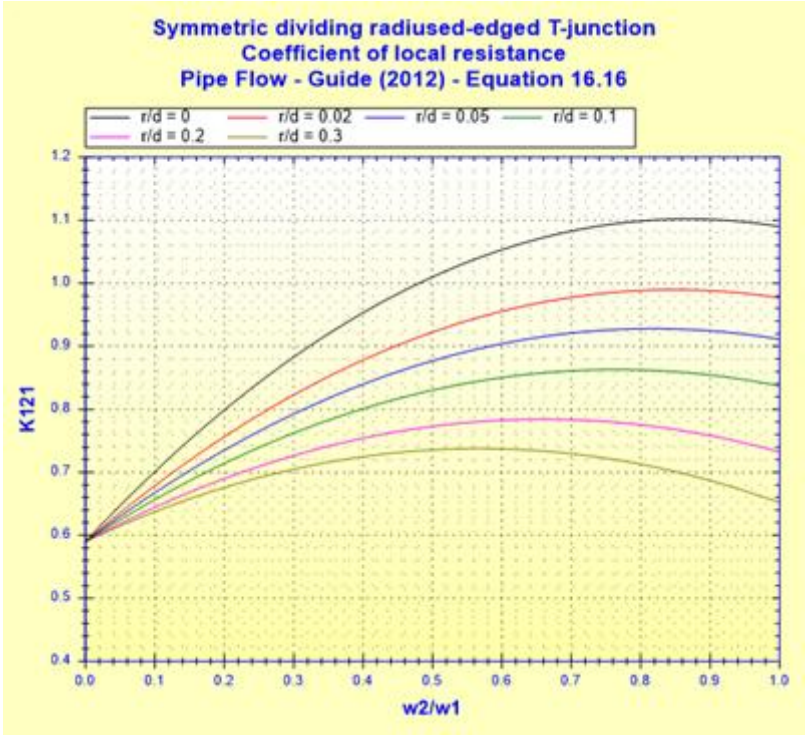
Pressure loss coefficient of the left branch:



Coefficient based on mean velocity in the common branch:

$$K_{12_1} = 0.59 + \left(1.18 - 1.84 \cdot \sqrt{\frac{r}{d}} + 1.16 \cdot \frac{r}{d}\right) \cdot \frac{w_2}{w_1} - \left(0.68 - 1.04 \cdot \sqrt{\frac{r}{d}} + 1.16 \cdot \frac{r}{d}\right) \cdot \frac{w_2^2}{w_1^2}$$

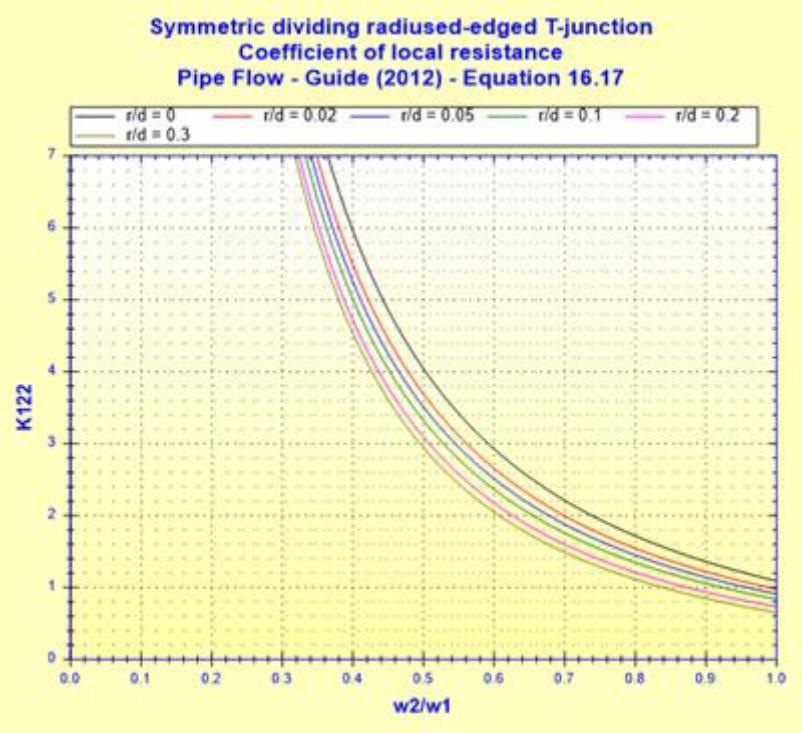
([1] equation 16.16)



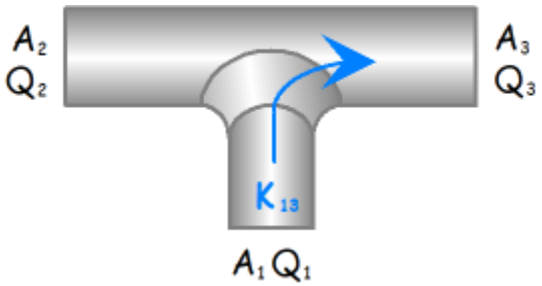
Coefficient based on mean velocity in the left branch:

$$K_{12_2} = 0.59 \cdot \frac{W_1^2}{W_2^2} + \left(1.18 - 1.84 \cdot \sqrt{\frac{r}{d}} + 1.16 \cdot \frac{r}{d}\right) \cdot \frac{W_1}{W_2} - 0.68 + 1.04 \cdot \sqrt{\frac{r}{d}} - 1.16 \cdot \frac{r}{d}$$

([1] equation 16.17)



Pressure loss coefficient of the right branch:

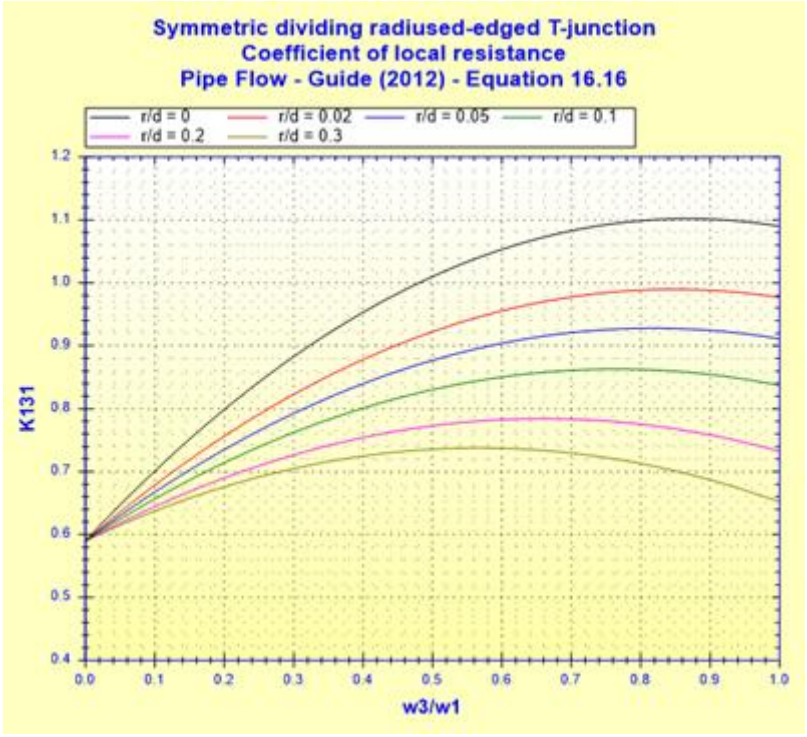


Note: for the right branch, the formulas are the same as those of the left branch, with subscript 3 instead of subscript 2.

Coefficient based on mean velocity in the common branch:

$$K_{13_1} = 0.59 + \left(1.18 - 1.84 \cdot \sqrt{\frac{r}{d}} + 1.16 \cdot \frac{r}{d}\right) \cdot \frac{W_3}{W_1} - \left(0.68 - 1.04 \cdot \sqrt{\frac{r}{d}} + 1.16 \cdot \frac{r}{d}\right) \cdot \frac{W_3^2}{W_1^2}$$

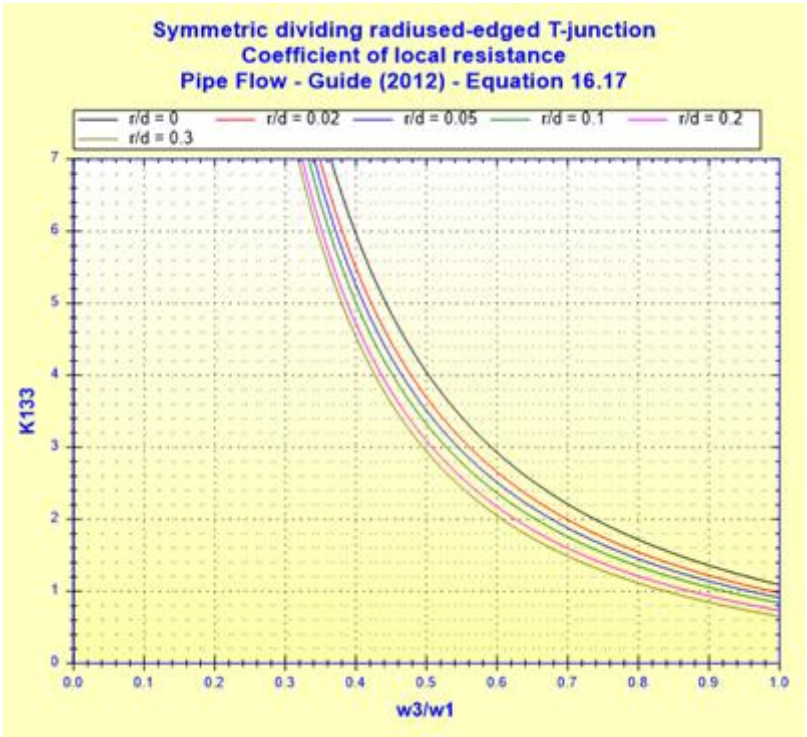
([1] equation 16.16)



Coefficient based on mean velocity in the left branch:

$$K_{13_3} = 0.59 \cdot \frac{W_1^{\,2}}{W_3^{\,2}} + \left(1.18 - 1.84 \cdot \sqrt{\frac{r}{d}} + 1.16 \cdot \frac{r}{d}\right) \cdot \frac{W_1}{W_3} - 0.68 + 1.04 \cdot \sqrt{\frac{r}{d}} - 1.16 \cdot \frac{r}{d}$$

([1] equation 16.17)



Pressure loss in the left branch (Pa):

$$\Delta P_{12} = K_{12_1} \cdot \frac{\rho_m \cdot W_1^2}{2}$$

Pressure loss in the right branch (Pa):

$$\Delta P_{13} = K_{13_1} \cdot \frac{\rho_m \cdot W_1^2}{2}$$

Head loss of fluid in the left branch (m):

$$\Delta H_{12} = K_{12_1} \cdot \frac{W_1^2}{2 \cdot g}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{13} = K_{13_1} \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss in the left branch (W):

$$Wh_{12} = \Delta P_{12} \cdot Q_2$$

Hydraulic power loss in the right branch (W):

$$Wh_{13} = \Delta P_{13} \cdot Q_3$$

Symbols, Definitions, SI Units:

d	Inside diameter of the three branches (m)
d_1	Diameter of the common branch (m)
d_2	Diameter of the left branch (m)
d_3	Diameter of the right branch
A_1	Cross-sectional area of the common branch (m^2)
A_2	Cross-sectional area of the left branch (m^2)
A_3	Cross-sectional area of the right branch (m^2)
Q_1	Volume flow rate in the common branch (m^3/s)

V_1 Mean velocity in the common branch (m/s)

Q_2 Volume flow rate in the left branch (m^3/s)

V_2 Mean velocity in the left branch (m/s)

Q_3 Volume flow rate in the right branch (m^3/s)

V_3 Mean velocity in the right branch (m/s)

w_1 Mass flow rate in the common branch (kg/s)

w_2 Mass flow rate in the left branch (kg/s)

w_3 Mass flow rate in the right branch (kg/s)

NRe_1 Reynolds number in the common branch ()

NRe_2 Reynolds number in the left branch ()

NRe_3 Reynolds number in the right branch ()

r Rounded radius (m)

K_{121} Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

K_{131} Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

K_{122} Pressure loss coefficient of the left branch (based on mean velocity in the left branch) ()

K_{133} Pressure loss coefficient of the right branch (based on mean velocity in the right branch) ()

ΔP_{12} Pressure loss in the left branch (Pa)

ΔP_{13} Pressure loss in the right branch (Pa)

ΔH_{12} Head loss of fluid in the left branch (m)

ΔH_{13} Head loss of fluid in the right branch (m)

Wh_{12} Hydraulic power loss in the left branch (W)

Wh_{13} Hydraulic power loss in the right branch (W)

ρ_m Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($NRe_1 \geq 10^4$)
- three legs of equal area ($d_1 = d_2 = d_3$)
- relative radius of the round (r/d) lower than or equal to 0.3d
- ratio of mass flow rates (w_2 / w_1) and (w_3 / w_1) between 0.2 and 0.8
  note: for mass flow ratios less than 0.2 or greater than 0.8, pressure loss coefficients are extrapolated

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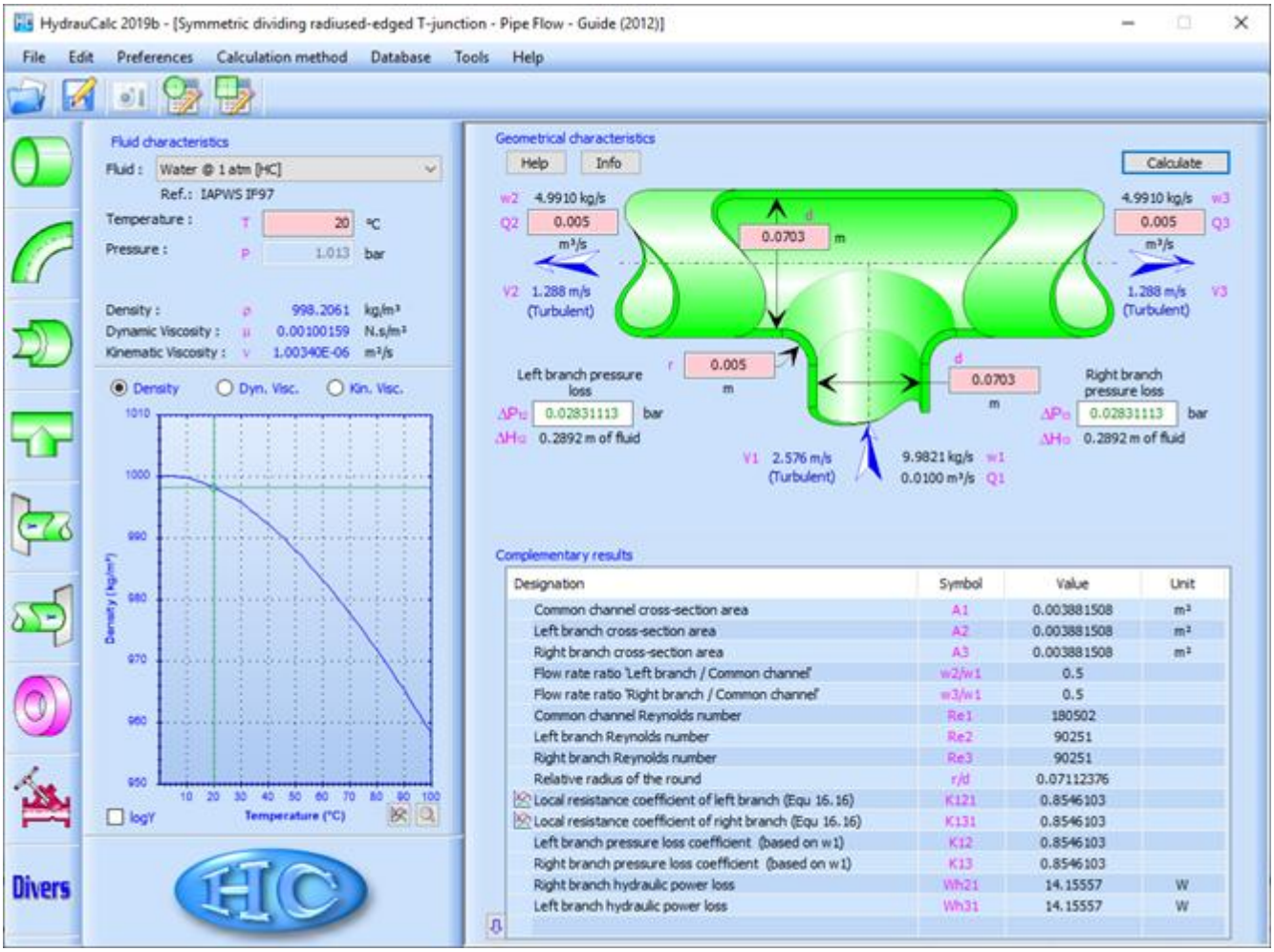
Example of application:

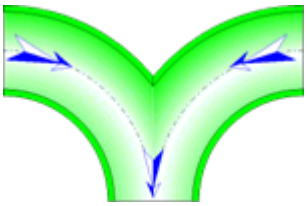


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.4.9 Symmetric combining T-junction with smooth turn through 90°

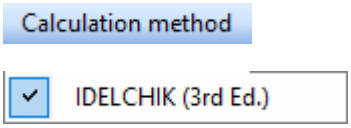
Circular cross-section



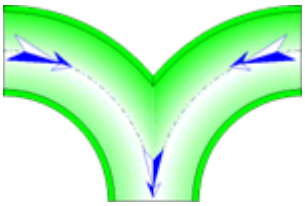
For the calculation of the pressure loss coefficient of symmetric combining T-junction with smooth turn through 90°, the calculation method is described in the following reference document:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

The only calculation method offered appears in the "Calculation method" menu and is activated by default.



2.4.9.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric combining T-junction with smooth turn through 90°.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the common branch (m^2):

$$F_c = \pi \cdot \frac{D_c^2}{4}$$

Cross-sectional area of the left branch (m^2):

$$F_{1s} = \frac{F_c}{2}$$

Cross-sectional area of the right branch (m^2):

$$F_{2s} = \frac{F_c}{2}$$

Diameter of the left branch (m) :

$$D_{1s} = \sqrt{\frac{4 \cdot F_{1s}}{\pi}}$$

Diameter of the right branch (m) :

$$D_{2s} = \sqrt{\frac{4 \cdot F_{2s}}{\pi}}$$

Volume flow rate in the common branch (m^3/s):

$$Q_c = Q_{1s} + Q_{2s}$$

Mean velocity in the left branch (m/s):

$$w_{1s} = \frac{Q_{1s}}{F_{1s}}$$

Mean velocity in the right branch (m/s):

$$w_{2s} = \frac{Q_{2s}}{F_{2s}}$$

Mean velocity in the common branch (m/s):

$$w_c = \frac{Q_c}{F_c}$$

Mass flow rate in the left branch (kg/s):

$$G_{1s} = Q_{1s} \cdot \rho$$

Mass flow rate in the right branch (kg/s):

$$G_{2s} = Q_{2s} \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_c = Q_c \cdot \rho$$

Reynolds number in the left branch:

$$\mathrm{Re}_{1s} = \frac{w_{1s} \cdot D_{1s}}{\nu}$$

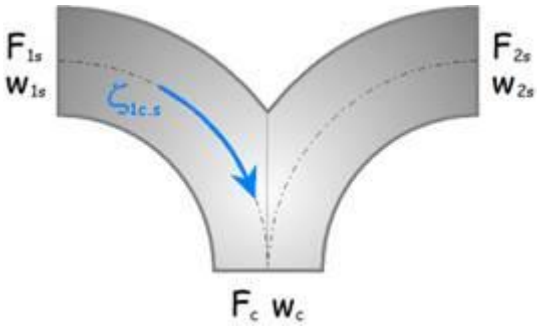
Reynolds number in the right branch:

$$\mathrm{Re}_{2s} = \frac{w_{2s} \cdot D_{2s}}{\nu}$$

Reynolds number in the common branch:

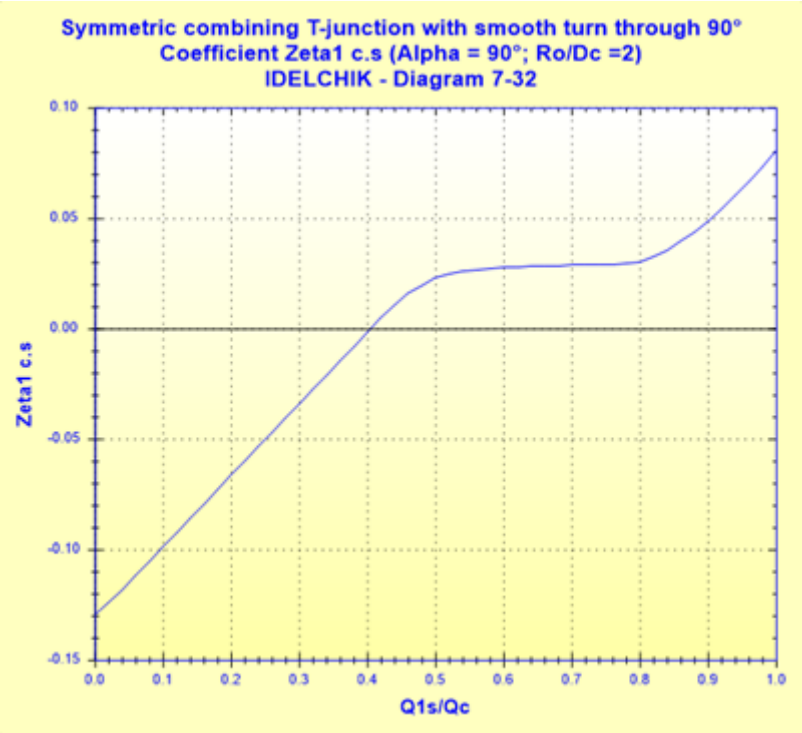
$$\mathrm{Re}_c = \frac{w_c \cdot D_c}{\nu}$$

Pressure loss coefficient of the left branch (based on mean velocity in the common branch):

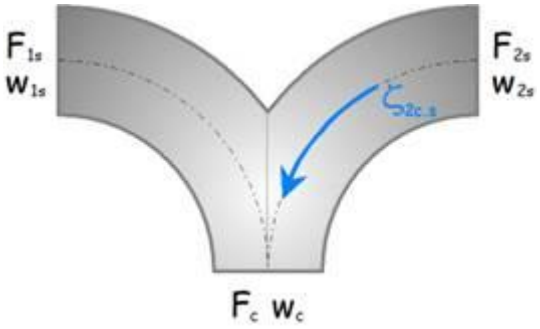


$$\zeta_{1c.s} = f\left(\frac{Q_{1s}}{Q_c}\right)$$

([1] diagram 7-32)



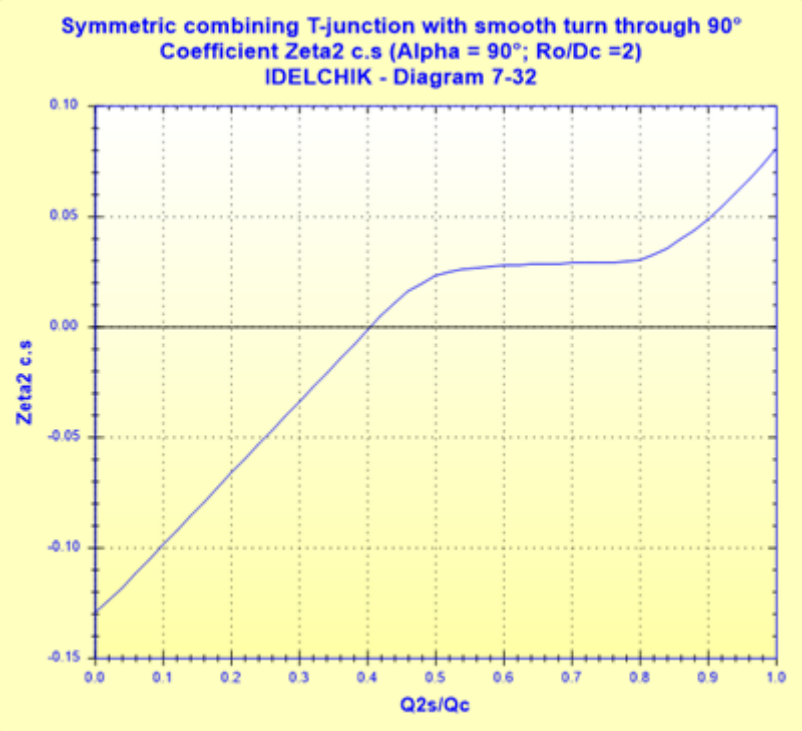
Pressure loss coefficient of the right branch(based on mean velocity in the common branch):



Note: for the right branch, the formulas are the same as those of the left branch, with subscript 2 instead of subscript 1.

$$\zeta_{2c.s} = f\left(\frac{Q_{2s}}{Q_c}\right)$$

([1] diagram 7-32)



Pressure loss in the left branch (Pa):

$$\Delta P_{1c.s} = \zeta_{1c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Pressure loss in the right branch (Pa):

$$\Delta P_{2c.s} = \zeta_{2c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Head loss of fluid in the left branch (m):

$$\Delta H_{1c.s} = \zeta_{1c.s} \cdot \frac{W_c^{\,2}}{2 \cdot g}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{2c.s} = \zeta_{2c.s} \cdot \frac{W_c^{\,2}}{2 \cdot g}$$

Hydraulic power loss in the left branch (W):

$$Wh_{1s} = \Delta P_{1c.s} \cdot Q_c$$

Hydraulic power loss in the right branch (W):

$$Wh_{2s} = \Delta P_{2c.s} \cdot Q_c$$

Symbols, Definitions, SI Units:

D_{1s}	Diameter of the left branch (m)
D_{2s}	Diameter of the right branch (m)
D_c	Diameter of the common branch (m)
F_{1s}	Cross-sectional area of the left branch (m^2)
F_{2s}	Cross-sectional area of the right branch (m^2)
F_c	Cross-sectional area of the common branch (m^2)
Q_{1s}	Volume flow rate in the left branch (m^3/s)
w_{1s}	Mean velocity in the left branch (m/s)
Q_{2s}	Volume flow rate in the right branch (m^3/s)
w_{2s}	Mean velocity in the right branch (m/s)
Q_c	Volume flow rate in the common branch (m^3/s)
w_c	Mean velocity in the common branch (m/s)
G_{1s}	Mass flow rate in the left branch (kg/s)
G_{2s}	Mass flow rate in the right branch (kg/s)
G_c	Mass flow rate in the common branch (kg/s)
Re_{1s}	Reynolds number in the left branch ()
Re_{2s}	Reynolds number in the right branch ()
Re_c	Reynolds number in the common branch ()
$\zeta_{1c.s}$	Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()
$\zeta_{2c.s}$	Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()
ΔP_{1s}	Pressure loss in the left branch (Pa)
ΔP_{2s}	Pressure loss in the right branch(Pa)

ΔH_{1s} Head loss of fluid in the left branch (m)

ΔH_{2s} Head loss of fluid in the right branch (m)

Wh_{1s} Hydraulic power loss in the left branch (W)

Wh_{2s} Hydraulic power loss in the right branch (W)

ρ Fluid density (kg/m³)

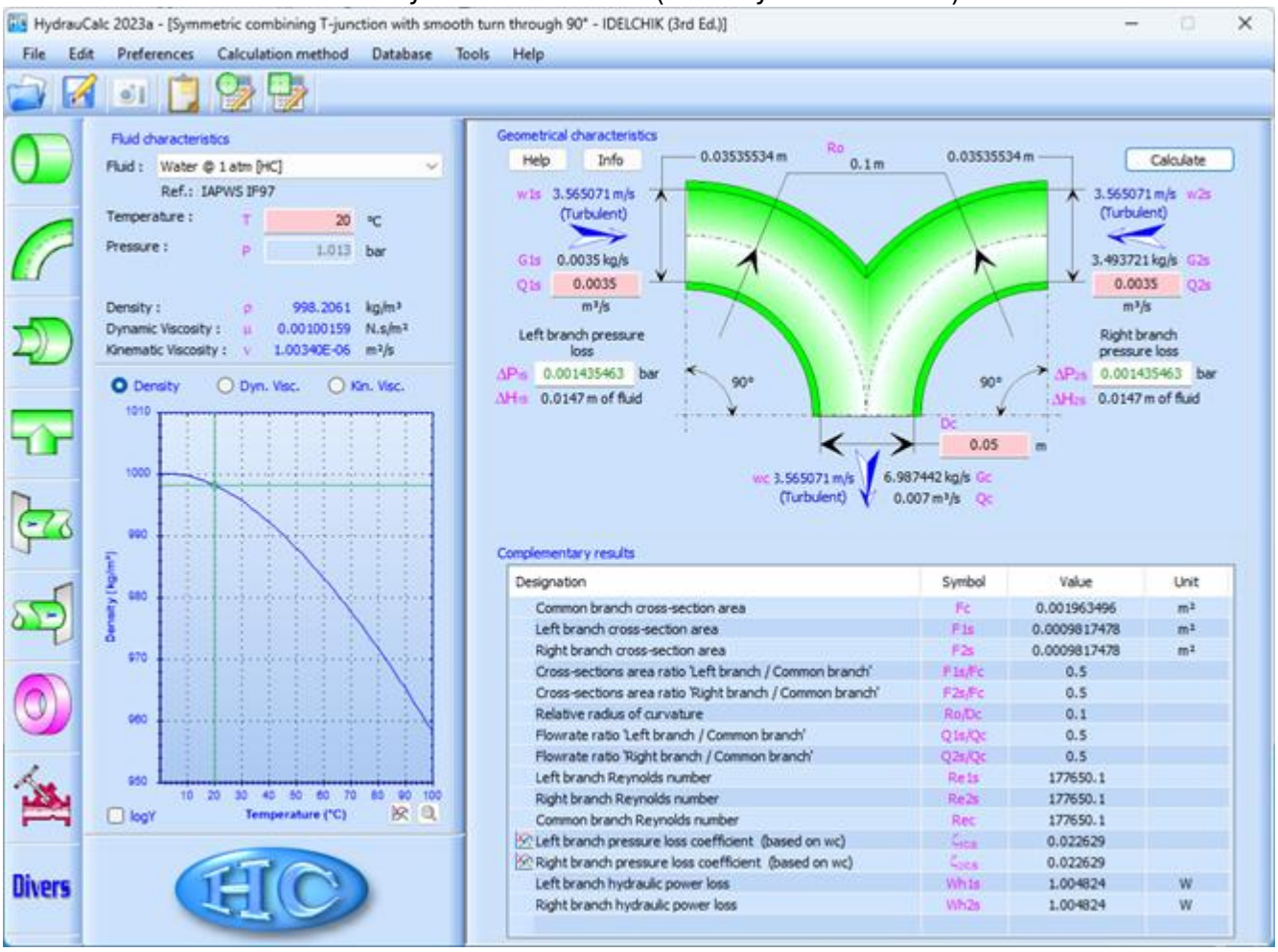
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- flow regime: turbulent ($Re_c \geq 10^4$)
- curvature angle of each bend: 90°
- relative curvature: (R_0/D_c) = 2
- cross-sectional area ratio: (F_{1s}/F_c) = (F_{2s}/F_c) = 0.5

Example of application:

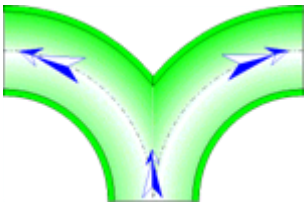


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.4.10 Symmetric dividing T-junction with Smooth turn through 90°

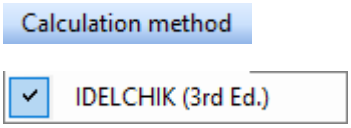
Circular cross-section



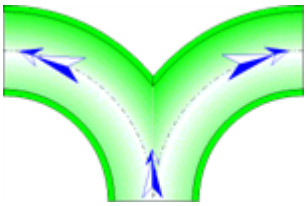
For the calculation of the pressure loss coefficient of symmetric dividing T-junction with smooth turn through 90°, the calculation method is described in the following reference document:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

The only calculation method offered appears in the "Calculation method" menu and is activated by default.



2.4.10.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric dividing T-junction with smooth turn through 90°.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the common branch (m^2):

$$F_c = \pi \cdot \frac{D_c^2}{4}$$

Cross-sectional area of the left branch (m^2):

$$F_{1s} = \frac{F_c}{2}$$

Cross-sectional area of the right branch (m^2):

$$F_{2s} = \frac{F_c}{2}$$

Diameter of the left branch (m) :

$$D_{1s} = \sqrt{\frac{4 \cdot F_{1s}}{\pi}}$$

Diameter of the right branch (m) :

$$D_{2s} = \sqrt{\frac{4 \cdot F_{2s}}{\pi}}$$

Volume flow rate in the left branch (m^3/s):

$$Q_{1s} = \frac{Q_c}{2}$$

Volume flow rate in the right branch (m^3/s):

$$Q_{2s} = \frac{Q_c}{2}$$

Mean velocity in the left branch (m/s):

$$w_{1s} = \frac{Q_{1s}}{F_{1s}}$$

Mean velocity in the right branch (m/s):

$$w_{2s} = \frac{Q_{2s}}{F_{2s}}$$

Mean velocity in the common branch (m/s):

$$w_c = \frac{Q_c}{F_c}$$

Mass flow rate in the left branch (kg/s):

$$G_{1s} = Q_{1s} \cdot \rho$$

Mass flow rate in the right branch (kg/s):

$$G_{2s} = Q_{2s} \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_c = Q_c \cdot \rho$$

Reynolds number in the left branch:

$$\mathrm{Re}_{1s} = \frac{w_{1s} \cdot D_{1s}}{\nu}$$

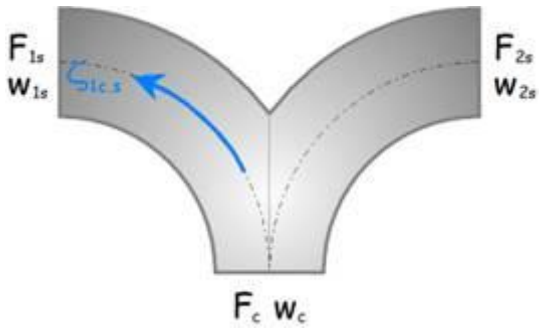
Reynolds number in the right branch:

$$\mathrm{Re}_{2s} = \frac{w_{2s} \cdot D_{2s}}{\nu}$$

Reynolds number in the common branch:

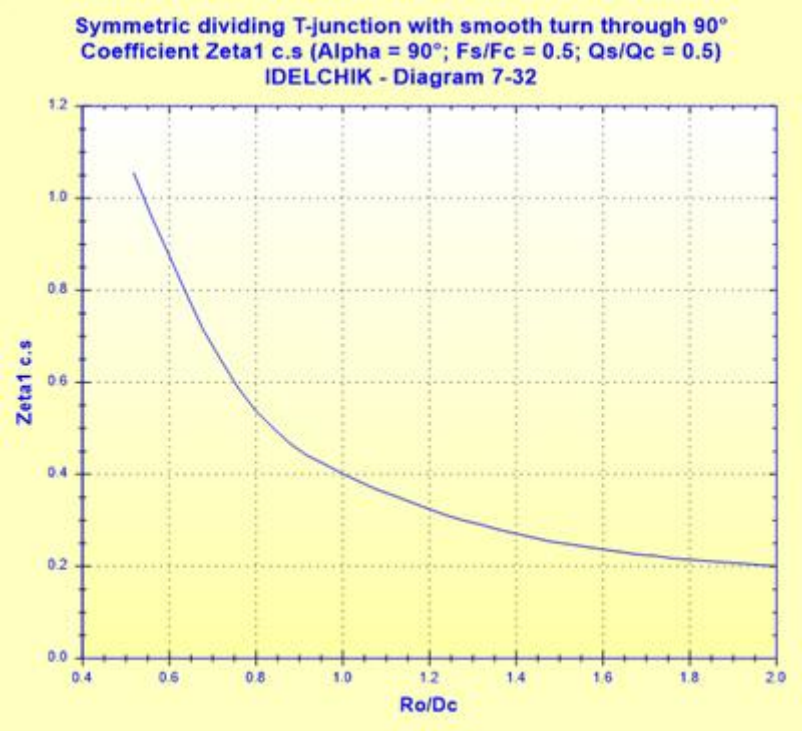
$$\mathrm{Re}_c = \frac{w_c \cdot D_c}{\nu}$$

Pressure loss coefficient of the left branch (based on mean velocity in the common branch):



$$\zeta_{1c.s} = f\left(\frac{R_0}{D_c}\right)$$

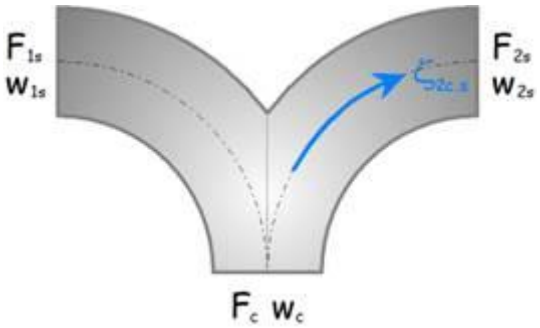
([1] diagram 7-32)



$$\zeta_{1s} = \frac{\zeta_{1c.s}}{(Q_{1s} \cdot F_c / Q_c \cdot F_{1s})^2}$$

([1] diagram 7-32)

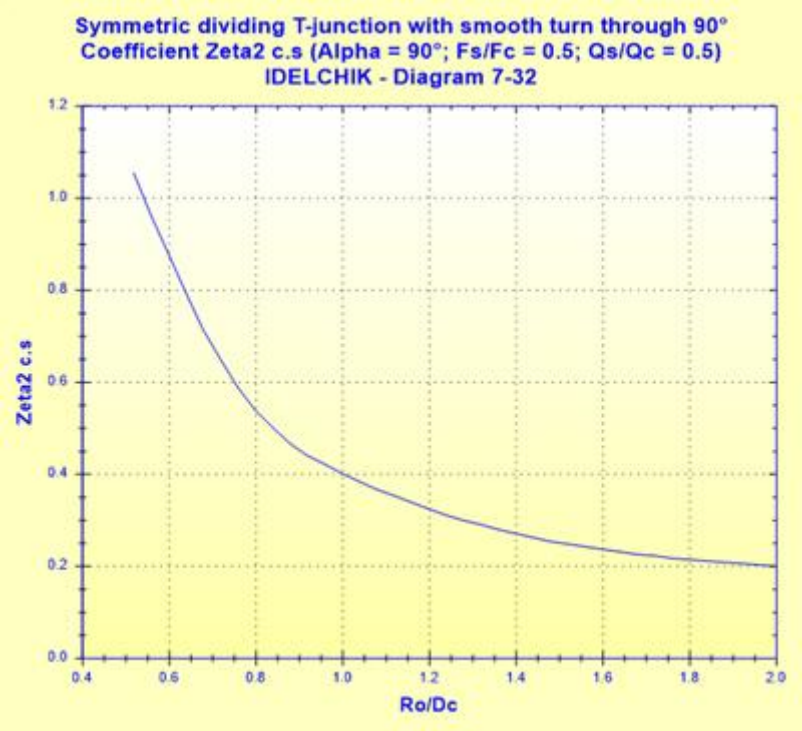
Pressure loss coefficient of the right branch(based on mean velocity in the common branch):



Note: for the right branch, the formulas are the same as those of the left branch, with subscript 2 instead of subscript 1.

$$\zeta_{2c.s} = f\left(\frac{R_0}{D_c}\right)$$

([1] diagram 7-32)



$$\zeta_{2s} = \frac{\zeta_{2c.s}}{(Q_{2s} \cdot F_c / Q_c \cdot F_{2s})^2}$$ ([1] diagram 7-32)

Pressure loss in the left branch (Pa):

$$\Delta P_{1s} = \zeta_{1s} \cdot \frac{\rho \cdot W_{1s}^2}{2}$$

Pressure loss in the right branch (Pa):

$$\Delta P_{2s} = \zeta_{2s} \cdot \frac{\rho \cdot W_{2s}^2}{2}$$

Head loss of fluid in the left branch (m):

$$\Delta H_{1s} = \zeta_{1s} \cdot \frac{W_{1s}^2}{2 \cdot g}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{2s} = \zeta_{2s} \cdot \frac{W_{2s}^2}{2 \cdot g}$$

Hydraulic power loss in the left branch (W):

$$Wh_{1s} = \Delta P_{1c.s} \cdot Q_c$$

Hydraulic power loss in the right branch (W):

$$Wh_{2s} = \Delta P_{2c.s} \cdot Q_c$$

Symbols, Definitions, SI Units:

D_{1s}	Diameter of the left branch (m)
D_{2s}	Diameter of the right branch (m)
D_c	Diameter of the common branch (m)
F_{1s}	Cross-sectional area of the left branch (m^2)
F_{2s}	Cross-sectional area of the right branch (m^2)
F_c	Cross-sectional area of the common branch (m^2)
Q_{1s}	Volume flow rate in the left branch (m^3/s)
w_{1s}	Mean velocity in the left branch (m/s)
Q_{2s}	Volume flow rate in the right branch (m^3/s)
w_{2s}	Mean velocity in the right branch (m/s)
Q_c	Volume flow rate in the common branch (m^3/s)
w_c	Mean velocity in the common branch (m/s)
G_{1s}	Mass flow rate in the left branch (kg/s)
G_{2s}	Mass flow rate in the right branch (kg/s)
G_c	Mass flow rate in the common branch (kg/s)
Re_{1s}	Reynolds number in the left branch ()
Re_{2s}	Reynolds number in the right branch ()
Re_c	Reynolds number in the common branch ()
$\zeta_{1c.s}$	Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

$\zeta_{2c.s}$ Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

ΔP_{1s} Pressure loss in the left branch (Pa)

ΔP_{2s} Pressure loss in the right branch(Pa)

ΔH_{1s} Head loss of fluid in the left branch (m)

ΔH_{2s} Head loss of fluid in the right branch (m)

Wh_{1s} Hydraulic power loss in the left branch (W)

Wh_{2s} Hydraulic power loss in the right branch (W)

ρ Fluid density (kg/m³)

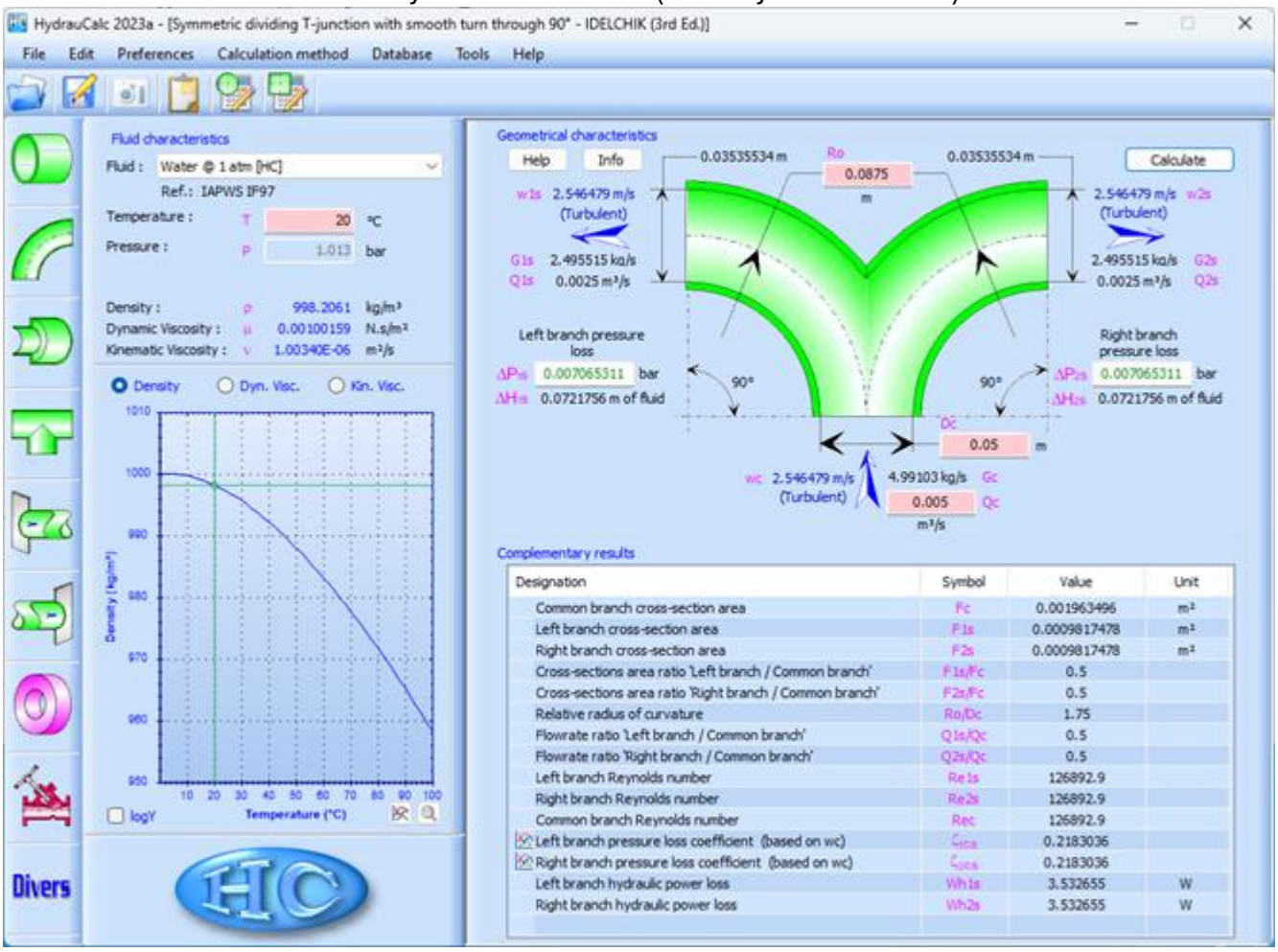
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- flow regime: turbulent ($Re_c \geq 10^4$)
- curvature angle of each bend: 90°
- flowrate ratio: $(Q_{1s}/Q_c) = (Q_{2s}/Q_c) = 0.5$
- cross-sectional area ratio: $(F_{1s}/F_c) = (F_{2s}/F_c) = 0.5$

Example of application:

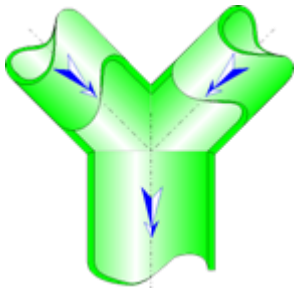


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.4.11 Symmetric combining Y-junction with branches of unequal sections

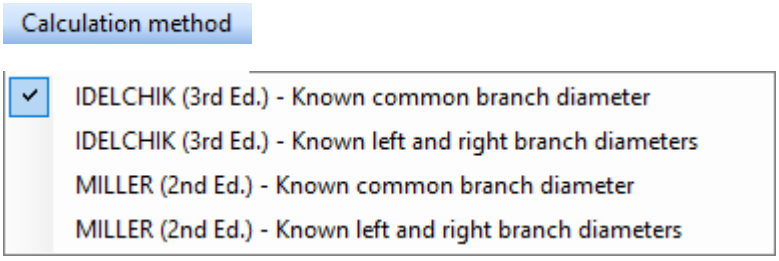
Circular cross-section



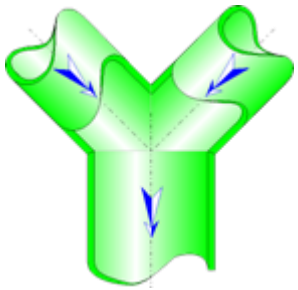
For the calculation of the pressure loss coefficient of symmetric combining Y-junctions. For this component, the diameters of the right and left branches are equal, and the section of the common branch is equal to the sum of the sections of the right and left branches. The user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.) – Know common branch diameter"



2.4.11.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric combining Y-junction. For this component, the diameters of the right and left branches are equal, and the common branch area is equal to the sum of the areas of the right and left branches.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

■ Case of known common branch diameter

Cross-sectional area of the common branch (m^2):

$$F_c = \pi \cdot \frac{D_c^2}{4}$$

Cross-sectional area of the right branch (m^2):

$$F_{1s} = \frac{F_c}{2}$$

Cross-sectional area of the left branch (m^2):

$$F_{2s} = \frac{F_c}{2}$$

Diameter of the right branch (m) :

$$D_{1s} = \sqrt{\frac{4 \cdot F_{1s}}{\pi}}$$

Diameter of the left branch (m) :

$$D_{2s} = \sqrt{\frac{4 \cdot F_{2s}}{\pi}}$$

■ Case of known left and right branch diameters

Cross-sectional area of the right branch (m²) :

$$F_{1s} = \pi \cdot \frac{D_{1s}^{\ 2}}{4}$$

Cross-sectional area of the left branch (m²) :

$$F_{2s} = \pi \cdot \frac{D_{2s}^{\ 2}}{4}$$

Cross-sectional area of the common branch (m²) :

$$F_c = 2 \cdot F_{1s} = 2 \cdot F_{2s}$$

Diameter of the common branch (m) :

$$D_c = \sqrt{\frac{4 \cdot F_c}{\pi}}$$

Volume flow rate in the common branch (m³/s):

$$Q_c = Q_{1s} + Q_{2s}$$

Mean velocity in the right branch (m/s):

$$w_{1s} = \frac{Q_{1s}}{F_{1s}}$$

Mean velocity in the left branch (m/s):

$$w_{2s} = \frac{Q_{2s}}{F_{2s}}$$

Mean velocity in the common branch (m/s):

$$w_c = \frac{Q_c}{F_c}$$

Mass flow rate in the right branch (kg/s):

$$G_{1s} = Q_{1s} \cdot \rho$$

Mass flow rate in the left branch (kg/s):

$$G_{2s} = Q_{2s} \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_c = Q_c \cdot \rho$$

Reynolds number in the right branch:

$$\mathrm{Re}_{1s} = \frac{w_{1s} \cdot D_s}{\nu}$$

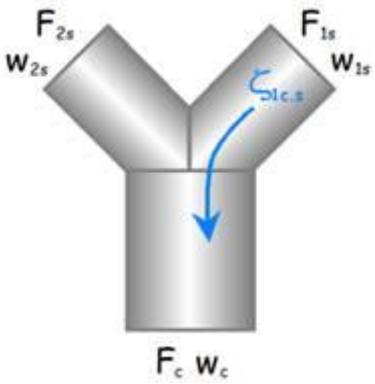
Reynolds number in the left branch:

$$\mathrm{Re}_{2s} = \frac{w_{2s} \cdot D_s}{\nu}$$

Reynolds number in the common branch:

$$Re_c = \frac{w_c \cdot D_c}{\nu}$$

Pressure loss coefficient of the right branch (based on mean velocity in the common branch):



- Angle $\alpha = 15°$

$$\zeta_{1c.s} = 7.3 \cdot \frac{Q_{1s}}{Q_c} + 0.07 \cdot \left[\left(\frac{Q_{1s}}{Q_c} \right)^4 + \left(1 - \frac{Q_{1s}}{Q_c} \right)^4 \right] - 3.7 \cdot \left(\frac{Q_{1s}}{Q_c} \right)^2 - 2.64$$

([1] diagram 7.30)

- Angle $\alpha = 30°$

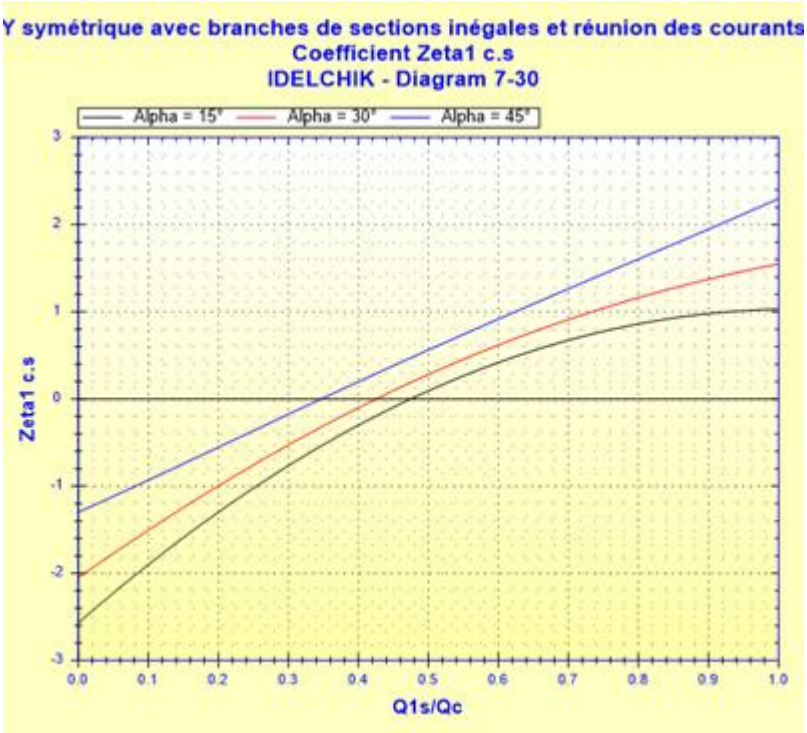
$$\zeta_{1c.s} = 6.6 \cdot \frac{Q_{1s}}{Q_c} + 0.25 \cdot \left[\left(\frac{Q_{1s}}{Q_c} \right)^4 + \left(1 - \frac{Q_{1s}}{Q_c} \right)^4 \right] - 3.0 \cdot \left(\frac{Q_{1s}}{Q_c} \right)^2 - 2.30$$

([1] diagram 7.30)

- Angle $\alpha = 45°$

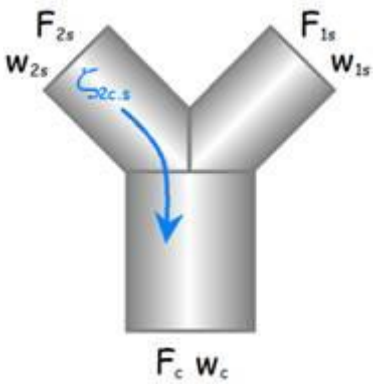
$$\zeta_{1c.s} = 5.6 \cdot \frac{Q_{1s}}{Q_c} + 0.50 \cdot \left[\left(\frac{Q_{1s}}{Q_c} \right)^4 + \left(1 - \frac{Q_{1s}}{Q_c} \right)^4 \right] - 2.0 \cdot \left(\frac{Q_{1s}}{Q_c} \right)^2 - 1.80$$

([1] diagram 7.30)



For any angles α between 15 ° and 45 °, the coefficient $\zeta_{1c.s}$ is obtained by linear interpolation between the values of $\zeta_{1c.s}$ calculated at 15 °, 30 ° and 45 °.

Pressure loss coefficient of the left branch (based on mean velocity in the common branch):



Note: for the left branch, the formulas are the same as those of the right branch, with subscript 2 instead of subscript 1.

- Angle $\alpha = 15°$

$$\zeta_{2c.s} = 7.3 \cdot \frac{Q_{2s}}{Q_c} + 0.07 \cdot \left[\left(\frac{Q_{2s}}{Q_c} \right)^4 + \left(1 - \frac{Q_{2s}}{Q_c} \right)^4 \right] - 3.7 \cdot \left(\frac{Q_{2s}}{Q_c} \right)^2 - 2.64$$

([1] diagram 7.30)

- Angle $\alpha = 30°$

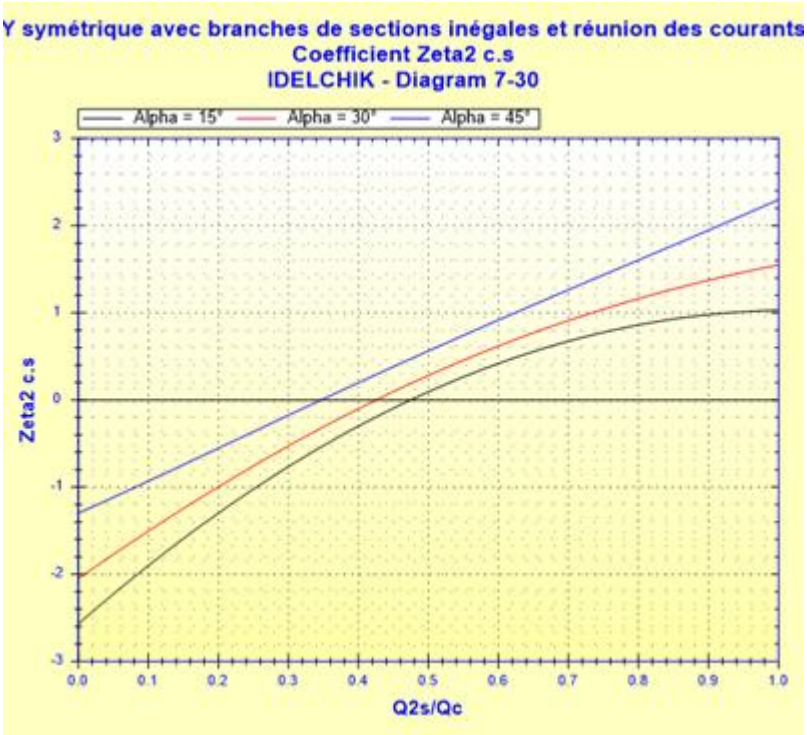
$$\zeta_{2c.s} = 6.6 \cdot \frac{Q_{2s}}{Q_c} + 0.25 \cdot \left[\left(\frac{Q_{2s}}{Q_c} \right)^4 + \left(1 - \frac{Q_{2s}}{Q_c} \right)^4 \right] - 3.0 \cdot \left(\frac{Q_{2s}}{Q_c} \right)^2 - 2.30$$

([1] diagram 7.30)

- Angle $\alpha = 45°$

$$\zeta_{2c.s} = 5.6 \cdot \frac{Q_{2s}}{Q_c} + 0.50 \cdot \left[\left(\frac{Q_{2s}}{Q_c} \right)^4 + \left(1 - \frac{Q_{2s}}{Q_c} \right)^4 \right] - 2.0 \cdot \left(\frac{Q_{2s}}{Q_c} \right)^2 - 1.80$$

([1] diagram 7.30)



For any angles α between 15 ° and 45 °, the coefficient $\zeta_{2c.s}$ is obtained by linear interpolation between the values of $\zeta_{2c.s}$ calculated at 15 °, 30 ° and 45 °.

Pressure loss in the right branch (Pa):

$$\Delta P_{1c.s} = \zeta_{1c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Pressure loss in the left branch (Pa):

$$\Delta P_{2c.s} = \zeta_{2c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{1c.s} = \zeta_{1c.s} \cdot \frac{w_c^2}{2 \cdot g}$$

Head loss of fluid in the left branch (m):

$$\Delta H_{2c.s} = \zeta_{2c.s} \cdot \frac{w_c^2}{2 \cdot g}$$

Hydraulic power loss in the right branch (W):

$$Wh_{1s} = \Delta P_{1c.s} \cdot Q_{1s}$$

Hydraulic power loss in the left branch (W):

$$Wh_{2s} = \Delta P_{2c.s} \cdot Q_{2s}$$

Symbols, Definitions, SI Units:

α	Half angle of the right and left branches (°)
D_s	Diameter of the right and left branches (m)
D_c	Diameter of the common branch (m)
F_{1s}	Cross-sectional area of the right branch (m^2)
F_{2s}	Cross-sectional area of the left branch (m^2)
F_c	Cross-sectional area of the common branch (m^2)
Q_{1s}	Volume flow rate in the right branch (m^3/s)
w_{1s}	Mean velocity in the right branch (m/s)
Q_{2s}	Volume flow rate in the left branch (m^3/s)
w_{2s}	Mean velocity in the left branch (m/s)
Q_c	Volume flow rate in the common branch (m^3/s)
w_c	Mean velocity in the common branch (m/s)
G_{1s}	Mass flow rate in the right branch (kg/s)
G_{2s}	Mass flow rate in the left branch (kg/s)
G_c	Mass flow rate in the common branch (kg/s)

Re_{1s} Reynolds number in the right branch ()

Re_{2s} Reynolds number in the left branch ()

Re_c Reynolds number in the common branch ()

$\zeta_{1c.s}$ Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

$\zeta_{2c.s}$ Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

ΔP_{1s} Pressure loss in the right branch (Pa)

ΔP_{2s} Pressure loss in the left branch (Pa)

ΔH_{1s} Head loss of fluid in the right branch (m)

ΔH_{2s} Head loss of fluid in the left branch (m)

Wh_{1s} Hydraulic power loss in the right branch (W)

Wh_{2s} Hydraulic power loss in the left branch (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

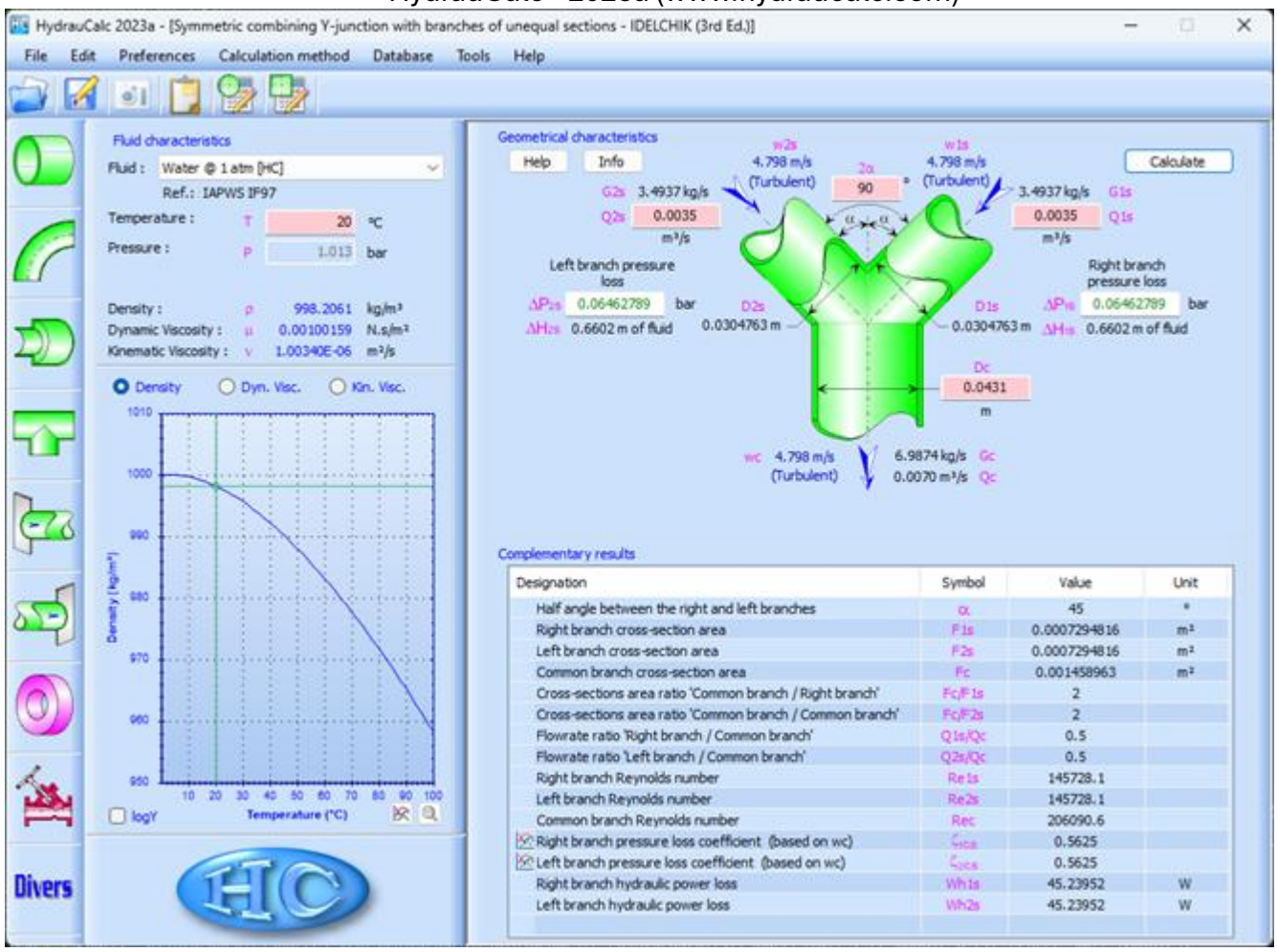
g Gravitational acceleration (m/s²)

Validity range:

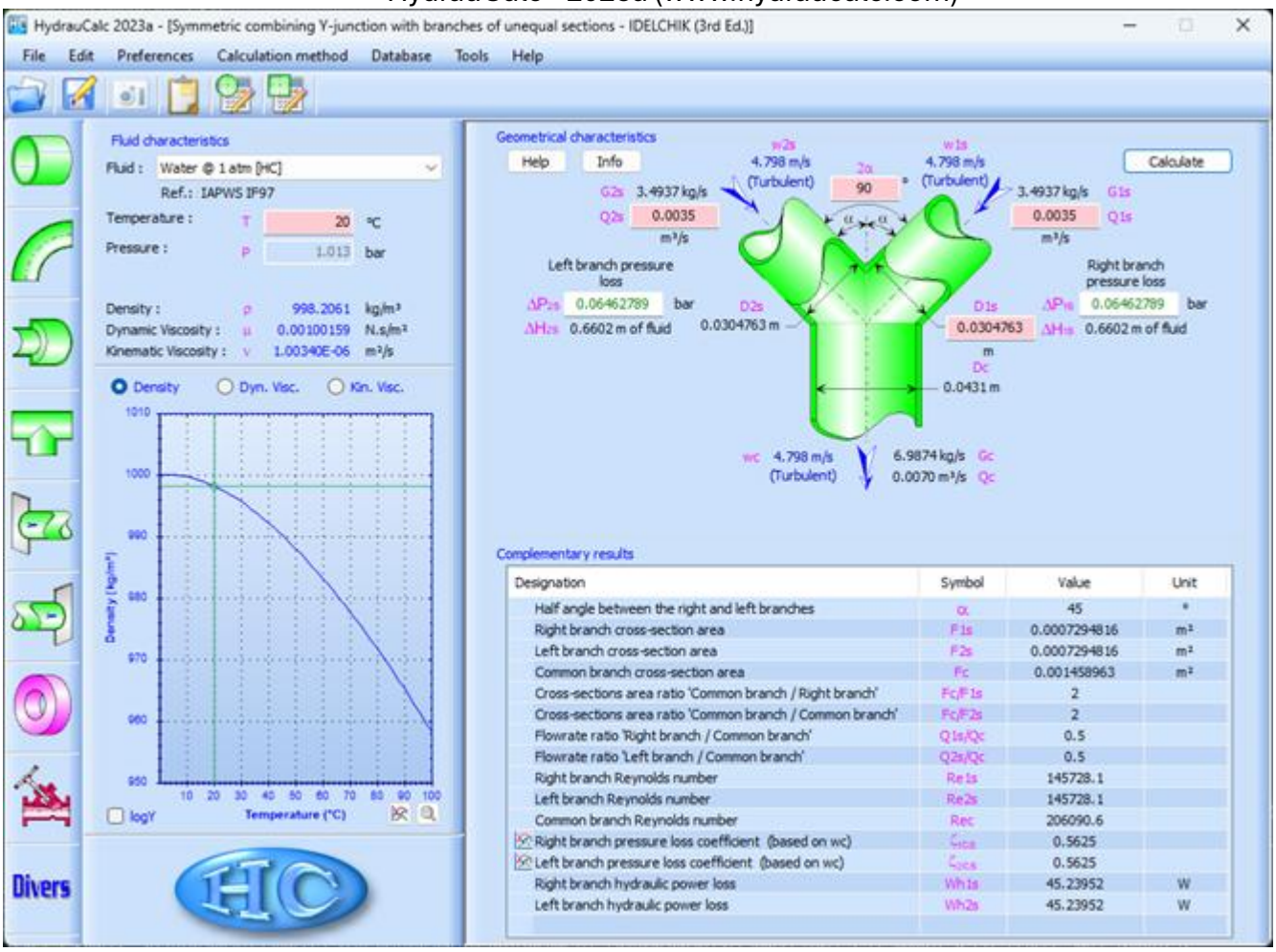
- flow regime: turbulent ($Re_c \geq 10^4$)
- angle between the right and left branches: between 30° and 90° ($15° \leq \alpha \leq 45°$)
- common branch area equal to the sum of the areas of the right and left branches ($F_c = F_{1s} + F_{2s}$ and $F_{1s} = F_{2s}$)

Example of application:

■ Case of known common branch diameters



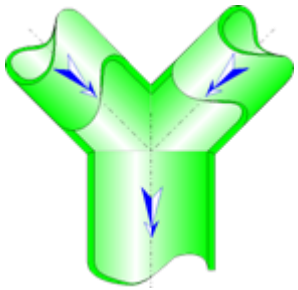
■ Case of known left and right branch diameters



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.4.11.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric combining Y-junction. For this component, the diameters of the right and left branches are equal, and the section of the common branch is equal to the sum of the sections of the right and left branches.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

■ Case of known common branch diameter

Cross-sectional area of the common branch (m^2):

$$A_3 = \pi \cdot \frac{D_3^2}{4}$$

Cross-sectional area of the left branch (m^2):

$$A_1 = \frac{A_3}{2}$$

Cross-sectional area of the right branch (m^2):

$$A_2 = \frac{A_3}{2}$$

Diameter of the left branch (m) :

$$D_1 = \sqrt{\frac{4 \cdot A_1}{\pi}}$$

Diameter of the right branch (m) :

$$D_2 = \sqrt{\frac{4 \cdot A_2}{\pi}}$$

■ Case of known left and right branch diameters

Cross-sectional area of the left branch (m^2) :

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Cross-sectional area of the right branch (m^2) :

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Cross-sectional area of the common branch (m^2) :

$$A_3 = 2 \cdot A_1 = 2 \cdot A_2$$

Diameter of the common branch (m) :

$$D_3 = \sqrt{\frac{4 \cdot A_3}{\pi}}$$

Volume flow rate in the common branch (m^3/s):

$$Q_3 = Q_1 + Q_2$$

Mean velocity in the left branch (m/s):

$$U_1 = \frac{Q_1}{A_1}$$

Mean velocity in the right branch (m/s):

$$U_2 = \frac{Q_2}{A_2}$$

Mean velocity in the common branch (m/s):

$$U_3 = \frac{Q_3}{A_3}$$

Mass flow rate in the left branch (kg/s):

$$G_1 = Q_1 \cdot \rho$$

Mass flow rate in the right branch (kg/s):

$$G_2 = Q_2 \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_3 = Q_3 \cdot \rho$$

Reynolds number in the left branch:

$$\mathrm{Re}_1 = \frac{U_1 \cdot D_1}{\nu}$$

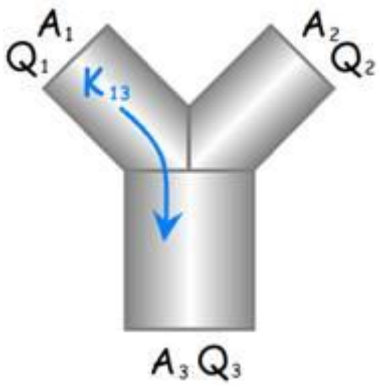
Reynolds number in the right branch:

$$\mathrm{Re}_2 = \frac{U_2 \cdot D_2}{\nu}$$

Reynolds number in the common branch:

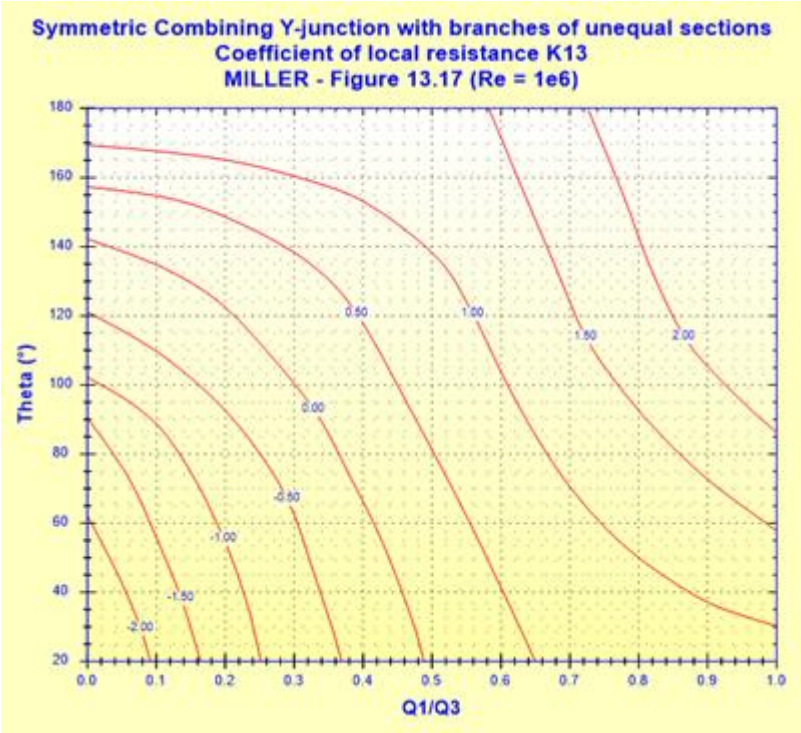
$$\mathrm{Re}_3 = \frac{U_3 \cdot D_3}{\nu}$$

Pressure loss coefficient of the left branch (based on mean velocity in the common branch):

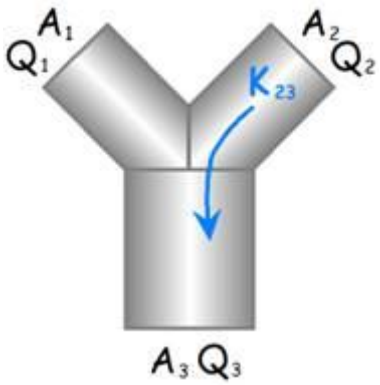


$$K_{13} = f\left(\frac{Q_1}{Q_3}, \theta\right)$$

([1] figure 13.17)

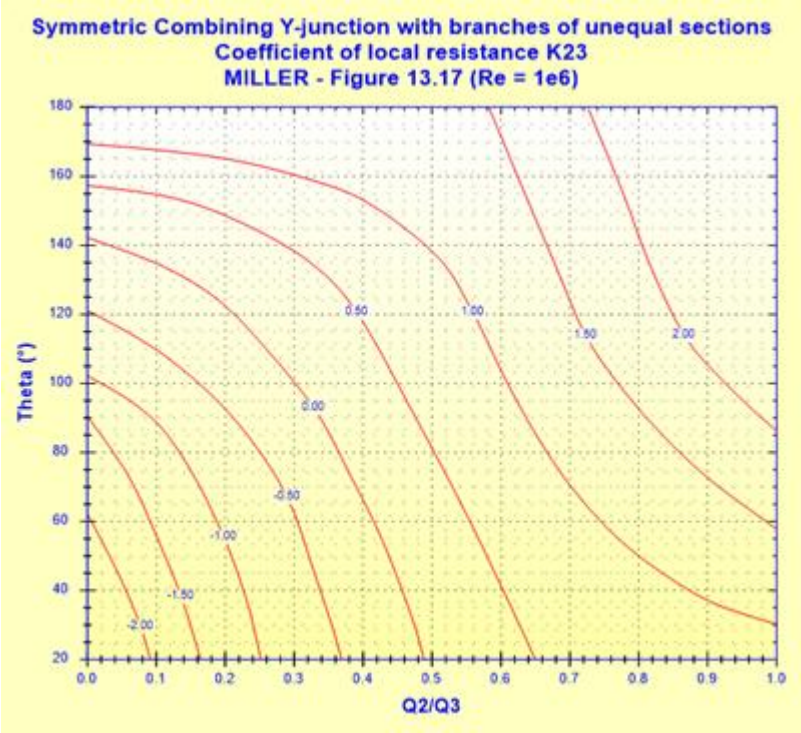


Pressure loss coefficient of the right branch (based on mean velocity in the common branch):



$$K_{23} = f\left(\frac{Q_2}{Q_3}, \theta\right)$$

([1] figure 13.17)



Pressure loss in the left branch (Pa):

$$\Delta P_{13} = K_{13} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.1)

Pressure loss in the right branch (Pa):

$$\Delta P_{23} = K_{23} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.2)

Head loss of fluid in the left branch (m):

$$\Delta H_{13} = K_{13} \cdot \frac{U_3^2}{2 \cdot g}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{23} = K_{23} \cdot \frac{U_3^2}{2 \cdot g}$$

Hydraulic power loss in the left branch (W):

$$Wh_{13} = \Delta P_{13} \cdot Q_1$$

Hydraulic power loss in the right branch (W):

$$Wh_{23} = \Delta P_{23} \cdot Q_2$$

Symbols, Definitions, SI Units:

θ	Angle of the right and left branches (°)
D_1	Diameter of the left branch (m)
D_2	Diameter of the right branch (m)
D_3	Diameter of the common branch (m)
A_1	Cross-sectional area of the left branch (m^2)
A_2	Cross-sectional area of the right branch (m^2)
A_3	Cross-sectional area of the common branch (m^2)
Q_1	Volume flow rate in the left branch (m^3/s)
U_1	Mean velocity in the left branch (m/s)
Q_2	Volume flow rate in the right branch (m^3/s)
U_2	Mean velocity in the right branch (m/s)
Q_3	Volume flow rate in the common branch (m^3/s)
U_3	Mean velocity in the common branch (m/s)
G_1	Mass flow rate in the left branch (kg/s)
G_2	Mass flow rate in the right branch (kg/s)

G_3 Mass flow rate in the common branch (kg/s)

Re_1 Reynolds number in the left branch ()

Re_2 Reynolds number in the right branch ()

Re_3 Reynolds number in the common branch ()

K_{13} Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

K_{23} Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

ΔP_{13} Pressure loss in the left branch (Pa)

ΔP_{23} Pressure loss in the right branch (Pa)

ΔH_{13} Head loss of fluid in the left branch (m)

ΔH_{23} Head loss of fluid in the right branch (m)

Wh_{13} Hydraulic power loss in the left branch (W)

Wh_{23} Hydraulic power loss in the right branch (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

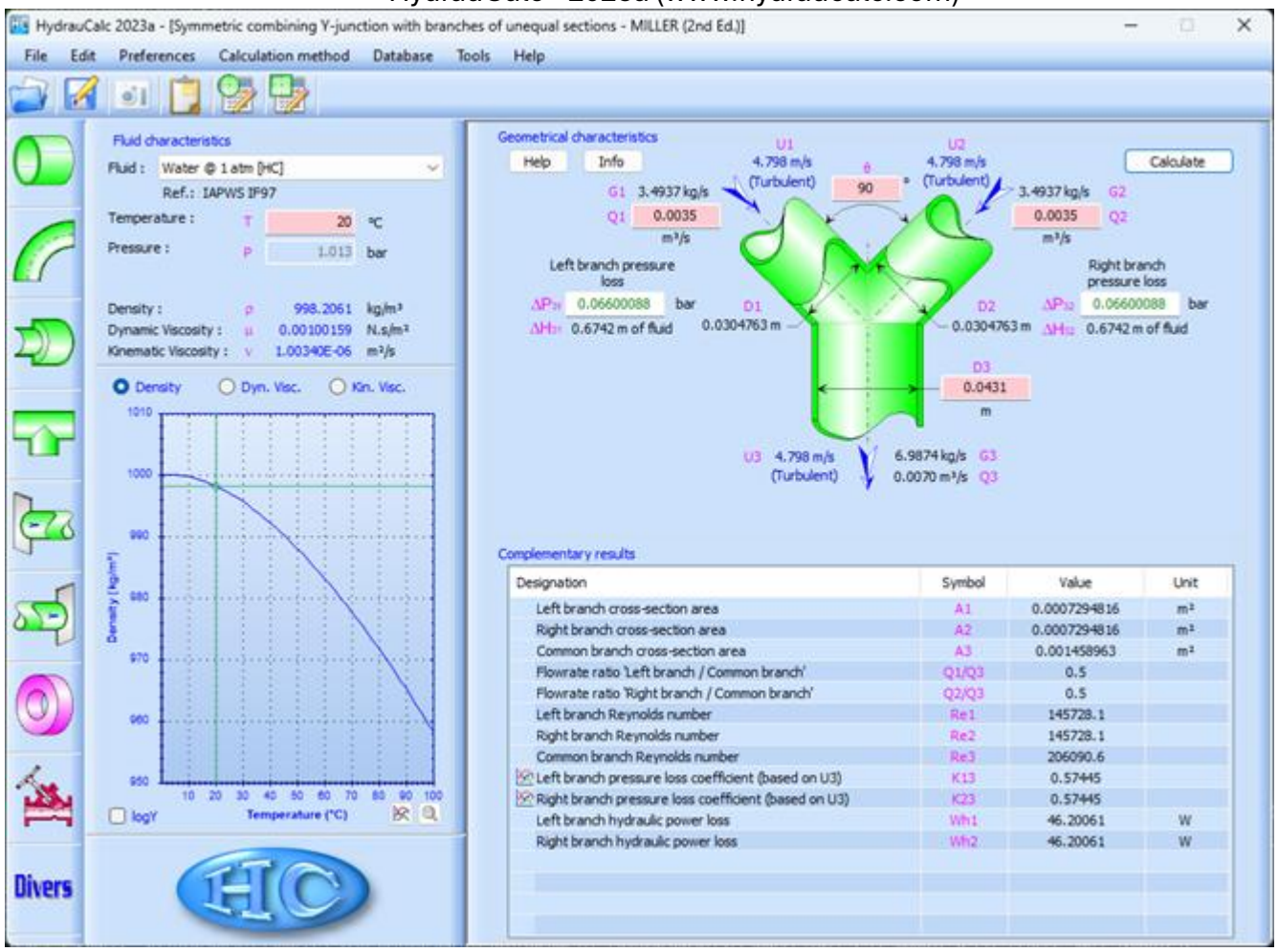
g Gravitational acceleration (m/s²)

Validity range:

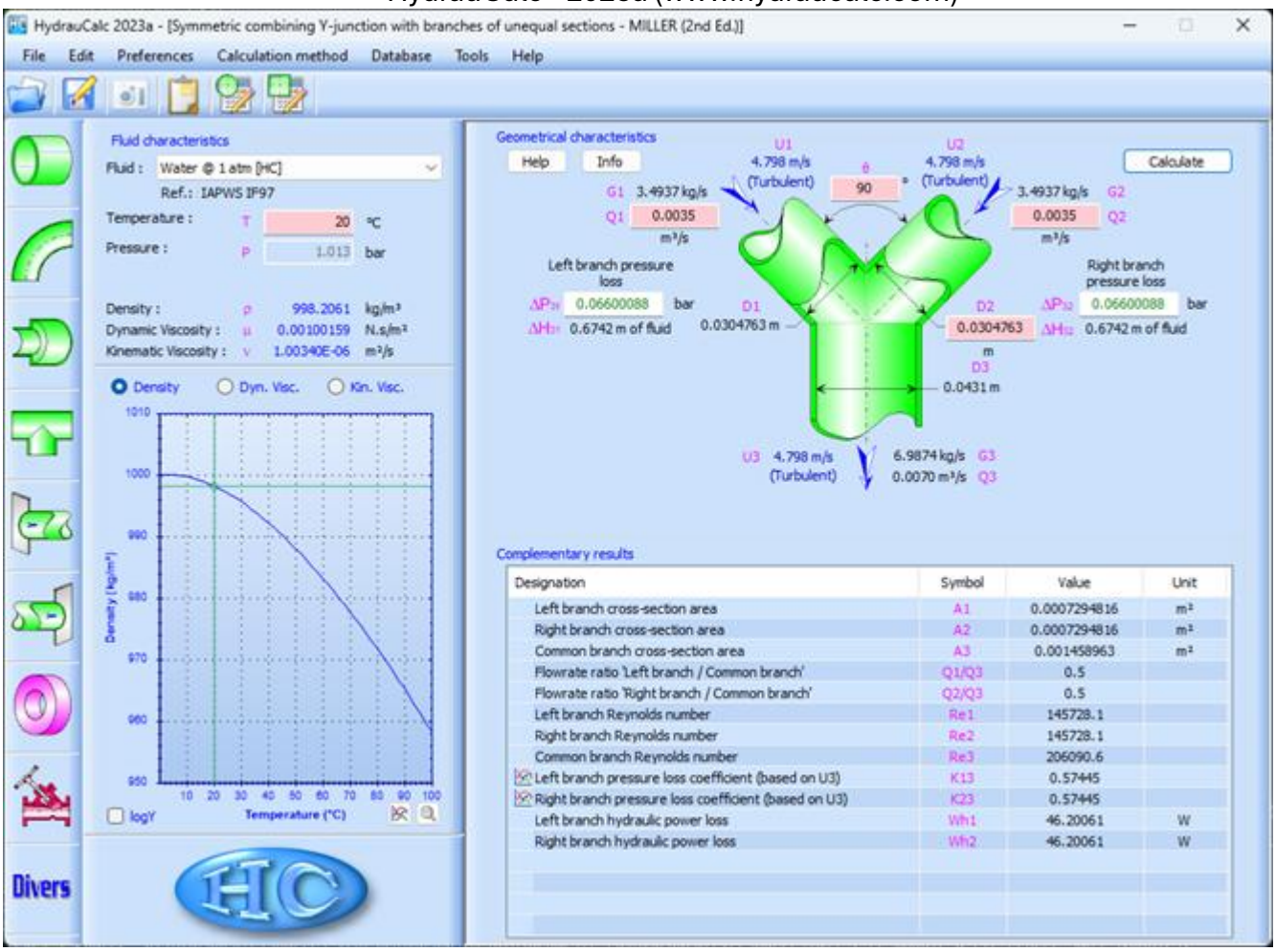
- flow regime: turbulent ($Re_3 \geq 10^5$)
- angle of the right and left branches: between 20° and 180° ($20° \leq \theta \leq 180°$)
- common branch area: equal to the sum of the areas of the right and left branches ($A_3 = A_1 + A_2$ and $A_1 = A_2$)

Example of application:

■ Case of known common branch diameter



■ Case of known left and right branch diameters



References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

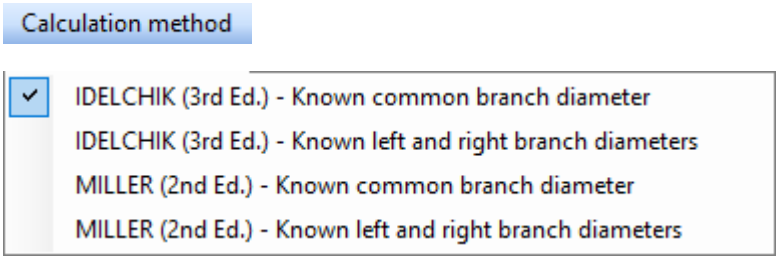
2.4.12 Symmetric dividing Y-junction with branches of unequal sections

Circular cross-section

For the calculation of the pressure loss coefficient of symmetric combining Y-junctions. For this component, the diameters of the right and left branches are equal, and the section of the common branch is equal to the sum of the sections of the right and left branches. The user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.) – Know common branch diameter"



2.4.12.1 IDELCHIK

Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric dividing Y-junction. For this component, the diameters of the right and left branches are equal, and the common branch area is equal to the sum of the areas of the right and left branches.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

■ Case of known common branch diameter

Cross-sectional area of the common branch (m^2):

$$F_c = \pi \cdot \frac{D_c^2}{4}$$

Cross-sectional area of the right branch (m^2):

$$F_{1s} = \frac{F_c}{2}$$

Cross-sectional area of the left branch (m^2):

$$F_{2s} = \frac{F_c}{2}$$

Diameter of the right branch (m) :

$$D_{1s} = \sqrt{\frac{4 \cdot F_{1s}}{\pi}}$$

Diameter of the left branch (m) :

$$D_{2s} = \sqrt{\frac{4 \cdot F_{2s}}{\pi}}$$

■ Case of known left and right branch diameters

Cross-sectional area of the right branch (m²) :

$$F_{1s} = \pi \cdot \frac{D_{1s}^{\ 2}}{4}$$

Cross-sectional area of the left branch (m²) :

$$F_{2s} = \pi \cdot \frac{D_{2s}^{\ 2}}{4}$$

Cross-sectional area of the common branch (m²) :

$$F_c = 2 \cdot F_{1s} = 2 \cdot F_{2s}$$

Diameter of the common branch (m) :

$$D_c = \sqrt{\frac{4 \cdot F_c}{\pi}}$$

Volume flow rate in the common branch (m³/s):

$$Q_c = Q_{1s} + Q_{2s}$$

Mean velocity in the right branch (m/s):

$$w_{1s} = \frac{Q_{1s}}{F_{1s}}$$

Mean velocity in the left branch (m/s):

$$w_{2s} = \frac{Q_{2s}}{F_{2s}}$$

Mean velocity in the common branch (m/s):

$$w_c = \frac{Q_c}{F_c}$$

Mass flow rate in the right branch (kg/s):

$$G_{1s} = Q_{1s} \cdot \rho$$

Mass flow rate in the left branch (kg/s):

$$G_{2s} = Q_{2s} \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_c = Q_c \cdot \rho$$

Reynolds number in the right branch:

$$\mathrm{Re}_{1s} = \frac{w_{1s} \cdot D_s}{\nu}$$

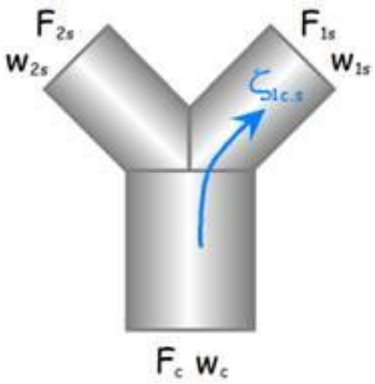
Reynolds number in the left branch:

$$\mathrm{Re}_{2s} = \frac{w_{2s} \cdot D_s}{\nu}$$

Reynolds number in the common branch:

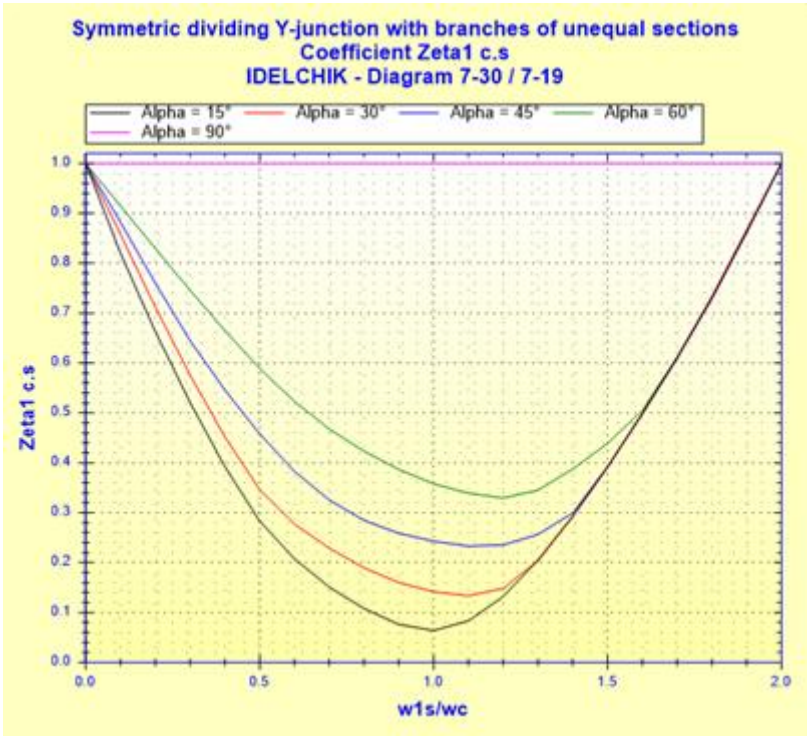
$$Re_c = \frac{w_c \cdot D_c}{\nu}$$

Pressure loss coefficient of the right branch (based on mean velocity in the common branch):

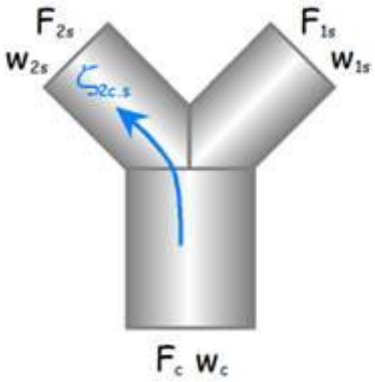


$$\zeta_{1c.s} = f\left(\frac{W_{1s}}{W_c}, \alpha\right)$$

([1] diagram 7.30)

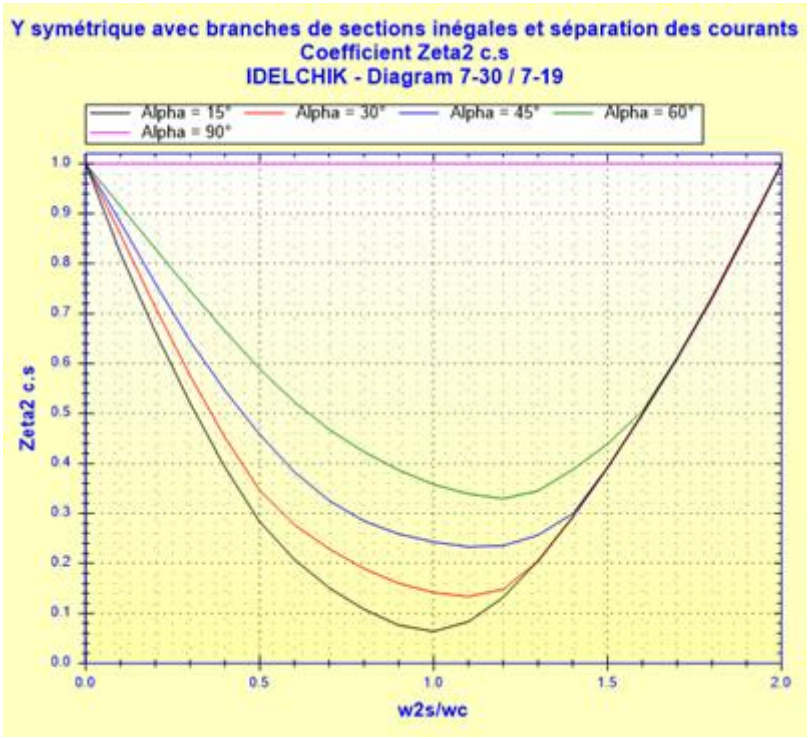


Pressure loss coefficient of the left branch (based on mean velocity in the common branch):



$$\zeta_{2c.s} = f\left(\frac{W_{2s}}{W_c}, \alpha\right)$$

([1] diagramme 7.30)



Pressure loss in the right branch (Pa):

$$\Delta P_{1c.s} = \zeta_{1c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Pressure loss in the left branch (Pa):

$$\Delta P_{2c.s} = \zeta_{2c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{1c.s} = \zeta_{1c.s} \cdot \frac{w_c^{\,2}}{2 \cdot g}$$

Head loss of fluid in the left branch (m):

$$\Delta H_{2c.s} = \zeta_{2c.s} \cdot \frac{w_c^{\,2}}{2 \cdot g}$$

Hydraulic power loss in the right branch (W):

$$Wh_{1s} = \Delta P_{1c.s} \cdot Q_{1s}$$

Hydraulic power loss in the left branch (W):

$$Wh_{2s} = \Delta P_{2c.s} \cdot Q_{2s}$$

Symbols, Definitions, SI Units:

α	Half angle of the right and left branches (°)
D_s	Diameter of the right and left branches (m)
D_c	Diameter of the common branch (m)
F_{1s}	Cross-sectional area of the right branch (m^2)
F_{2s}	Cross-sectional area of the left branch (m^2)
F_c	Cross-sectional area of the common branch (m^2)
Q_{1s}	Volume flow rate in the right branch (m^3/s)
w_{1s}	Mean velocity in the right branch (m/s)
Q_{2s}	Volume flow rate in the left branch (m^3/s)
w_{2s}	Mean velocity in the left branch (m/s)
Q_c	Volume flow rate in the common branch (m^3/s)
w_c	Mean velocity in the common branch (m/s)
G_{1s}	Mass flow rate in the right branch (kg/s)
G_{2s}	Mass flow rate in the left branch (kg/s)

G_c Mass flow rate in the common branch (kg/s)

Re_{1s} Reynolds number in the right branch ()

Re_{2s} Reynolds number in the left branch ()

Re_c Reynolds number in the common branch ()

$\zeta_{1c.s}$ Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

$\zeta_{2c.s}$ Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

ΔP_{1s} Pressure loss in the right branch (Pa)

ΔP_{2s} Pressure loss in the left branch (Pa)

ΔH_{1s} Head loss of fluid in the right branch (m)

ΔH_{2s} Head loss of fluid in the left branch (m)

Wh_{1s} Hydraulic power loss in the right branch (W)

Wh_{2s} Hydraulic power loss in the left branch (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

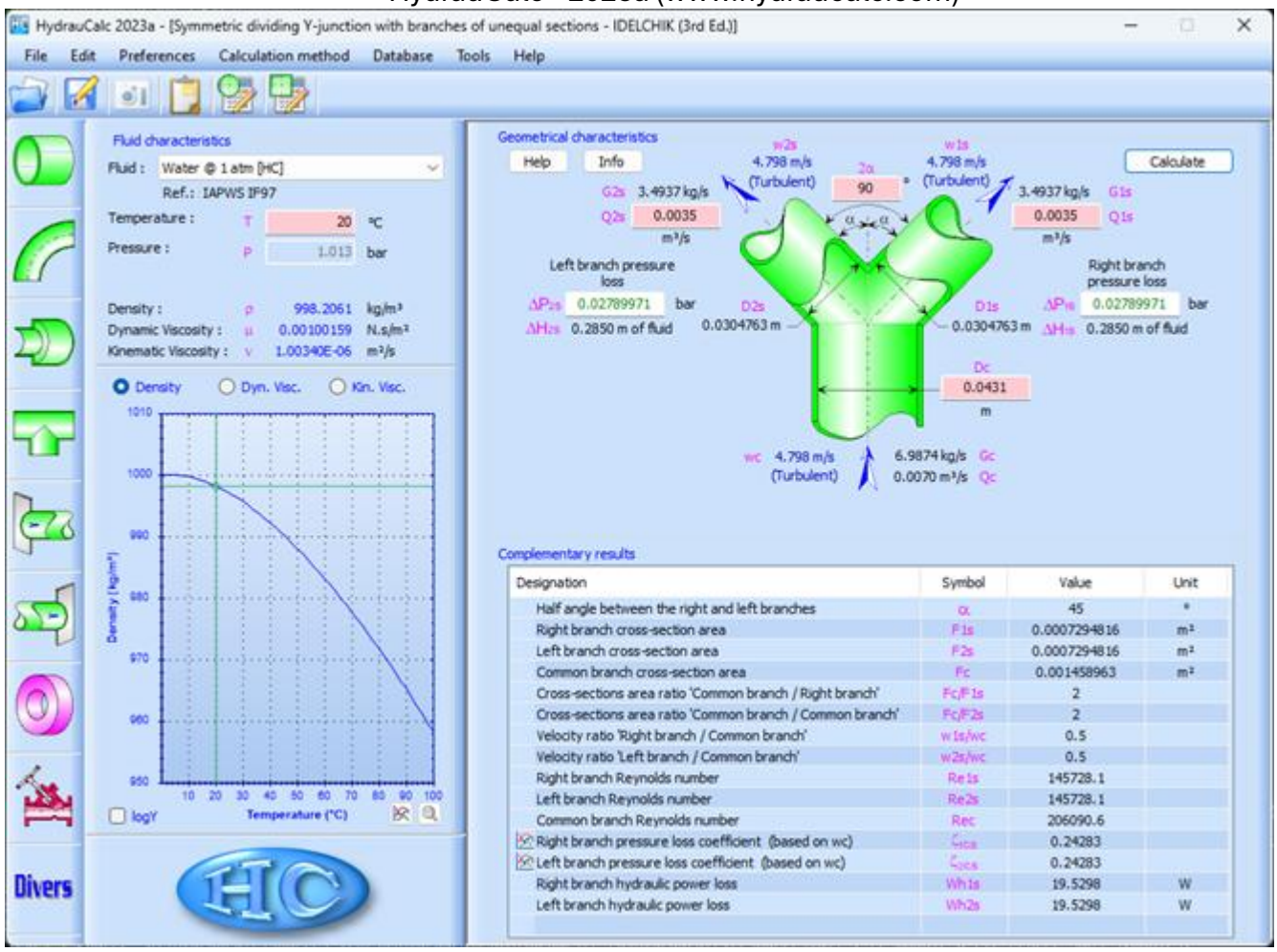
g Gravitational acceleration (m/s²)

Validity range:

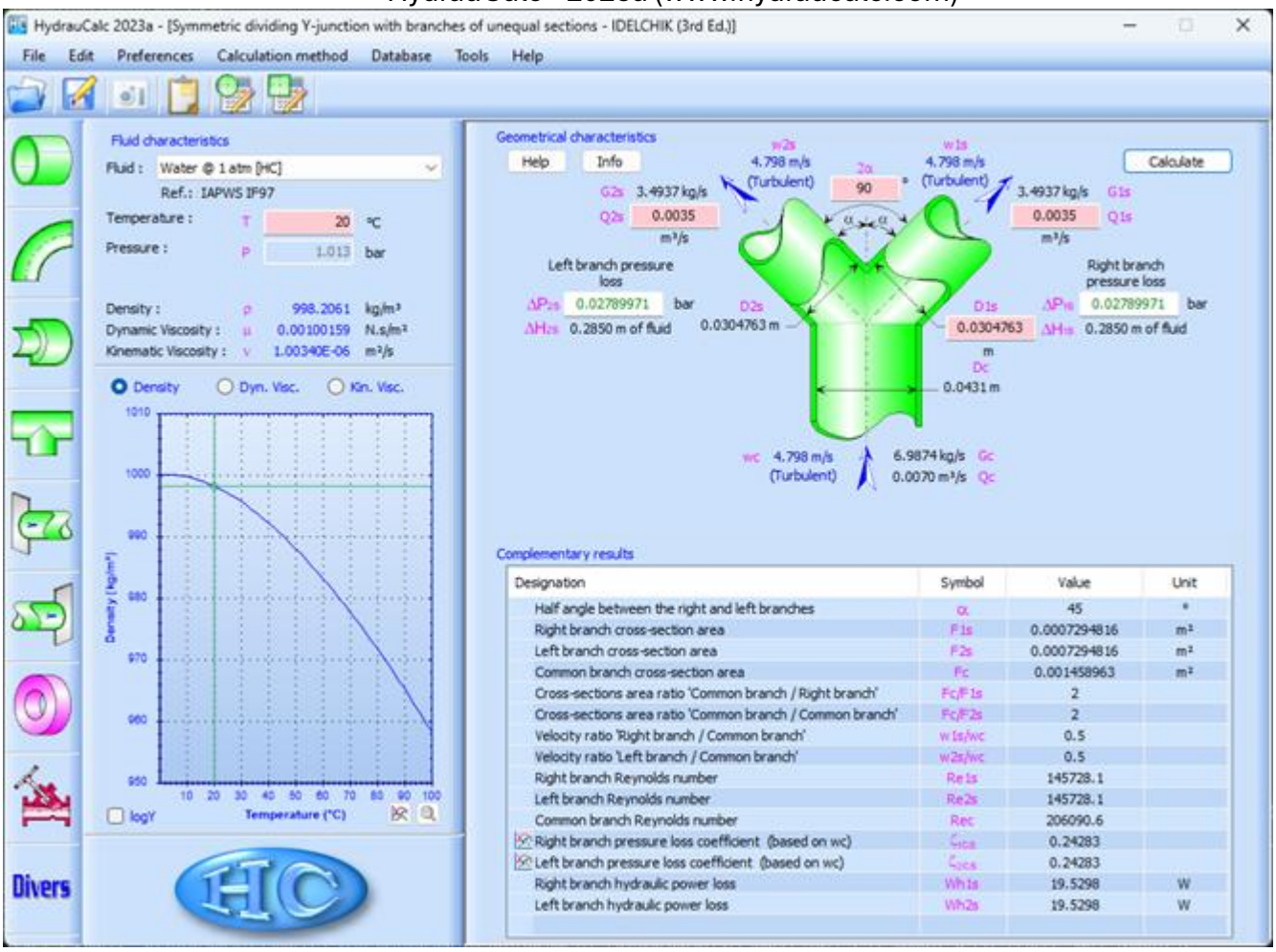
- turbulent flow regime ($Re_c \geq 10^4$)
- angle between the right and left branches between 30° and 180° ($15° \leq \alpha \leq 90°$)
- common branch area equal to the sum of the areas of the right and left branches ($F_c = F_{1s} + F_{2s}$ and $F_{1s} = F_{2s}$)

Example of application:

■ Case of known common branch diameters



■ Case of known left and right branch diameters



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.4.12.2 MILLER

Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric dividing Y-junction. For this component, the diameters of the right and left branches are equal, and the common branch area is equal to the sum of the areas of the right and left branches.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

■ Case of known common branch diameter

Cross-sectional area of the common branch (m^2):

$$A_3 = \pi \cdot \frac{D_3^2}{4}$$

Cross-sectional area of the left branch (m^2):

$$A_1 = \frac{A_3}{2}$$

Cross-sectional area of the right branch (m^2):

$$A_2 = \frac{A_3}{2}$$

Diameter of the left branch (m) :

$$D_1 = \sqrt{\frac{4 \cdot A_1}{\pi}}$$

Diameter of the right branch (m) :

$$D_2 = \sqrt{\frac{4 \cdot A_2}{\pi}}$$

■ Case of known left and right branch diameters

Cross-sectional area of the left branch (m²) :

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Cross-sectional area of the right branch (m²) :

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Cross-sectional area of the common branch (m²) :

$$A_3 = 2 \cdot A_1 = 2 \cdot A_2$$

Diameter of the common branch (m) :

$$D_3 = \sqrt{\frac{4 \cdot A_3}{\pi}}$$

Volume flow rate in the common branch (m³/s):

$$Q_3 = Q_1 + Q_2$$

Mean velocity in the left branch (m/s):

$$U_1 = \frac{Q_1}{A_1}$$

Mean velocity in the right branch (m/s):

$$U_2 = \frac{Q_2}{A_2}$$

Mean velocity in the common branch (m/s):

$$U_3 = \frac{Q_3}{A_3}$$

Mass flow rate in the left branch (kg/s):

$$G_1 = Q_1 \cdot \rho$$

Mass flow rate in the right branch (kg/s):

$$G_2 = Q_2 \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_3 = Q_3 \cdot \rho$$

Reynolds number in the left branch:

$$\mathrm{Re}_1 = \frac{U_1 \cdot D_1}{\nu}$$

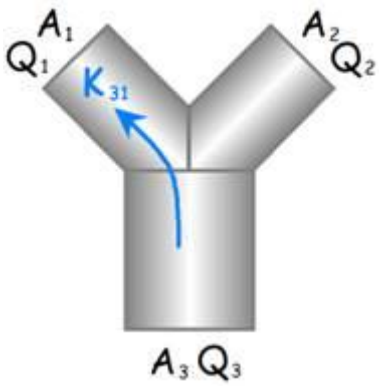
Reynolds number in the right branch:

$$\mathrm{Re}_2 = \frac{U_2 \cdot D_2}{\nu}$$

Reynolds number in the common branch:

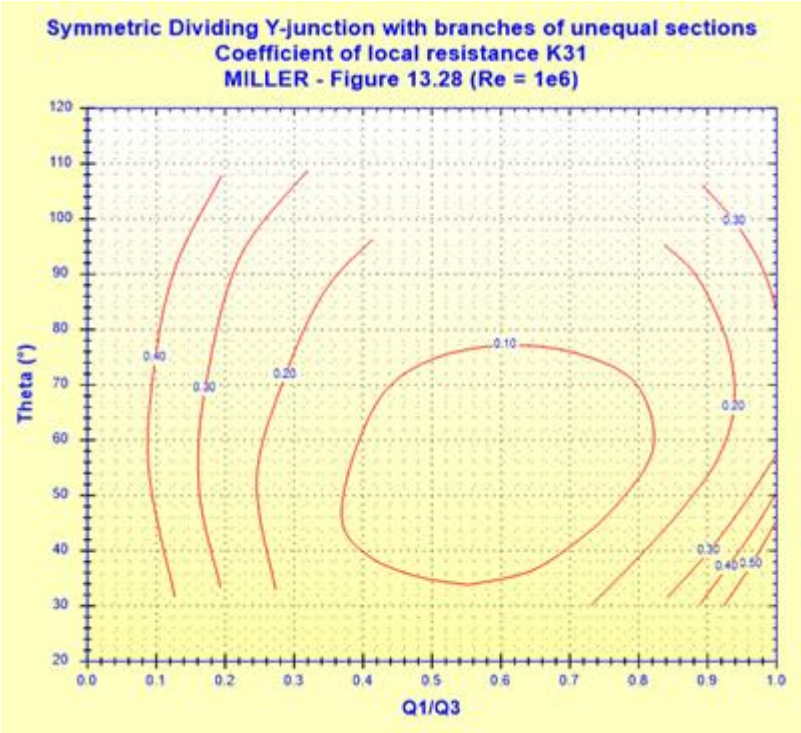
$$\mathrm{Re}_3 = \frac{U_3 \cdot D_3}{\nu}$$

Pressure loss coefficient of the left branch (based on mean velocity in the common branch):

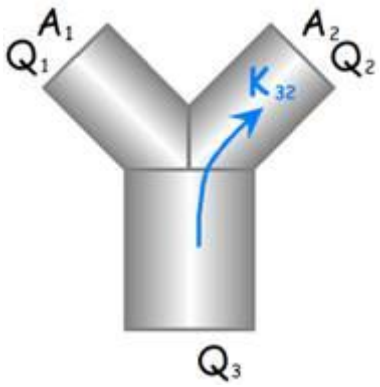


$$K_{31} = f\left(\frac{Q_1}{Q_3}, \theta\right)$$

([1] figure 13.28)

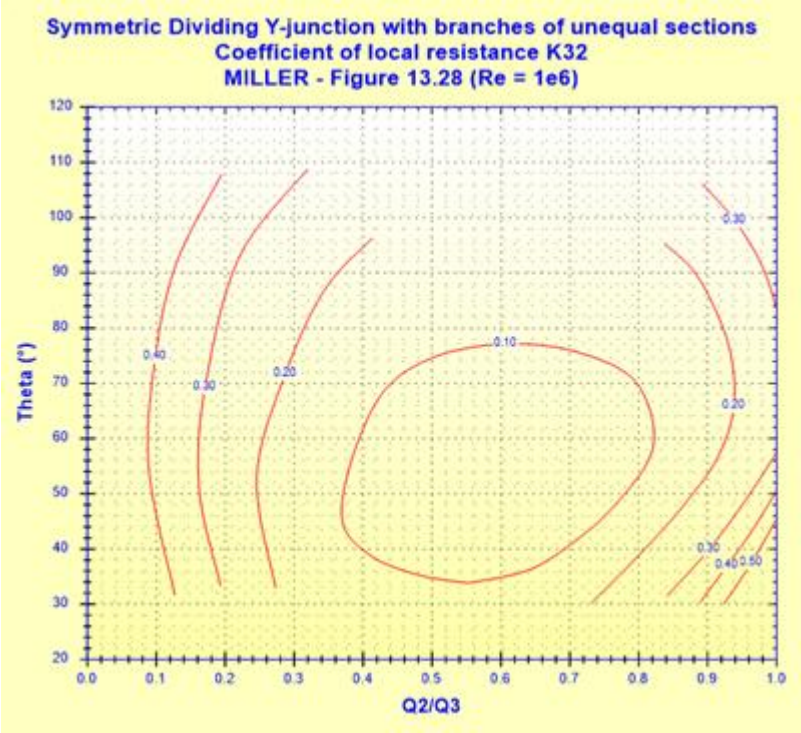


Pressure loss coefficient of the right branch (based on mean velocity in the common branch):



$$K_{32} = f\left(\frac{Q_2}{Q_3}, \theta\right)$$

([1] figure 13.28)



Pressure loss in the left branch (Pa):

$$\Delta P_{13} = K_{13} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.1)

Pressure loss in the right branch (Pa):

$$\Delta P_{23} = K_{23} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.2)

Head loss of fluid in the left branch (m):

$$\Delta H_{13} = K_{13} \cdot \frac{U_3^2}{2 \cdot g}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{23} = K_{23} \cdot \frac{U_3^2}{2 \cdot g}$$

Hydraulic power loss in the left branch (W):

$$Wh_{13} = \Delta P_{13} \cdot Q_1$$

Hydraulic power loss in the right branch (W):

$$Wh_{23} = \Delta P_{23} \cdot Q_2$$

Symbols, Definitions, SI Units:

θ	Angle of the right and left branches (°)
D_1	Diameter of the left branch (m)
D_2	Diameter of the right branch (m)
D_3	Diameter of the common branch (m)
A_1	Cross-sectional area of the left branch (m^2)
A_2	Cross-sectional area of the right branch (m^2)
A_3	Cross-sectional area of the common branch (m^2)
Q_1	Volume flow rate in the left branch (m^3/s)
U_1	Mean velocity in the left branch (m/s)
Q_2	Volume flow rate in the right branch (m^3/s)
U_2	Mean velocity in the right branch (m/s)
Q_3	Volume flow rate in the common branch (m^3/s)
U_3	Mean velocity in the common branch (m/s)
G_1	Mass flow rate in the left branch (kg/s)
G_2	Mass flow rate in the right branch (kg/s)

G_3 Mass flow rate in the common branch (kg/s)

Re_1 Reynolds number in the left branch ()

Re_2 Reynolds number in the right branch ()

Re_3 Reynolds number in the common branch ()

K_{13} Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

K_{23} Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

ΔP_{13} Pressure loss in the left branch (Pa)

ΔP_{23} Pressure loss in the right branch (Pa)

ΔH_{13} Head loss of fluid in the left branch (m)

ΔH_{23} Head loss of fluid in the right branch (m)

Wh_{13} Hydraulic power loss in the left branch (W)

Wh_{23} Hydraulic power loss in the right branch (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

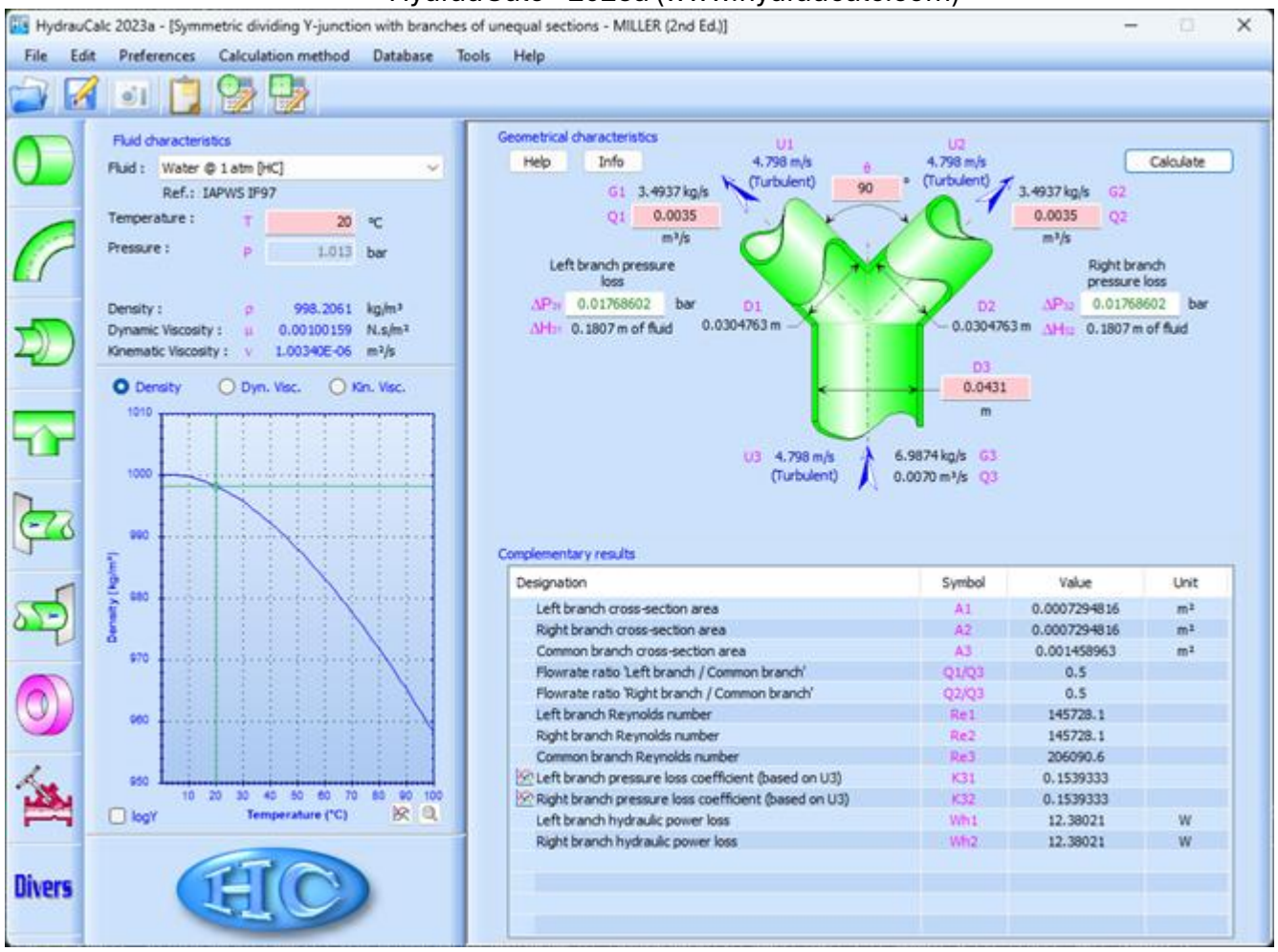
g Gravitational acceleration (m/s²)

Validity range:

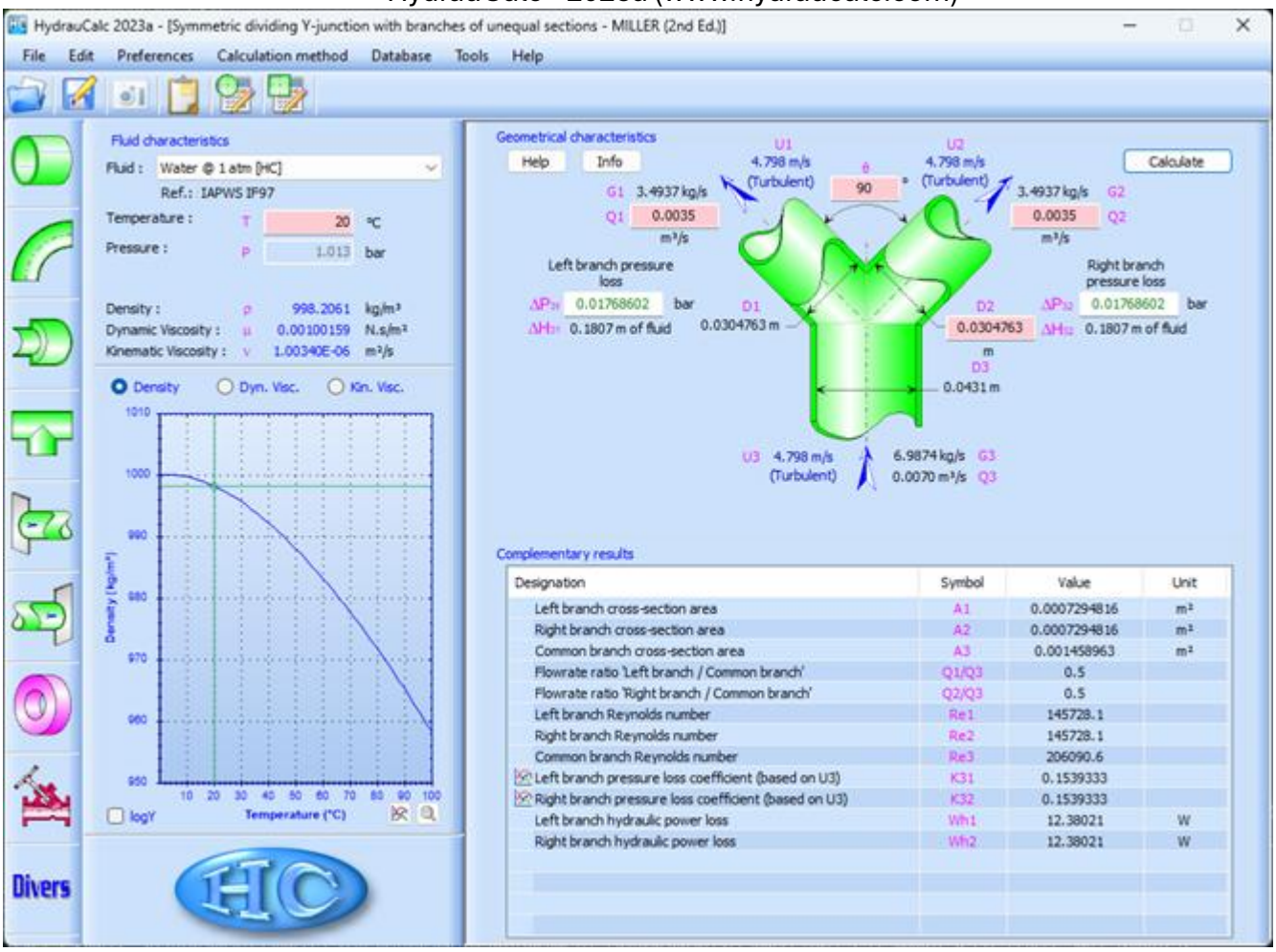
- flow regime: turbulent ($Re_3 \geq 10^5$)
- angle of the right and left branches: between 30° and 110° ($30° \leq \theta \leq 110°$)
- common branch area: equal to the sum of the areas of the right and left branches ($A_3 = A_1 + A_2$ and $A_1 = A_2$)

Example of application:

■ Case of known common branch diameter



■ Case of known left and right branch diameters



References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

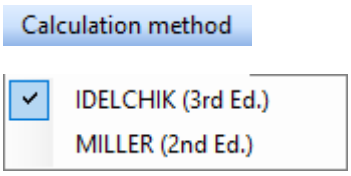
2.4.13 Symmetric combining Y-junction with branches of equal sections

Circular cross-section

For the calculation of the pressure loss coefficient of symmetric combining Y-junctions. For this component, the diameters of the right, left and common branches are equal. The user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.4.13.1 IDELCHIK

Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric combining Y-junction. For this component, the diameters of the right, left and common branches are equal.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the three branches (m^2):

$$F_{1s} = \pi \cdot \frac{D_{1s}^2}{4}$$

$$F_{2s} = \pi \cdot \frac{D_{2s}^2}{4}$$

$$F_c = \pi \cdot \frac{D_c^2}{4}$$

with $D_{1s} = D_{2s} = D_c = D$

Volume flow rate in the common branch (m^3/s):

$$Q_c = Q_{1s} + Q_{2s}$$

Mean velocity in the right branch (m/s):

$$w_{1s} = \frac{Q_{1s}}{F_{1s}}$$

Mean velocity in the left branch (m/s):

$$w_{2s} = \frac{Q_{2s}}{F_{2s}}$$

Mean velocity in the common branch (m/s):

$$w_c = \frac{Q_c}{F_c}$$

Mass flow rate in the right branch (kg/s):

$$G_{1s} = Q_{1s} \cdot \rho$$

Mass flow rate in the left branch (kg/s):

$$G_{2s} = Q_{2s} \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_c = Q_c \cdot \rho$$

Reynolds number in the right branch:

$$\mathrm{Re}_{1s} = \frac{w_{1s} \cdot D_s}{\nu}$$

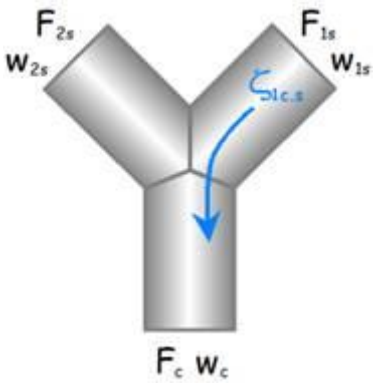
Reynolds number in the left branch:

$$Re_{2s} = \frac{w_{2s} \cdot D_s}{\nu}$$

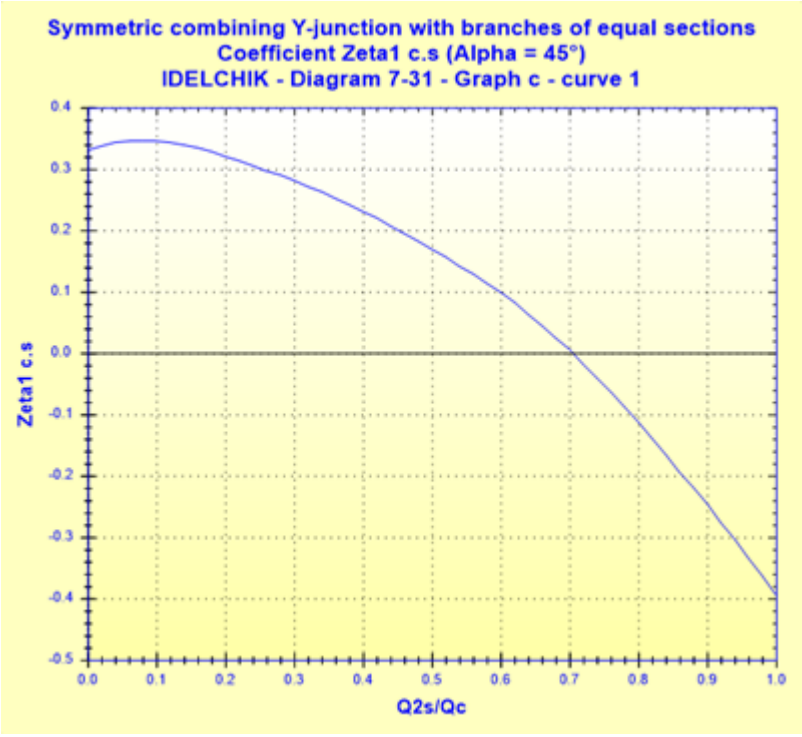
Reynolds number in the common branch:

$$Re_c = \frac{w_c \cdot D_c}{\nu}$$

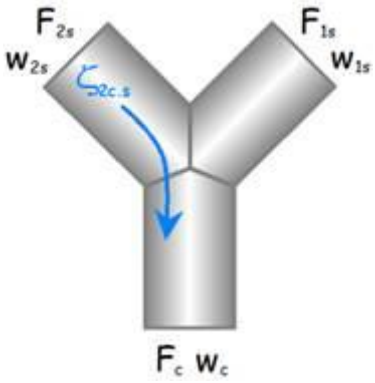
Pressure loss coefficient of the right branch (based on mean velocity in the common branch):



$$\zeta_{1c.s} = f\left(\frac{Q_{2S}}{Q_C}\right)$$ ([1] figure 7.31)



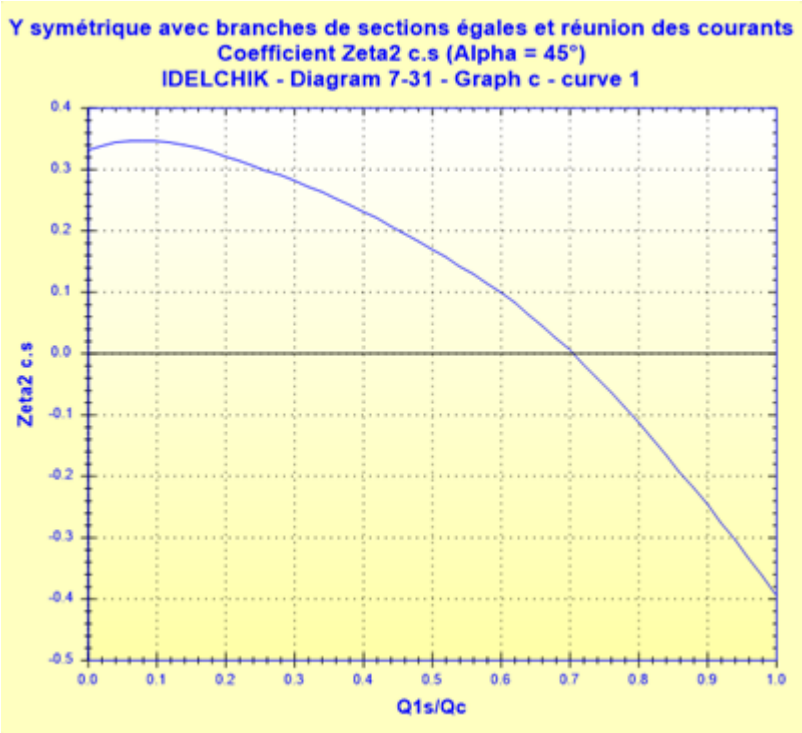
Pressure loss coefficient of the left branch (based on mean velocity in the common branch):



Note: for the left branch, the formulas are the same as those of the right branch, with subscript 2 instead of subscript 1.

$$\zeta_{2c.s} = f\left(\frac{Q_{1S}}{Q_C}\right)$$

([1] figure 7.31)



Pressure loss in the right branch (Pa):

$$\Delta P_{1c.s} = \zeta_{1c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Pressure loss in the left branch (Pa):

$$\Delta P_{2c.s} = \zeta_{2c.s} \cdot \frac{\rho \cdot w_c^{\,2}}{2}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{1c.s} = \zeta_{1c.s} \cdot \frac{w_c^{\,2}}{2 \cdot g}$$

Head loss of fluid in the left branch (m):

$$\Delta H_{2c.s} = \zeta_{2c.s} \cdot \frac{w_c^{\,2}}{2 \cdot g}$$

Hydraulic power loss in the right branch (W):

$$Wh_{1s} = \Delta P_{1c.s} \cdot Q_{1s}$$

Hydraulic power loss in the left branch (W):

$$Wh_{2s} = \Delta P_{2c.s} \cdot Q_{2s}$$

Symbols, Definitions, SI Units:

α	Half angle between the right and left branches (°)
D	Inside diameter of the three branches (m)
D_{1s}	Diameter of the right branches (m)
D_{2s}	Diameter of the left branches (m)
D_c	Diameter of the common branch (m)
F_{1s}	Cross-sectional area of the right branch (m^2)
F_{2s}	Cross-sectional area of the left branch (m^2)
F_c	Cross-sectional area of the common branch (m^2)
Q_{1s}	Volume flow rate in the right branch (m^3/s)
w_{1s}	Mean velocity in the right branch (m/s)
Q_{2s}	Volume flow rate in the left branch (m^3/s)

w_{2s} Mean velocity in the left branch (m/s)

Q_c Volume flow rate in the common branch (m^3/s)

w_c Mean velocity in the common branch (m/s)

G_{1s} Mass flow rate in the right branch (kg/s)

G_{2s} Mass flow rate in the left branch (kg/s)

G_c Mass flow rate in the common branch (kg/s)

Re_{1s} Reynolds number in the right branch ()

Re_{2s} Reynolds number in the left branch ()

Re_c Reynolds number in the common branch ()

$\zeta_{1c.s}$ Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

$\zeta_{2c.s}$ Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

ΔP_{1s} Pressure loss in the right branch (Pa)

ΔP_{2s} Pressure loss in the left branch (Pa)

ΔH_{1s} Head loss of fluid in the right branch (m)

ΔH_{2s} Head loss of fluid in the left branch (m)

Wh_{1s} Hydraulic power loss in the right branch (W)

Wh_{2s} Hydraulic power loss in the left branch (W)

ρ Fluid density (kg/m^3)

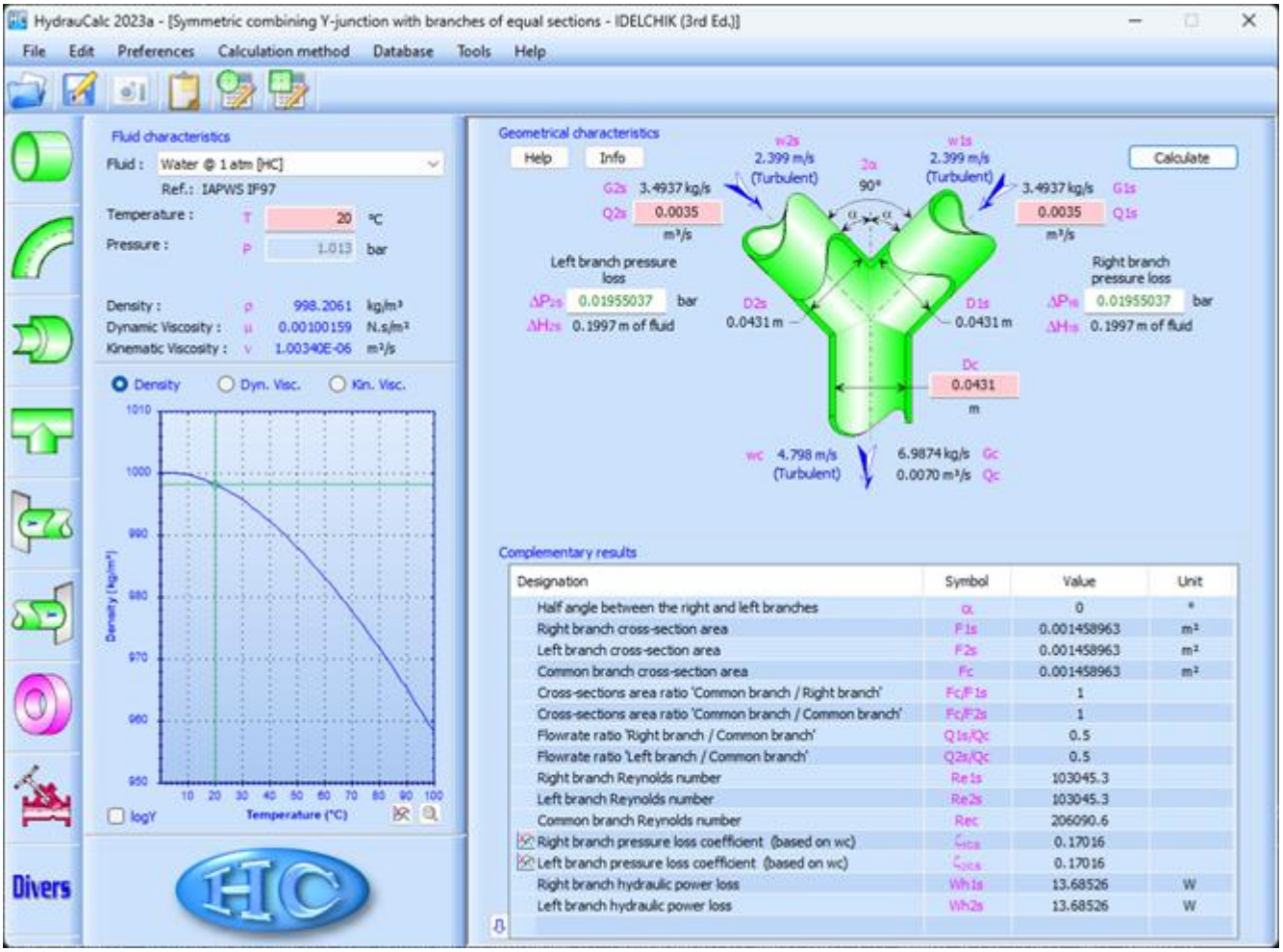
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re_c \geq 10^4$)
- angle between the right and left branches egal to 90° (α = 45°)
- equal section of the three branches ($F_{1s} = F_{2s} = F_c$)

Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.4.13.2 MILLER

Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric combining Y-junction. For this component, the diameters of the right, left and common branches are equal.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the three branches (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

$$A_3 = \pi \cdot \frac{D_3^2}{4}$$

with $D_1 = D_2 = D_3 = D$

Volume flow rate in the common branch (m^3/s):

$$Q_3 = Q_1 + Q_2$$

Mean velocity in the left branch (m/s):

$$U_1 = \frac{Q_1}{A_1}$$

Mean velocity in the right branch (m/s):

$$U_2 = \frac{Q_2}{A_2}$$

Mean velocity in the common branch (m/s):

$$U_3 = \frac{Q_3}{A_3}$$

Mass flow rate in the left branch (kg/s):

$$G_1 = Q_1 \cdot \rho$$

Mass flow rate in the right branch (kg/s):

$$G_2 = Q_2 \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_3 = Q_3 \cdot \rho$$

Reynolds number in the left branch:

$$\mathrm{Re}_1 = \frac{U_1 \cdot D_1}{\nu}$$

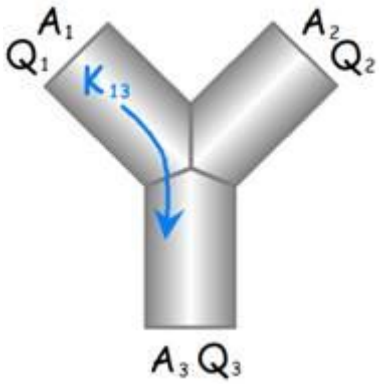
Reynolds number in the right branch:

$$\mathrm{Re}_2 = \frac{U_2 \cdot D_2}{\nu}$$

Reynolds number in the common branch:

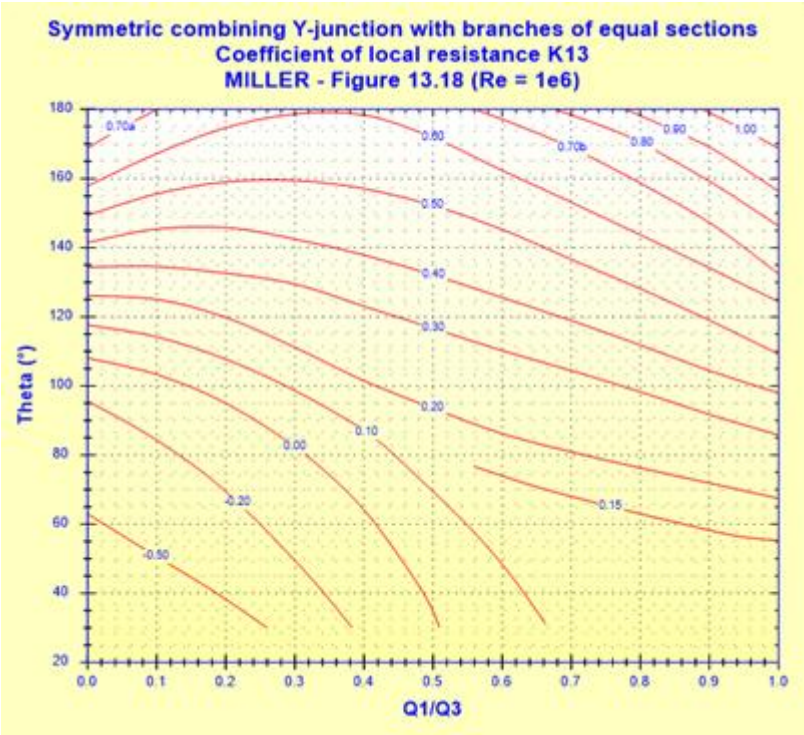
$$Re_3 = \frac{U_3 \cdot D_3}{\nu}$$

Pressure loss coefficient of the left branch (based on mean velocity in the common branch):

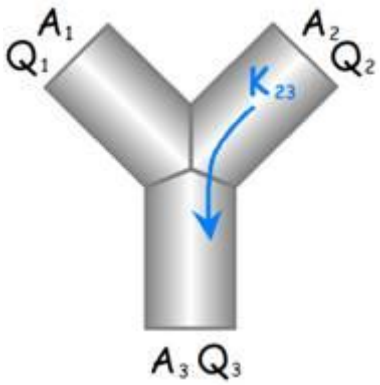


$$K_{13} = f\left(\frac{Q_1}{Q_3}, \theta\right)$$

([1] figure 13.18)

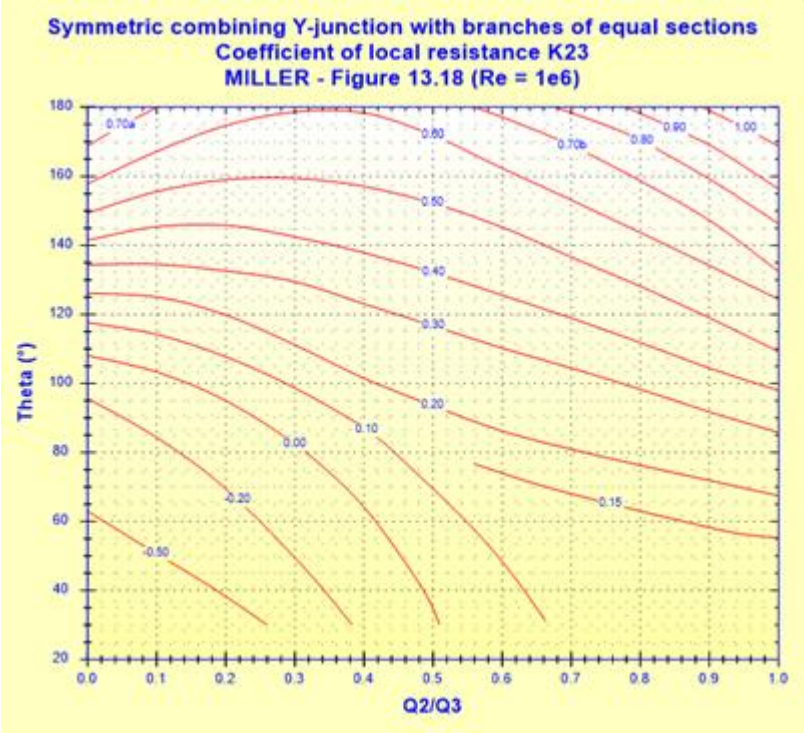


Pressure loss coefficient of the right branch (based on mean velocity in the common branch):



$$K_{23} = f\left(\frac{Q_2}{Q_3}, \theta\right)$$

([1] figure 13.18)



Pressure loss in the left branch (Pa):

$$\Delta P_{13} = K_{13} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.1)

Pressure loss in the right branch (Pa):

$$\Delta P_{23} = K_{23} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.2)

Head loss of fluid in the left branch (m):

$$\Delta H_{13} = K_{13} \cdot \frac{U_3^2}{2 \cdot g}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{23} = K_{23} \cdot \frac{U_3^2}{2 \cdot g}$$

Hydraulic power loss in the left branch (W):

$$Wh_{13} = \Delta P_{13} \cdot Q_1$$

Hydraulic power loss in the right branch (W):

$$Wh_{23} = \Delta P_{23} \cdot Q_2$$

Symbols, Definitions, SI Units:

θ	Angle between the right and left branches (°)
D	Inside diameter of the three branches (m)
D_1	Diameter of the left branch (m)
D_2	Diameter of the right branch (m)
D_3	Diameter of the common branch (m)
A_1	Cross-sectional area of the left branch (m^2)
A_2	Cross-sectional area of the right branch (m^2)
A_3	Cross-sectional area of the common branch (m^2)
Q_1	Volume flow rate in the left branch (m^3/s)
U_1	Mean velocity in the left branch (m/s)
Q_2	Volume flow rate in the right branch (m^3/s)
U_2	Mean velocity in the right branch (m/s)
Q_3	Volume flow rate in the common branch (m^3/s)
U_3	Mean velocity in the common branch (m/s)
G_1	Mass flow rate in the left branch (kg/s)

G_2 Mass flow rate in the right branch (kg/s)

G_3 Mass flow rate in the common branch (kg/s)

Re_1 Reynolds number in the left branch ()

Re_2 Reynolds number in the right branch ()

Re_3 Reynolds number in the common branch ()

K_{13} Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

K_{23} Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

ΔP_{13} Pressure loss in the left branch (Pa)

ΔP_{23} Pressure loss in the right branch (Pa)

ΔH_{13} Head loss of fluid in the left branch (m)

ΔH_{23} Head loss of fluid in the right branch (m)

Wh_{13} Hydraulic power loss in the left branch (W)

Wh_{23} Hydraulic power loss in the right branch (W)

ρ Fluid density (kg/m³)

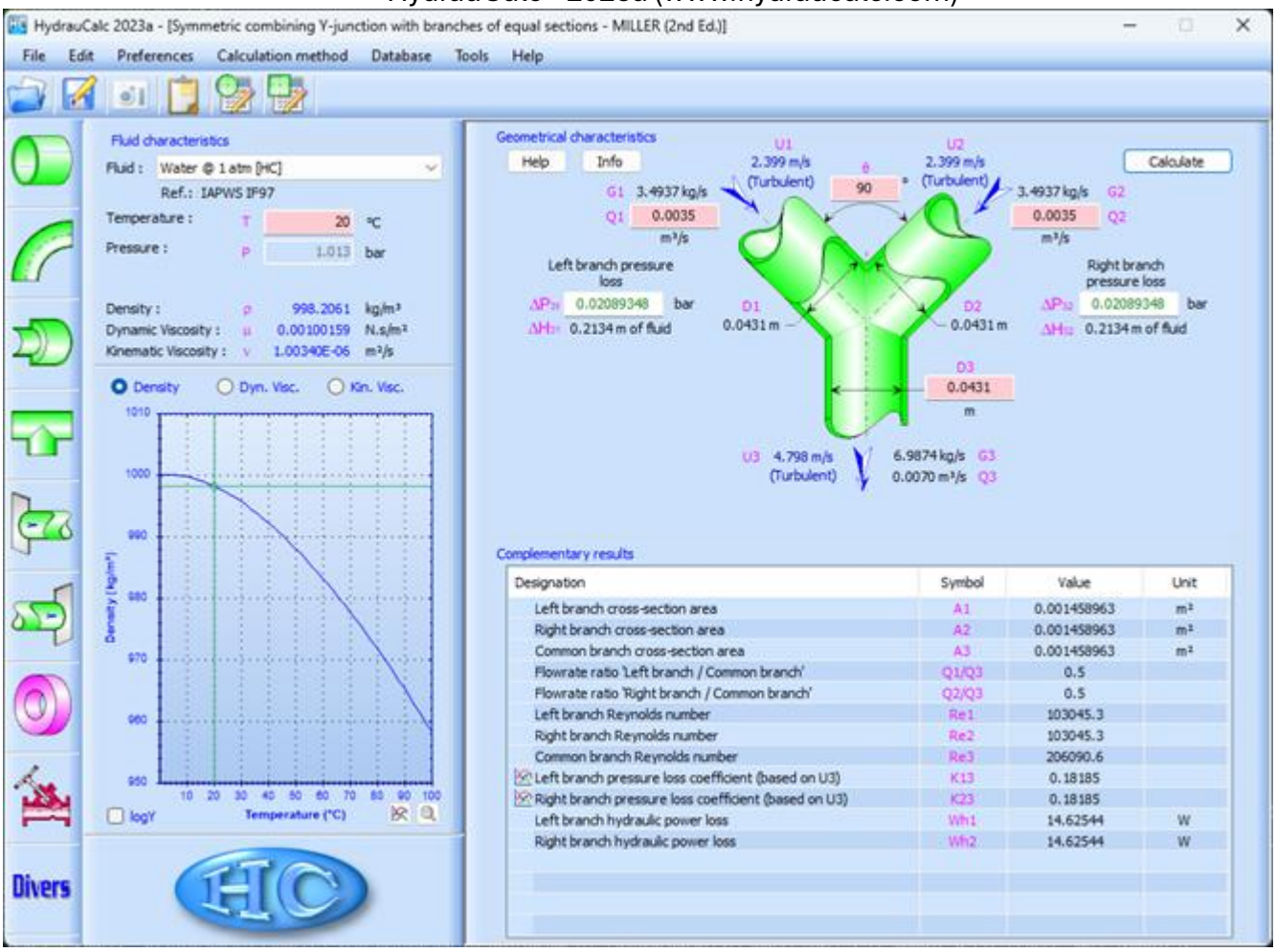
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($Re_3 \geq 10^5$)
- angle between the right and left branches between 20° and 180° ($20° \leq \theta \leq 180°$)
- equal section of the three branches ($A_1 = A_2 = A_3$)

Example of application:

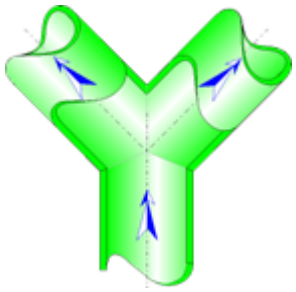


References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

2.4.14 Symmetric dividing Y-junction with branches of equal sections

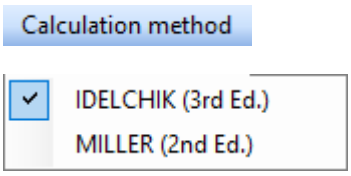
Circular Cross-Section



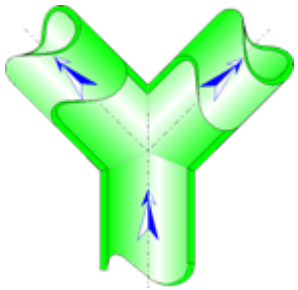
For the calculation of the pressure loss coefficient of symmetric combining Y-junctions. For this component, the diameters of the right, left and common branches are equal. The user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.4.14.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric dividing Y-junction. For this component, the diameters of the right, left and common branches are equal.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the three branches (m^2):

$$F_{1s} = \pi \cdot \frac{D_{1s}^2}{4}$$

$$F_{2s} = \pi \cdot \frac{D_{2s}^2}{4}$$

$$F_c = \pi \cdot \frac{D_c^2}{4}$$

with $D_{1s} = D_{2s} = D_c = D$

Volume flow rate in the common branch (m^3/s):

$$Q_c = Q_{1s} + Q_{2s}$$

Mean velocity in the right branch (m/s):

$$w_{1s} = \frac{Q_{1s}}{F_{1s}}$$

Mean velocity in the left branch (m/s):

$$w_{2s} = \frac{Q_{2s}}{F_{2s}}$$

Mean velocity in the common branch (m/s):

$$w_c = \frac{Q_c}{F_c}$$

Mass flow rate in the right branch (kg/s):

$$G_{1s} = Q_{1s} \cdot \rho$$

Mass flow rate in the left branch (kg/s):

$$G_{2s} = Q_{2s} \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_c = Q_c \cdot \rho$$

Reynolds number in the right branch:

$$\mathrm{Re}_{1s} = \frac{w_{1s} \cdot D_s}{\nu}$$

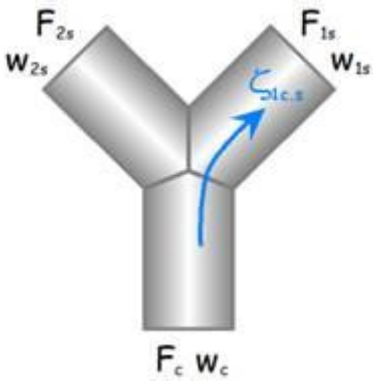
Reynolds number in the left branch:

$$Re_{2s} = \frac{w_{2s} \cdot D_s}{\nu}$$

Reynolds number in the common branch:

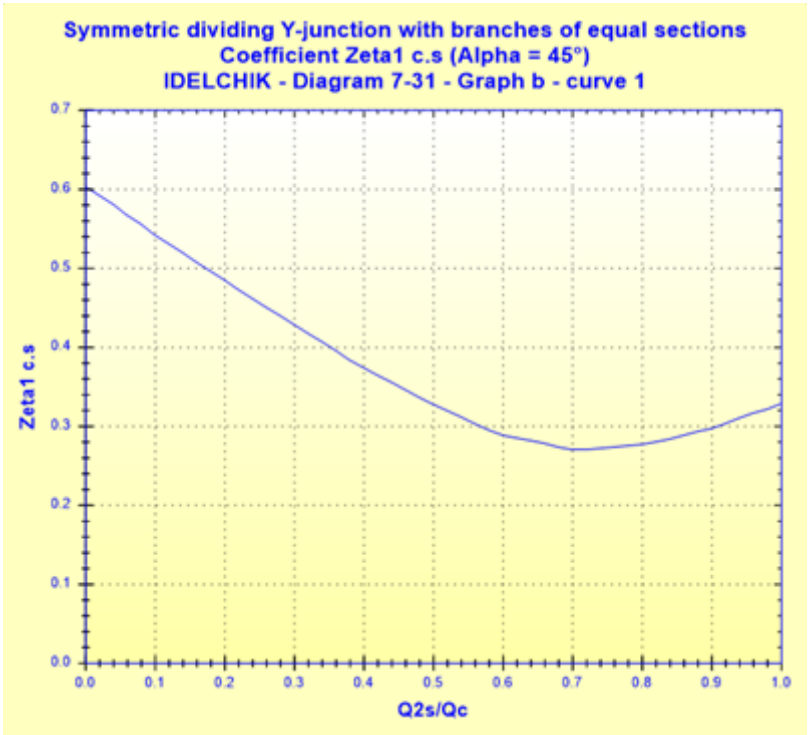
$$Re_c = \frac{w_c \cdot D_c}{\nu}$$

Pressure loss coefficient of the right branch (based on mean velocity in the common branch):

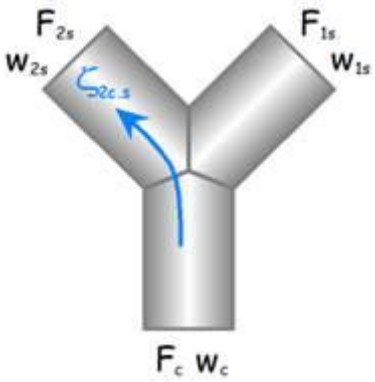


$$\zeta_{1c.s} = f\left(\frac{Q_{2s}}{W_c}\right)$$

([1] diagram 7.31)

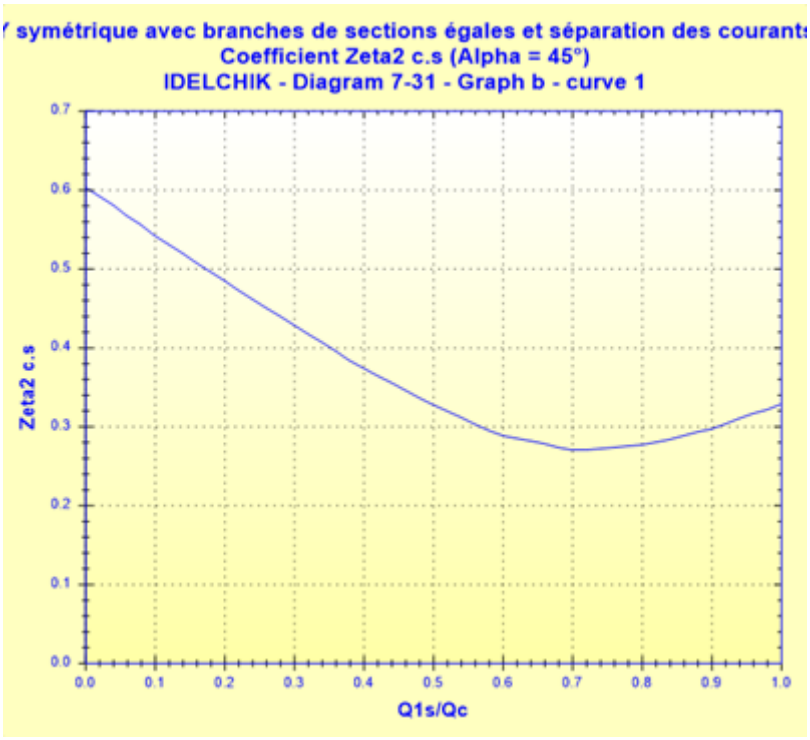


Pressure loss coefficient of the left branch (based on mean velocity in the common branch):



$$\zeta_{2c.s} = f\left(\frac{Q_{1s}}{Q_c}\right)$$

([1] diagram 7.31)



Pressure loss in the right branch (Pa):

$$\Delta P_{1c.s} = \zeta_{1c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Pressure loss in the left branch (Pa):

$$\Delta P_{2c.s} = \zeta_{2c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{1c.s} = \zeta_{1c.s} \cdot \frac{w_c^2}{2 \cdot g}$$

Head loss of fluid in the left branch (m):

$$\Delta H_{2c.s} = \zeta_{2c.s} \cdot \frac{w_c^2}{2 \cdot g}$$

Hydraulic power loss in the right branch (W):

$$Wh_{1s} = \Delta P_{1c.s} \cdot Q_{1s}$$

Hydraulic power loss in the left branch (W):

$$Wh_{2s} = \Delta P_{2c.s} \cdot Q_{2s}$$

Symbols, Definitions, SI Units:

α	Half angle between the right and left branches (°)
D	Inside diameter of the three branches (m)
D_{1s}	Diameter of the right branches (m)
D_{2s}	Diameter of the left branches (m)
D_c	Diameter of the common branch (m)
F_{1s}	Cross-sectional area of the right branch (m^2)
F_{2s}	Cross-sectional area of the left branch (m^2)
F_c	Cross-sectional area of the common branch (m^2)
Q_{1s}	Volume flow rate in the right branch (m^3/s)
w_{1s}	Mean velocity in the right branch (m/s)
Q_{2s}	Volume flow rate in the left branch (m^3/s)
w_{2s}	Mean velocity in the left branch (m/s)
Q_c	Volume flow rate in the common branch (m^3/s)

w_c Mean velocity in the common branch (m/s)

G_{1s} Mass flow rate in the right branch (kg/s)

G_{2s} Mass flow rate in the left branch (kg/s)

G_c Mass flow rate in the common branch (kg/s)

Re_{1s} Reynolds number in the right branch ()

Re_{2s} Reynolds number in the left branch ()

Re_c Reynolds number in the common branch ()

$\zeta_{1c.s}$ Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

$\zeta_{2c.s}$ Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

ΔP_{1s} Pressure loss in the right branch (Pa)

ΔP_{2s} Pressure loss in the left branch (Pa)

ΔH_{1s} Head loss of fluid in the right branch (m)

ΔH_{2s} Head loss of fluid in the left branch (m)

Wh_{1s} Hydraulic power loss in the right branch (W)

Wh_{2s} Hydraulic power loss in the left branch (W)

ρ Fluid density (kg/m³)

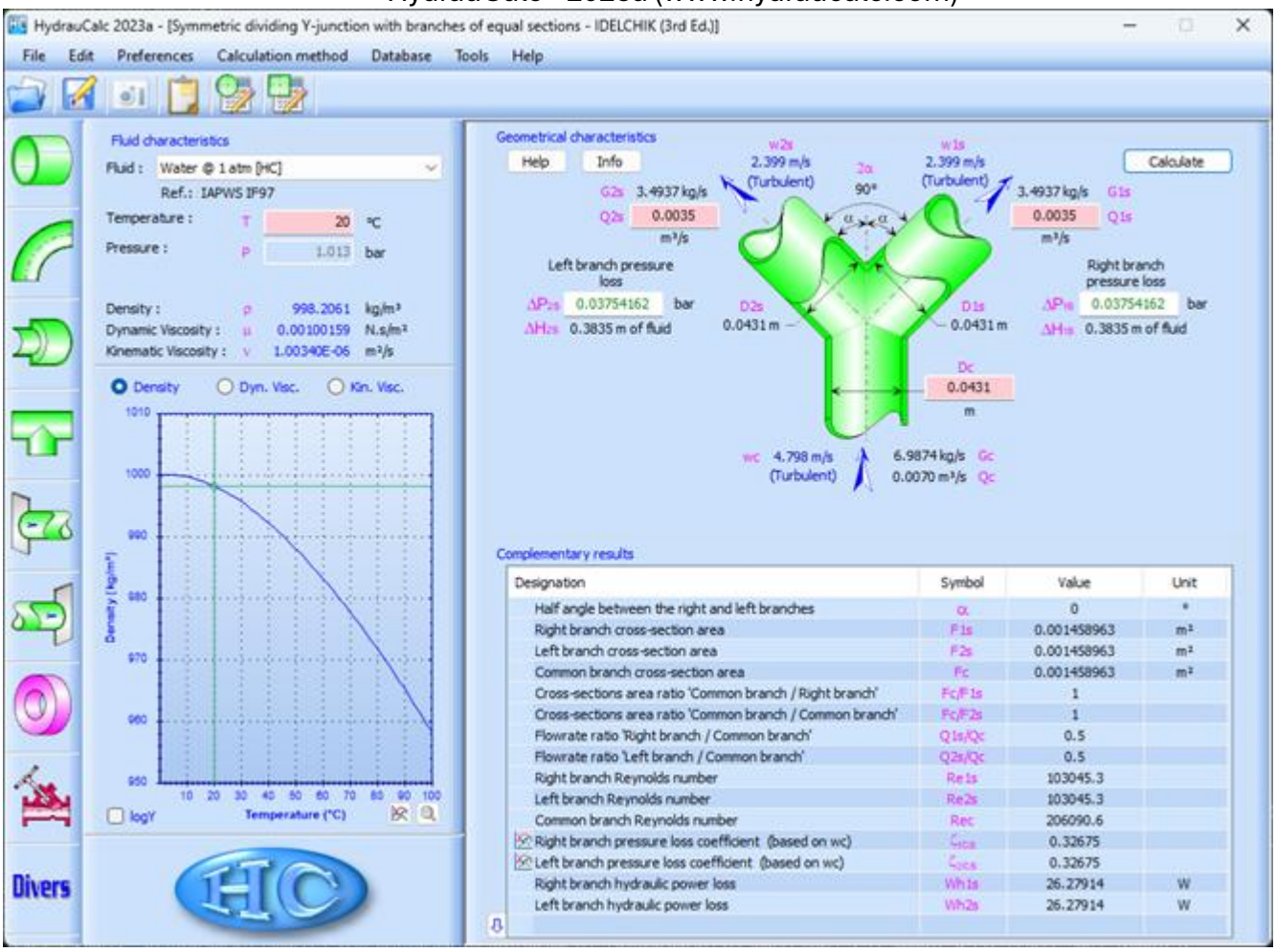
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($Re_c \geq 10^4$)
- angle between the right and left branches egal to 90° (α = 45°)
- equal section of the three branches ($F_{1s} = F_{2s} = F_c$)

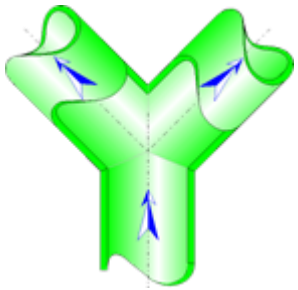
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.4.14.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a symmetric dividing Y-junction. For this component, the diameters of the right, left and common branches are equal.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the three branches (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

$$A_3 = \pi \cdot \frac{D_3^2}{4}$$

with $D_1 = D_2 = D_3 = D$

Volume flow rate in the common branch (m^3/s):

$$Q_3 = Q_1 + Q_2$$

Mean velocity in the left branch (m/s):

$$U_1 = \frac{Q_1}{A_1}$$

Mean velocity in the right branch (m/s):

$$U_2 = \frac{Q_2}{A_2}$$

Mean velocity in the common branch (m/s):

$$U_3 = \frac{Q_3}{A_3}$$

Mass flow rate in the left branch (kg/s):

$$G_1 = Q_1 \cdot \rho$$

Mass flow rate in the right branch (kg/s):

$$G_2 = Q_2 \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_3 = Q_3 \cdot \rho$$

Reynolds number in the left branch:

$$\mathrm{Re}_1 = \frac{U_1 \cdot D_1}{\nu}$$

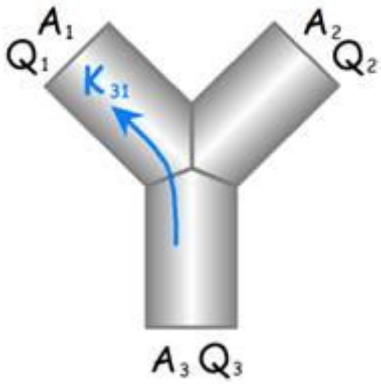
Reynolds number in the right branch:

$$\mathrm{Re}_2 = \frac{U_2 \cdot D_2}{\nu}$$

Reynolds number in the common branch:

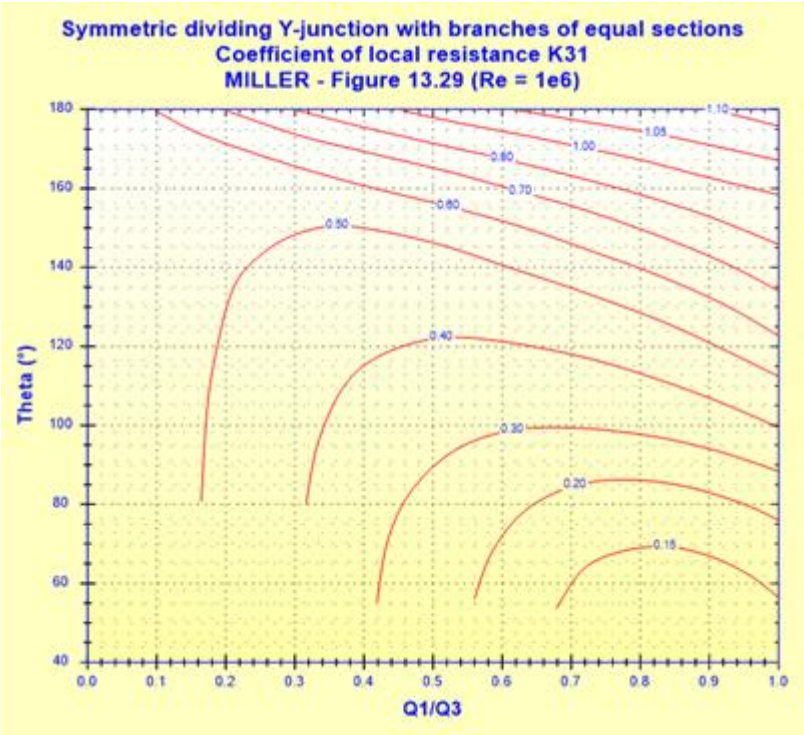
$$Re_3 = \frac{U_3 \cdot D_3}{\nu}$$

Pressure loss coefficient of the left branch (based on mean velocity in the common branch):

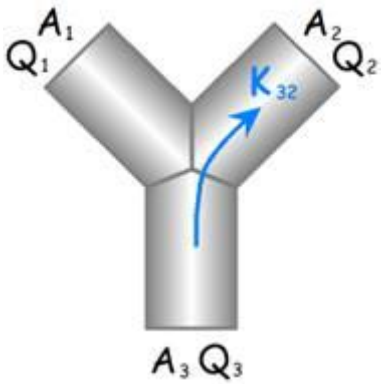


$$K_{31} = f\left(\frac{Q_1}{Q_3}, \theta\right)$$

([1] figure 13.29)

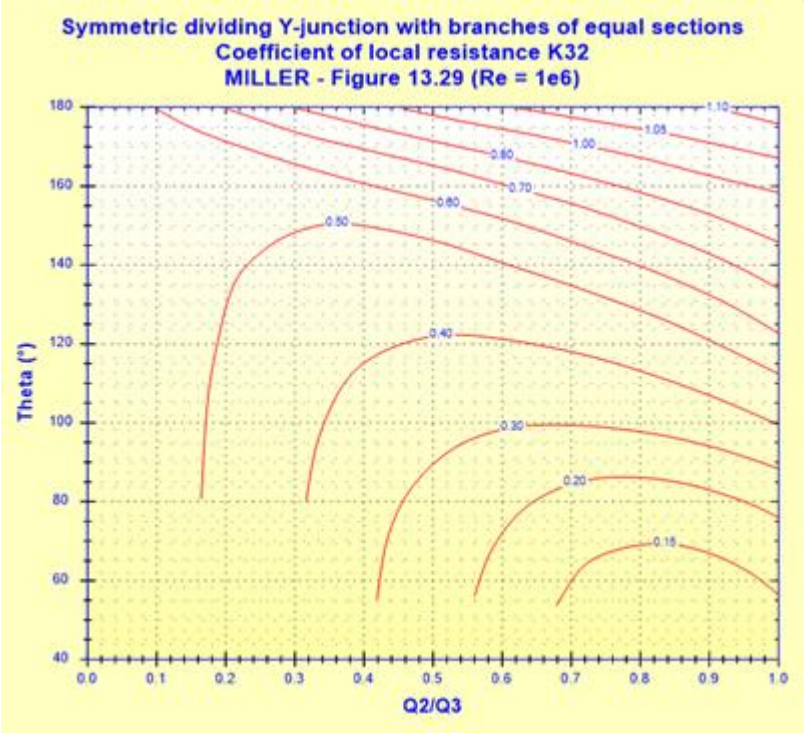


Pressure loss coefficient of the right branch (based on mean velocity in the common branch):



$$K_{32} = f\left(\frac{Q_2}{Q_3}, \theta\right)$$

([1] figure 13.29)



Pressure loss in the left branch (Pa):

$$\Delta P_{13} = K_{13} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.1)

Pressure loss in the right branch (Pa):

$$\Delta P_{23} = K_{23} \cdot \frac{\rho \cdot U_3^2}{2}$$

([1] equation 13.2)

Head loss of fluid in the left branch (m):

$$\Delta H_{13} = K_{13} \cdot \frac{U_3^2}{2 \cdot g}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{23} = K_{23} \cdot \frac{U_3^2}{2 \cdot g}$$

Hydraulic power loss in the left branch (W):

$$Wh_{13} = \Delta P_{13} \cdot Q_1$$

Hydraulic power loss in the right branch (W):

$$Wh_{23} = \Delta P_{23} \cdot Q_2$$

Symbols, Definitions, SI Units:

θ	Angle between the right and left branches (°)
D	Inside diameter of the three branches (m)
D_1	Diameter of the left branch (m)
D_2	Diameter of the right branch (m)
D_3	Diameter of the common branch (m)
A_1	Cross-sectional area of the left branch (m^2)
A_2	Cross-sectional area of the right branch (m^2)
A_3	Cross-sectional area of the common branch (m^2)
Q_1	Volume flow rate in the left branch (m^3/s)
U_1	Mean velocity in the left branch (m/s)
Q_2	Volume flow rate in the right branch (m^3/s)
U_2	Mean velocity in the right branch (m/s)
Q_3	Volume flow rate in the common branch (m^3/s)
U_3	Mean velocity in the common branch (m/s)
G_1	Mass flow rate in the left branch (kg/s)

G_2 Mass flow rate in the right branch (kg/s)

G_3 Mass flow rate in the common branch (kg/s)

Re_1 Reynolds number in the left branch ()

Re_2 Reynolds number in the right branch ()

Re_3 Reynolds number in the common branch ()

K_{13} Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

K_{23} Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

ΔP_{13} Pressure loss in the left branch (Pa)

ΔP_{23} Pressure loss in the right branch (Pa)

ΔH_{13} Head loss of fluid in the left branch (m)

ΔH_{23} Head loss of fluid in the right branch (m)

Wh_{13} Hydraulic power loss in the left branch (W)

Wh_{23} Hydraulic power loss in the right branch (W)

ρ Fluid density (kg/m³)

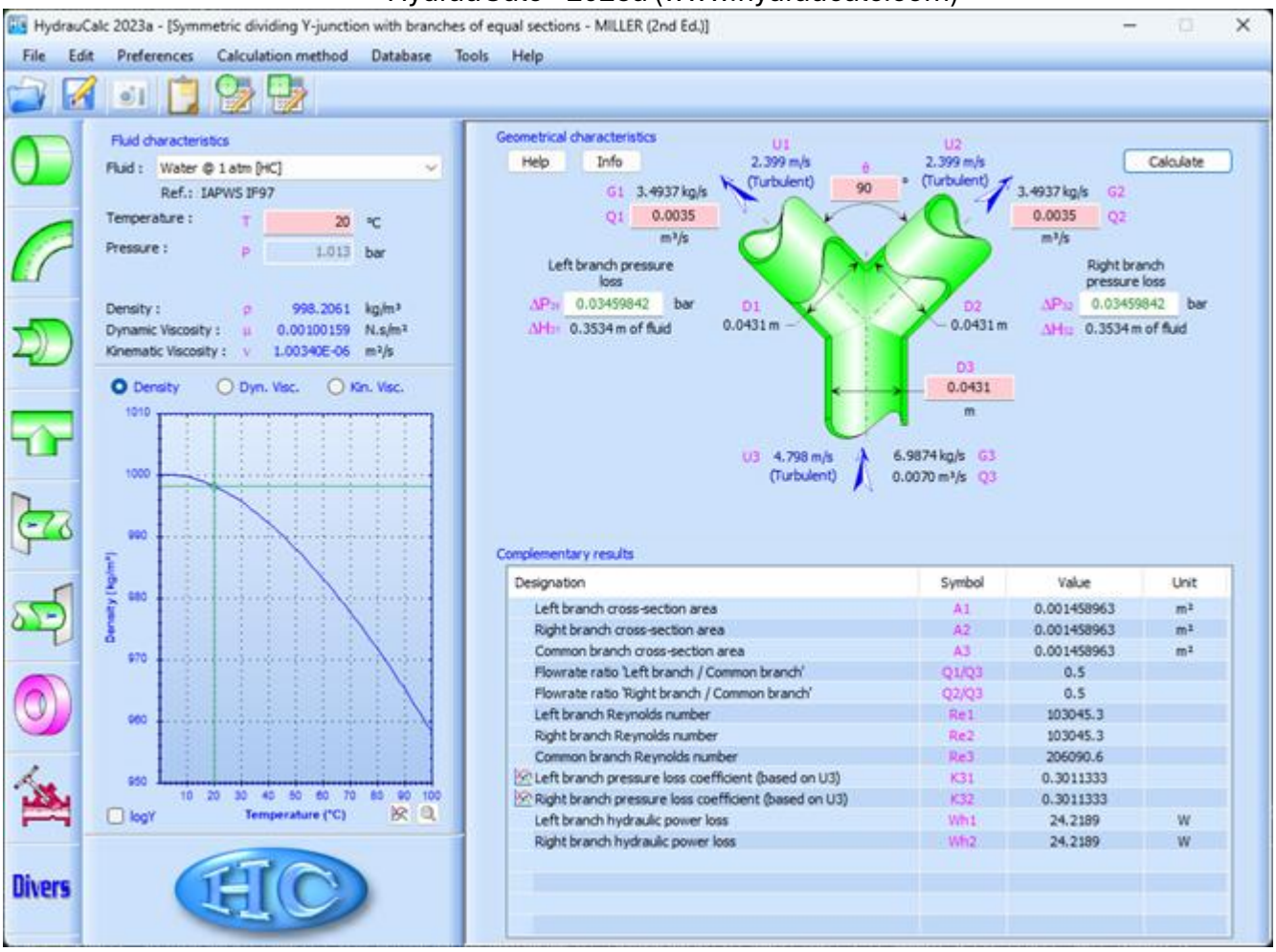
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($Re_3 \geq 10^5$)
- angle of the right and left branches between 60° and 180° ($60° \leq \theta \leq 180°$)
- equal section of the three branches ($A_1 = A_2 = A_3$)

Example of application:

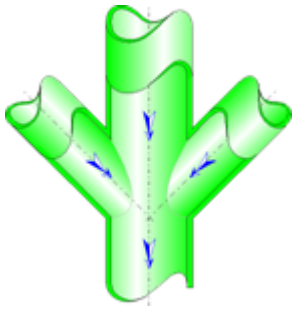


References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

2.4.15 Four-way combining junction with branches of unequal sections

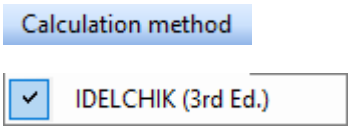
Circular Cross-Section



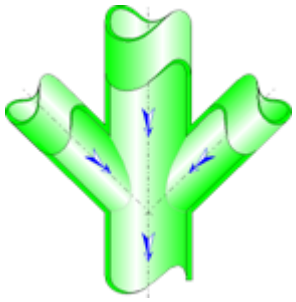
For the calculation of the pressure loss coefficient of a four-way combining junction, the calculation method is described in the following reference document:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

The only calculation method offered appears in the "Calculation method" menu and is activated by default.



2.4.15.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a four-way combining junction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the straight branch (m^2):

$$F_{st} = \pi \cdot \frac{D_{st}^2}{4}$$

Cross-sectional area of the right branch (m^2) :

$$F_{1s} = \pi \cdot \frac{D_s^2}{4}$$

Cross-sectional area of the left branch (m^2) :

$$F_{2s} = \pi \cdot \frac{D_s^2}{4}$$

Cross-sectional area of the common branch (m^2):

$$F_c = \pi \cdot \frac{D_{st}^2}{4}$$

Volume flow rate in the common branch (m^3/s):

$$Q_c = Q_{st} + Q_{1s} + Q_{2s}$$

Mean velocity in the straight branch (m/s):

$$w_{st} = \frac{Q_{st}}{F_c}$$

Mean velocity in the right branch (m/s):

$$w_{1s} = \frac{Q_{1s}}{F_{1s}}$$

Mean velocity in the left branch (m/s):

$$w_{2s} = \frac{Q_{2s}}{F_{2s}}$$

Mean velocity in the common branch (m/s):

$$w_c = \frac{Q_c}{F_c}$$

Mass flow rate in the straight branch (kg/s):

$$G_{st} = Q_{st} \cdot \rho$$

Mass flow rate in the right branch (kg/s):

$$G_{1s} = Q_{1s} \cdot \rho$$

Mass flow rate in the left branch (kg/s):

$$G_{2s} = Q_{2s} \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_c = Q_c \cdot \rho$$

Reynolds number in the straight branch:

$$\mathrm{Re}_{st} = \frac{w_{st} \cdot D_c}{\nu}$$

Reynolds number in the right branch:

$$\mathrm{Re}_{1s} = \frac{w_{1s} \cdot D_s}{\nu}$$

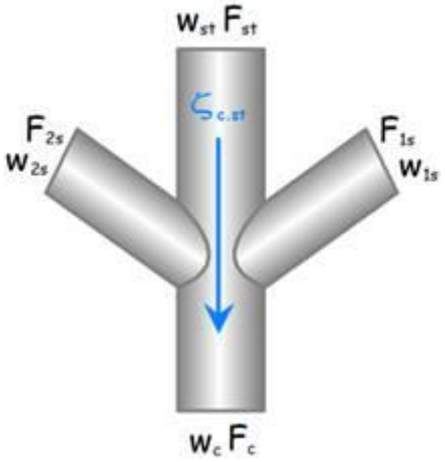
Reynolds number in the left branch:

$$\mathrm{Re}_{2s} = \frac{w_{2s} \cdot D_s}{\nu}$$

Reynolds number in the common branch:

$$\mathrm{Re}_c = \frac{w_c \cdot D_c}{\nu}$$

Pressure loss coefficient of the straight branch (based on mean velocity in the common branch):



- Angle $\alpha = 15$ °

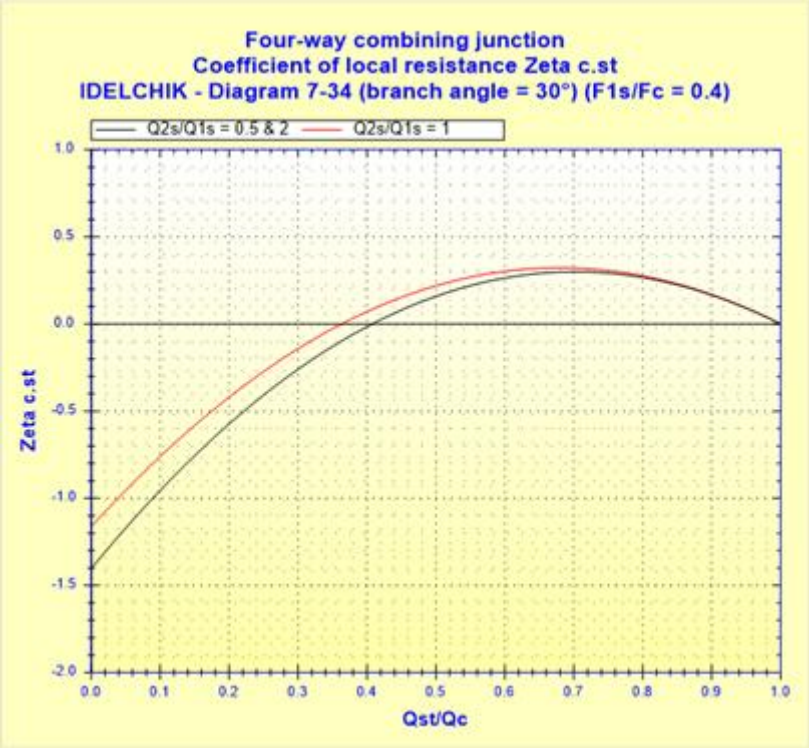
$$\zeta_{c.st} = 1 + \left(\frac{Q_{st}}{Q_c}\right)^2 - \left(\frac{Q_{st}}{Q_c}\right)^2 \cdot \frac{1 + \frac{Q_{st}}{Q_c}}{\left(0.75 + 0.25 \cdot \frac{Q_{st}}{Q_c}\right)^2} - 1.93 \cdot \left(\frac{Q_{st}}{Q_c}\right)^2 \cdot \frac{F_c}{F_{1s}} \cdot \frac{1 + \left(\frac{Q_{2s}}{Q_{1s}}\right)^2}{\left(1 + \frac{Q_{2s}}{Q_{1s}}\right)^2} \cdot \left(\frac{Qc}{Q_{st}} - 1\right)^2$$

([1] diagram 7-33)

- Angle $\alpha = 30$ °

$$\zeta_{c.st} = 1 + \left(\frac{Q_{st}}{Q_c}\right)^2 - \left(\frac{Q_{st}}{Q_c}\right)^2 \cdot \frac{1 + \frac{Q_{st}}{Q_c}}{\left(0.75 + 0.25 \cdot \frac{Q_{st}}{Q_c}\right)^2} - 1.73 \cdot \left(\frac{Q_{st}}{Q_c}\right)^2 \cdot \frac{F_c}{F_{1s}} \cdot \frac{1 + \left(\frac{Q_{2s}}{Q_{1s}}\right)^2}{\left(1 + \frac{Q_{2s}}{Q_{1s}}\right)^2} \cdot \left(\frac{Qc}{Q_{st}} - 1\right)^2$$

([1] diagram 7-34)



- Angle $\alpha = 45$ °

$$\zeta_{c.st} = 1 + \left(\frac{Q_{st}}{Q_c}\right)^2 - \left(\frac{Q_{st}}{Q_c}\right)^2 \cdot \frac{1 + \frac{Q_{st}}{Q_c}}{\left(0.75 + 0.25 \cdot \frac{Q_{st}}{Q_c}\right)^2} - 1.42 \cdot \left(\frac{Q_{st}}{Q_c}\right)^2 \cdot \frac{F_c}{F_{1s}} \cdot \frac{1 + \left(\frac{Q_{2s}}{Q_{1s}}\right)^2}{\left(1 + \frac{Q_{2s}}{Q_{1s}}\right)^2} \cdot \left(\frac{Qc}{Q_{st}} - 1\right)^2$$

([1] diagram 7-35)

- Angle $\alpha = 60$ °

$$\zeta_{c.st} = 1 + \left(\frac{Q_{st}}{Q_c}\right)^2 - \left(\frac{Q_{st}}{Q_c}\right)^2 \cdot \frac{1 + \frac{Q_{st}}{Q_c}}{\left(0.75 + 0.25 \cdot \frac{Q_{st}}{Q_c}\right)^2} - \left(\frac{Q_{st}}{Q_c}\right)^2 \cdot \frac{F_c}{F_{1s}} \cdot \frac{1 + \left(\frac{Q_{2s}}{Q_{1s}}\right)^2}{\left(1 + \frac{Q_{2s}}{Q_{1s}}\right)^2} \cdot \left(\frac{Qc}{Q_{st}} - 1\right)^2$$

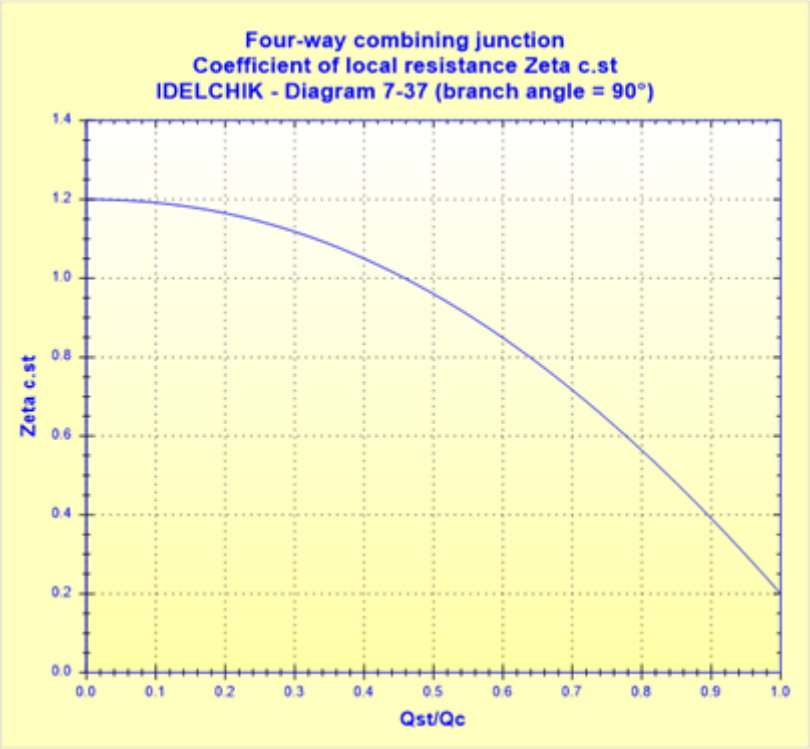
([1] diagram 7-36)

- Angle $\alpha = 90$ °

$$\zeta_{c.st} = 1.2 + \left(\frac{Q_{st}}{Q_c}\right)^2 - \left(\frac{Q_{st}}{Q_c}\right)^2 \cdot \frac{1 + \frac{Q_{st}}{Q_c}}{\left(0.75 + 0.25 \cdot \frac{Q_{st}}{Q_c}\right)^2}$$

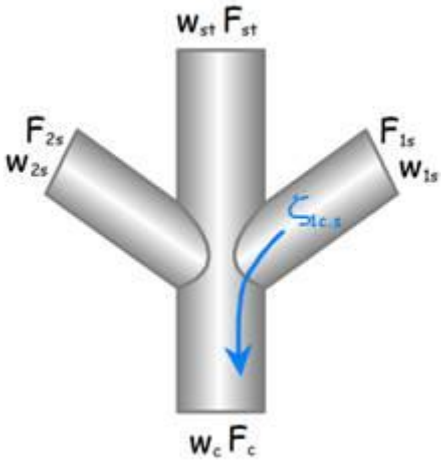
([1] diagram 7-37)

In this formula, the coefficient '1' of the original formula has been replaced by the value '1.2' to be consistent with the graphs presented in diagram 7-37



For any angles α between 15 ° and 90 °, the coefficient $\zeta_{c.st}$ is obtained by linear interpolation between the values of $\zeta_{c.st}$ calculated at 15 °, 30 °, 45 °, 60 ° and 90 °.

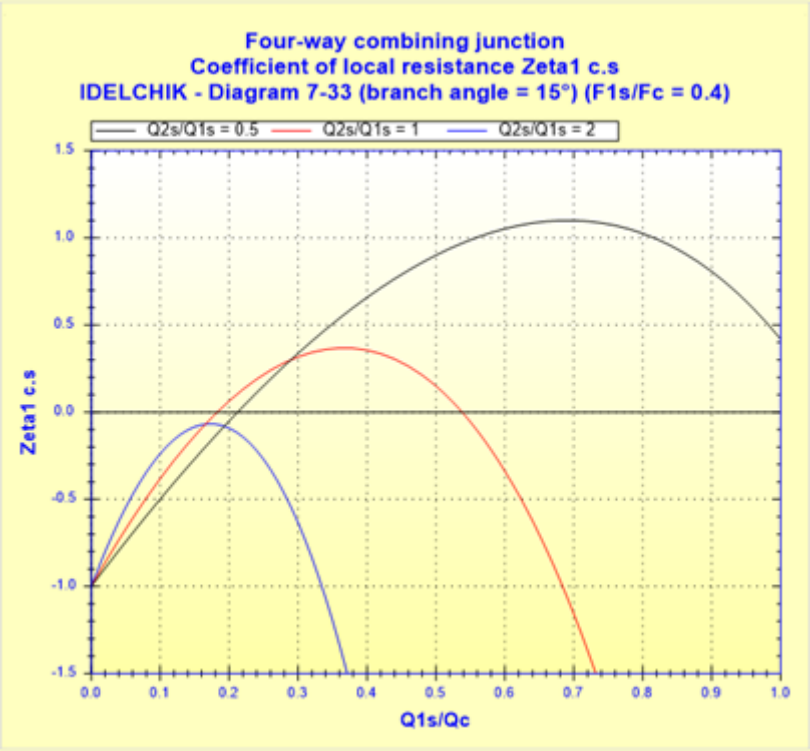
Pressure loss coefficient of the right branch (based on mean velocity in the common branch):



- Angle $\alpha = 15$ °

$$\zeta_{1c.s} = 1 + \left(\frac{Q_{1s}}{Q_c} \cdot \frac{F_c}{F_{1s}}\right)^2 - 8 \cdot \left(\frac{Q_{1s}}{Q_c}\right)^2 \cdot \frac{\left[\frac{Q_c}{Q_{1s}} - \left(1 + \frac{Q_{2s}}{Q_{1s}}\right)\right]^2}{4 - \left(1 + \frac{Q_{2s}}{Q_{1s}}\right) \cdot \frac{Q_{1s}}{Q_c}} - 1.93 \cdot \left(\frac{Q_{1s}}{Q_c}\right)^2 \cdot \frac{F_c}{F_{1s}} \left[1 + \left(\frac{Q_{2s}}{Q_{1s}}\right)^2\right]$$

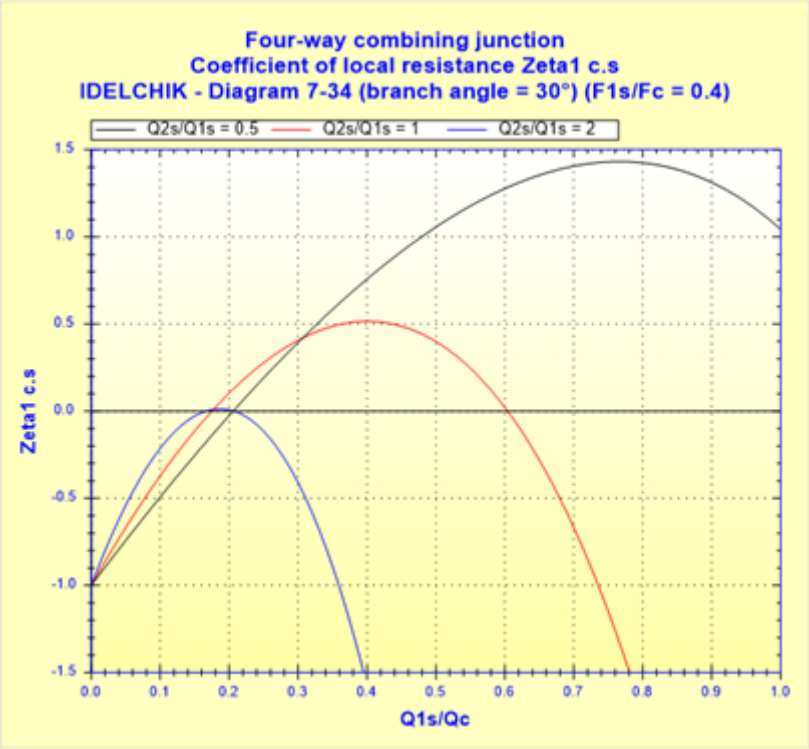
([1] diagram 7-33)



- Angle $\alpha = 30$ °

$$\zeta_{1c.s} = 1 + \left(\frac{Q_{1s}}{Q_c} \cdot \frac{F_c}{F_{1s}}\right)^2 - 8 \cdot \left(\frac{Q_{1s}}{Q_c}\right)^2 \cdot \frac{\left[\frac{Q_c}{Q_{1s}} - \left(1 + \frac{Q_{2s}}{Q_{1s}}\right)\right]^2}{4 - \left(1 + \frac{Q_{2s}}{Q_{1s}}\right) \cdot \frac{Q_{1s}}{Q_c}} - 1.73 \cdot \left(\frac{Q_{1s}}{Q_c}\right)^2 \cdot \frac{F_c}{F_{1s}} \left[1 + \left(\frac{Q_{2s}}{Q_{1s}}\right)^2\right]$$

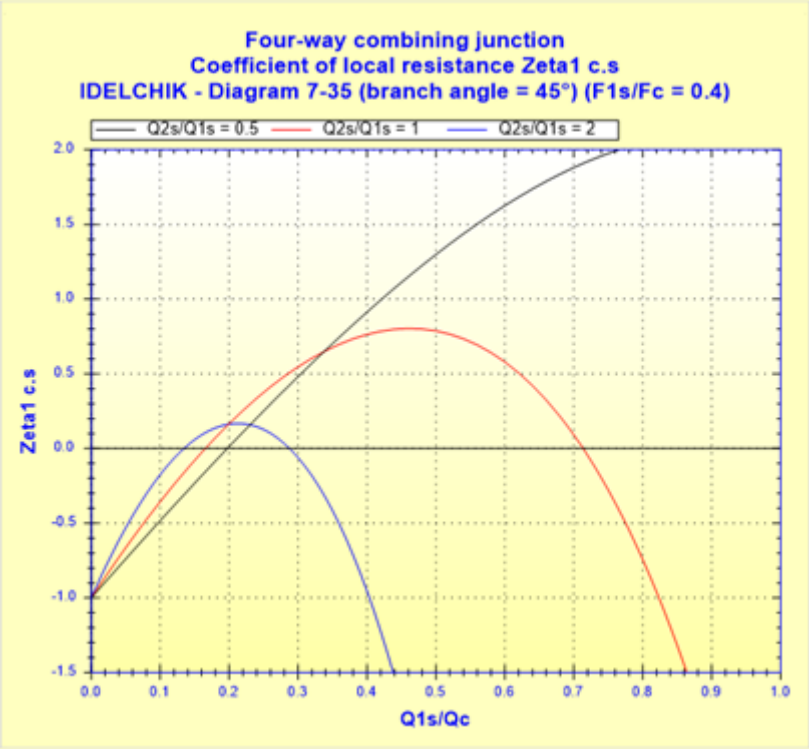
([1] diagram 7-34)



- Angle $\alpha = 45$ °

$$\zeta_{1c.s} = 1 + \left(\frac{Q_{1s}}{Q_c} \cdot \frac{F_c}{F_{1s}}\right)^2 - 8 \cdot \left(\frac{Q_{1s}}{Q_c}\right)^2 \cdot \frac{\left[\frac{Q_c}{Q_{1s}} - \left(1 + \frac{Q_{2s}}{Q_{1s}}\right)\right]^2}{4 - \left(1 + \frac{Q_{2s}}{Q_{1s}}\right) \cdot \frac{Q_{1s}}{Q_c}} - 1.42 \cdot \left(\frac{Q_{1s}}{Q_c}\right)^2 \cdot \frac{F_c}{F_{1s}} \left[1 + \left(\frac{Q_{2s}}{Q_{1s}}\right)^2\right]$$

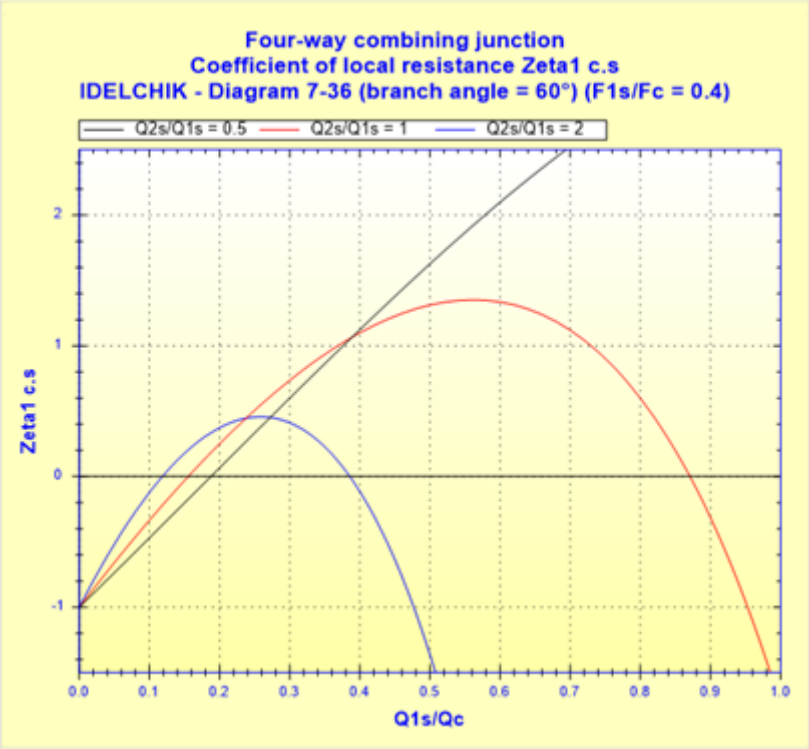
([1] diagram 7-35)



- Angle $\alpha = 60$ °

$$\zeta_{1c.s} = 1 + \left(\frac{Q_{1s}}{Q_c} \cdot \frac{F_c}{F_{1s}}\right)^2 - 8 \cdot \left(\frac{Q_{1s}}{Q_c}\right)^2 \cdot \frac{\left[\frac{Q_c}{Q_{1s}} - \left(1 + \frac{Q_{2s}}{Q_{1s}}\right)\right]^2}{4 - \left(1 + \frac{Q_{2s}}{Q_{1s}}\right) \cdot \frac{Q_{1s}}{Q_c}} - \left(\frac{Q_{1s}}{Q_c}\right)^2 \cdot \frac{F_c}{F_{1s}} \left[1 + \left(\frac{Q_{2s}}{Q_{1s}}\right)^2\right]$$

([1] diagram 7-36)

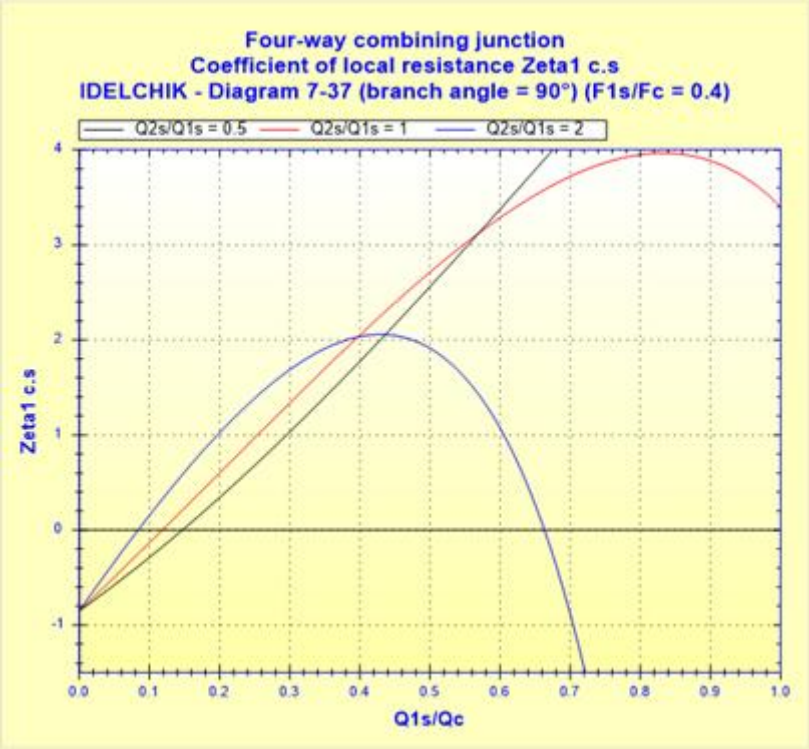


- Angle $\alpha = 90$ °

$$\zeta_{1c.s} = 1.15 + \left(\frac{Q_{1s}}{Q_c} \cdot \frac{F_c}{F_{1s}}\right)^2 - 8 \cdot \left(\frac{Q_{1s}}{Q_c}\right)^2 \cdot \frac{\left[\frac{Q_c}{Q_{1s}} - \left(1 + \frac{Q_{2s}}{Q_{1s}}\right)\right]^2}{4 - \left(1 + \frac{Q_{2s}}{Q_{1s}}\right) \cdot \frac{Q_{1s}}{Q_c}}$$

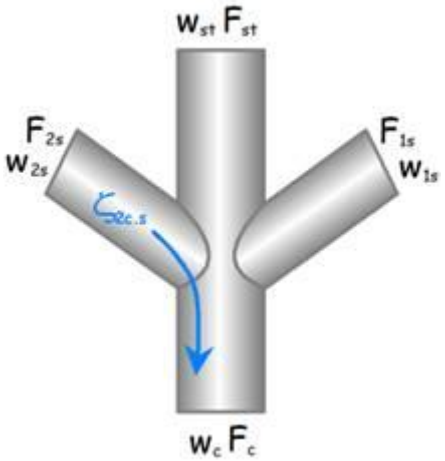
([1] diagram 7-37)

In this formula, the coefficient '1' of the original formula has been replaced by the value '1.15' to be consistent with the graphs presented in diagram 7-37



For any angles α between 15 ° and 90 °, the coefficient $\zeta_{1c.s}$ is obtained by linear interpolation between the values of $\zeta_{1c.s}$ calculated at 15 °,30 °, 45 °, 60 ° and 90 °.

Pressure loss coefficient of the left branch (based on mean velocity in the common branch):

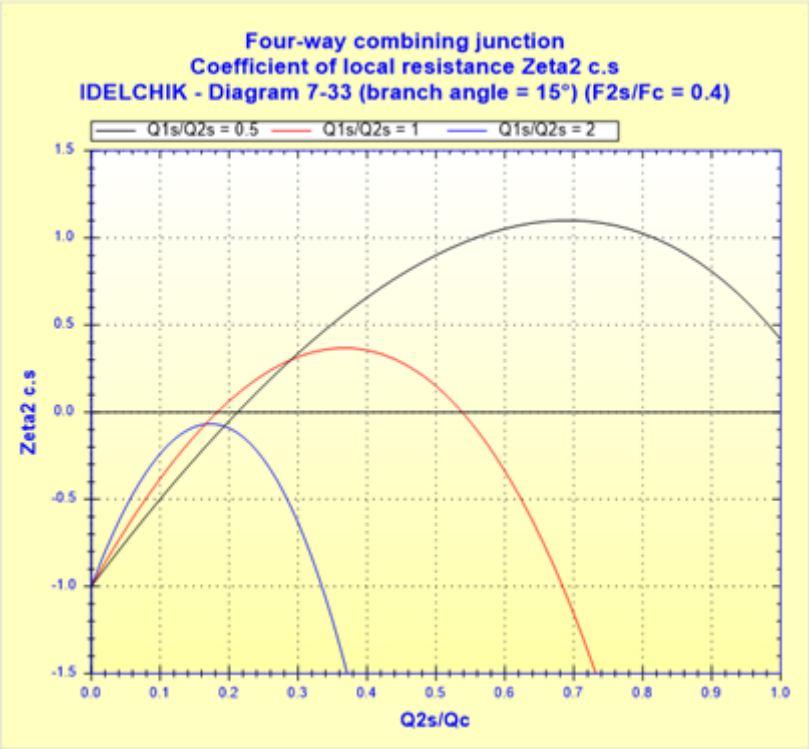


- Angle α = 15 °

$$\zeta_{2c.s} = 1 + \left(\frac{Q_{2s}}{Q_c} \cdot \frac{F_c}{F_{2s}}\right)^2 - 8 \cdot \left(\frac{Q_{2s}}{Q_c}\right)^2 \cdot \frac{\left[\frac{Q_c}{Q_{2s}} - \left(1 + \frac{Q_{1s}}{Q_{2s}}\right)\right]^2}{4 - \left(1 + \frac{Q_{1s}}{Q_{2s}}\right) \cdot \frac{Q_{2s}}{Q_c}} - 1.93 \cdot \left(\frac{Q_{2s}}{Q_c}\right)^2 \cdot \frac{F_c}{F_{2s}} \left[1 + \left(\frac{Q_{1s}}{Q_{2s}}\right)^2\right]$$

([1]

diagram 7-33)

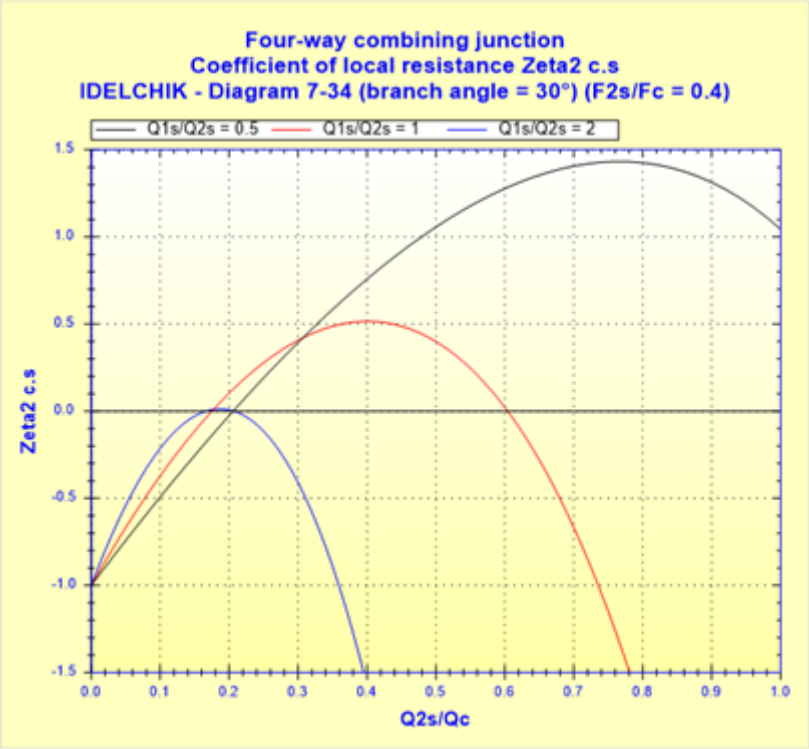


- Angle $\alpha = 30$ °

$$\zeta_{2c.s} = 1 + \left(\frac{Q_{2s}}{Q_c} \cdot \frac{F_c}{F_{2s}}\right)^2 - 8 \cdot \left(\frac{Q_{2s}}{Q_c}\right)^2 \cdot \frac{\left[\frac{Q_c}{Q_{2s}} - \left(1 + \frac{Q_{1s}}{Q_{2s}}\right)\right]^2}{4 - \left(1 + \frac{Q_{1s}}{Q_{2s}}\right) \cdot \frac{Q_{2s}}{Q_c}} - 1.73 \cdot \left(\frac{Q_{2s}}{Q_c}\right)^2 \cdot \frac{F_c}{F_{2s}} \left[1 + \left(\frac{Q_{1s}}{Q_{2s}}\right)^2\right]$$

([1]

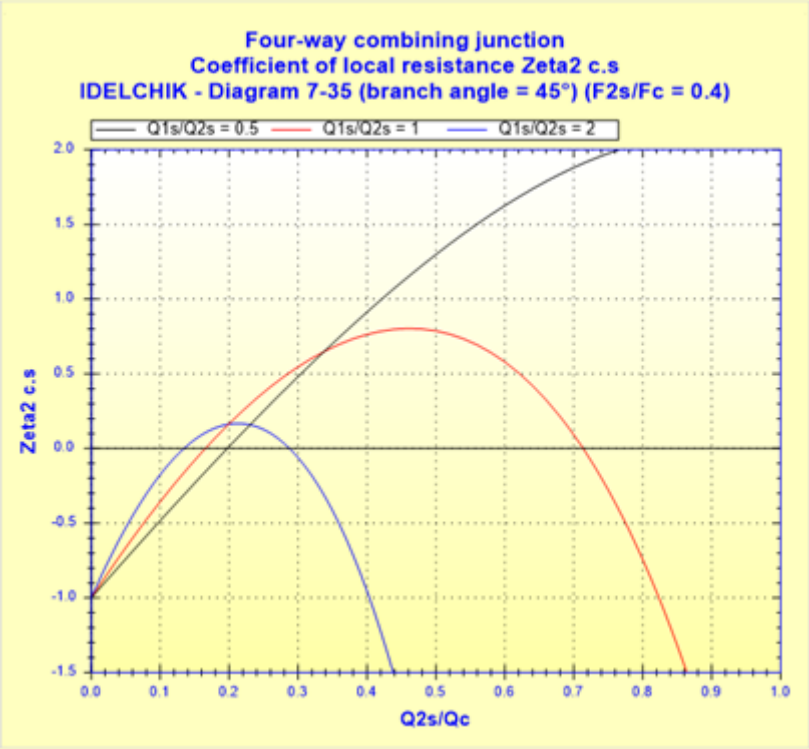
diagram 7-34)



- Angle $\alpha = 45$ °

$$\zeta_{2c.s} = 1 + \left(\frac{Q_{2s}}{Q_c} \cdot \frac{F_c}{F_{2s}}\right)^2 - 8 \cdot \left(\frac{Q_{2s}}{Q_c}\right)^2 \cdot \frac{\left[\frac{Q_c}{Q_{2s}} - \left(1 + \frac{Q_{1s}}{Q_{2s}}\right)\right]^2}{4 - \left(1 + \frac{Q_{1s}}{Q_{2s}}\right) \cdot \frac{Q_{2s}}{Q_c}} - 1.42 \cdot \left(\frac{Q_{2s}}{Q_c}\right)^2 \cdot \frac{F_c}{F_{2s}} \left[1 + \left(\frac{Q_{1s}}{Q_{2s}}\right)^2\right]$$

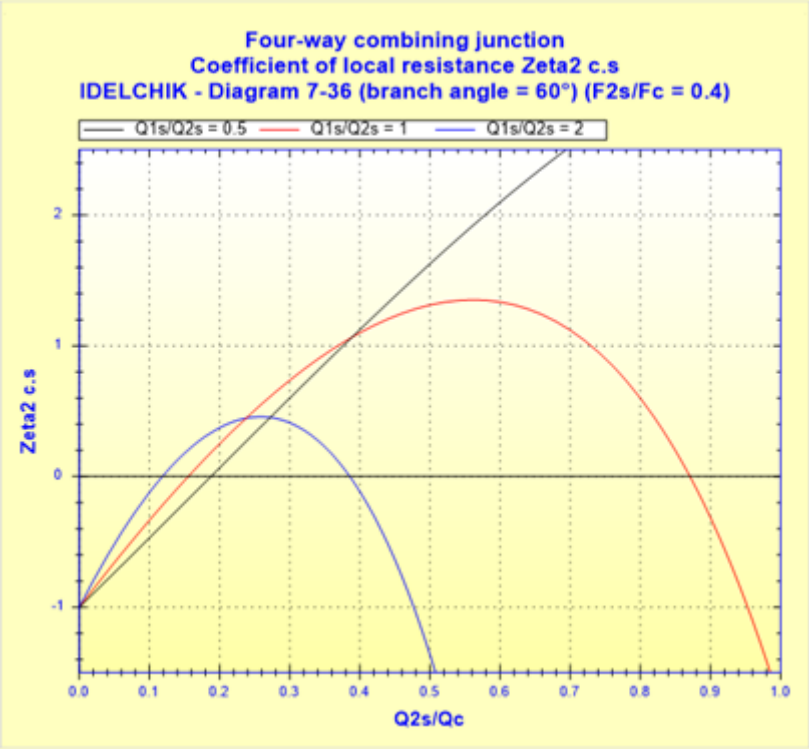
([1] diagram 7-35)



- Angle $\alpha = 60$ °

$$\zeta_{2c.s} = 1 + \left(\frac{Q_{2s}}{Q_c} \cdot \frac{F_c}{F_{2s}}\right)^2 - 8 \cdot \left(\frac{Q_{2s}}{Q_c}\right)^2 \cdot \frac{\left[\frac{Q_c}{Q_{2s}} - \left(1 + \frac{Q_{1s}}{Q_{2s}}\right)\right]^2}{4 - \left(1 + \frac{Q_{1s}}{Q_{2s}}\right) \cdot \frac{Q_{2s}}{Q_c}} - \left(\frac{Q_{2s}}{Q_c}\right)^2 \cdot \frac{F_c}{F_{2s}} \left[1 + \left(\frac{Q_{1s}}{Q_{2s}}\right)^2\right]$$

([1] diagram 7-36)



- Angle $\alpha = 90$ °

$$\zeta_{2c.s} = 1.15 + \left(\frac{Q_{2s}}{Q_c} \cdot \frac{F_c}{F_{2s}}\right)^2 - 8 \cdot \left(\frac{Q_{2s}}{Q_c}\right)^2 \cdot \frac{\left[\frac{Q_c}{Q_{2s}} - \left(1 + \frac{Q_{1s}}{Q_{2s}}\right)\right]^2}{4 - \left(1 + \frac{Q_{1s}}{Q_{2s}}\right) \cdot \frac{Q_{2s}}{Q_c}}$$

([1] diagram 7-37)

In this formula, the coefficient '1' of the original formula has been replaced by the value '1.15' to be consistent with the graphs presented in diagram 7-37

For any angles α between 15 ° and 90 °, the coefficient $\zeta_{2c.s}$ is obtained by linear interpolation between the values of $\zeta_{2c.s}$ calculated at 15 °, 30 °, 45 °, 60 ° and 90 °.

Pressure loss in the straight branch (Pa):

$$\Delta P_{c.st} = \zeta_{c.st} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Pressure loss in the right branch (Pa):

$$\Delta P_{1c.s} = \zeta_{1c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Pressure loss in the left branch (Pa):

$$\Delta P_{2c.s} = \zeta_{2c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Head loss of fluid in the straight branch (m):

$$\Delta H_{c.st} = \zeta_{c.st} \cdot \frac{W_c^{\,2}}{2 \cdot g}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{1c.s} = \zeta_{1c.s} \cdot \frac{w_c^{\,2}}{2 \cdot g}$$

Head loss of fluid in the left branch (m):

$$\Delta H_{2c.s} = \zeta_{2c.s} \cdot \frac{w_c^{\,2}}{2 \cdot g}$$

Hydraulic power loss in the right branch (W):

$$Wh_{1s} = \Delta P_{1c.s} \cdot Q_{1s}$$

Hydraulic power loss in the left branch (W):

$$Wh_{2s} = \Delta P_{2c.s} \cdot Q_{2s}$$

Hydraulic power loss in the straight branch (W):

$$Wh_{st} = \Delta P_{c.st} \cdot Q_{st}$$

Symbols, Definitions, SI Units:

α	Angle of the right and left branches (°)
D_{st}	Diameter of the straight and common branches (m)
D_s	Diameter of the right and left branches (m)
F_{st}	Cross-sectional area of the straight branch (m^2)
F_{1s}	Cross-sectional area of the right branch (m^2)
F_{2s}	Cross-sectional area of the left branch (m^2)
F_c	Cross-sectional area of the common branch (m^2)
Q_{st}	Volume flow rate in the straight branch (m^3/s)
w_{st}	Mean velocity in the straight branch (m/s)
Q_{1s}	Volume flow rate in the right branch (m^3/s)
w_{1s}	Mean velocity in the right branch (m/s)

Q_{2s} Volume flow rate in the left branch (m^3/s)

w_{2s} Mean velocity in the left branch (m/s)

Q_c Volume flow rate in the common branch (m^3/s)

w_c Mean velocity in the common branch (m/s)

G_{st} Mass flow rate in the straight branch (kg/s)

G_{1s} Mass flow rate in the right branch (kg/s)

G_{2s} Mass flow rate in the left branch (kg/s)

G_c Mass flow rate in the common branch (kg/s)

Re_{st} Reynolds number in the straight branch ()

Re_{1s} Reynolds number in the right branch ()

Re_{2s} Reynolds number in the left branch ()

Re_c Reynolds number in the common branch ()

$\zeta_{c.st}$ Pressure loss coefficient of the straight branch (based on mean velocity in the common branch) ()

$\zeta_{1c.s}$ Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

$\zeta_{2c.s}$ Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

ΔP_{st} Pressure loss in the straight branch (Pa)

ΔP_{1s} Pressure loss in the right branch (Pa)

ΔP_{2s} Pressure loss in the left branch (Pa)

ΔH_{st} Head loss of fluid in the straight branch (m)

ΔH_{1s} Head loss of fluid in the right branch (m)

ΔH_{2s} Head loss of fluid in the left branch (m)

Wh_{st} Hydraulic power loss in the straight branch (W)

Wh_{1s} Hydraulic power loss in the right branch (W)

Wh_{2s} Hydraulic power loss in the left branch (W)

ρ Fluid density (kg/m³)

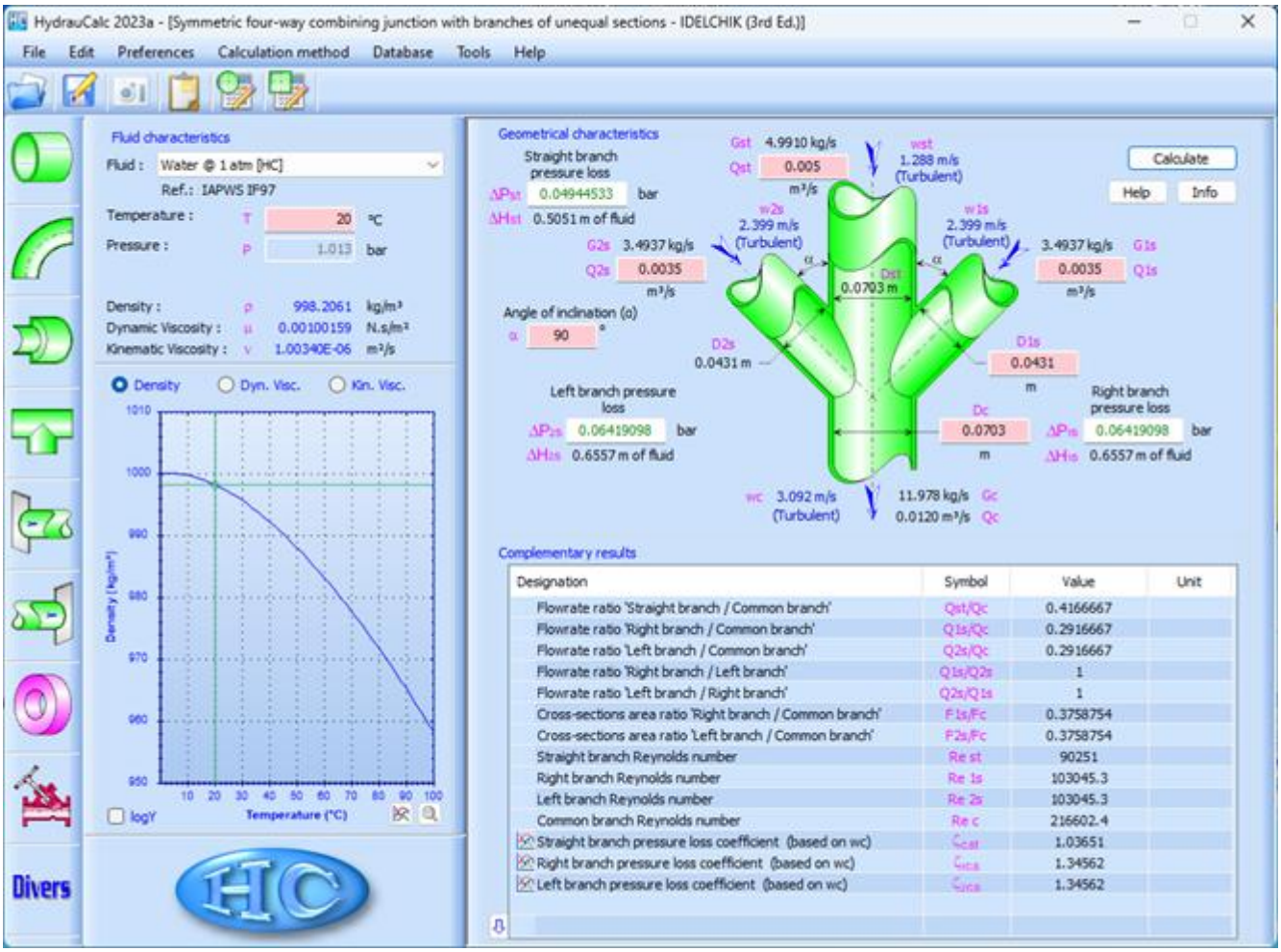
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- flow regime: turbulent ($Re_c \geq 10^4$)
- common branch area: equal to the sum of the areas of the right and left branches ($F_c = F_{1s} + F_{2s}$)
- angles of the lateral branches: egal and between 15 ° and 90 ° ($15° \leq \alpha \leq 90°$)

Example of application:

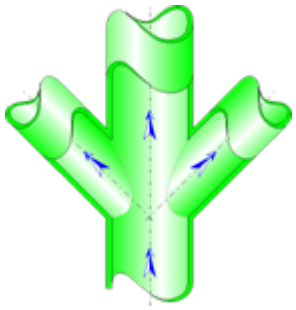


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.4.16 Four-way dividing junction with branches of unequal sections

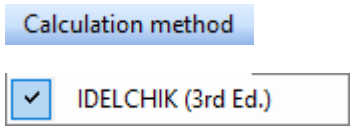
Circular cross-section



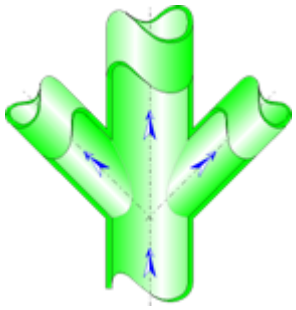
For the calculation of the pressure loss coefficient of a four-way dividing junction, the calculation method is described in the following reference document:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

The only calculation method offered appears in the "Calculation method" menu and is activated by default.



2.4.16.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a four-way dividing junction.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Cross-sectional area of the straight branch (m^2):

$$F_{st} = \pi \cdot \frac{D_{st}^2}{4}$$

Cross-sectional area of the right branch (m^2) :

$$F_{1s} = \pi \cdot \frac{D_s^2}{4}$$

Cross-sectional area of the left branch (m^2) :

$$F_{2s} = \pi \cdot \frac{D_s^2}{4}$$

Cross-sectional area of the common branch (m^2):

$$F_c = \pi \cdot \frac{D_{st}^2}{4}$$

Volume flow rate in the common branch (m^3/s):

$$Q_c = Q_{st} + Q_{1s} + Q_{2s}$$

Mean velocity in the straight branch (m/s):

$$w_{st} = \frac{Q_{st}}{F_c}$$

Mean velocity in the right branch (m/s):

$$w_{1s} = \frac{Q_{1s}}{F_{1s}}$$

Mean velocity in the left branch (m/s):

$$w_{2s} = \frac{Q_{2s}}{F_{2s}}$$

Mean velocity in the common branch (m/s):

$$w_c = \frac{Q_c}{F_c}$$

Mass flow rate in the straight branch (kg/s):

$$G_{st} = Q_{st} \cdot \rho$$

Mass flow rate in the right branch (kg/s):

$$G_{1s} = Q_{1s} \cdot \rho$$

Mass flow rate in the left branch (kg/s):

$$G_{2s} = Q_{2s} \cdot \rho$$

Mass flow rate in the common branch (kg/s):

$$G_c = Q_c \cdot \rho$$

Reynolds number in the straight branch:

$$\mathrm{Re}_{st} = \frac{w_{st} \cdot D_c}{\nu}$$

Reynolds number in the right branch:

$$\mathrm{Re}_{1s} = \frac{w_{1s} \cdot D_s}{\nu}$$

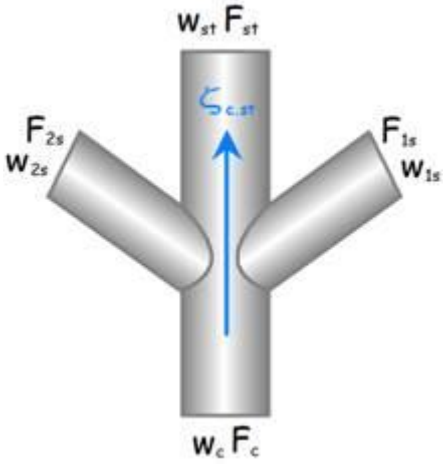
Reynolds number in the left branch:

$$\mathrm{Re}_{2s} = \frac{w_{2s} \cdot D_s}{\nu}$$

Reynolds number in the common branch:

$$\mathrm{Re}_c = \frac{w_c \cdot D_c}{\nu}$$

Pressure loss coefficient of the straight branch (based on mean velocity in the common branch):



$$\zeta_{c.st} = \tau_{st} \cdot \left(\frac{Q_s}{Q_c}\right)^2$$

([1] diagram 7-20)

with:

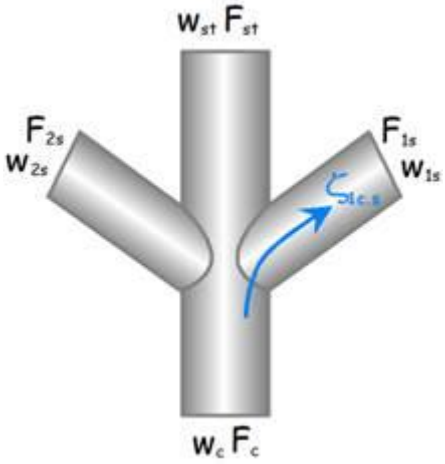
Values of τ_{st}

F_s / F_c	≤ 0.4	> 0.4	
Q_s / Q_c	0 - 1.0	≤ 0.5	> 0.5
τ_{st}	0.4	$2 \cdot \left(2 \cdot \frac{Q_s}{Q_c} - 1\right)$	$0.3 \cdot \left(2 \cdot \frac{Q_s}{Q_c} - 1\right)$

([1] diagram 7-20)

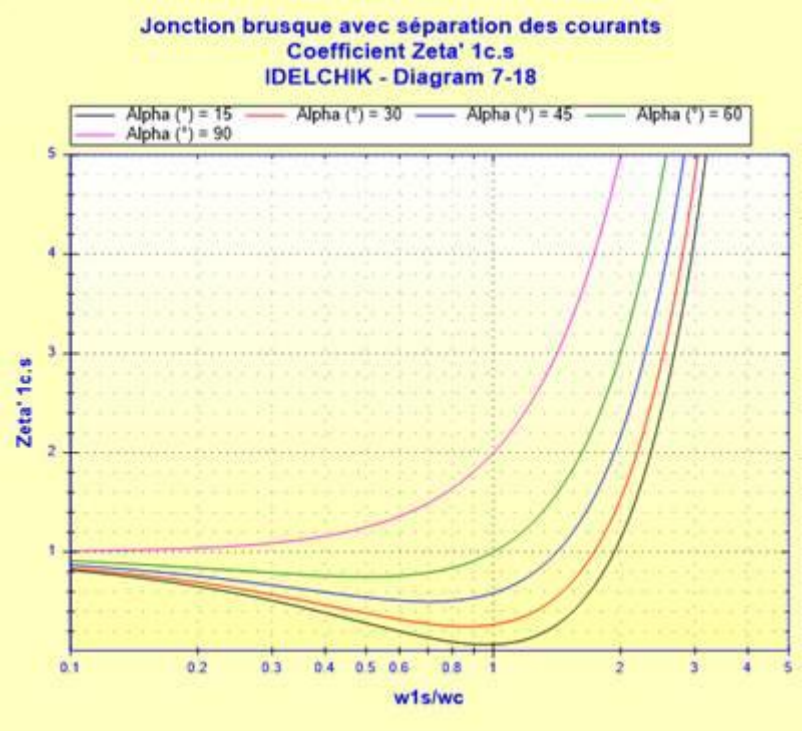
with: $Q_s = Max(Q_{1s}, Q_{2s})$

Pressure loss coefficient of the right branch (based on mean velocity in the common branch):



$$\zeta'_{1c.s} = 1 + \left(\frac{W_{1s}}{W_c}\right)^2 - 2 \cdot \left(\frac{W_{1s}}{W_c}\right) \cdot \cos(\alpha)$$

([1] diagram 7-18)



- $\alpha < 60°$

$$\zeta_{1c.s} = A' \cdot \zeta'_{1c.s}$$ ([1] diagram 7-18)

avec :

Valeurs de A'

F_{1s} / F_c	≤ 0.35		> 0.35	
Q_{1s} / Q_c	≤ 0.4	> 0.4	≤ 0.6	> 0.6
A_1'	$1.1 - 0.7 \cdot \frac{Q_{1s}}{Q_c}$	0.85	$1.0 - 0.6 \cdot \frac{Q_{1s}}{Q_c}$	0.6

([1] table 7-4)

- $\alpha = 90°$
  - ♦ $D_s/D_c \leq 2/3$

$$\zeta_{1c.s} = \zeta'_{1c.s}$$ ([1] diagram 7-18)

  - ♦ $D_s/D_c = 1$

$$\zeta_{1c.s} = \zeta'_{1c.s} \cdot \left[1 + 0.3 \cdot \left(\frac{W_{1s}}{W_c}\right)^2\right]$$ ([1] diagram 7-18)

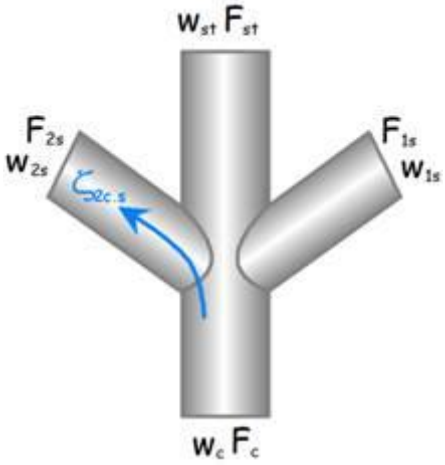
♦ $2/3 < D_s/D_c < 1$

For diameters ratios 'D_s/D_c' included between 2/3 and 1, the value of the pressure loss coefficient '$\zeta_{1c.s}$' at 90° is estimated by interpolation.

- $60° \leq \alpha < 90°$

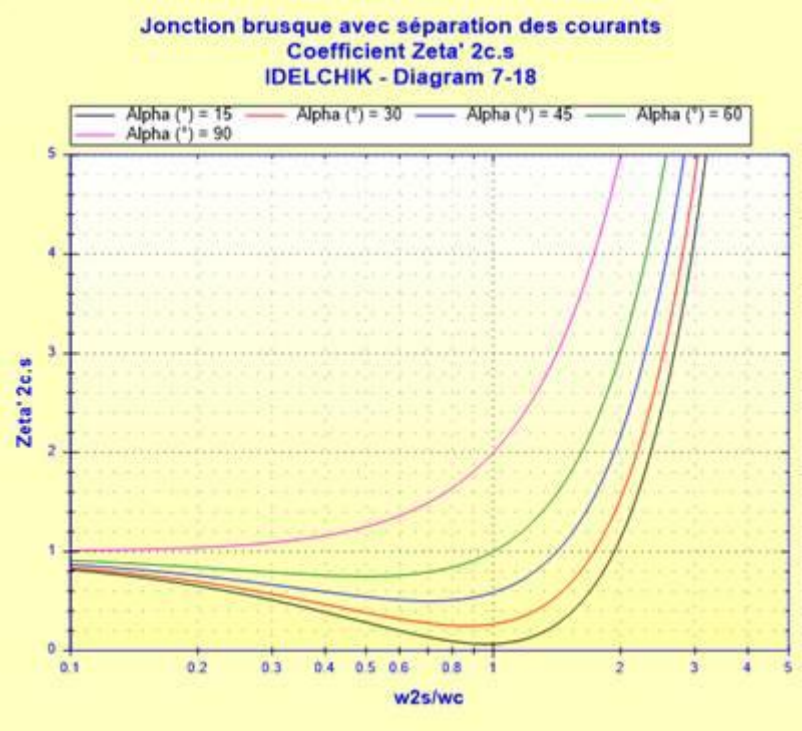
For angles 'α' between 60° and 90° the value of the pressure loss coefficient '$\zeta_{1c.s}$' is estimated by interpolation between the values calculated at 60° and those calculated at 90°.

Pressure loss coefficient of the left branch (based on mean velocity in the common branch):



$$\zeta'_{2c.s} = 1 + \left(\frac{w_{2s}}{w_c}\right)^2 - 2 \cdot \left(\frac{w_{2s}}{w_c}\right) \cdot \cos(\alpha)$$

([1] diagram 7-18)



- $\alpha < 60°$

$$\zeta_{2c.s} = A' \cdot \zeta'_{2c.s}$$ ([1] diagram 7-18)

avec :

Valeurs de A'

F_{2s} / F_c	≤ 0.35		> 0.35	
Q_{2s} / Q_c	≤ 0.4	> 0.4	≤ 0.6	> 0.6
A_2'	$1.1 - 0.7 \cdot \frac{Q_{2s}}{Q_c}$	0.85	$1.0 - 0.6 \cdot \frac{Q_{2s}}{Q_c}$	0.6

([1] table 7-4)

- $\alpha = 90°$
  - ♦ $D_s/D_c \leq 2/3$

$$\zeta_{2c.s} = \zeta'_{2c.s}$$ ([1] diagram 7-18)

  - ♦ $D_s/D_c = 1$

$$\zeta_{2c.s} = \zeta'_{2c.s} \cdot \left[1 + 0.3 \cdot \left(\frac{w_{2s}}{w_c}\right)^2\right]$$ ([1] diagram 7-18)

♦ $2/3 < D_s/D_c < 1$

For diameters ratios 'D_s/D_c' included between 2/3 and 1, the value of the pressure loss coefficient '$\zeta_{2c.s}$' at 90° is estimated by interpolation.

- $60° \leq \alpha < 90°$

For angles 'α' between 60° and 90° the value of the pressure loss coefficient '$\zeta_{2c.s}$' is estimated by interpolation between the values calculated at 60° and those calculated at 90°.

Pressure loss in the straight branch (Pa):

$$\Delta P_{c.st} = \zeta_{c.st} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Pressure loss in the right branch (Pa):

$$\Delta P_{1c.s} = \zeta_{1c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Pressure loss in the left branch (Pa):

$$\Delta P_{2c.s} = \zeta_{2c.s} \cdot \frac{\rho \cdot W_c^{\,2}}{2}$$

Head loss of fluid in the straight branch (m):

$$\Delta H_{c.st} = \zeta_{c.st} \cdot \frac{W_c^{\,2}}{2 \cdot g}$$

Head loss of fluid in the right branch (m):

$$\Delta H_{1c.s} = \zeta_{1c.s} \cdot \frac{W_c^{\,2}}{2 \cdot g}$$

Head loss of fluid in the left branch (m):

$$\Delta H_{2c.s} = \zeta_{2c.s} \cdot \frac{W_c^{\,2}}{2 \cdot g}$$

Hydraulic power loss in the right branch (W):

$$Wh_{1s} = \Delta P_{1c.s} \cdot Q_{1s}$$

Hydraulic power loss in the left branch (W):

$$Wh_{2s} = \Delta P_{2c.s} \cdot Q_{2s}$$

Hydraulic power loss in the straight branch (W):

$$Wh_{st} = \Delta P_{c.st} \cdot Q_{st}$$

Symbols, Definitions, SI Units:

α	Angle of the right and left branches (°)
D_{st}	Diameter of the straight and common branches (m)
D_s	Diameter of the right and left branches (m)
F_{st}	Cross-sectional area of the straight branch (m^2)
F_{1s}	Cross-sectional area of the right branch (m^2)
F_{2s}	Cross-sectional area of the left branch (m^2)
F_c	Cross-sectional area of the common branch (m^2)
Q_{st}	Volume flow rate in the straight branch (m^3/s)
w_{st}	Mean velocity in the straight branch (m/s)
Q_{1s}	Volume flow rate in the right branch (m^3/s)
w_{1s}	Mean velocity in the right branch (m/s)
Q_{2s}	Volume flow rate in the left branch (m^3/s)
w_{2s}	Mean velocity in the left branch (m/s)
Q_c	Volume flow rate in the common branch (m^3/s)
w_c	Mean velocity in the common branch (m/s)
G_{st}	Mass flow rate in the straight branch (kg/s)
G_{1s}	Mass flow rate in the right branch (kg/s)

G_{2s} Mass flow rate in the left branch (kg/s)

G_c Mass flow rate in the common branch (kg/s)

Re_{st} Reynolds number in the straight branch ()

Re_{1s} Reynolds number in the right branch ()

Re_{2s} Reynolds number in the left branch ()

Re_c Reynolds number in the common branch ()

$\zeta_{c.st}$ Pressure loss coefficient of the straight branch (based on mean velocity in the common branch) ()

$\zeta'_{1c.s}$ Coefficient of the right branch ()

$\zeta_{1c.s}$ Pressure loss coefficient of the right branch (based on mean velocity in the common branch) ()

$\zeta'_{2c.s}$ Coefficient of the left branch ()

$\zeta_{2c.s}$ Pressure loss coefficient of the left branch (based on mean velocity in the common branch) ()

ΔP_{st} Pressure loss in the straight branch (Pa)

ΔP_{1s} Pressure loss in the right branch (Pa)

ΔP_{2s} Pressure loss in the left branch (Pa)

ΔH_{st} Head loss of fluid in the straight branch (m)

ΔH_{1s} Head loss of fluid in the right branch (m)

ΔH_{2s} Head loss of fluid in the left branch (m)

Wh_{st} Hydraulic power loss in the straight branch (W)

Wh_{1s} Hydraulic power loss in the right branch (W)

Wh_{2s} Hydraulic power loss in the left branch (W)

ρ Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

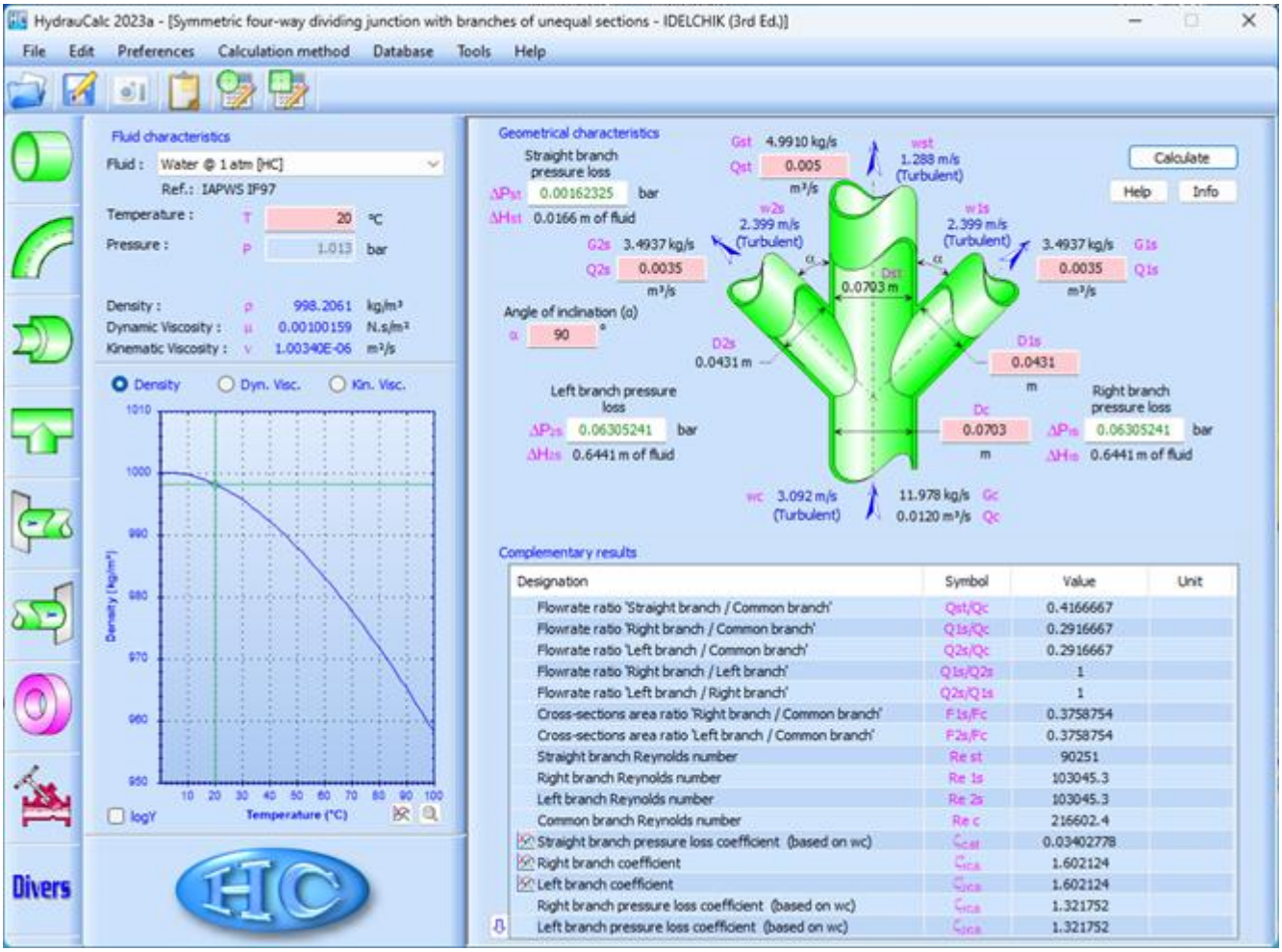
g Gravitational acceleration (m/s^2)

Validity range:

- flow regime: turbulent ($Re_c \geq 10^4$)
- common branch area: equal to the sum of the areas of the right and left branches ($F_c = F_{1s} + F_{2s}$)
- angles of the right and left branches: equal and between 30 ° and 90 ° ($30° \leq \alpha \leq 90°$)

note: for diameters ratios 'D_s/D_c' included between 2/3 and 1, the value of the pressure loss coefficients '$\zeta_{1c.s}$' and '$\zeta_{2c.s}$' at 90° is estimated by interpolation, for angles 'α' between 60° and 90° the value of the pressure loss coefficients '$\zeta_{1c.s}$' and '$\zeta_{2c.s}$' is estimated by interpolation between the values calculated at 60° and those calculated at 90°.

Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.5 Entrances

This subsection regroups the set of piping entrances elements that can be modeled and calculated. The types of piping entrance available are:

- Flush-Mounted Sharp-Edged Entrance - Circular Cross-Section

- Flush-Mounted Rounded Entrance - Circular Cross-Section

- Flush-Mounted Bevelled Entrance - Circular Cross-Section

- Sharp-Edged Entrance Mounted at a Distance - Circular Cross-Section

- Sharp-Edged Entrance Mounted at an Angle - Circular Cross-Section

- Entrance through a thick-edged orifice - Circular Cross-Section

- Entrance through a sharp-edged orifice - Circular Cross-Section

- Entrance through a round-edged orifice - Circular Cross-Section

- Entrance through a bevel-edged orifice - Circular Cross-Section

- Entrance through a thick-edged grid - Circular Cross-Section

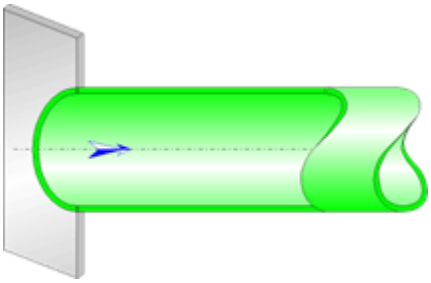
- Entrance through a sharp-edged grid - Circular Cross-Section

- Entrance through a round-edged grid - Circular Cross-Section

- Entrance through a bevel-edged grid - Circular Cross-Section

2.5.1 Flush-mounted sharp-edged entrance

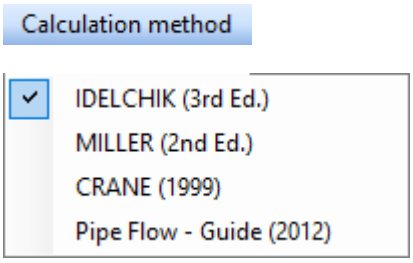
Circular Cross-Section



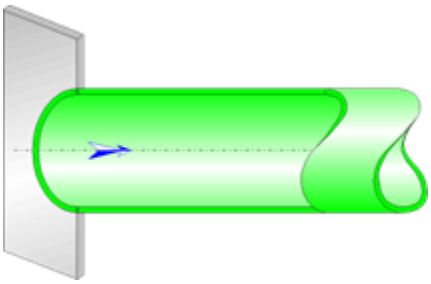
For the calculation of the pressure loss coefficient of flush-mounted sharp-edged entrances of piping, the user can choose from one of the methods described in the following four reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.5.1.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted sharp-edged entrance of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Pipe cross-sectional area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re} = \frac{w_0 \cdot D_0}{\nu}$$

Local resistance coefficient:

$$\zeta_{loc} = 0.5$$ ([1] diagram 3.1 with $b/D_h = 0$)

Total pressure loss coefficient (based on mean velocity in pipe):

$$\zeta = \zeta_{loc}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot w_0^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{w_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

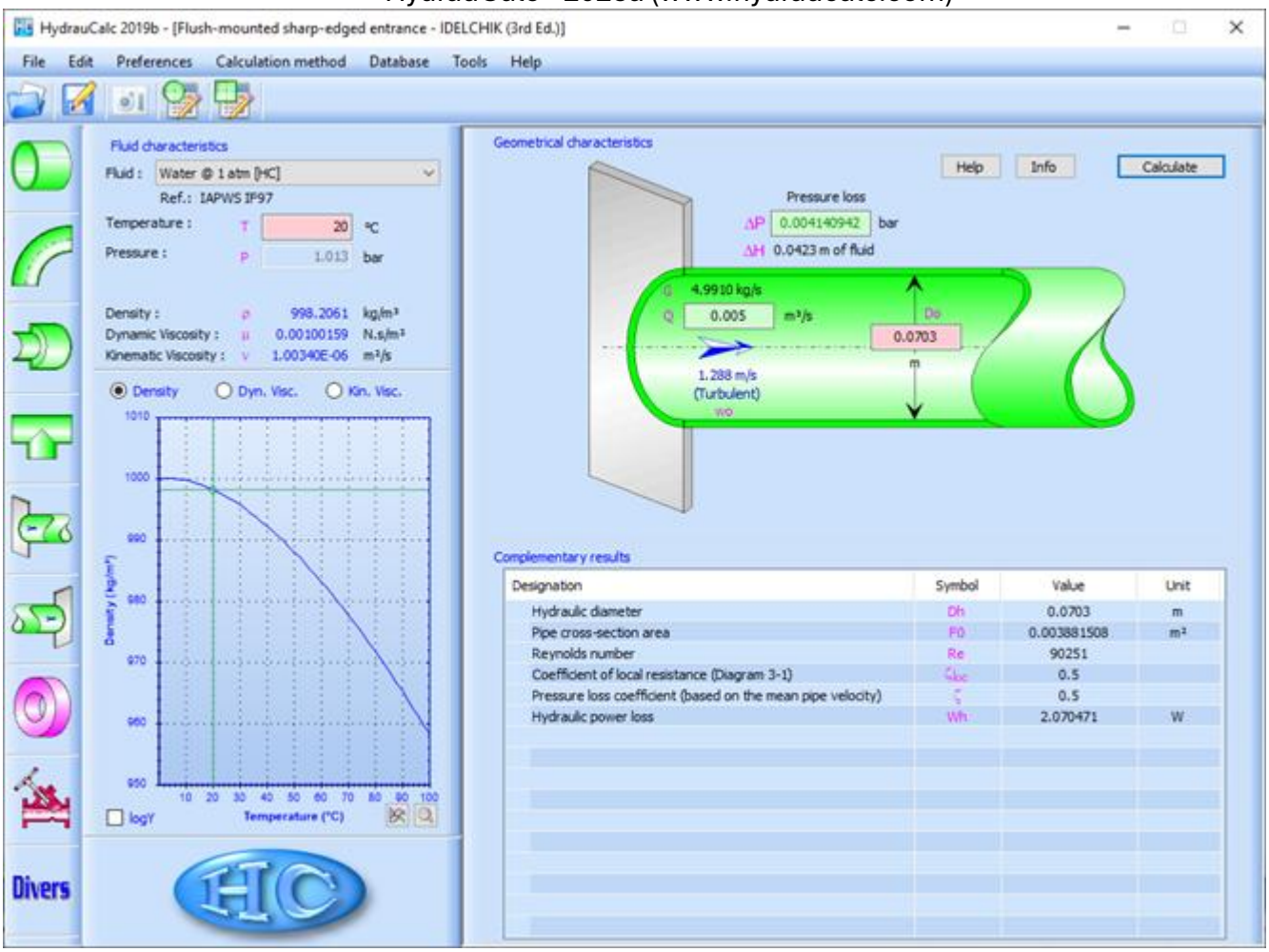
D_h	Hydraulic diameter (m)
D_0	Pipe diameter (m)
F_0	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)

Re	Reynolds number in pipe ()
ζ_{loc}	Local resistance coefficient ()
ζ	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m³)
ν	Fluid kinematic viscosity (m²/s)
g	Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)

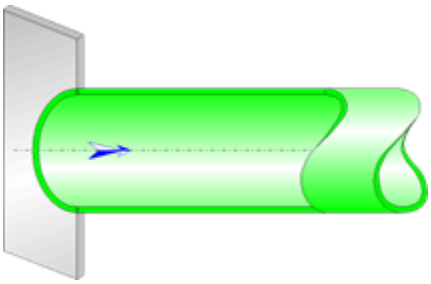
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.5.1.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted sharp-edged entrance of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity in pipe (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

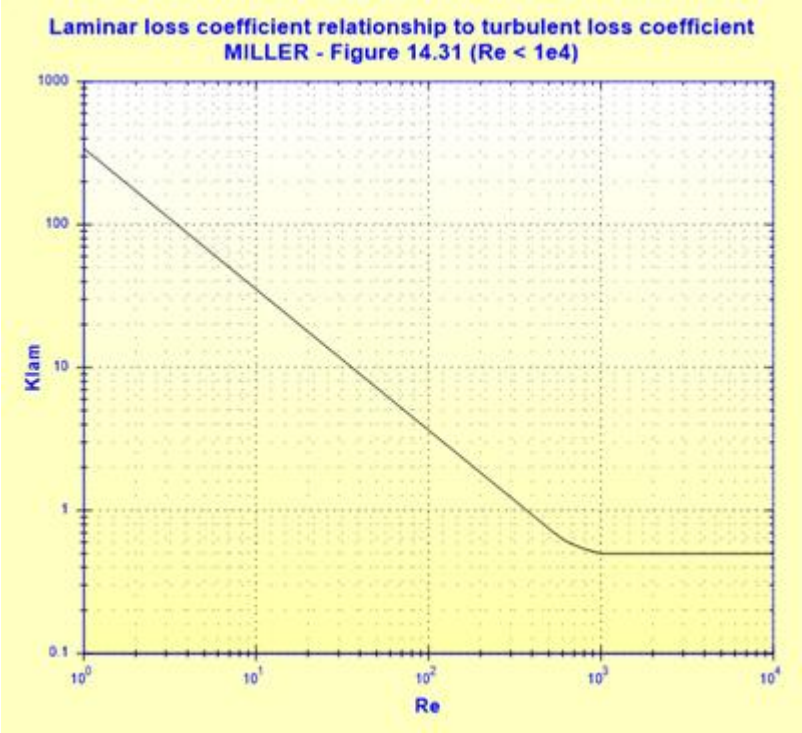
Local resistance coefficient:

- $\mathrm{Re} \geq 10^4$

  $$K_S = 0.5$$ ([1] figure 14.14+ with A2/A1 = 0 and r/d = 0)

- $\mathrm{Re} < 10^4$

  $$K_{lam} = f(\mathrm{Re})$$ ([1] figure 14.31 with K_{turb} = 0.5)



Reynolds Number Correction ($\mathrm{Re} < 10^4$):

$$C_{\mathrm{Re}} = \frac{K_{lam}}{K_s}$$

Total pressure loss coefficient (based on mean velocity in pipe):

- turbulent flow ($Re \geq 10^4$):

$$K = K_s$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in pipe ()
K_s	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

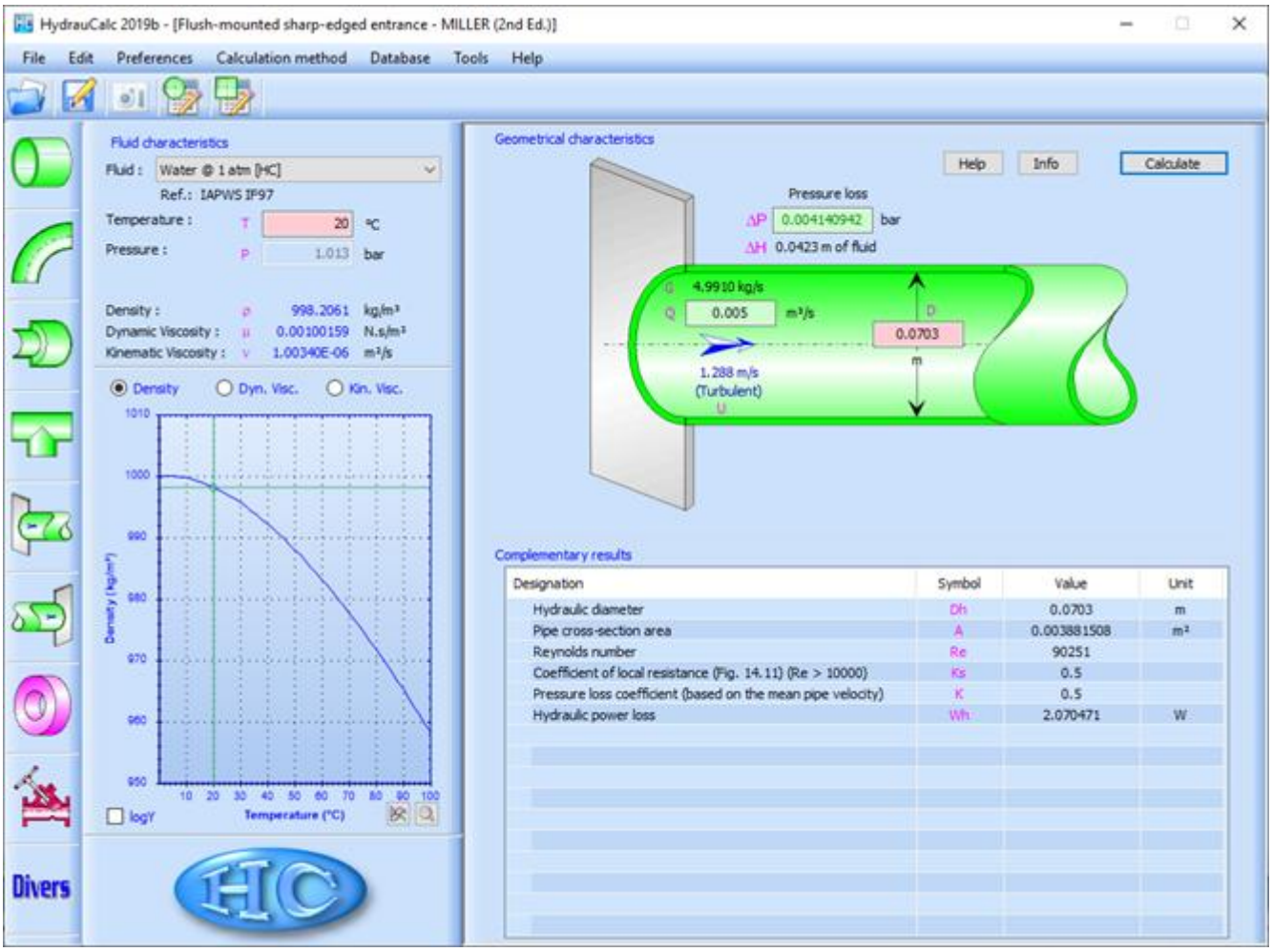
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar and turbulent

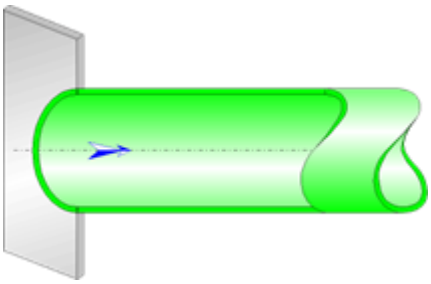
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.5.1.3 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted sharp-edged entrance of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$d_h = d$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity in pipe (m/s):

$$V = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

Local resistance coefficient ($N_{Re} \geq 10^4$):

$$K_2 = 0.57$$ ([1] §9.1.1)

Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_2$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_h	Hydraulic diameter (m)
d	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
V	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)

N_{Re} Reynolds number in pipe ()

K_2 Local resistance coefficient ()

K Total pressure loss coefficient (based on mean velocity in pipe) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m^3)

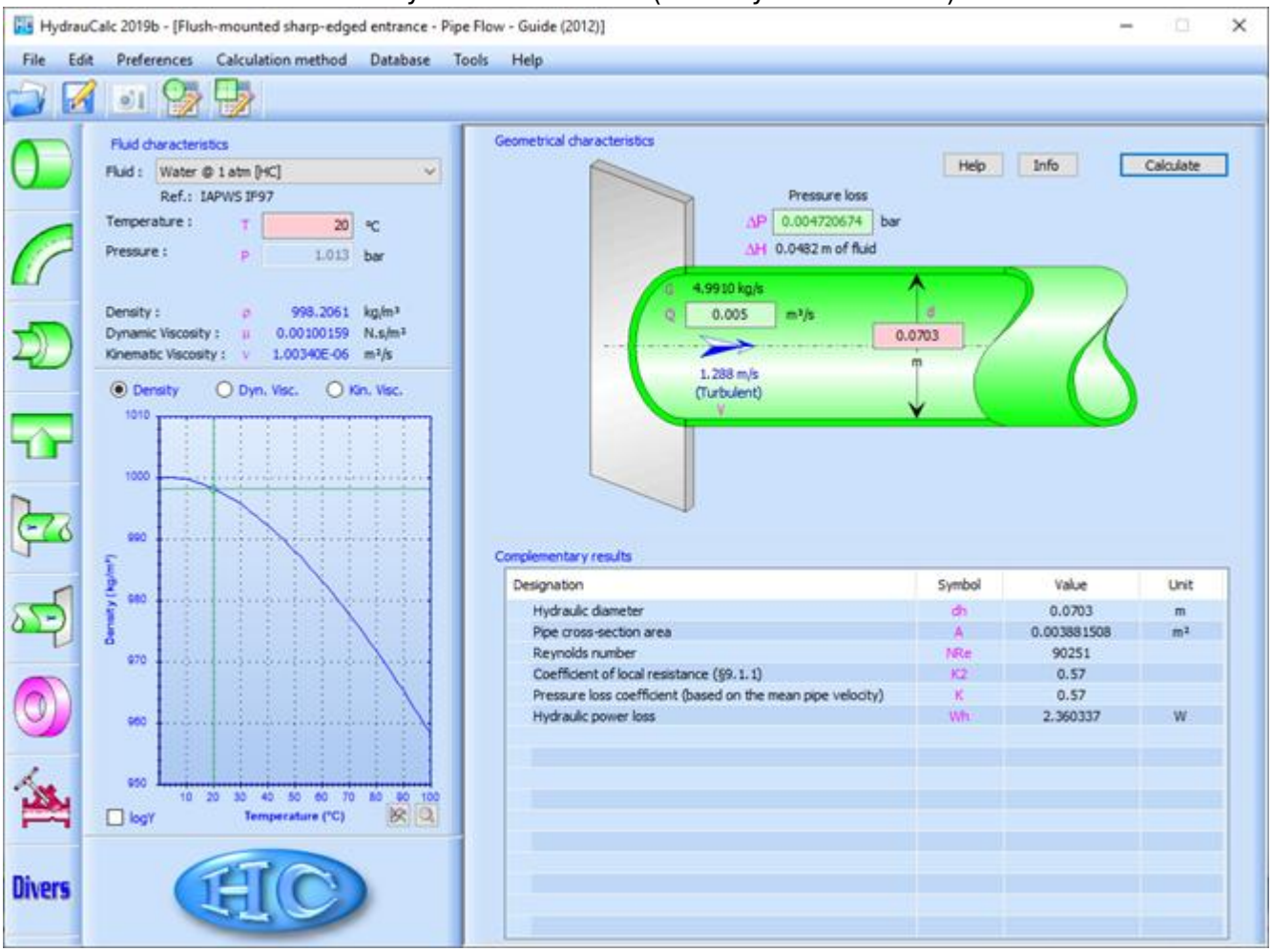
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in pipe ($N_{Re} \geq 10^4$)

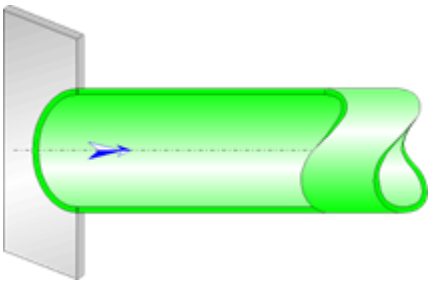
Example of application:



References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.5.1.4 CRANE



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted sharp-edged entrance of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity in pipe (m/s):

$$v = \frac{q}{A}$$

Mass flow rate (kg/s):

$$G = q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re} = \frac{v \cdot D}{\nu}$$

Local resistance coefficient ($\mathrm{Re} \geq 10^4$):

$$K_1 = 0.5$$ ([1] Appendix A-29)

Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_1$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot v^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot q$$

Symbols, Definitions, SI Units:

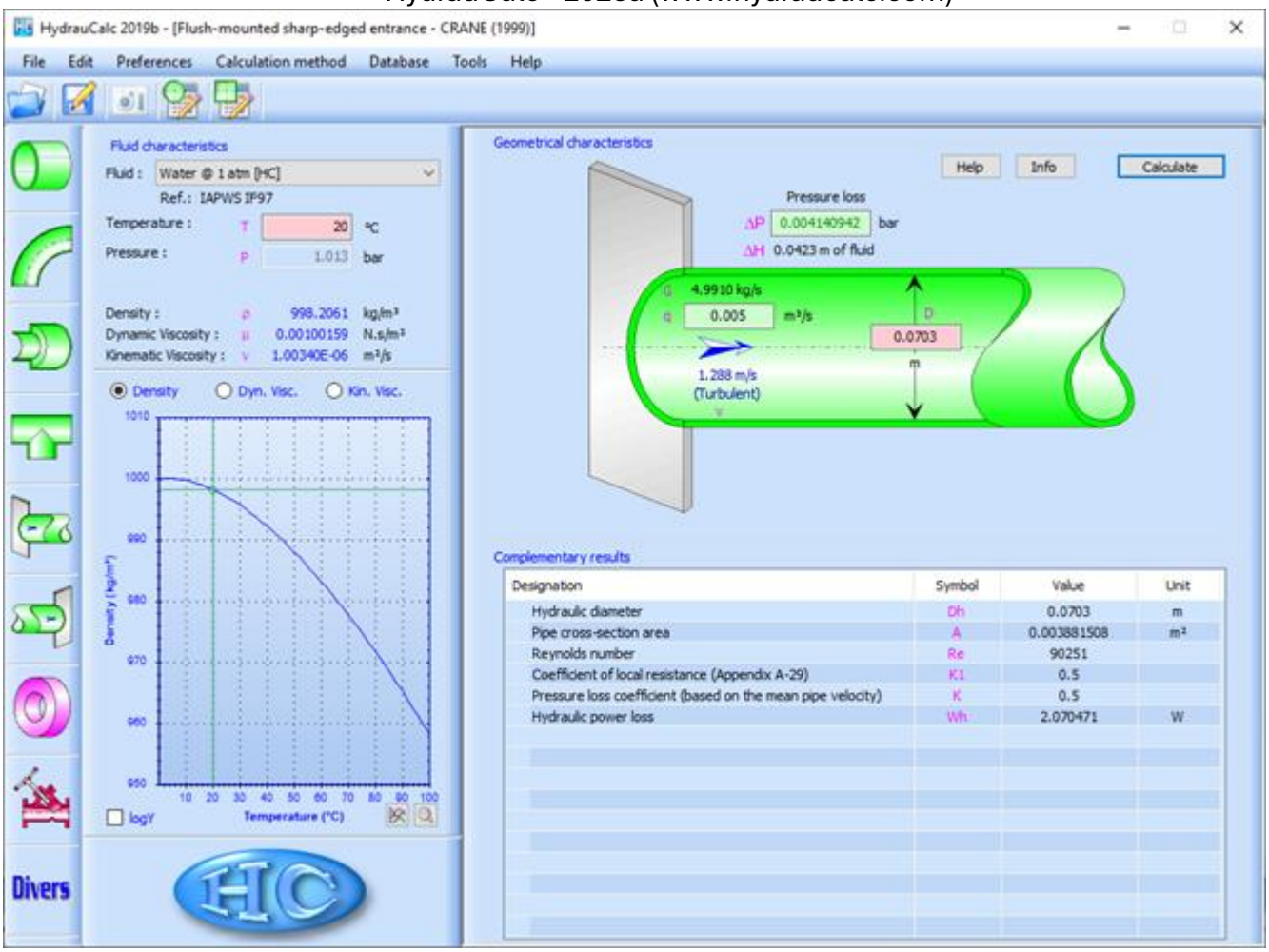
D_h	Hydraulic diameter (m)
D	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
q	Volume flow rate (m^3/s)
v	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)

Re	Reynolds number in pipe ()
K_1	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in pipe ($Re \geq 10^4$)

Example of application:

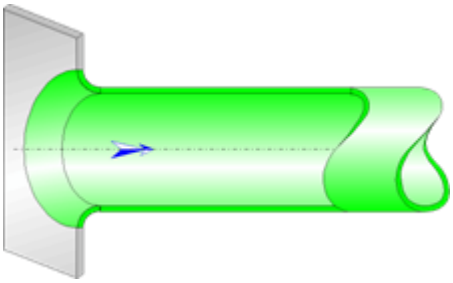


References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 – Edition 1999

2.5.2 Flush-mounted rounded entrance

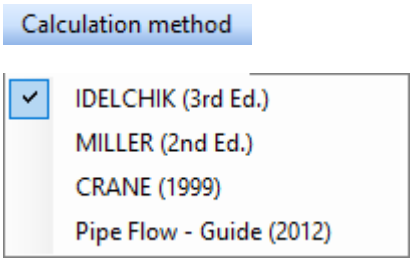
Circular Cross-Section



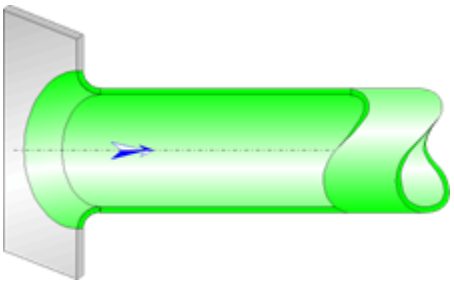
For the calculation of the pressure loss coefficient of flush-mounted rounded entrances of piping, the user can choose from one of the methods described in the following four reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.5.2.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted rounded entrance of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Pipe cross-sectional area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

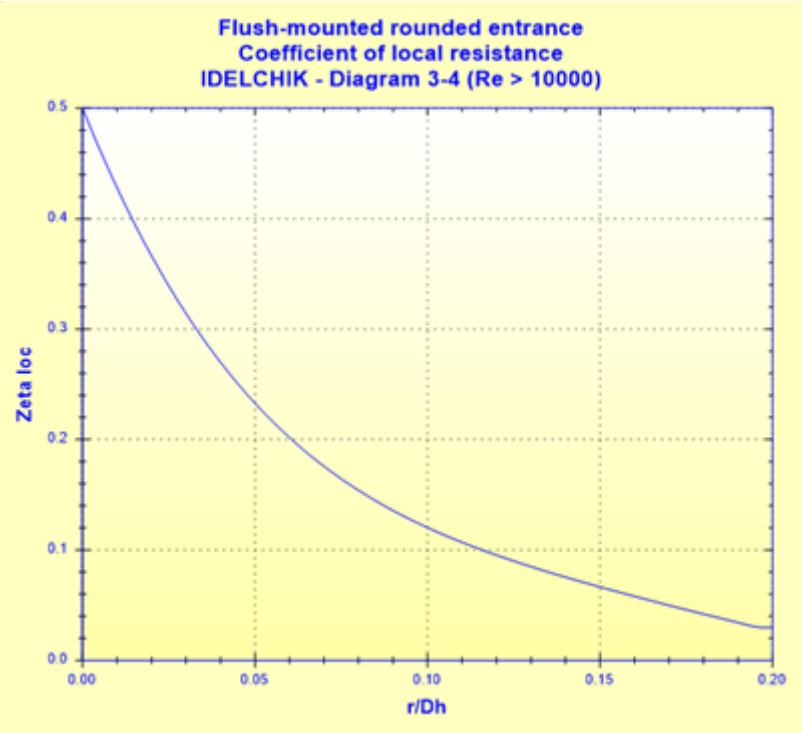
Reynolds number in pipe:

$$\mathrm{Re} = \frac{w_0 \cdot D_0}{\nu}$$

Local resistance coefficient:

- $r/D_h \le 0.2$

$$\zeta_{loc} = f(r/D_h)$$ ([1] diagram 3.4)



- $r/D_h > 0.2$

$$\zeta_{loc} = 0.03$$ ([1] diagram 3.4)

Total pressure loss coefficient (based on mean velocity in pipe):

$$\zeta = \zeta_{loc}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

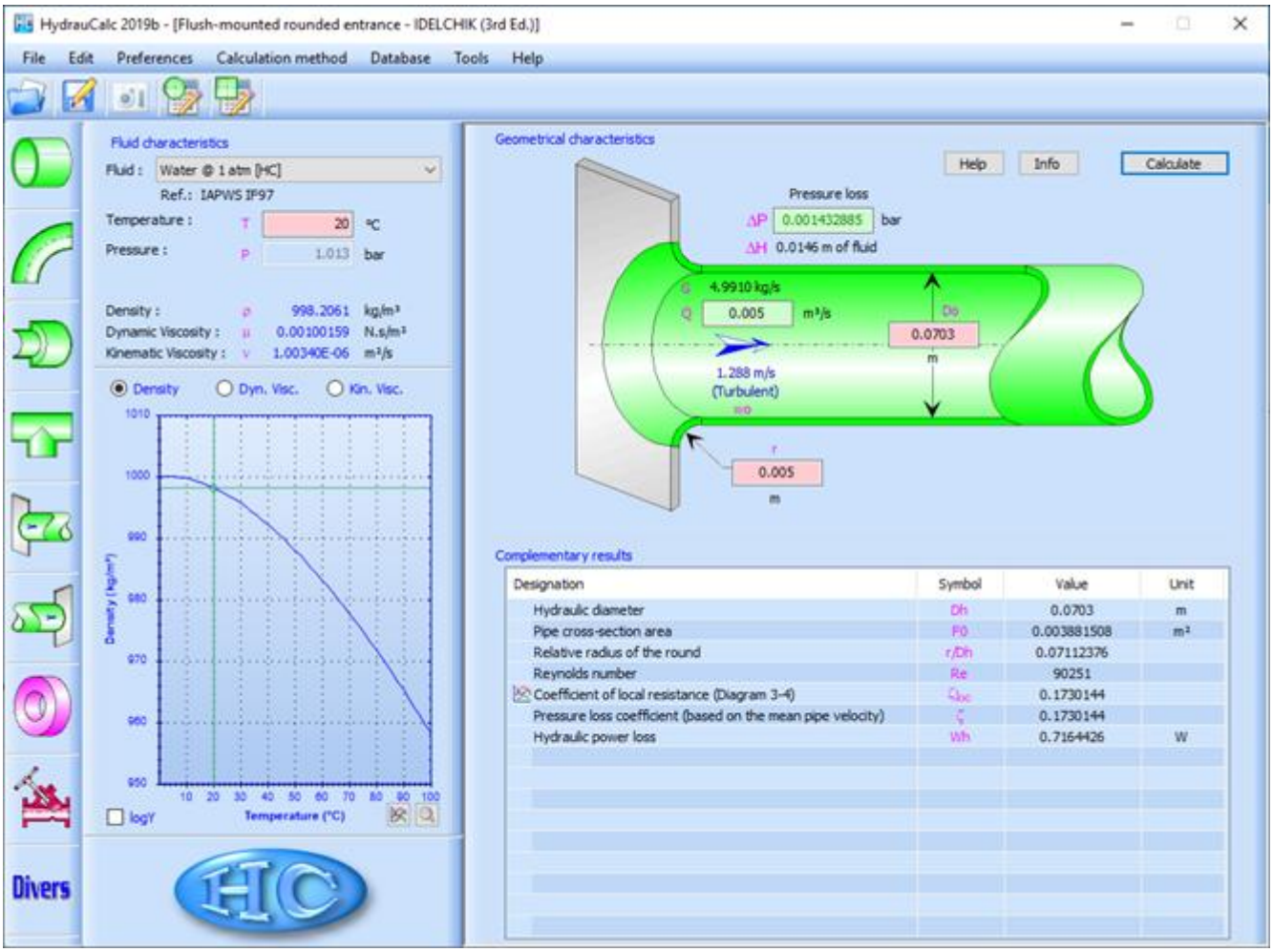
Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_0	Pipe diameter (m)
F_0	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in pipe ()
r	Radius of the round (m)
ζ_{loc}	Local resistance coefficient ()
ζ	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)

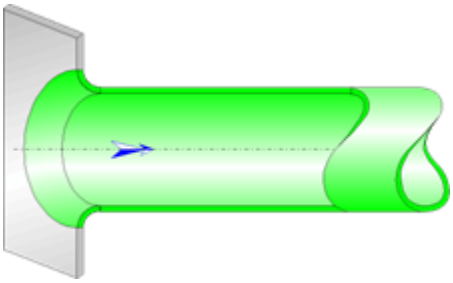
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.5.2.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted rounded entrance of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity in pipe (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

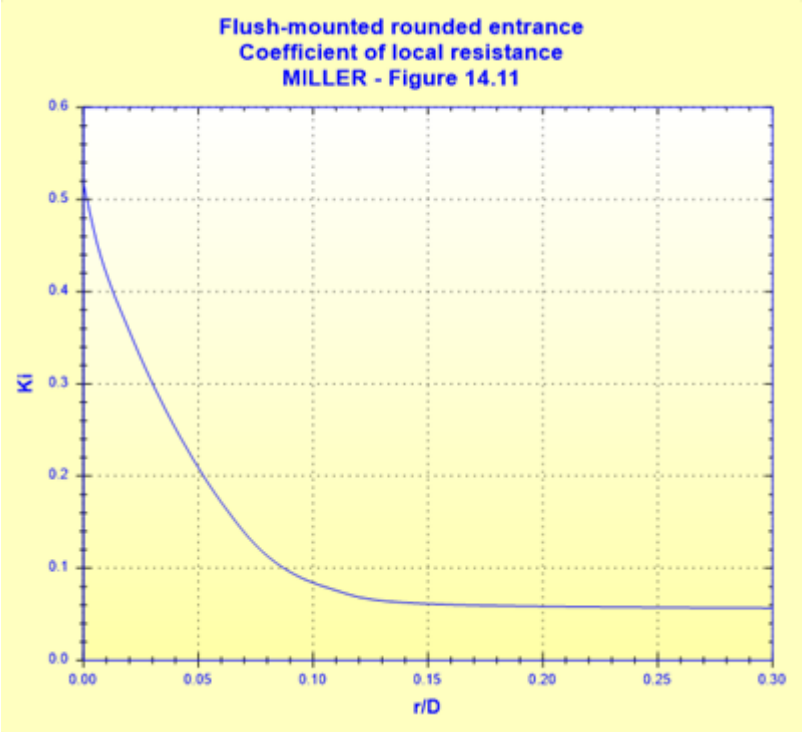
$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Local resistance coefficient:

- $\mathrm{Re} \geq 10^4$
  - $r/D \leq 0.3$

$$K_i = f\left(\frac{r}{D}\right)$$

([1] figure 14.11)



  - $r/D > 0.3$

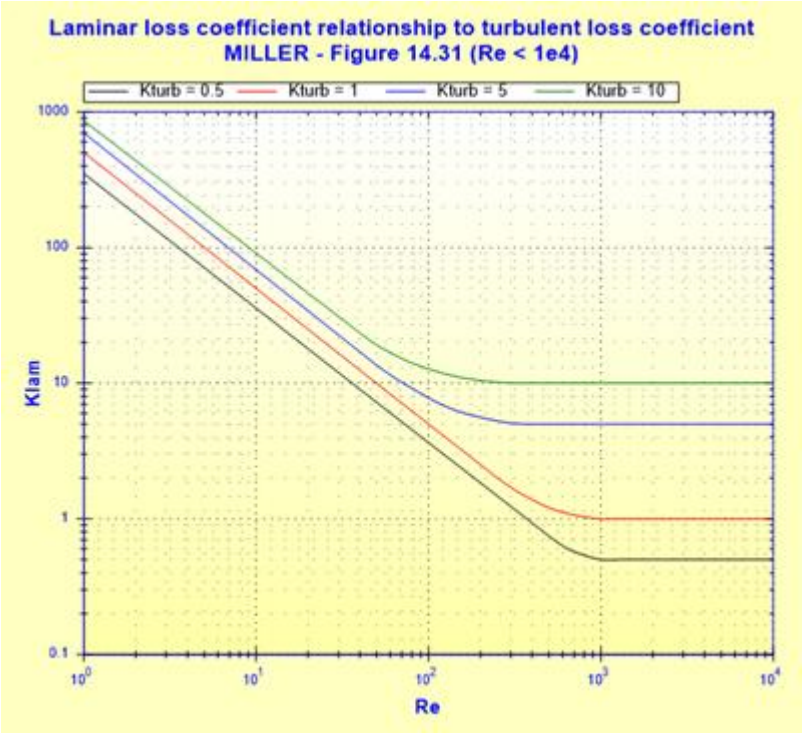
$$K_i = 0.567$$

([1] figure 14.12)

- $\mathrm{Re} < 10^4$

$$K_{lam} = f(\mathrm{Re}, K_{turb})$$

([1] figure 14.31 with $K_{turb} = K_i$)



Reynolds Number Correction ($Re < 10^4$):

$$C_{Re} = \frac{K_{lam}}{K_i}$$

Total pressure loss coefficient (based on mean velocity in pipe):

- turbulent flow ($Re \geq 10^4$):

$$K = K_i$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

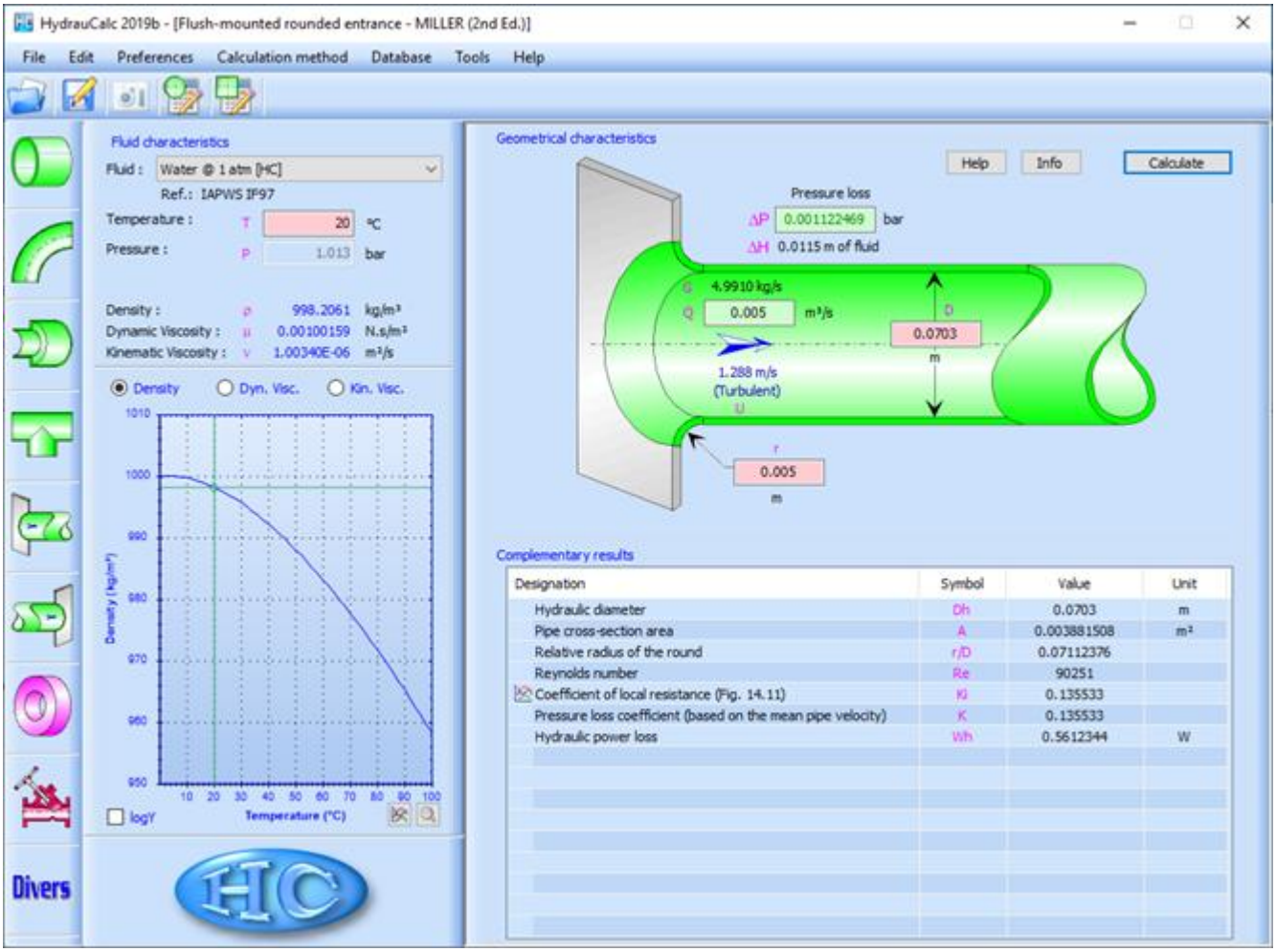
Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in pipe ()
r	Radius of the round (m)
K_i	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent

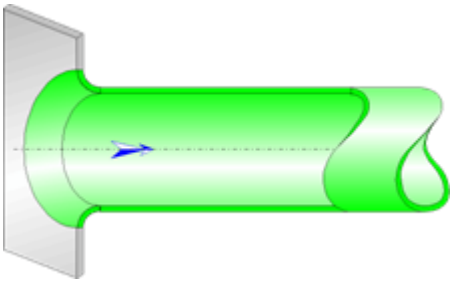
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.5.2.3 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted rounded entrance of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$d_h = d$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity in pipe (m/s):

$$V = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

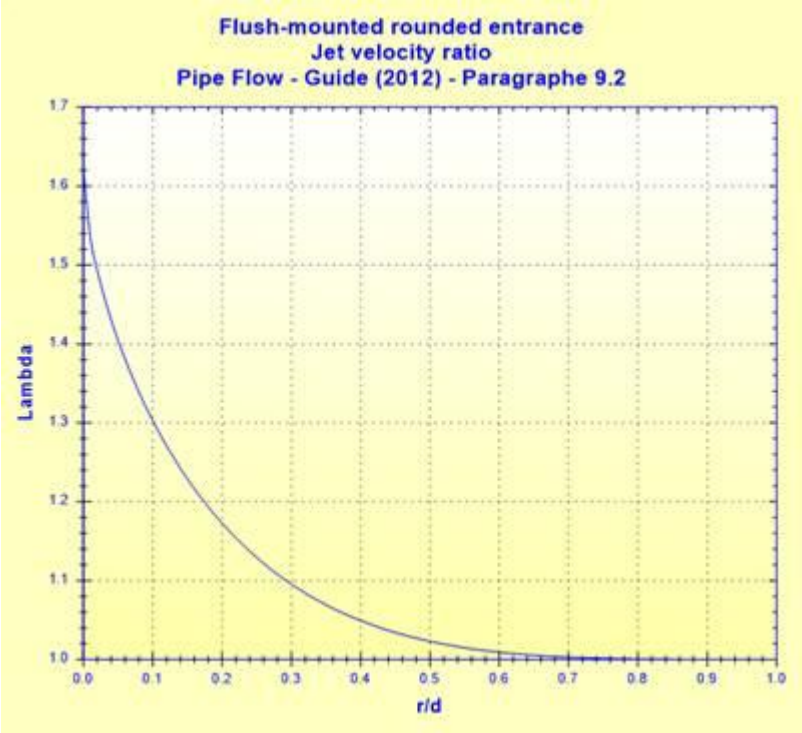
$$N_{Re} = \frac{V \cdot d}{\nu}$$

Jet velocity ratio:

- r/d < 1

$$\lambda = 1 + 0.622 \cdot \left[1 - 0.3 \cdot \sqrt{\frac{r}{d}} - 0.7 \cdot \frac{r}{d} \right]^4$$

([1] §9.2)



- r/d ≥ 1

$$\lambda = 1$$

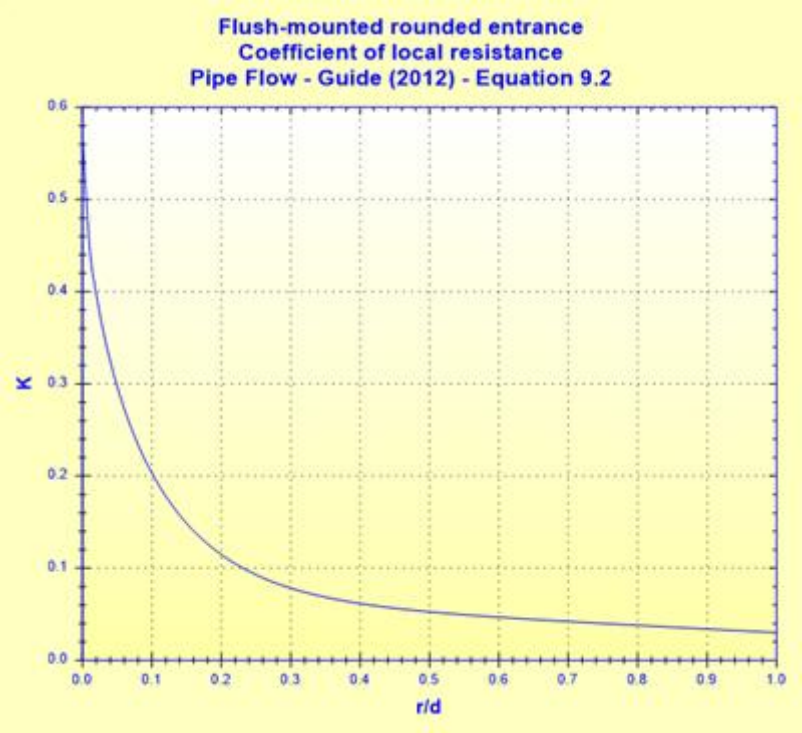
([1] § 9.2)

Coefficient of local resistance ($N_{Re} \geq 10^4$):

- r/d < 1

$$K_e = 0.0696 \cdot \left(1 - 0.569 \cdot \frac{r}{d} \right) \cdot \lambda^2 + (\lambda - 1)^2$$

([1] equation 9.2)



■ $r/d \geq 1$

$$K_e = 0.03$$ ([1] § 9.2)

Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_e$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot v^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

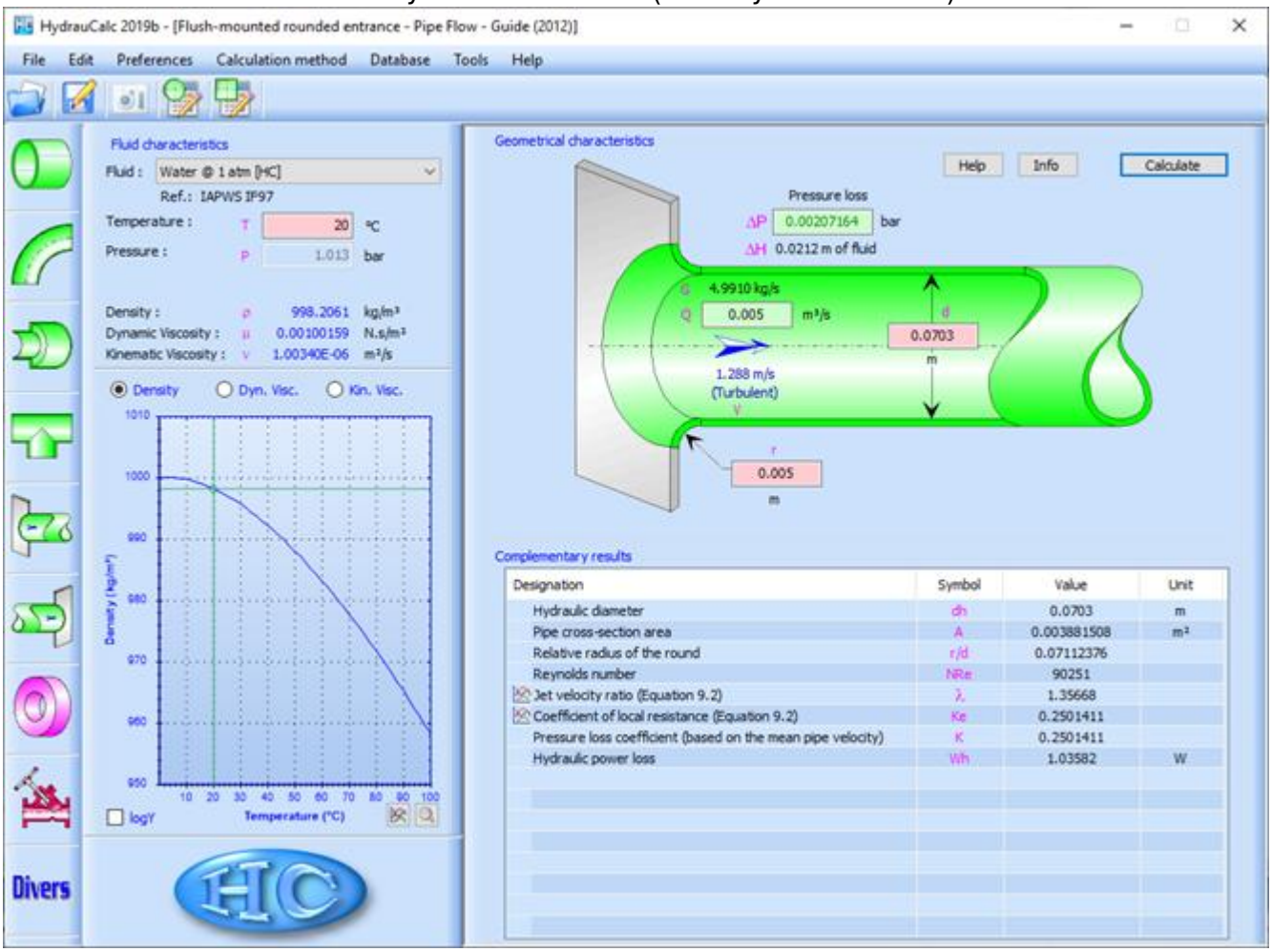
Symbols, Definitions, SI Units:

d_h	Hydraulic diameter (m)
d	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
V	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)
N_{Re}	Reynolds number in pipe ()
r	Radius of the round (m)
λ	Jet velocity ratio ()
K_e	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in pipe ($N_{Re} \geq 10^4$)

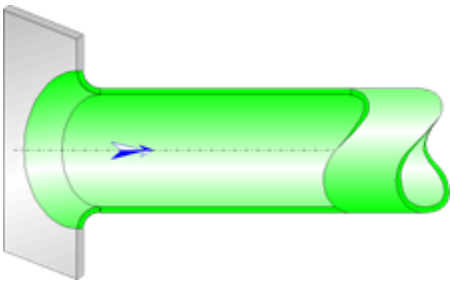
Example of application:



References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.5.2.4 CRANE



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted rounded entrance of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity in pipe (m/s):

$$v = \frac{q}{A}$$

Mass flow rate (kg/s):

$$G = q \cdot \rho$$

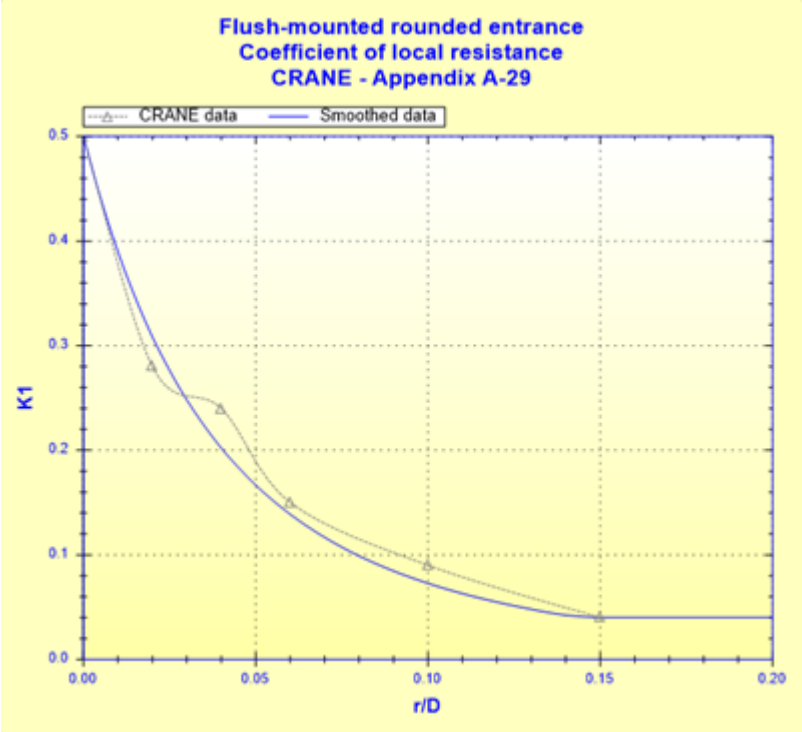
Reynolds number in pipe:

$$\mathrm{Re} = \frac{v \cdot D}{\nu}$$

Local resistance coefficient ($\mathrm{Re} \geq 10^4$):

- $r/D \leq 0.15$

$$K_1 = f\left(\frac{r}{D}\right)$$ ([1] Appendix A-29)



- $r/D > 0.15$

$$K_1 = 0.04$$ ([1] Appendix A-29)

Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_1$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot v^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot q$$

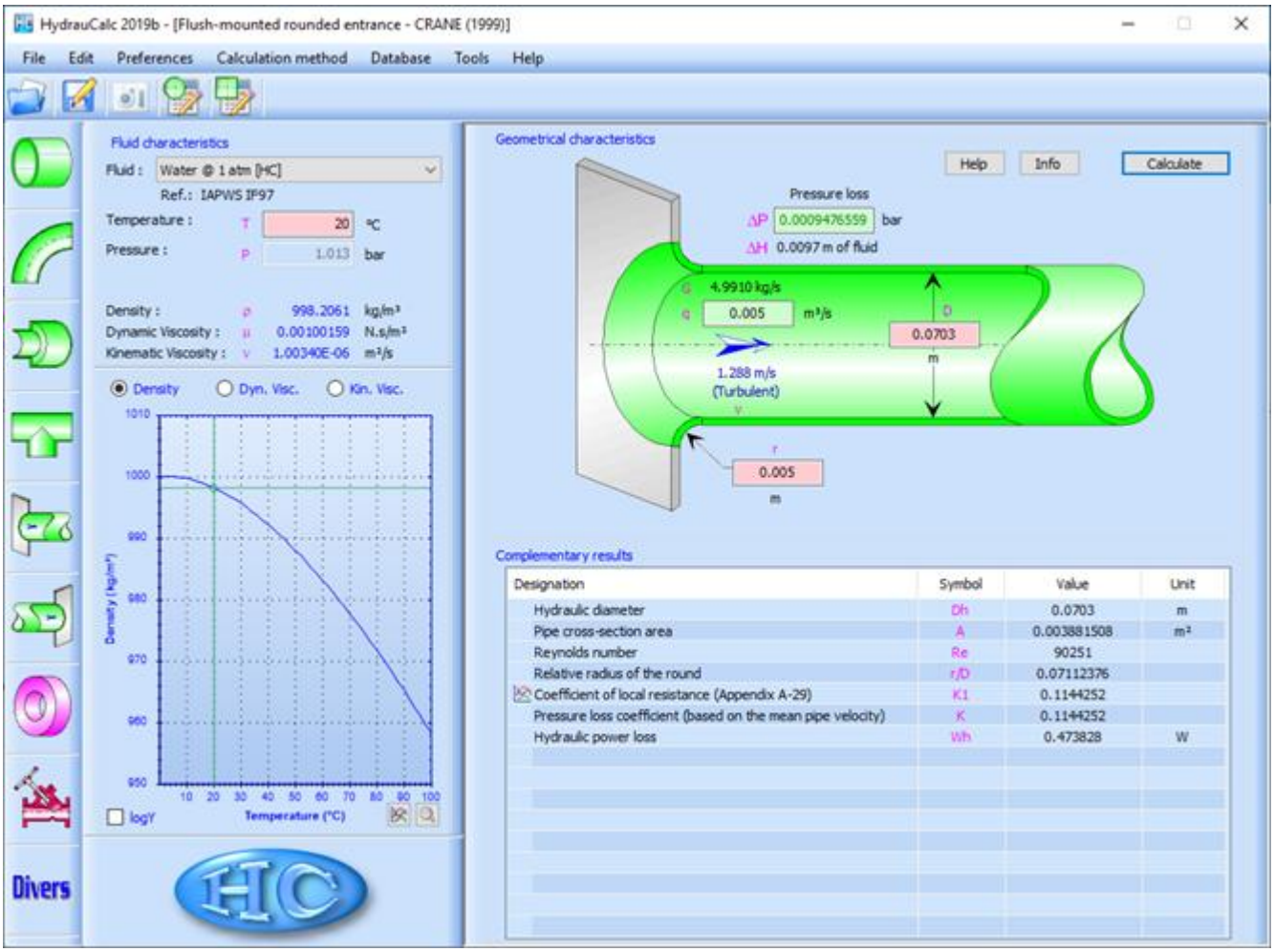
Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
q	Volume flow rate (m^3/s)
v	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in pipe ()
r	Radius of the round (m)
K_1	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in pipe ($Re \geq 10^4$)

Example of application:

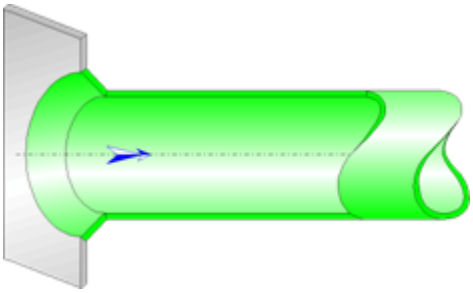


References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 – Edition 1999

2.5.3 Flush-mounted bevelled entrance

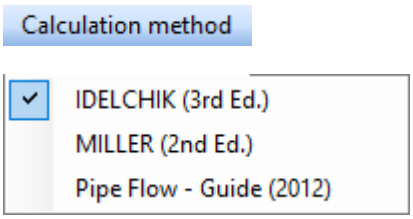
Circular Cross-Section



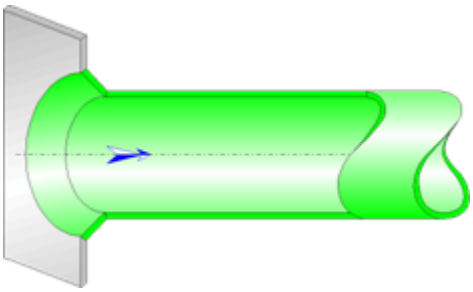
For the calculation of the pressure loss coefficient of flush-mounted bevelled entrances of piping, the user can choose from one of the methods described in the following three reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.5.3.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted bevelled entrance of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Pipe cross-sectional area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

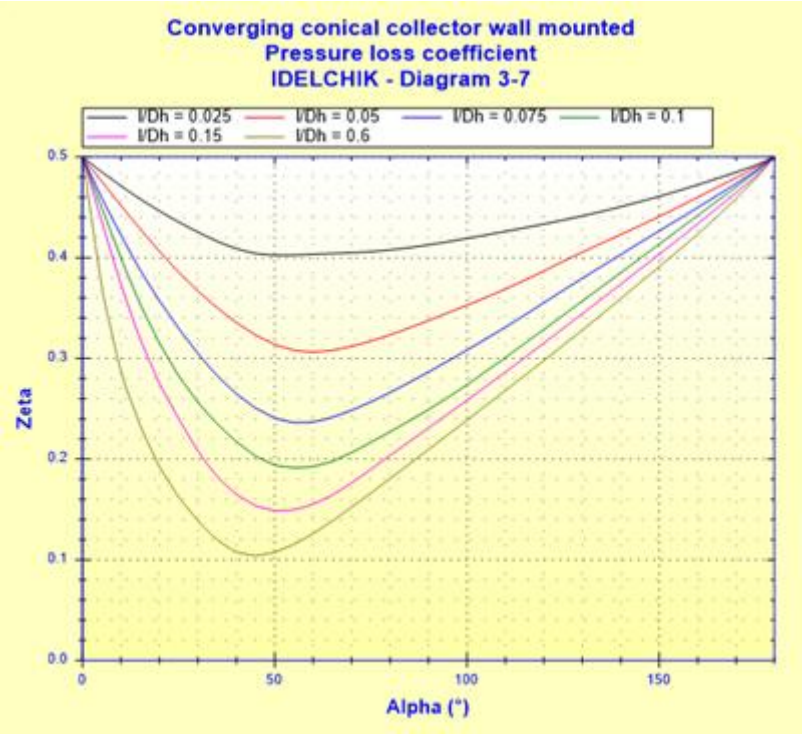
$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re} = \frac{W_0 \cdot D_0}{\nu}$$

Local resistance coefficient ($\mathrm{Re} \geq 10^4$):

$$\zeta_{loc} = f(\alpha, l/D_h)$$ ([1] diagram 3-7)



Total pressure loss coefficient (based on mean velocity in pipe):

$$\zeta = \zeta_{loc}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{w_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_0	Pipe diameter (m)
F_0	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in pipe ()
α	Top angle of cone (2 x bevel angle) (°)
l	Bevel length (m)
ζ_{loc}	Local resistance coefficient ()
ζ	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

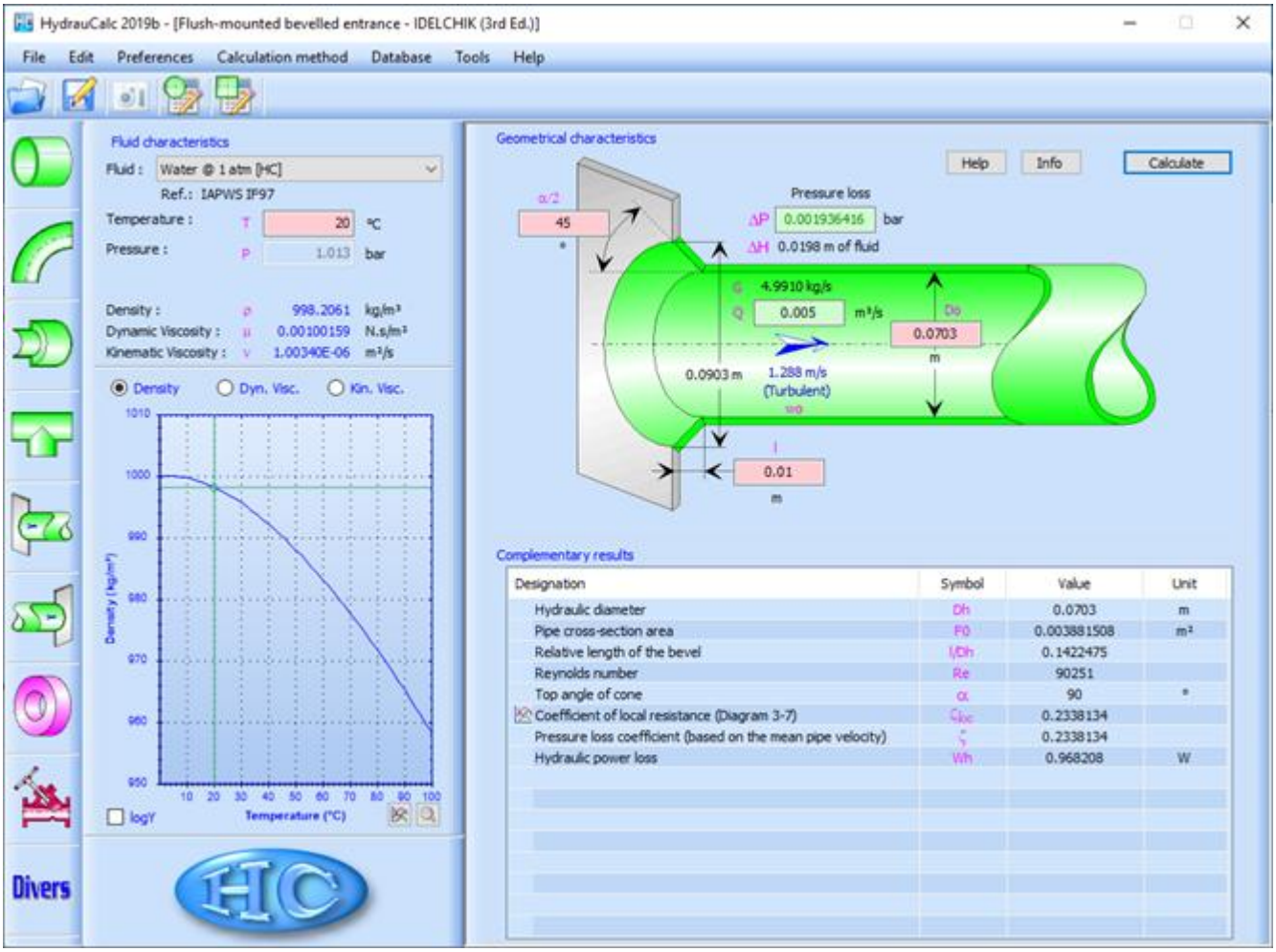
- turbulent flow regime in pipe ($Re \geq 10^4$)

- relative length of bevel (l/D_h) equal to or lower than 0.6

  note: for relative lengths of bevel "l/D_h" greater than 0.6, the local pressure loss coefficient is extrapolated

---

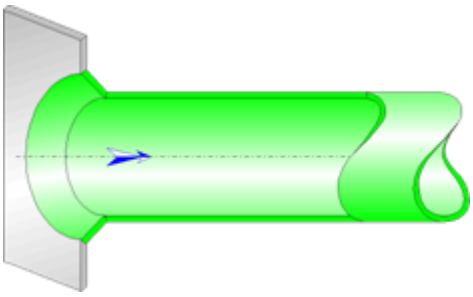
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.5.3.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted bevelled entrance of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D$$

Pipe cross-sectional area (m²):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity in pipe (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

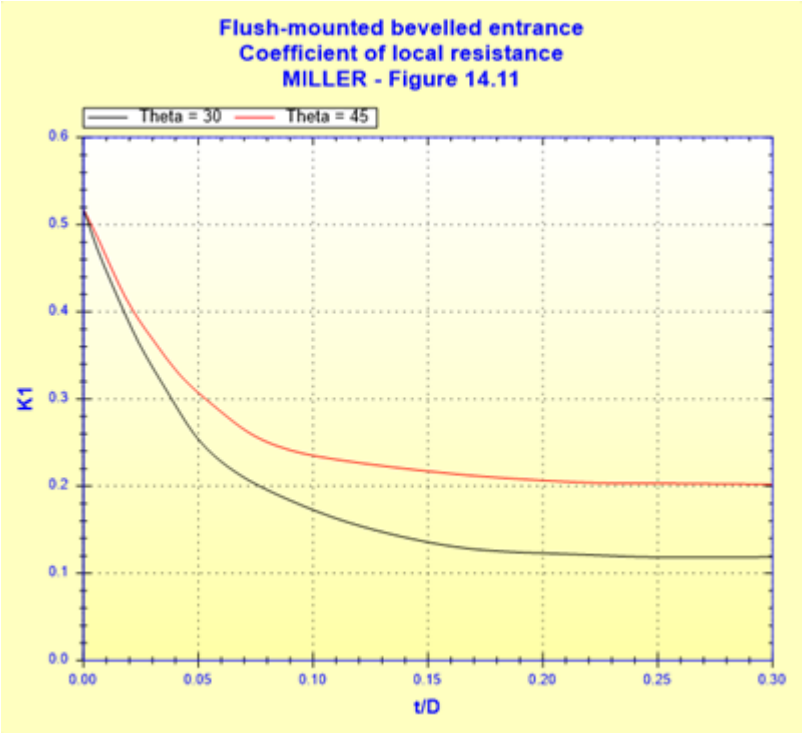
Reynolds number in pipe:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Local resistance coefficient:

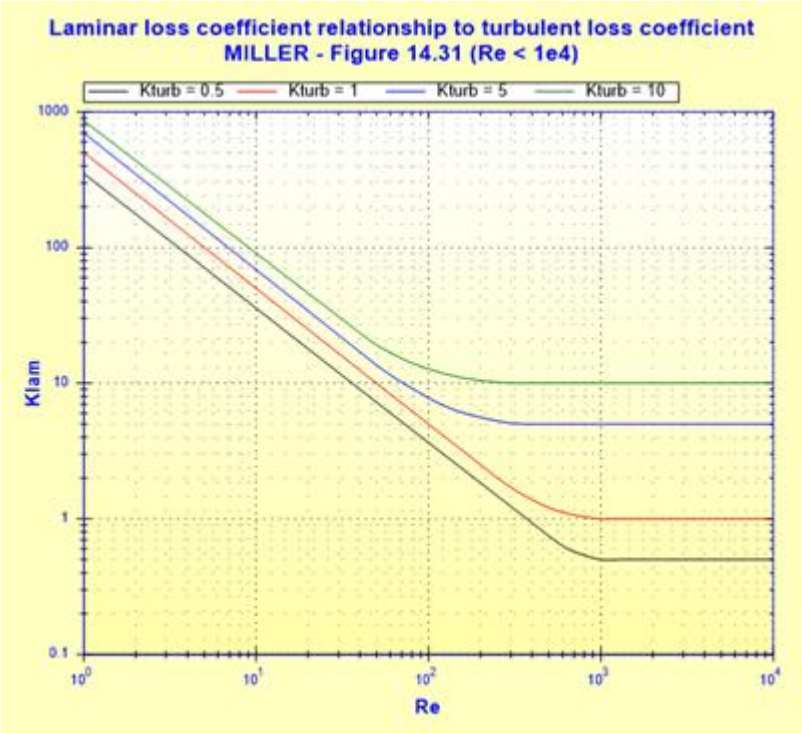
- $\mathrm{Re} \geq 10^4$

$$K_1 = f\left(\frac{t}{D}, \theta\right)$$ ([1] figure 14.11)



- $\mathrm{Re} < 10^4$

$$K_{lam} = f(\mathrm{Re}, K_{turb})$$ ([1] figure 14.31 with Kturb = K_1)



Reynolds Number Correction ($Re < 10^4$):

$$C_{Re} = \frac{K_{lam}}{K_1}$$

Total pressure loss coefficient (based on mean velocity in pipe):

- turbulent flow ($Re \geq 10^4$):

$$K = K_1$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

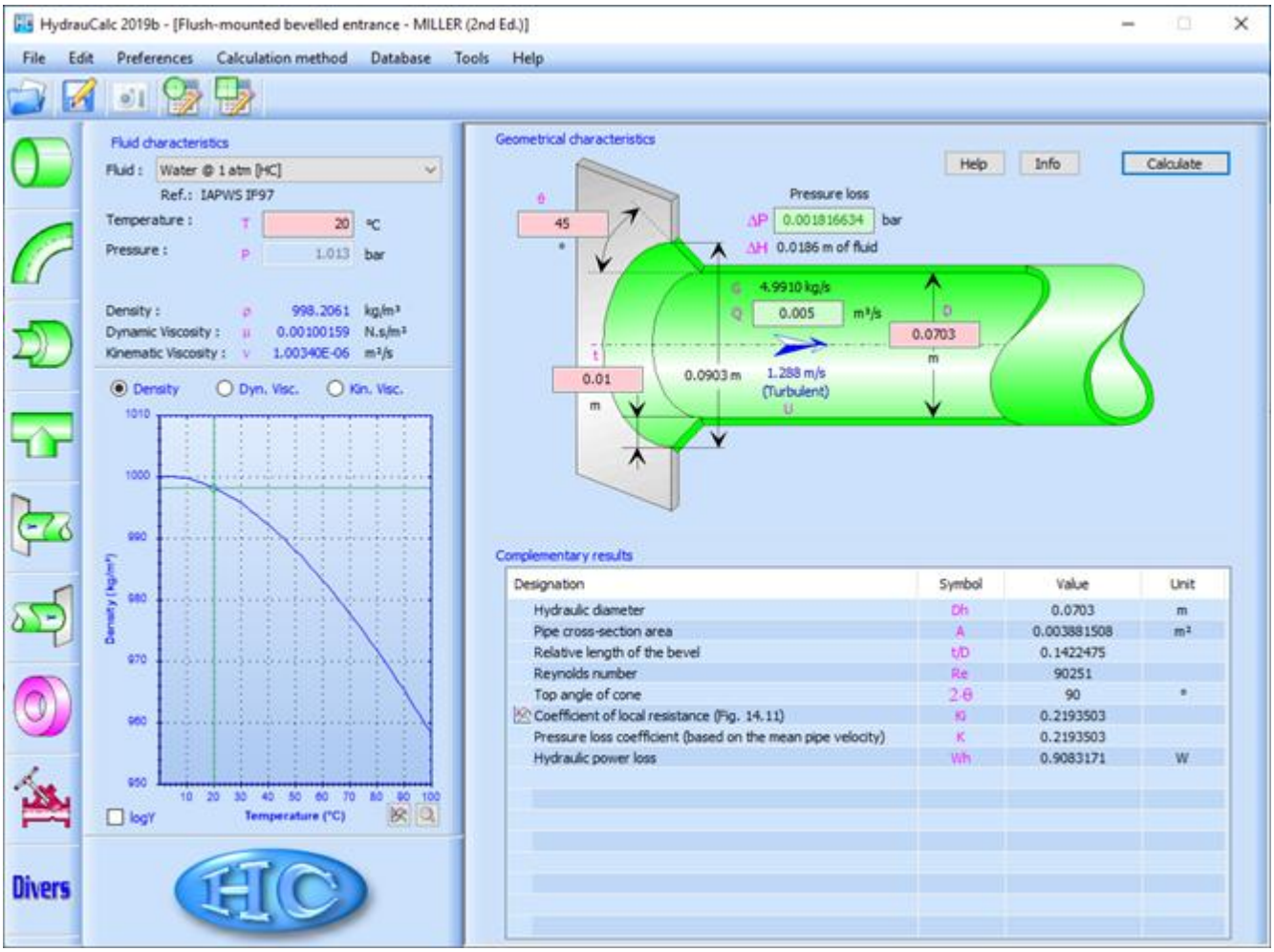
D_h	Hydraulic diameter (m)
D	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in pipe ()
α	Bevel angle (°)
t	Bevel height (m)
K_1	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- relative height of bevel (l/D_h) equal to or lower than 0.3
  note: for relative height of bevel greater than 0.3, the local resistance coefficient is extrapolated

---

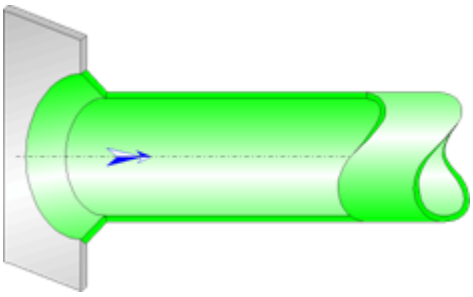
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.5.3.3 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted bevelled entrance of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$d_h = d$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity in pipe (m/s):

$$V = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

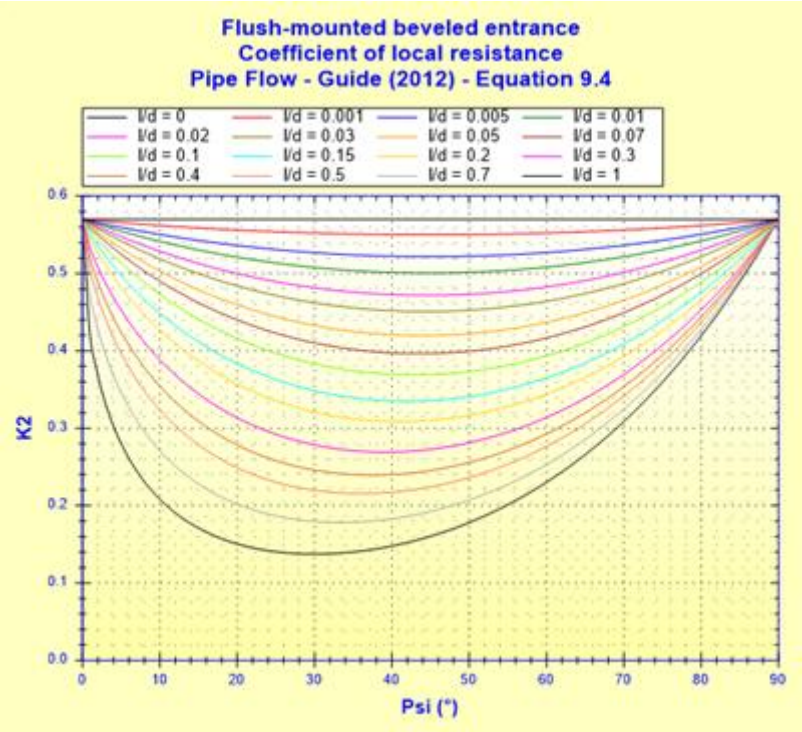
Reynolds number in pipe:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

Local resistance coefficient ($N_{Re} \geq 10^4$):

$$K_2 = 0.0696 \cdot \left[1 - C_b \cdot \frac{l}{d}\right] \cdot \lambda^2 + (\lambda - 1)^2$$

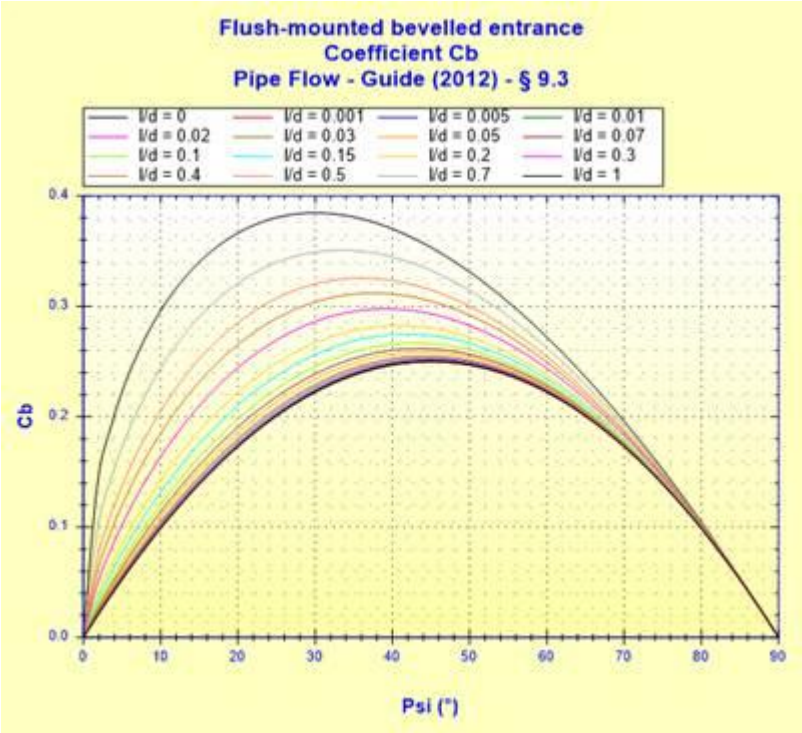
([1] equation 9.4)



With:

$$C_b = \left(1 - \frac{\Psi}{90}\right) \cdot \left(\frac{\Psi}{90}\right)^{\frac{1}{1+l/d}}$$

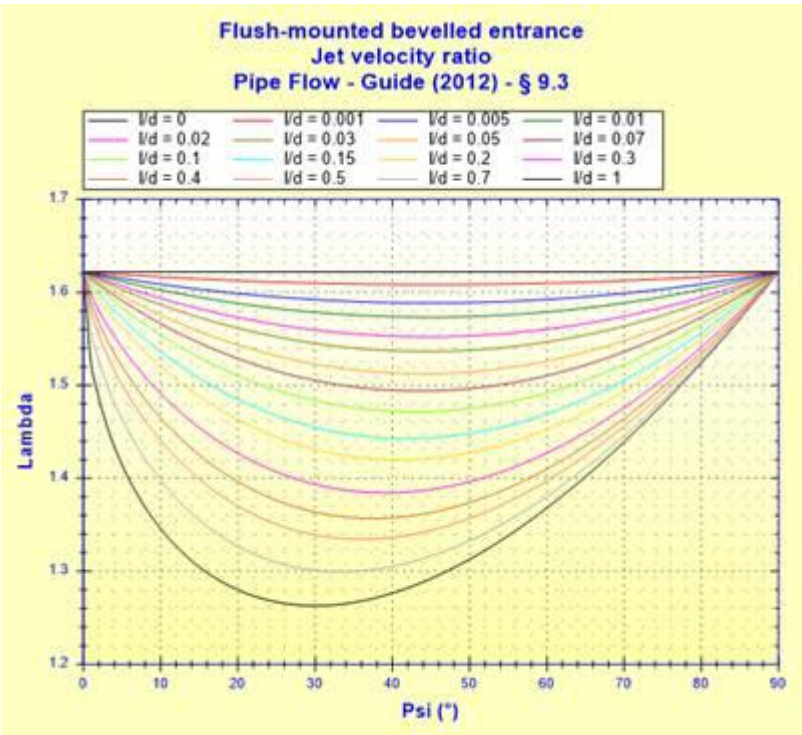
([1] §9.3)



And:

$$\lambda = 1 + 0.622 \cdot \left[1 - 1.5 \cdot C_b \cdot \left(\frac{l}{d} \right)^{\frac{1 - \sqrt[4]{l/d}}{2}} \right]$$

([1] §9.3)



Total pressure loss coefficient (based on mean velocity in minor diameter):

$$K = K_2$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_h	Hydraulic diameter (m)
d	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V	Mean velocity in pipe (m/s)
N_{Re}	Reynolds number in pipe ()
ψ	Bevel angle (°)
l	Bevel length ()
K_2	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)

ρ_m Fluid density (kg/m³)

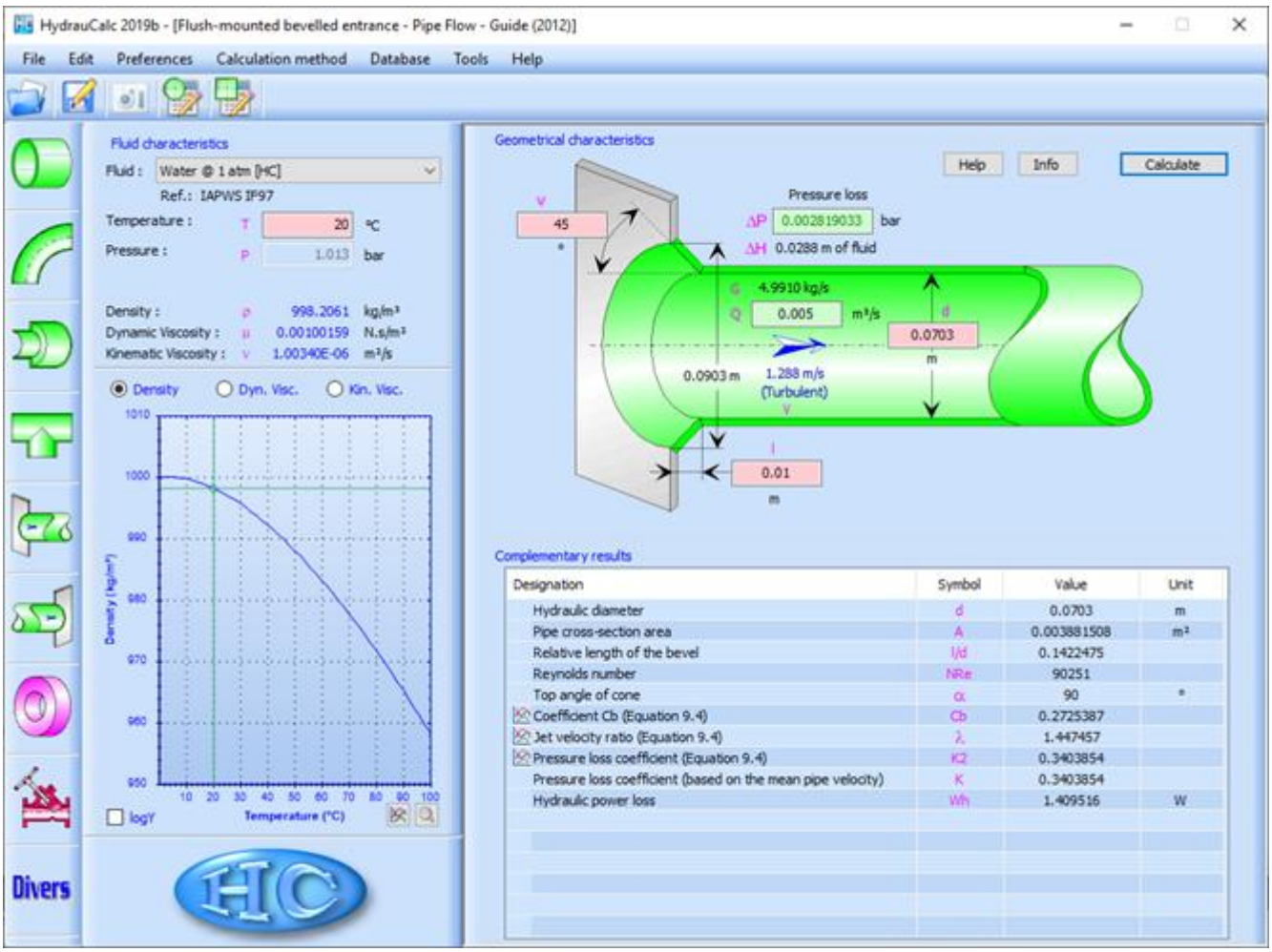
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime in pipe ($N_{Re} \geq 10^4$)
- relative length of bevel (l/d) equal to or lower than 1

Example of application:

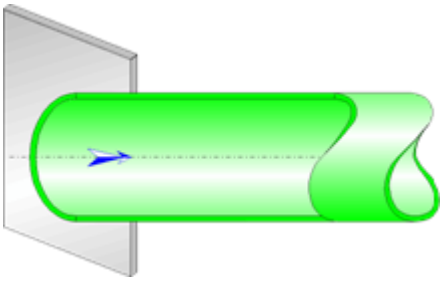


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.5.4 Sharp-edged entrance mounted at a distance

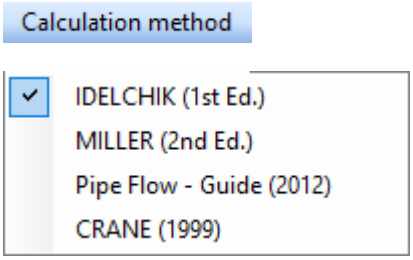
Circular Cross-Section



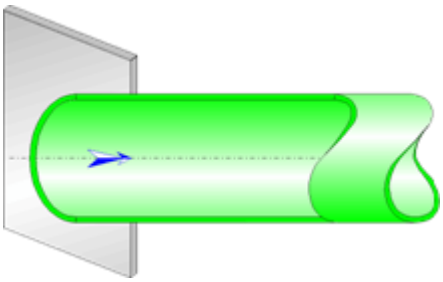
For the calculation of the pressure loss coefficient of flush-mounted sharp-edged entrances mounted at a distance of piping, the user can choose from one of the methods described in the following four reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.5.4.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted sharp-edged entrance of piping mounted at a distance.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Pipe cross-sectional area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

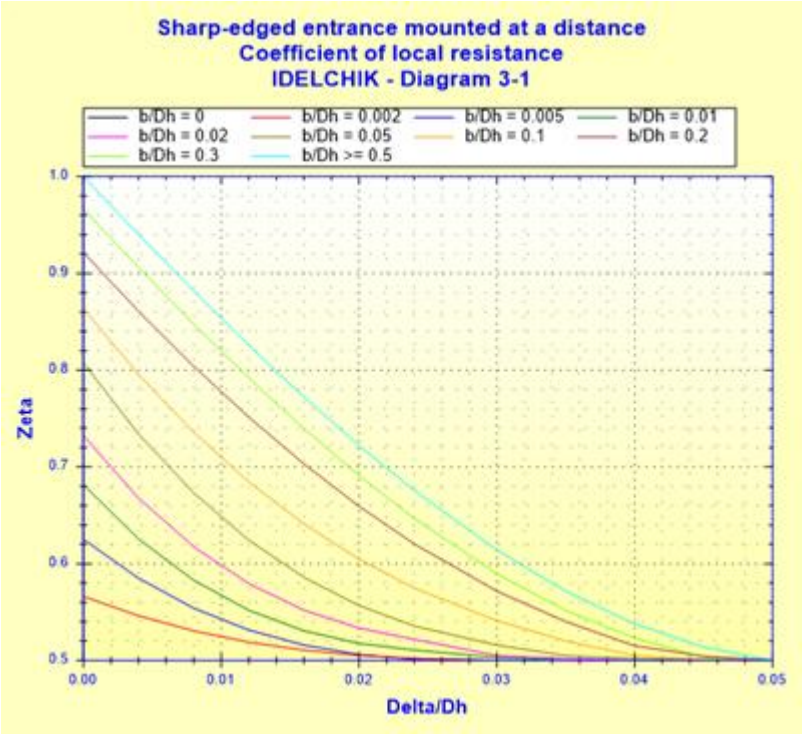
Reynolds number in pipe:

$$\mathrm{Re} = \frac{W_0 \cdot D_0}{\nu}$$

Local resistance coefficient:

- $\delta_1/Dh \le 0.05$

$$\zeta_{loc} = f\left(\frac{\delta_1}{D_h}, \frac{b}{D_h}\right)$$ ([1] diagram 3.1)



- $\delta_1/Dh > 0.05$

$$\zeta_{loc} = 0.5$$ ([1] diagram 3.1)

Total pressure loss coefficient (based on mean velocity in pipe):

$$\zeta = \zeta_{loc}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

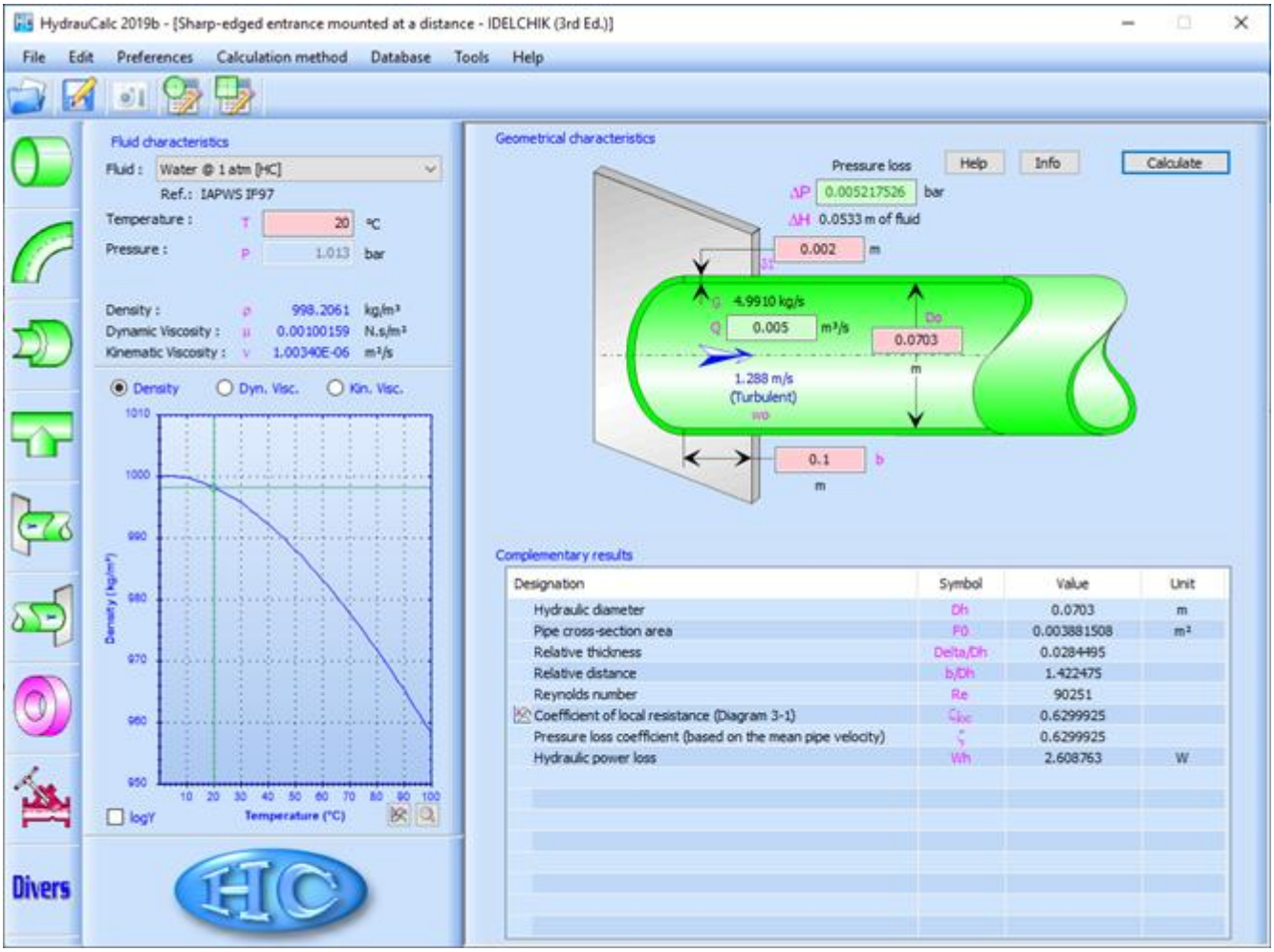
D_h	Hydraulic diameter (m)
D_0	Pipe diameter (m)
F_0	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in pipe ()
b	Distance from the wall (m)
δ_1	Pipe thickness (m)
ζ_{loc}	Local resistance coefficient ()
ζ	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)

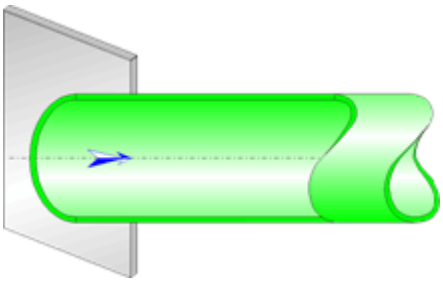
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.5.4.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted sharp-edged entrance of piping mounted at a distance.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity in pipe (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

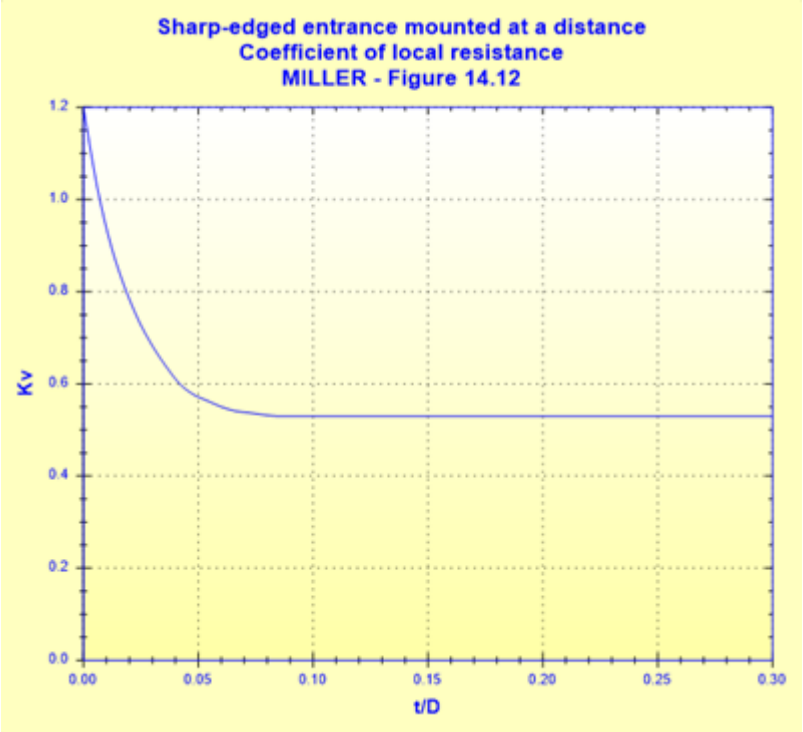
Reynolds number in pipe:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Local resistance coefficient:

- $\mathrm{Re} \geq 10^4$
  - $t/D \leq 0.3$

$$K_v = f\left(\frac{t}{D}\right)$$ ([1] figure 14.12)

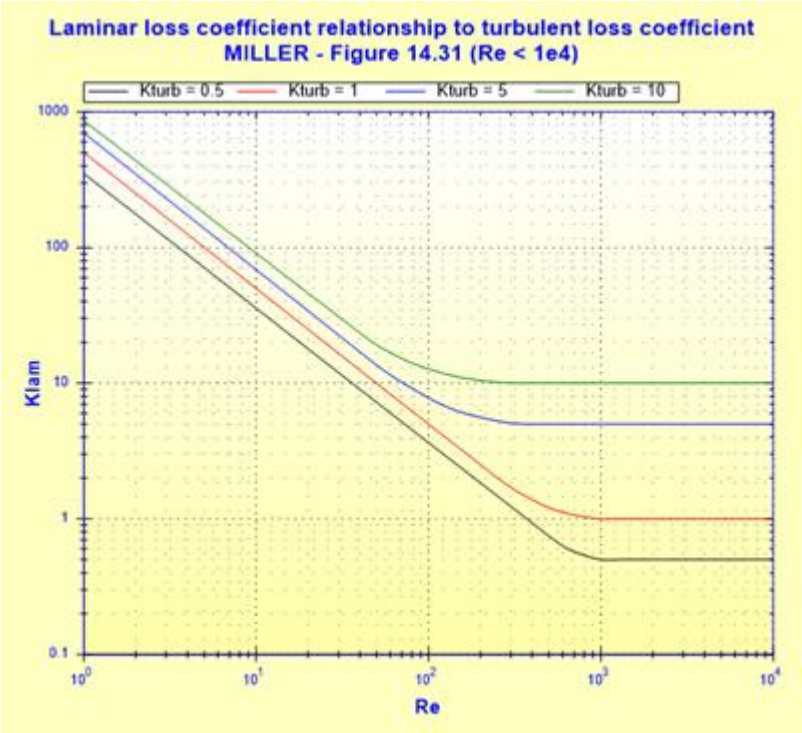


  - $t/D > 0.3$

$$K_v = 0.53$$ ([1] figure 14.12)

- $\mathrm{Re} < 10^4$

$$K_{lam} = f(\mathrm{Re}, K_{turb})$$ ([1] figure 14.31 with $K_{turb} = K_v$)



Reynolds Number Correction ($Re < 10^4$):

$$C_{Re} = \frac{K_{lam}}{K_v}$$

Total pressure loss coefficient (based on mean velocity in pipe):

- turbulent flow ($Re \geq 10^4$):

$$K = K_v$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

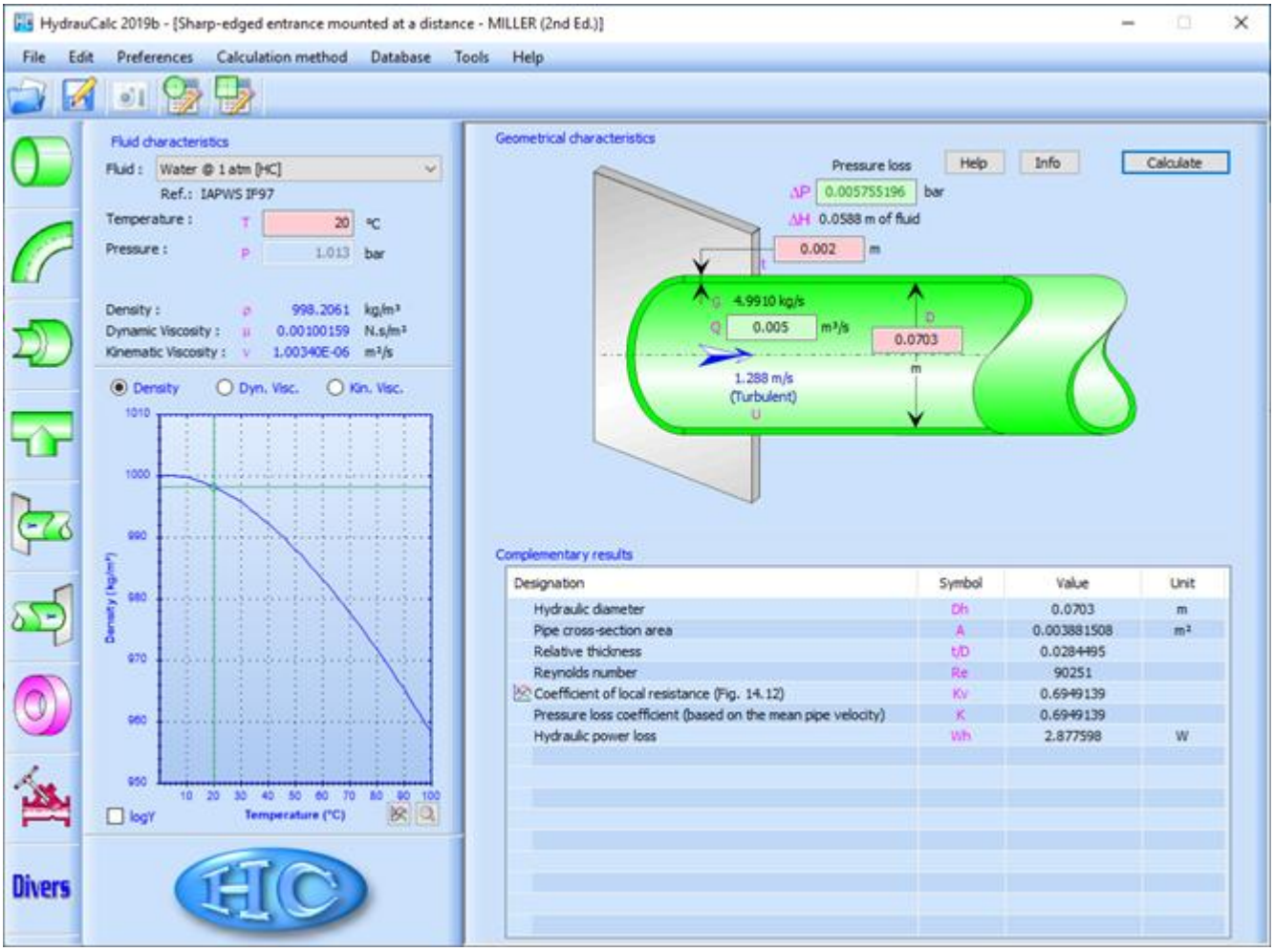
Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in pipe ()
t	Pipe thickness (m)
K_v	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent

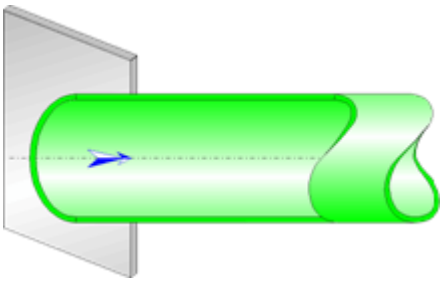
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.5.4.3 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted sharp-edged entrance of piping mounted at a distance.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$d_h = d$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity in pipe (m/s):

$$V = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

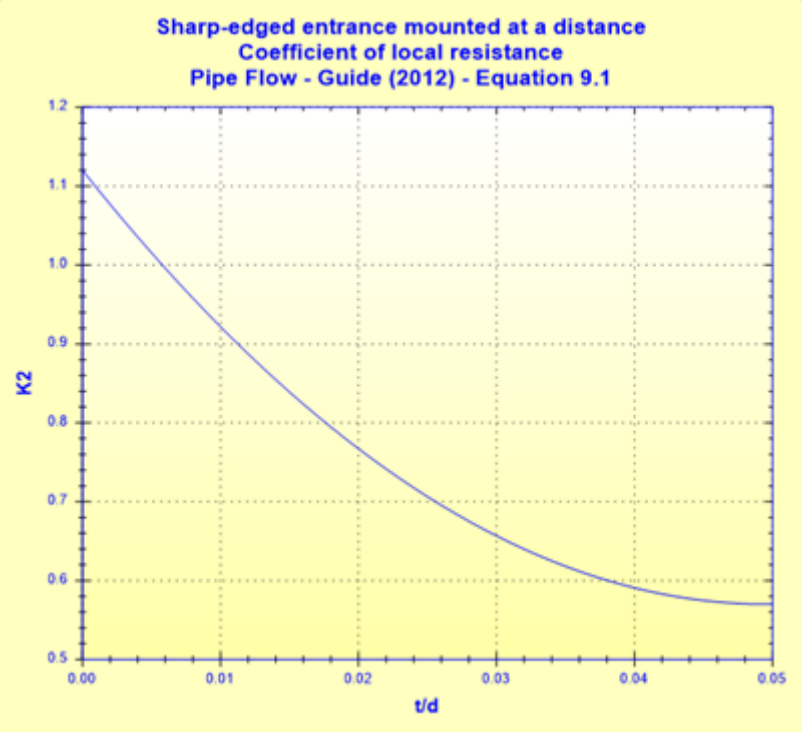
Reynolds number in pipe:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

Local resistance coefficient ($t/d \leq 0.05$):

$$K_2 = 1.12 - 22 \cdot \frac{t}{d} + 216 \cdot \left(\frac{t}{d}\right)^2 + 80 \cdot \left(\frac{t}{d}\right)^3$$

([1] equation 9.1)



Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_2$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

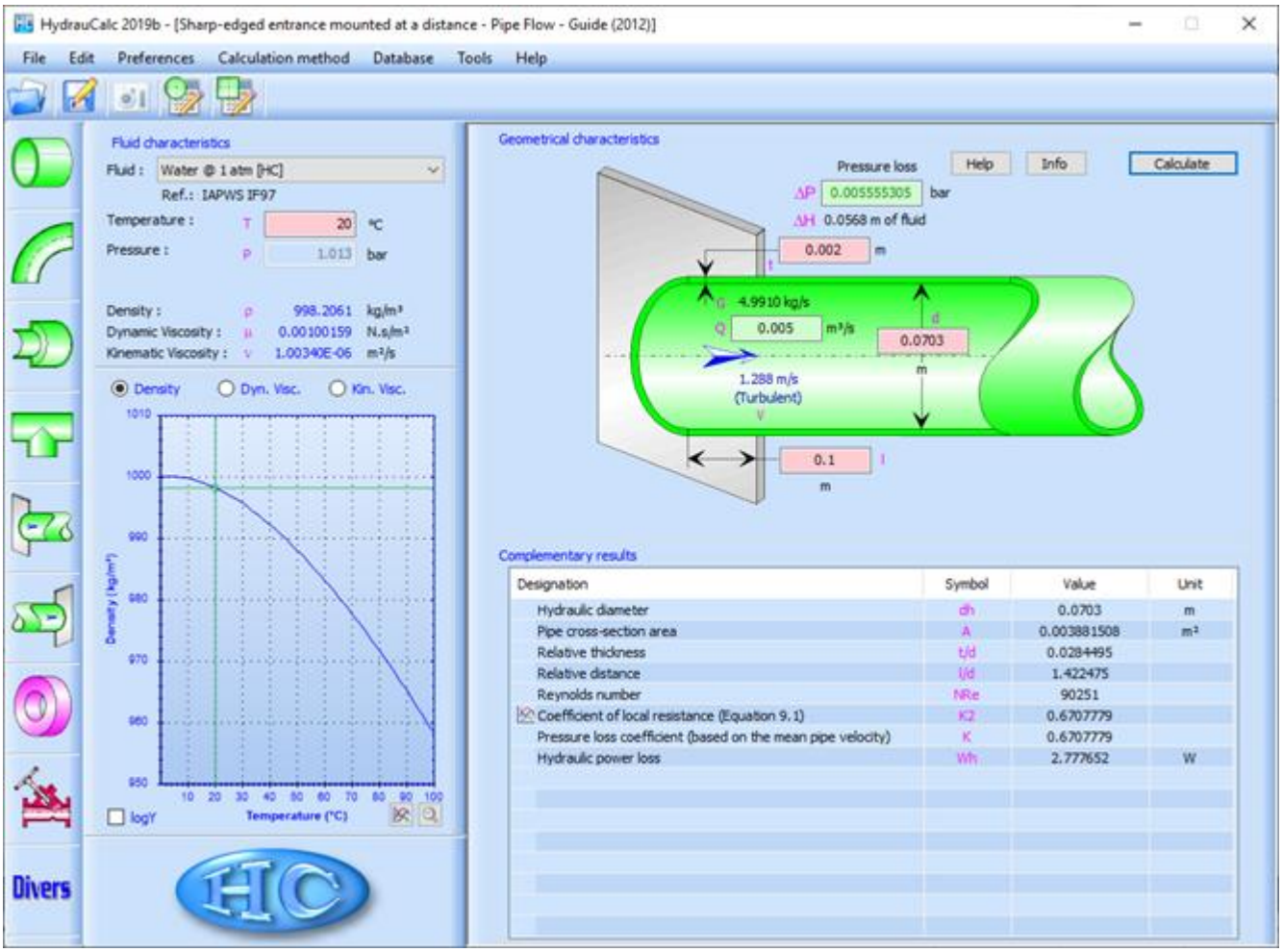
d_h	Hydraulic diameter (m)
d	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
V	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)
N_{Re}	Reynolds number in pipe ()
t	Pipe thickness (m)
l	Distance from the wall (m)
K_2	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in pipe ($N_{Re} \geq 10^4$)

- relative distance (l/d) equal to or greater than 0.5
- relative thickness (t/d) equal to or less than 0.05

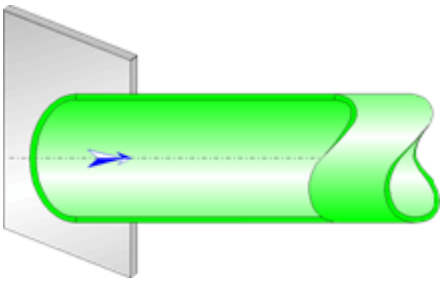
Example of application:



References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.5.4.4 CRANE



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted sharp-edged entrance of piping mounted at a distance.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity in pipe (m/s):

$$v = \frac{q}{A}$$

Mass flow rate (kg/s):

$$G = q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re} = \frac{v \cdot D}{\nu}$$

Local resistance coefficient ($\mathrm{Re} \geq 10^4$):

$$K_1 = 0.78$$ ([1] Appendix A-29)

Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_1$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot v^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot q$$

Symbols, Definitions, SI Units:

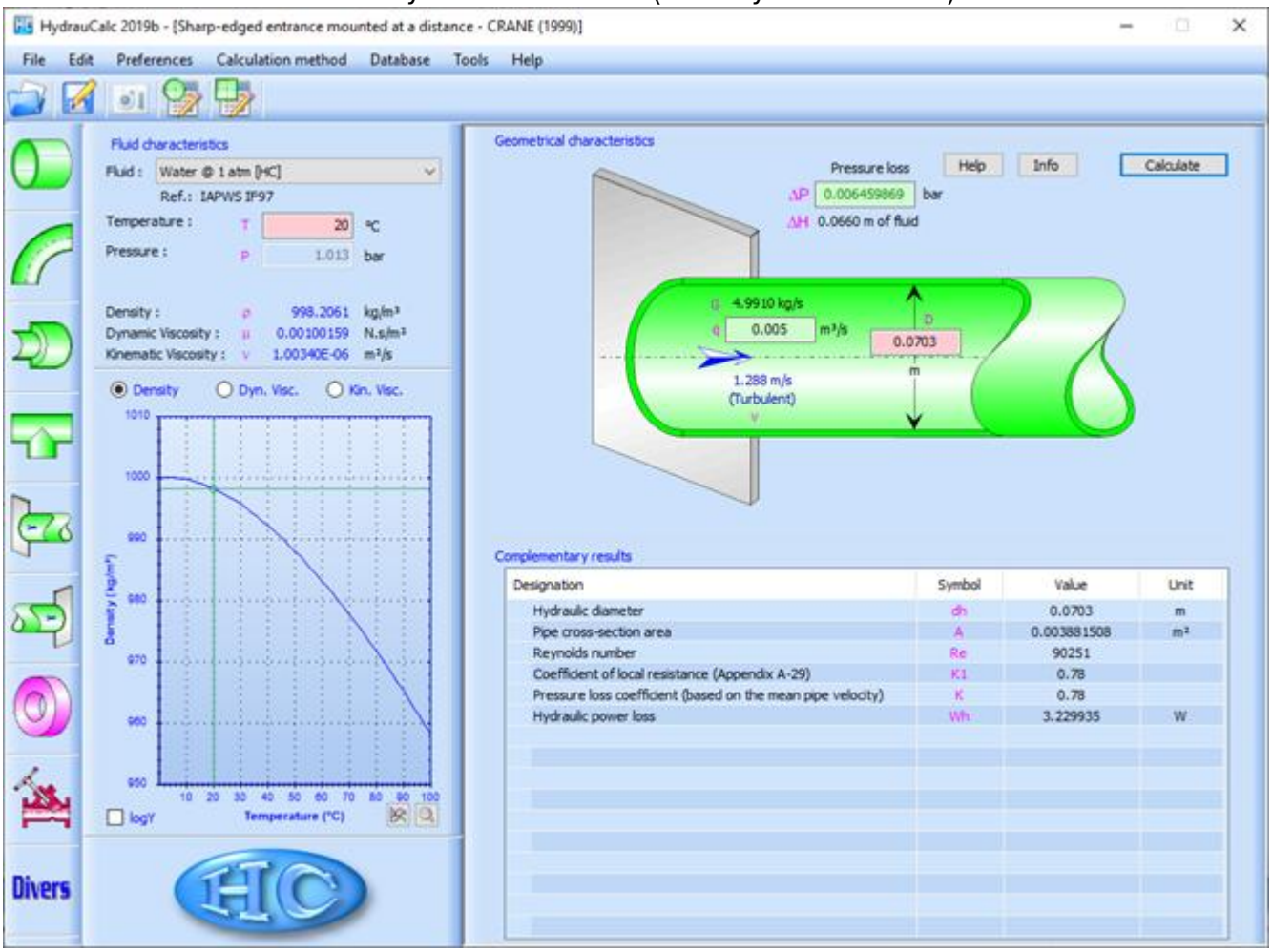
D_h	Hydraulic diameter (m)
D	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
q	Volume flow rate (m^3/s)
v	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)

Re	Reynolds number in pipe ()
K_1	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in pipe ($Re \geq 10^4$)

Example of application:

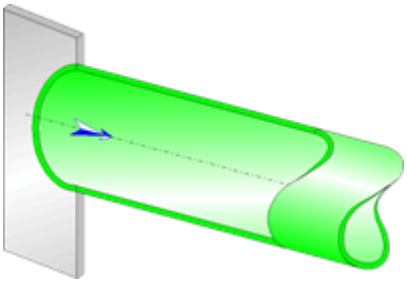


References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 – Edition 1999

2.5.5 Sharp-edged entrance mounted at an angle

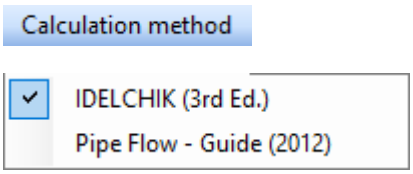
Circular Cross-Section



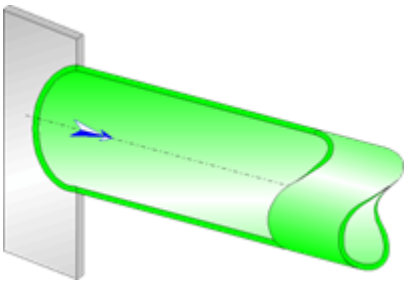
For the calculation of the pressure loss coefficient of flush-mounted sharp-edged entrances of piping mounted at an angle, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.5.5.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted sharp-edged entrance of piping mounted at an angle.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Pipe cross-sectional area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

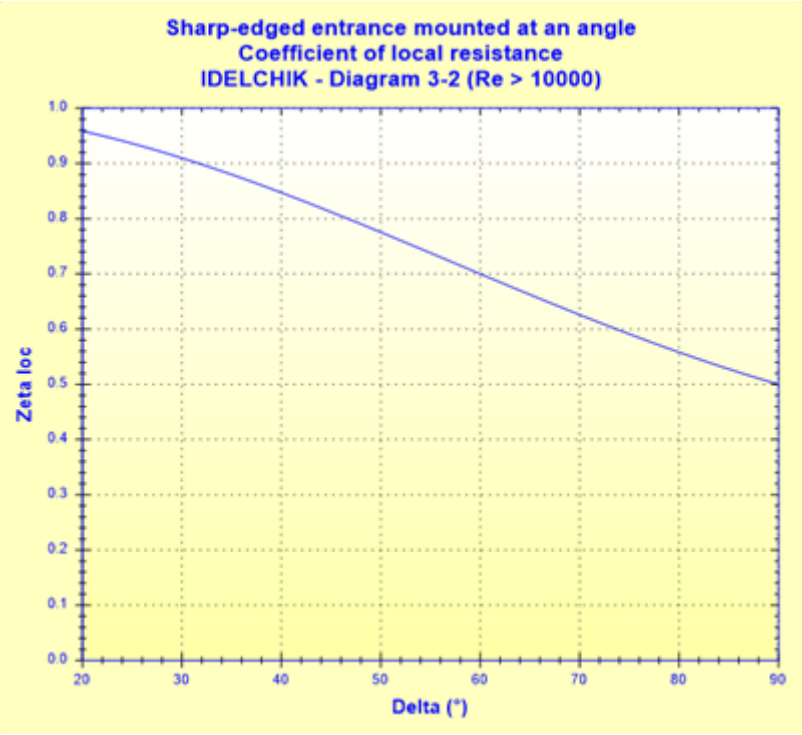
Reynolds number in pipe:

$$\mathrm{Re} = \frac{W_0 \cdot D_0}{\nu}$$

Local resistance coefficient:

$$\zeta_{loc} = 0.5 + 0.3 \cdot \cos(\delta) + 0.2 \cdot \cos^2(\delta)$$

([1] diagram 3.2)



Total pressure loss coefficient (based on mean velocity in pipe):

$$\zeta = \zeta_{loc}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{w_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

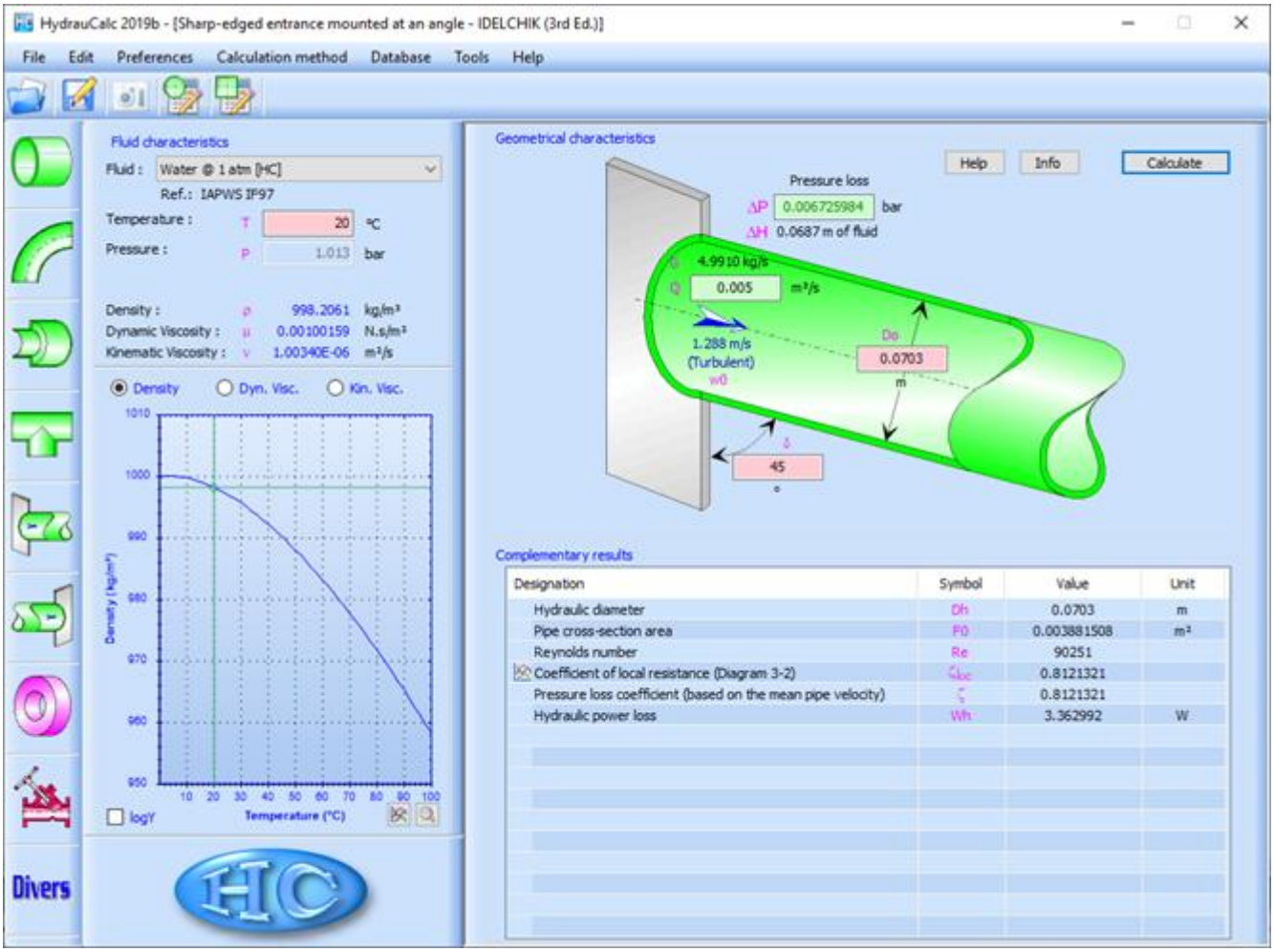
Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_0	Pipe diameter (m)
F_0	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in pipe ()
δ	Angle of inclination (°)
ζ_{loc}	Local resistance coefficient ()
ζ	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in the pipe ($Re \geq 10^4$)
- angle of inclination (δ) between 20° and 90°

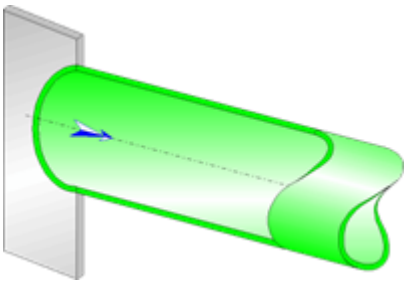
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.5.5.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted sharp-edged entrance of piping mounted at an angle.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$d_h = d$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity in pipe (m/s):

$$V = \frac{Q}{A}$$

Mass flow rate (kg/s):

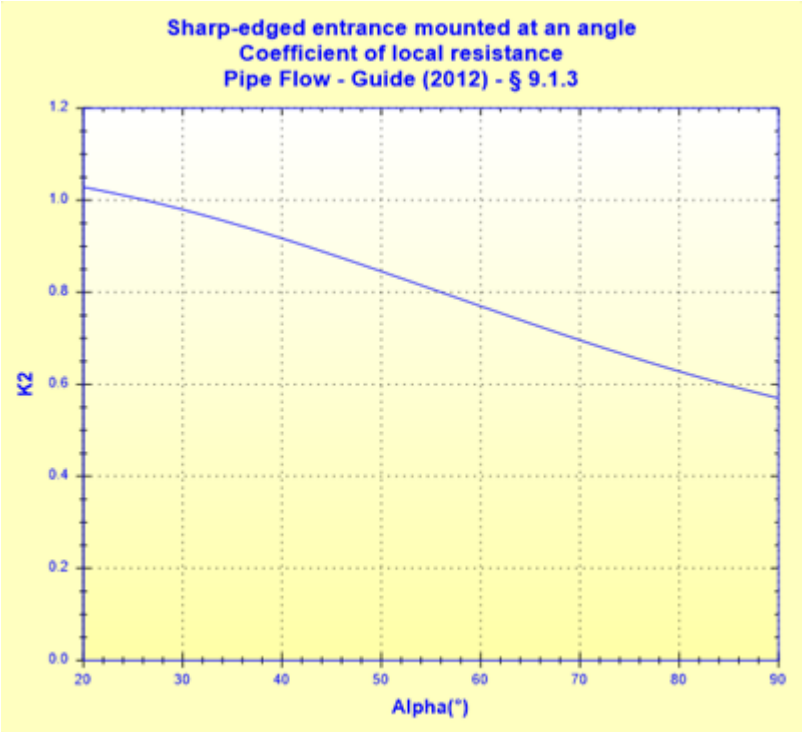
$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

Local resistance coefficient ($N_{Re} \geq 10^4$):

$$K_2 = 0.57 + 0.3 \cdot \cos(\alpha) + 0.2 \cdot \cos^2(\alpha)$$ ([1] § 9.1.3)



Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_2$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

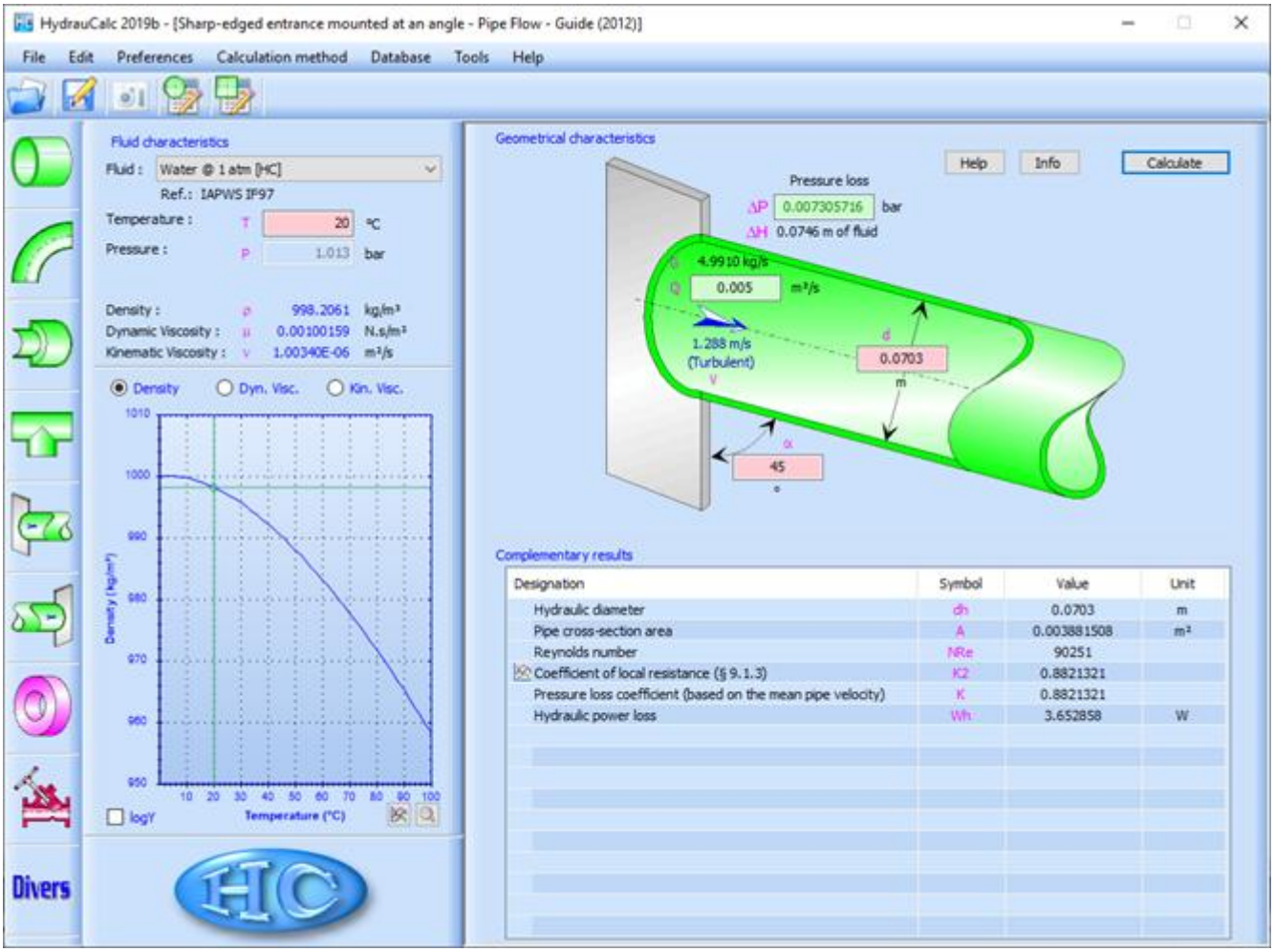
Symbols, Definitions, SI Units:

d_h	Hydraulic diameter (m)
d	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
V	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)
N_{Re}	Reynolds number in pipe ()
α	Angle of inclination (°)
K_2	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in the pipe ($Re \geq 10^4$)
- angle of inclination (α) between 20° and 90°

Example of application:

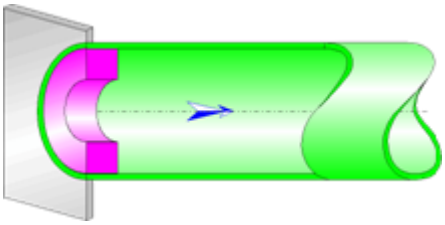


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.5.6 Entrance through a thick-edged orifice

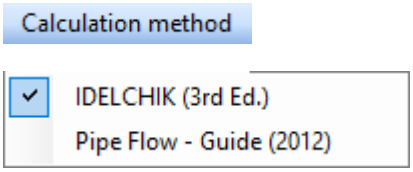
Circular Cross-Section



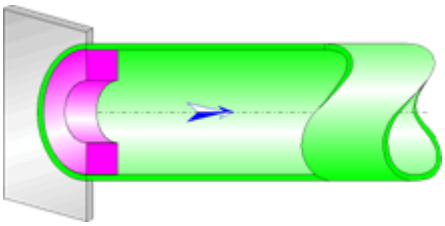
For the calculation of the pressure loss coefficient of a pipe entrance equipped with a thick-edged orifice, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.5.6.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe entrance equipped with a thick-edged orifice. Moreover, the head loss due to friction of the fluid on the inner walls of the orifice is also taken into account in this component and is calculated with Darcy's formula.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Orifice cross-section area (m²):

$$F_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Mean velocity in pipe (m/s):

$$W_0 = \frac{Q}{F_0}$$

Mean velocity in orifice (m/s):

$$W_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_0 = \frac{W_0 \cdot D_0}{\nu}$$

Reynolds number in orifice:

$$\mathrm{Re} = \frac{W_{or} \cdot D_{or}}{\nu}$$

Relative roughness in orifice walls:

$$\bar{\Delta} = \frac{\Delta}{D_{or}}$$

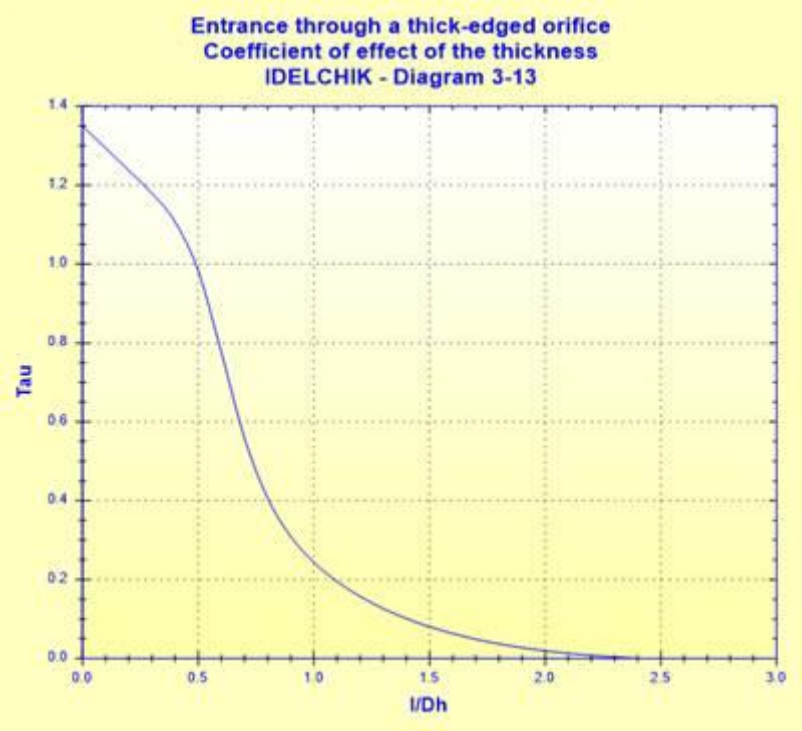
Coefficient of effect of the orifice thickness:

$$\tau = \left(2.4 - \frac{l}{D_h}\right) \cdot 10^{-\varphi\left(\frac{l}{D_h}\right)}$$

([1] diagram 3-13)

with:

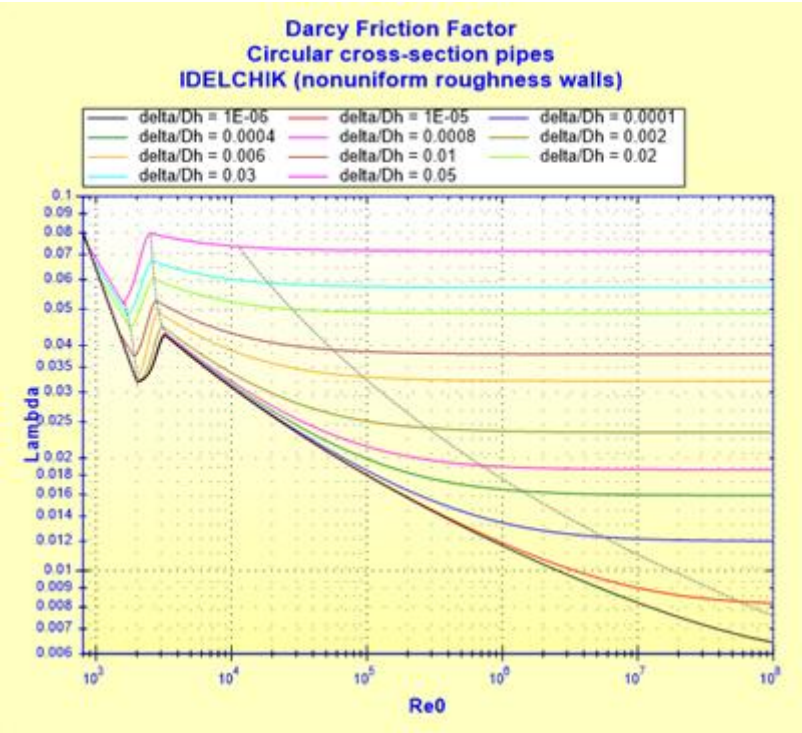
$$\varphi\left(\frac{l}{D_h}\right) = 0.25 + \frac{0.535 \cdot \left(\frac{l}{D_h}\right)^8}{0.05 + \left(\frac{l}{D_h}\right)^7}$$



Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}, \frac{\Delta}{D_h}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)

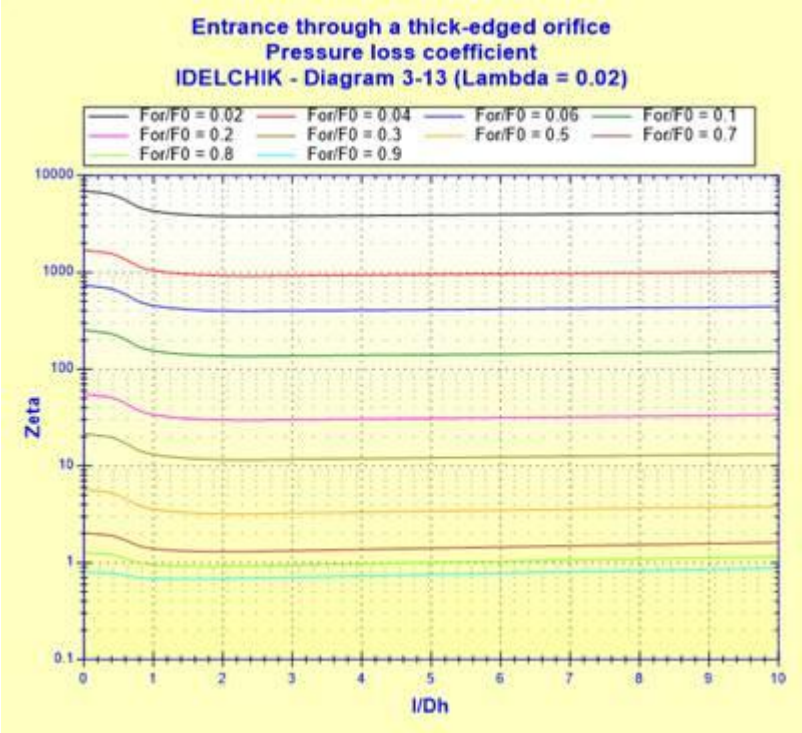


Local resistance coefficient (based on the mean pipe velocity):

■ Re ≥ 10^5

$$\zeta = \left[0.5 + \left(1 - \frac{F_{or}}{F_0}\right)^2 + \tau \cdot \left(1 - \frac{F_{or}}{F_0}\right) + \lambda \cdot \frac{l}{D_h}\right] \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-13)



([1] diagram 3-13 with λ = 0.02)

■ Re < 10^5

Quadratic local resistance coefficient:

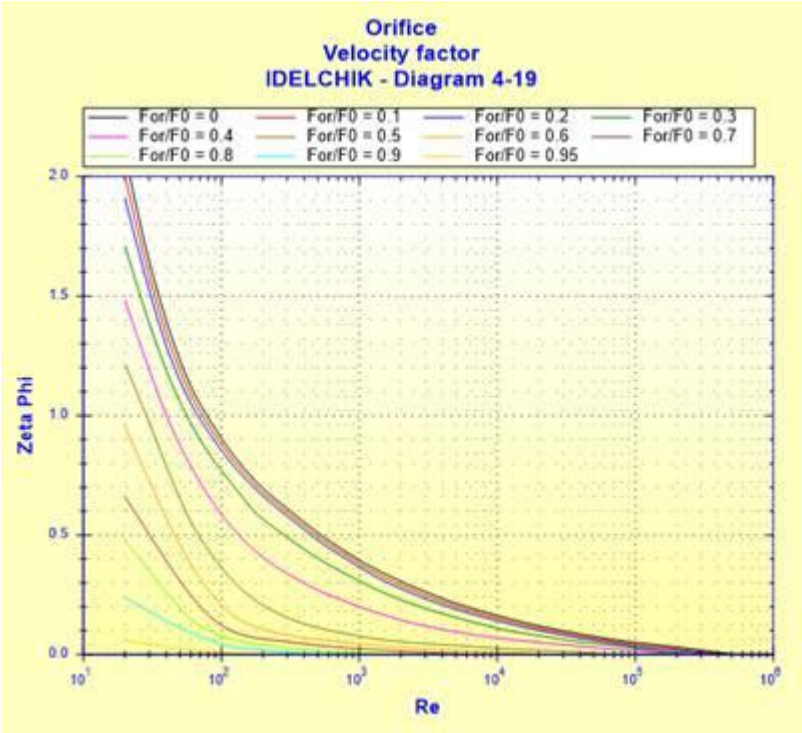
$$\zeta_{quad} = \left[0.5 + \left(1 - \frac{F_{or}}{F_0}\right)^2 + \tau \cdot \left(1 - \frac{F_{or}}{F_0}\right) + \lambda \cdot \frac{l}{D_h}\right] \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-13)

Velocity factor:

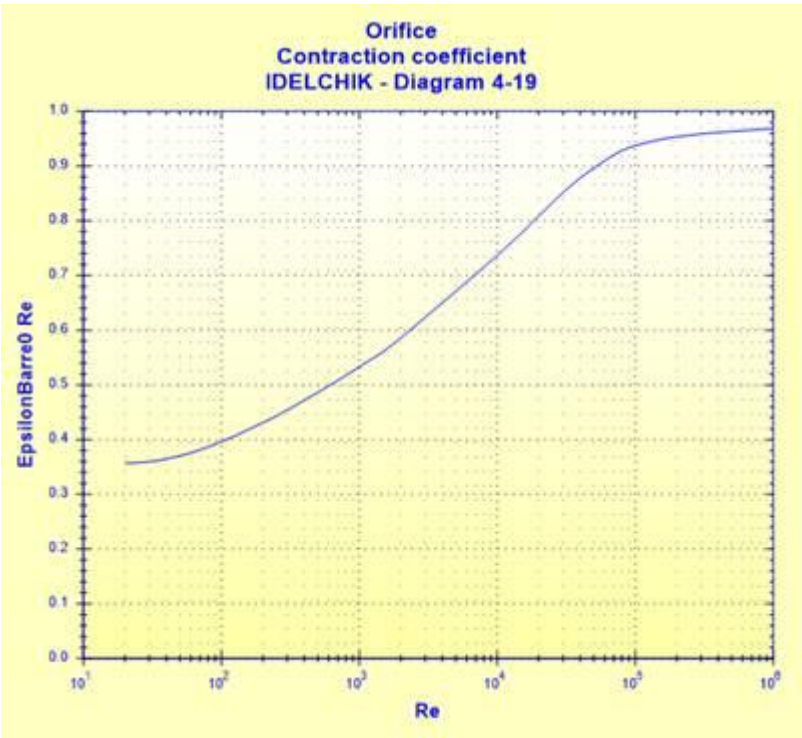
$$\zeta_\varphi = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$ ([1] diagram 4-19)



Local resistance coefficient:

- $30 < \mathrm{Re} < 10^5$

$$\zeta = \zeta_{\varphi} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0\mathrm{Re}} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $10 < \mathrm{Re} \leq 30$

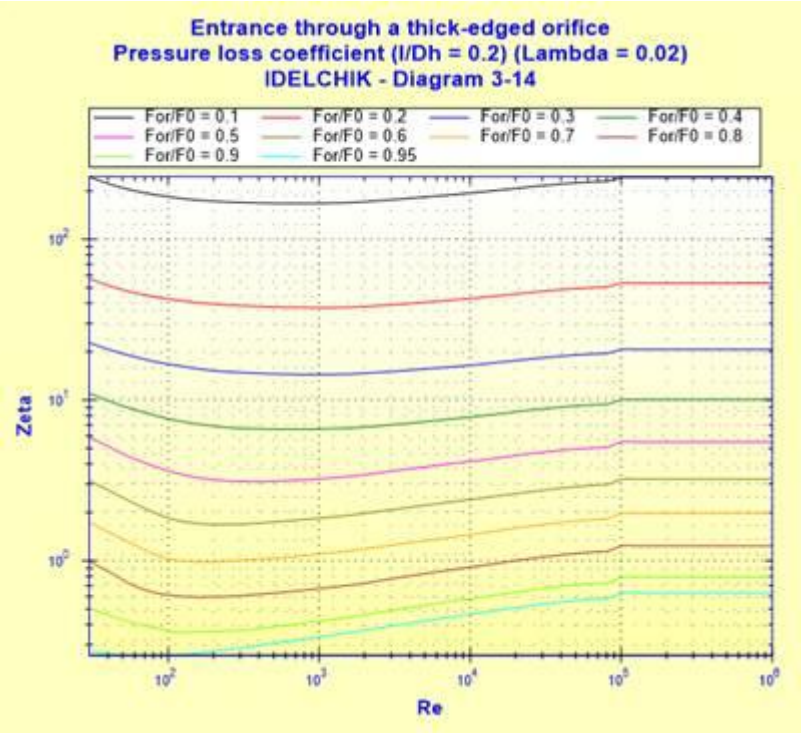
$$\zeta = \frac{33}{\mathrm{Re}} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0\mathrm{Re}} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $\mathrm{Re} \leq 10$

$$\zeta = \frac{33}{\mathrm{Re}} \cdot \left(\frac{F_0}{F_{or}} \right)^2$$

([1] diagram 3-14)



([1] diagram 3-14 with l/Dh = 0.2 and λ = 0.02)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_0	Pipe internal diameter (m)
F_0	Pipe cross-sectional area (m^2)
D_{or}	Orifice diameter (m)
F_{or}	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in pipe (m/s)
w_{or}	Mean velocity in orifice (m/s)
Re_0	Reynolds number in pipe ()
Re	Reynolds number in orifice ()
Δ	Absolute roughness of orifice walls (m)
$\bar{\Delta}$	Relative roughness of orifice walls ()
l	Orifice thickness (m)
τ	Coefficient of effect of the orifice thickness ()
λ	Darcy friction coefficient in orifice ()
ζ_{quad}	Quadratic pressure loss coefficient determined as $Re = 10^5$ ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)

ρ Fluid density (kg/m³)

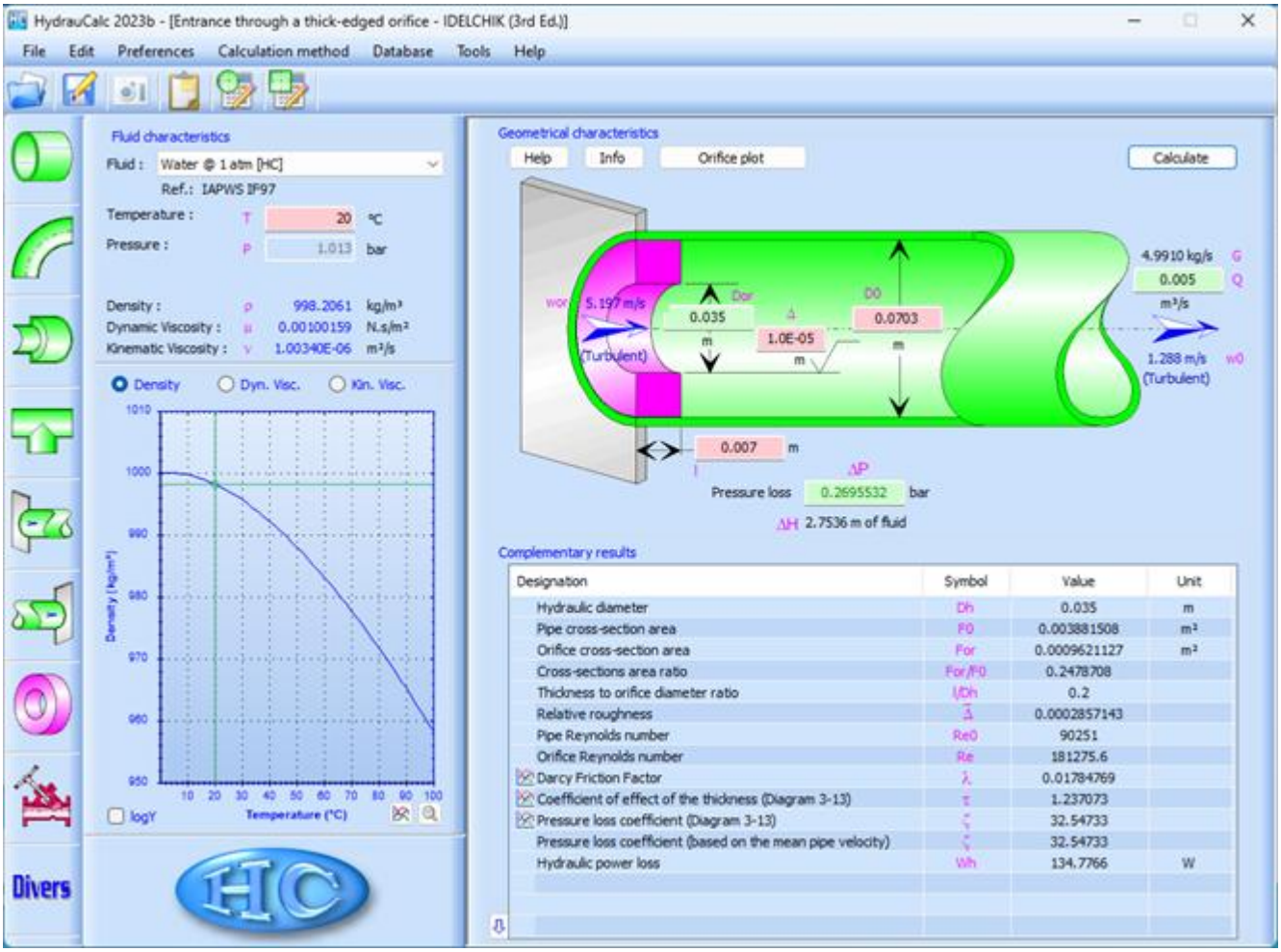
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- thickness to orifice diameter ratio (l/D_{or}) greater than 0.015

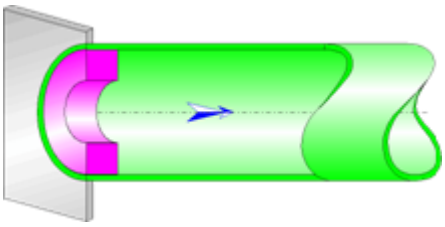
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.5.6.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe entrance equipped with a thick-edged orifice. Moreover, when the thickness of the orifice is greater than 1.4 times the diameter of the orifice, the head loss due to friction in the orifice is also taken into account because it becomes significant.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Ratio of orifice to pipe diameters:

$$\beta = \frac{d_o}{d}$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Orifice cross-sectional area (m^2):

$$A_o = \pi \cdot \frac{d_o{}^2}{4}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

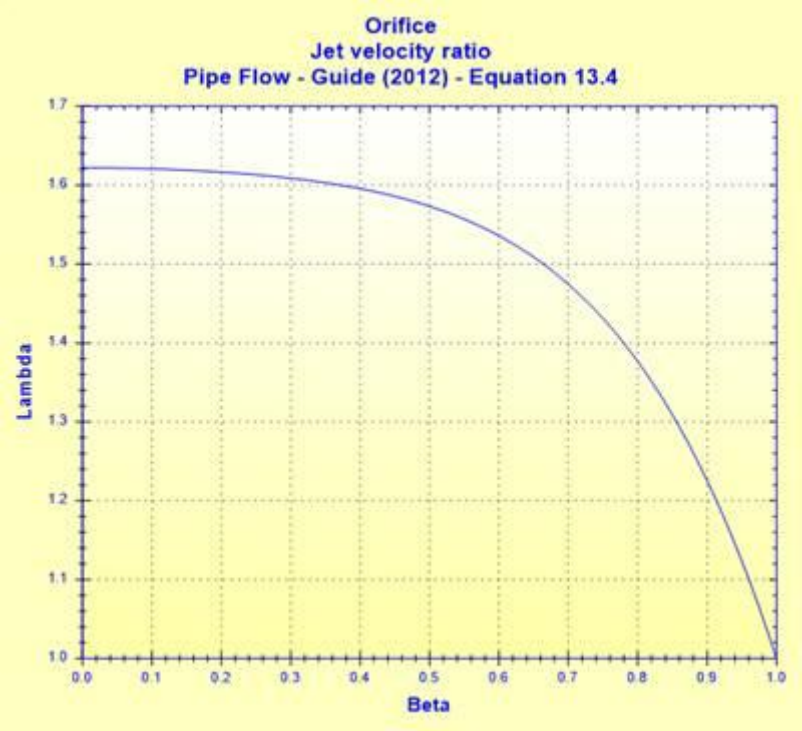
$$N_{Re} = \frac{V \cdot d}{\nu}$$

Reynolds number in orifice:

$$N_{Re_O} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left(1 - 0.215\beta^2 - 0.785\beta^5\right)$$ ([1] equation 13.4)



Velocity in vena contracta:

$$V_c = V_0 \cdot \lambda$$

Coefficient of local resistance ($NRe_o \geq 10^4$):

- Thickness to orifice diameter ratio (t/d_o) ≤ 1.4:

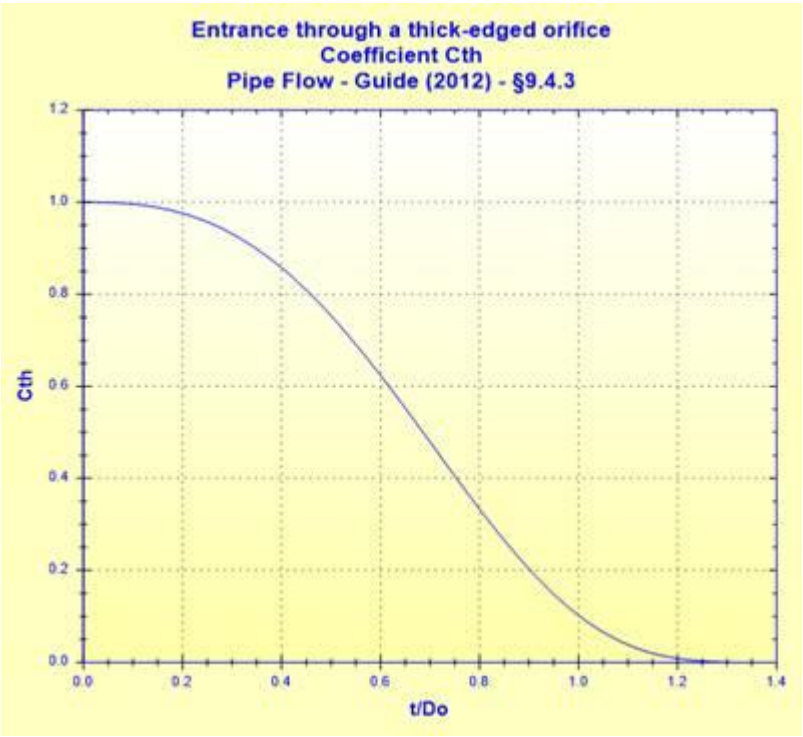
$$K_o = 0.183 + C_{th} \cdot \left[1.622 - \left(\frac{d_o}{d} \right)^2 \right]^2 + (1 - C_{th}) \cdot \left\{ 0.387 + \left[1 - \left(\frac{d_o}{d} \right)^2 \right]^2 \right\}$$

([1] equation 9.7)

with :

$$C_{th} = \left[1 - 0.50 \cdot \left(\frac{t}{1.4 d_o} \right)^{2.5} - 0.50 \cdot \left(\frac{t}{1.4 d_o} \right)^{3} \right]^{4.5}$$

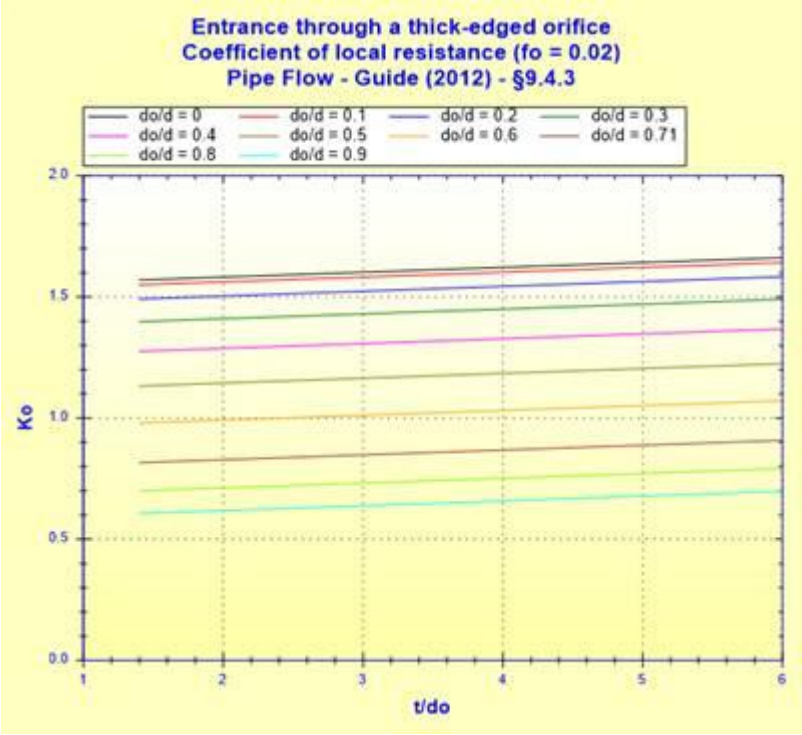
([1] §9.4.3)



- Thickness to orifice diameter ratio (t/d_o) > 1.4:

$$K_o = 0.57 + \left[1 - \left(\frac{d_o}{d}\right)^2\right]^2 + f_o \cdot \left[\frac{t}{d_o} - 1.4\right]$$

([1] §9.4.3)

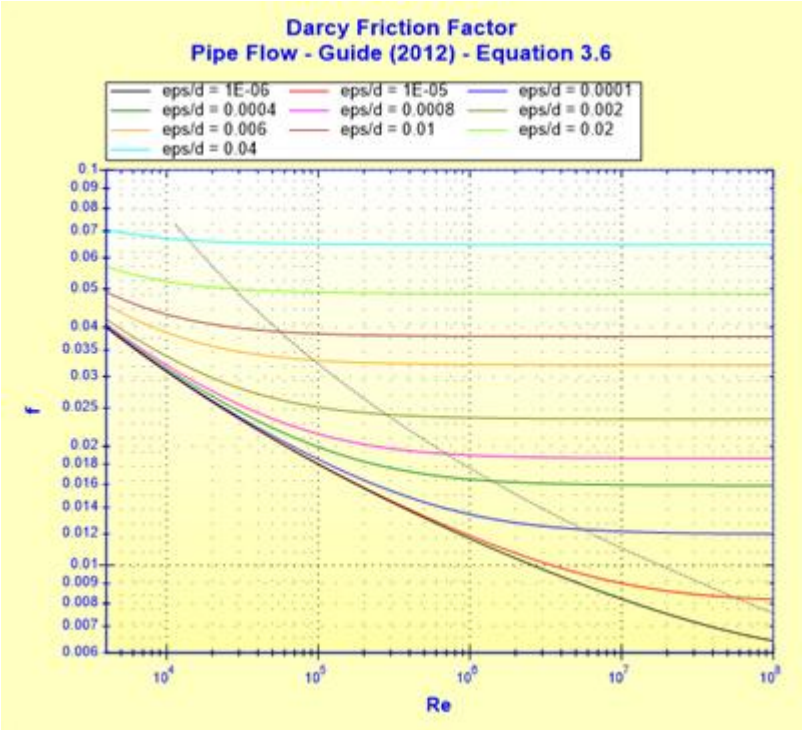


([1] §9.4.3 with fo = 0,02)

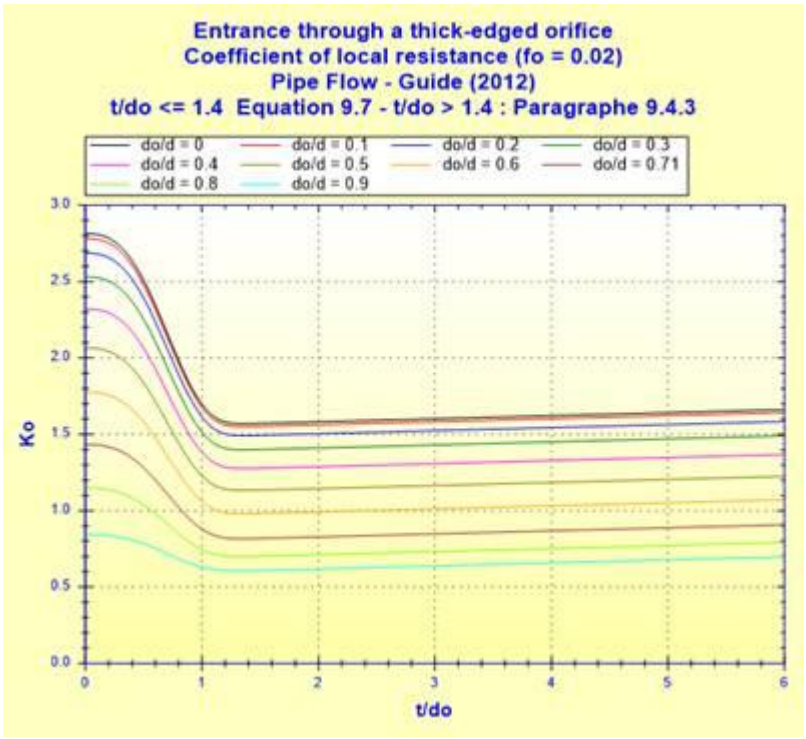
with :

$$f_o = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d_o} + \frac{2.51}{NRe_0 \cdot \sqrt{f_o}}\right)\right]^2}$$

Colebrook-White equation ([1] equation 3.6)



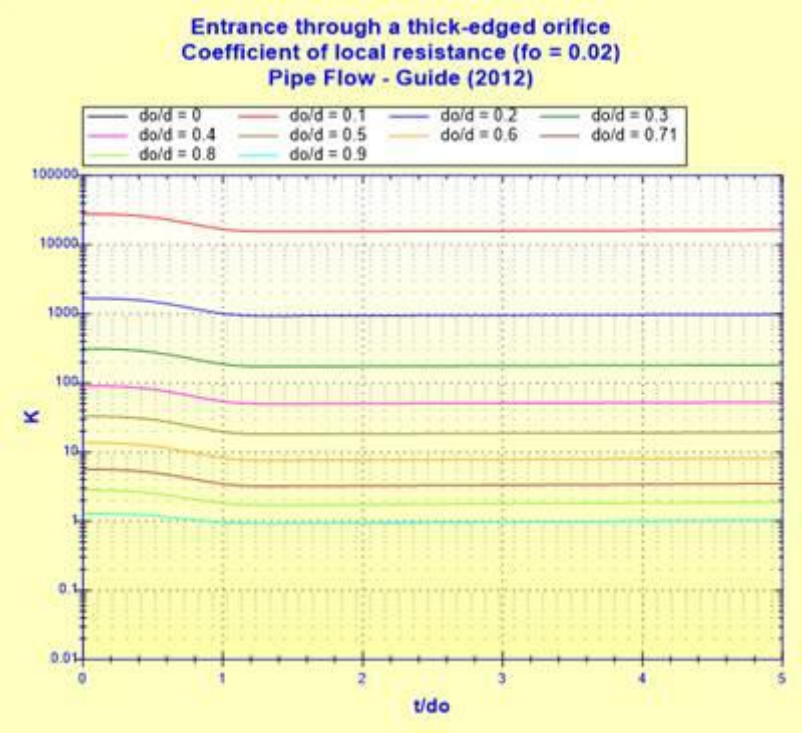
■ All thickness to orifice diameter ratios (t/d_o):



([1] equation 9.7 and §9.4.3 with fo = 0,02)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_o} \right)^2$$



(with fo = 0.02)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

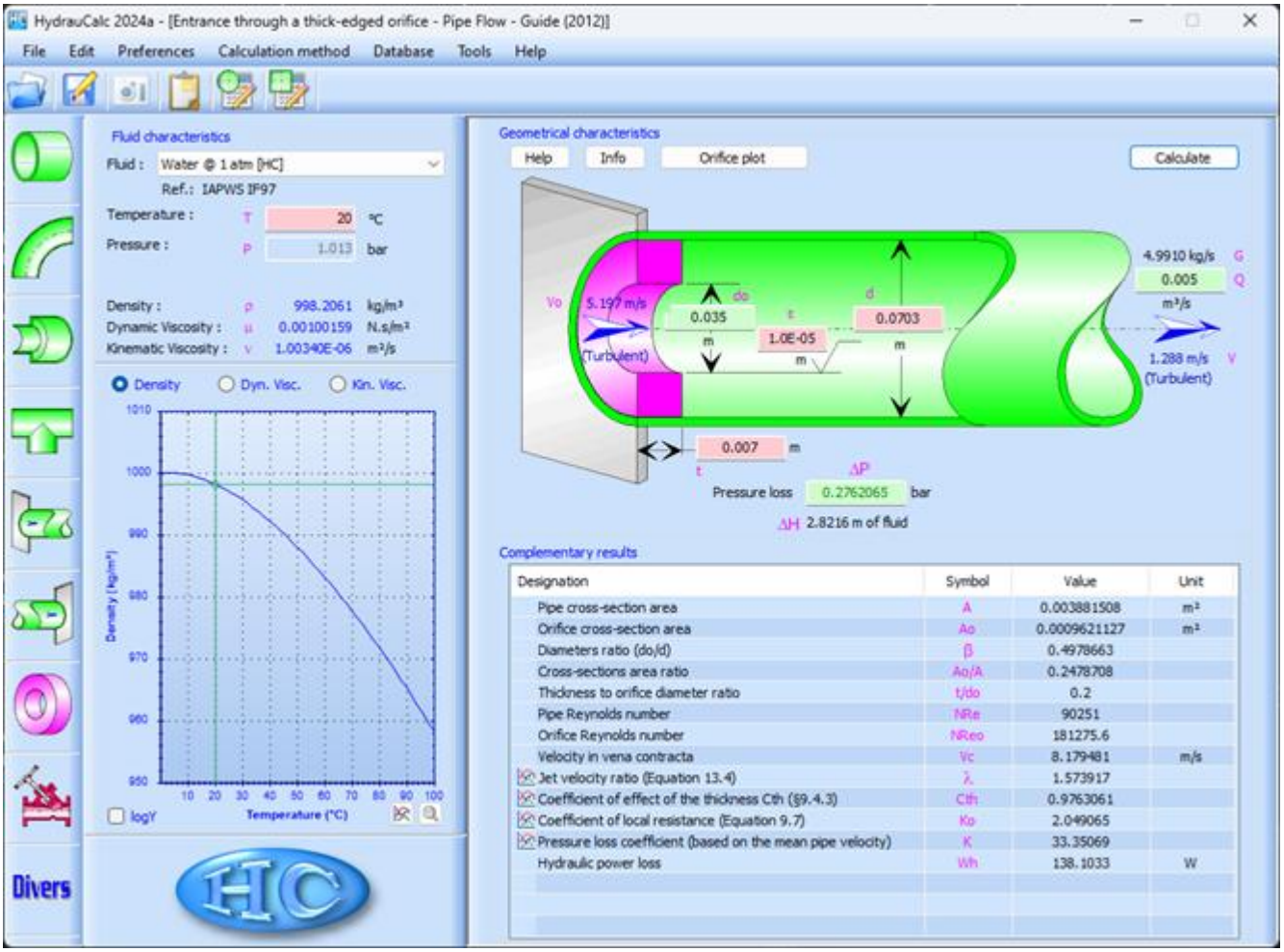
d_0	Orifice diameter (m)
d	Internal pipe diameter (m)
β	Ratio of orifice to pipe diameters ()

A_o	Orifice cross-sectional area (m^2)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
NRe_o	Reynolds number in orifice ()
NRe	Reynolds number in pipe ()
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
t	Thickness orifice (m)
K_o	Coefficient of local resistance ()
Cth	Coefficient of effect of the orifice thickness ()
ε	Absolute roughness of orifice walls (m)
f_o	Friction factor ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in orifice ($NRe_o \geq 10^4$)

Example of application:

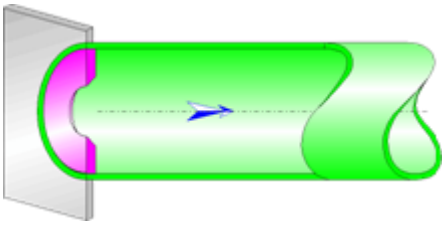


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.5.7 Entrance through a sharp-edged orifice

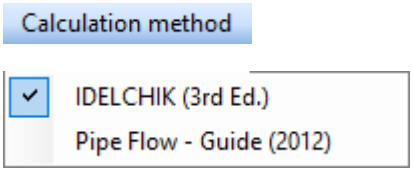
Circular Cross-Section



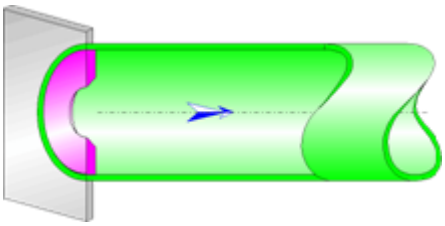
For the calculation of the pressure loss coefficient of a pipe entrance equipped with a sharp-edged orifice, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.5.7.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe entrance equipped with a sharp-edged orifice.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Orifice cross-section area (m^2):

$$F_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in orifice (m/s):

$$w_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Reynolds number in orifice:

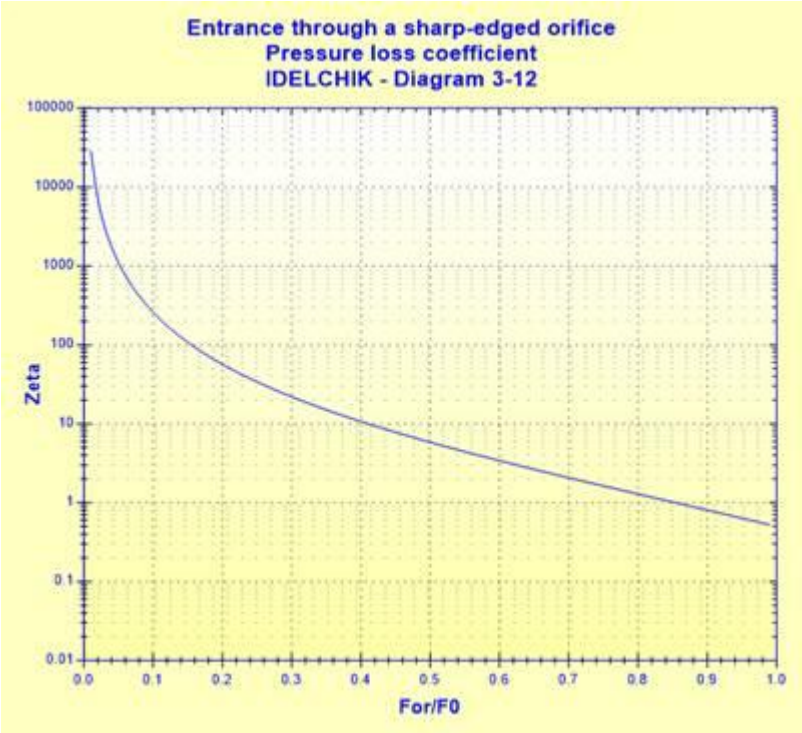
$$\mathrm{Re} = \frac{w_{or} \cdot D_{or}}{\nu}$$

Local resistance coefficient (based on the mean pipe velocity):

- $\mathrm{Re} \geq 10^5$

$$\zeta = \left[1.707 - \frac{F_{or}}{F_0}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-12)



■ $Re < 10^5$

Quadratic local resistance coefficient:

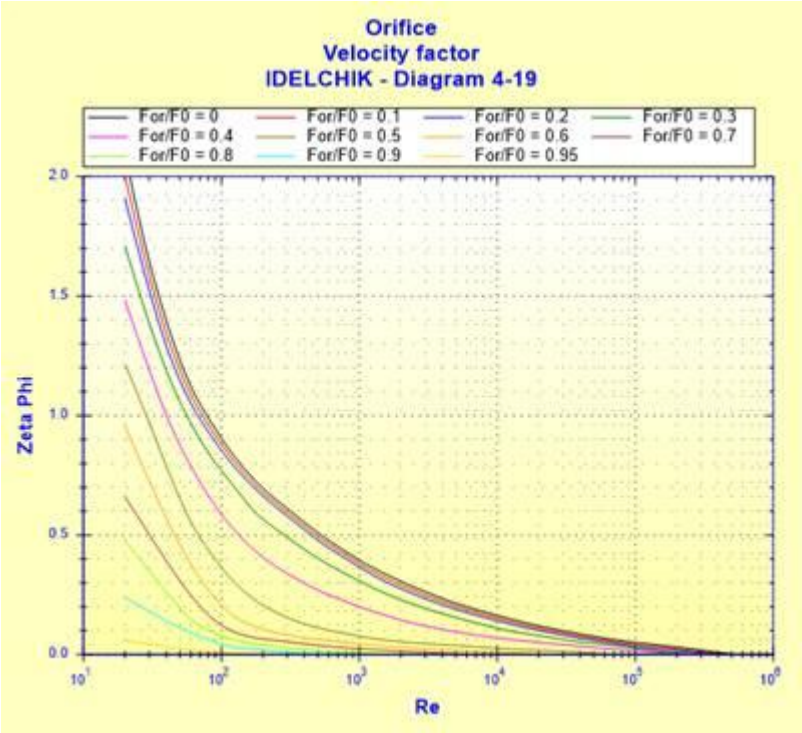
$$\zeta_{quad} = \left[1.707 - \frac{F_{or}}{F_0}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-12)

Velocity factor:

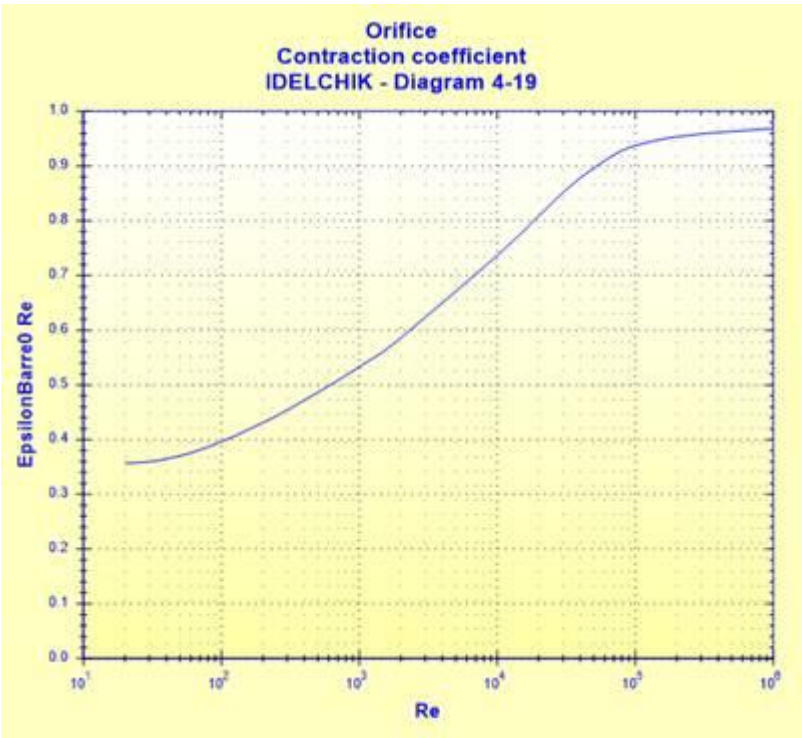
$$\zeta_{\varphi} = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$ ([1] diagram 4-19)



Local resistance coefficient:

- $30 < \mathrm{Re} < 10^5$

$$\zeta = \zeta_{\varphi} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0\mathrm{Re}} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $10 < \mathrm{Re} \leq 30$

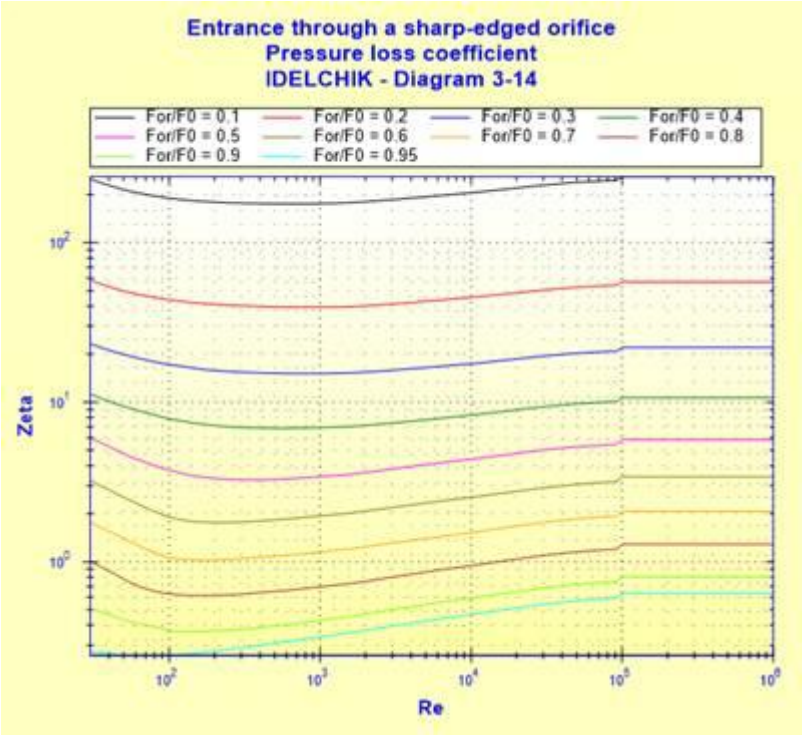
$$\zeta = \frac{33}{\mathrm{Re}} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0\mathrm{Re}} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $\mathrm{Re} \leq 10$

$$\zeta = \frac{33}{\mathrm{Re}} \cdot \left(\frac{F_0}{F_{or}} \right)^2$$

([1] diagram 3-14)



Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

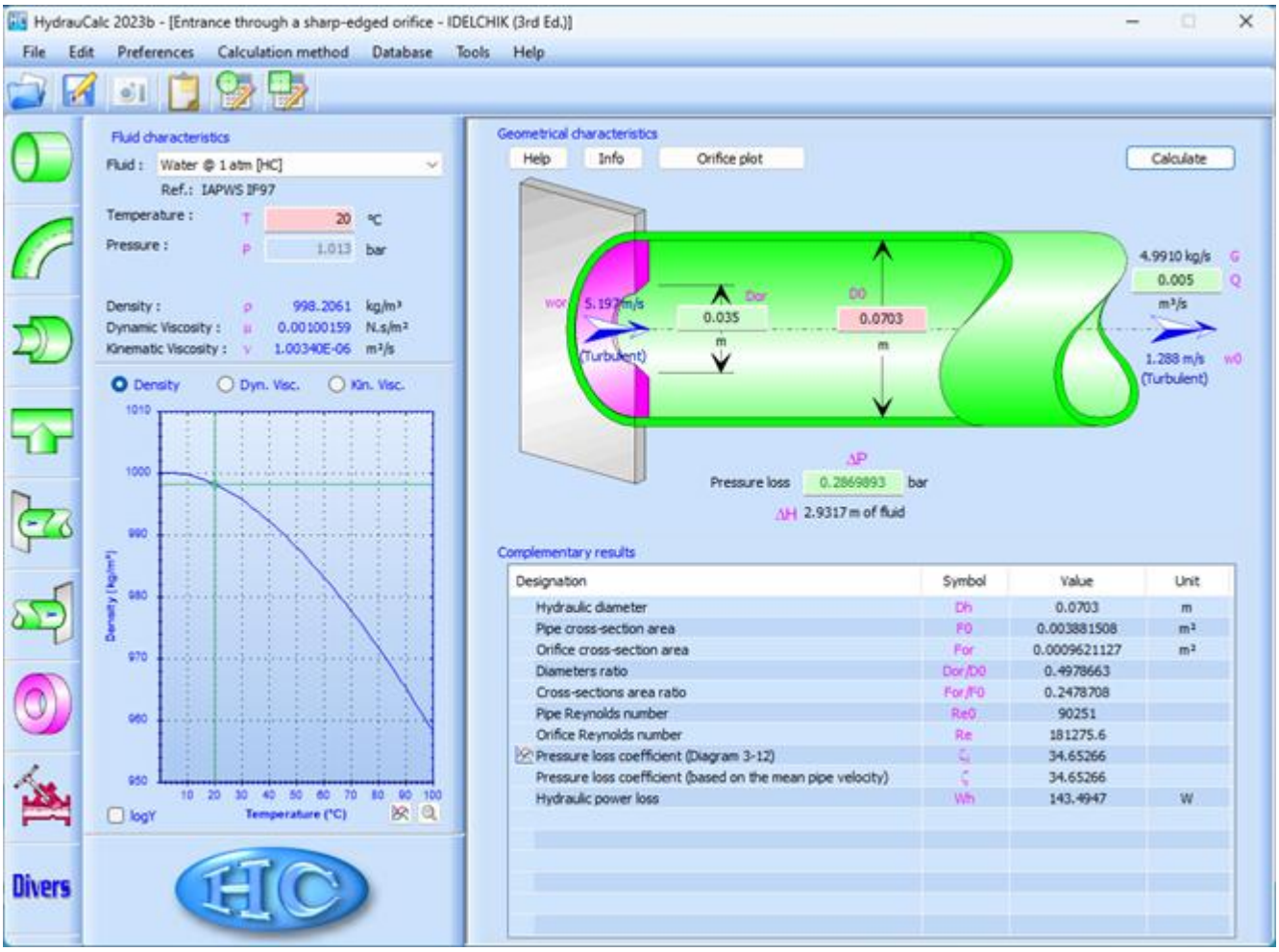
Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_0	Pipe internal diameter (m)
F_0	Pipe cross-sectional area (m^2)
D_{or}	Orifice diameter (m)
F_{or}	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in pipe (m/s)
w_{or}	Mean velocity in orifice (m/s)
Re_0	Reynolds number in pipe ()
Re	Reynolds number in orifice ()
l	Orifice thickness (m)
ζ_{quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- chamfer angle about 45°
- thickness to orifice diameter ratio (l/D_{or}) lower than or equal to 0.015

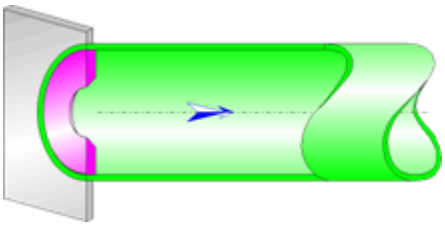
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.5.7.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe entrance equipped with a sharp-edged orifice.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Ratio of orifice to pipe diameter:

$$\beta = \frac{d_o}{d}$$

Pipe cross-sectional area (m²):

$$A = \pi \cdot \frac{d^2}{4}$$

Orifice cross-sectional area (m²):

$$A_o = \pi \cdot \frac{d_o^{\,2}}{4}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

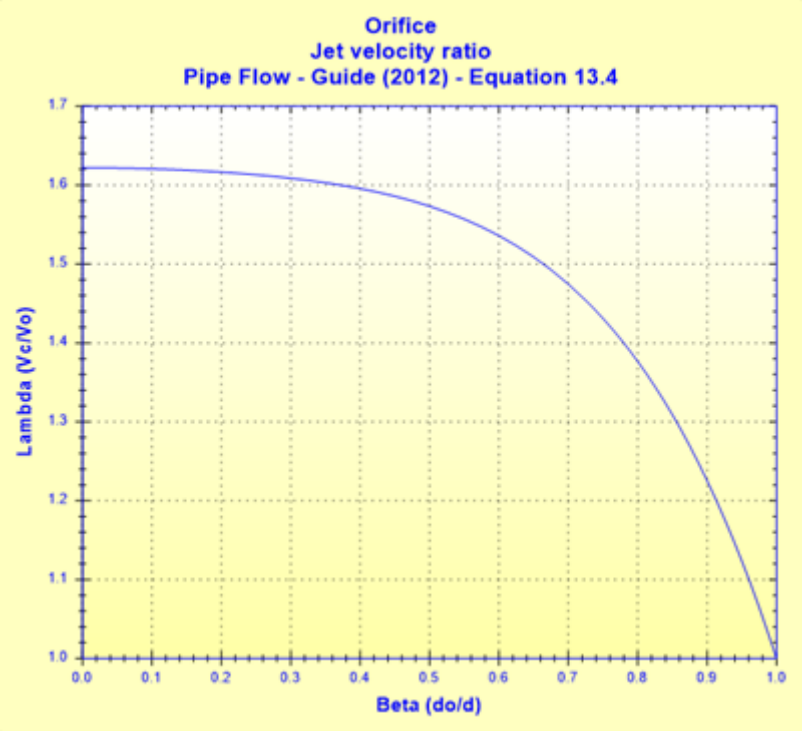
$$N_{Re} = \frac{V \cdot d}{\nu}$$

Reynolds number in orifice:

$$N_{Re_o} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left(1 - 0.215\beta^2 - 0.785\beta^5\right)$$ ([1] equation 13.4)



Velocity in vena contracta (m/s):

$$V_c = V_o \cdot \lambda$$

Vena contracta cross-sectional area (m^2):

$$A_c = \frac{Q}{V_c}$$

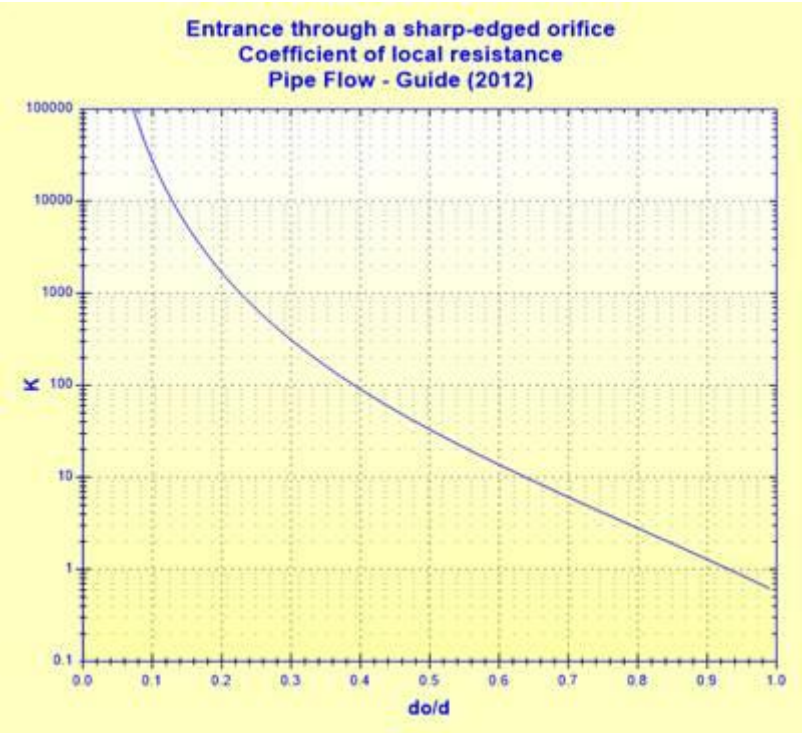
Coefficient of local resistance ($NRe_o \geq 10^4$):

$$K_o = 0.183 + \left[1.622 - \left(\frac{d_o}{d}\right)^2\right]^2$$

([1] equation 9.5)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_o} \right)^2$$



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_0	Orifice diameter (m)
d	Internal pipe diameter (m)
β	Ratio of orifice to pipe diameter ()
A_o	Orifice cross-sectional area (m^2)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in orifice diameter (m/s)
V	Mean velocity in pipe diameter (m/s)
NRe_o	Reynolds number in orifice ()
NRe	Reynolds number in pipe ()
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
K_o	Coefficient of local resistance ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m³)

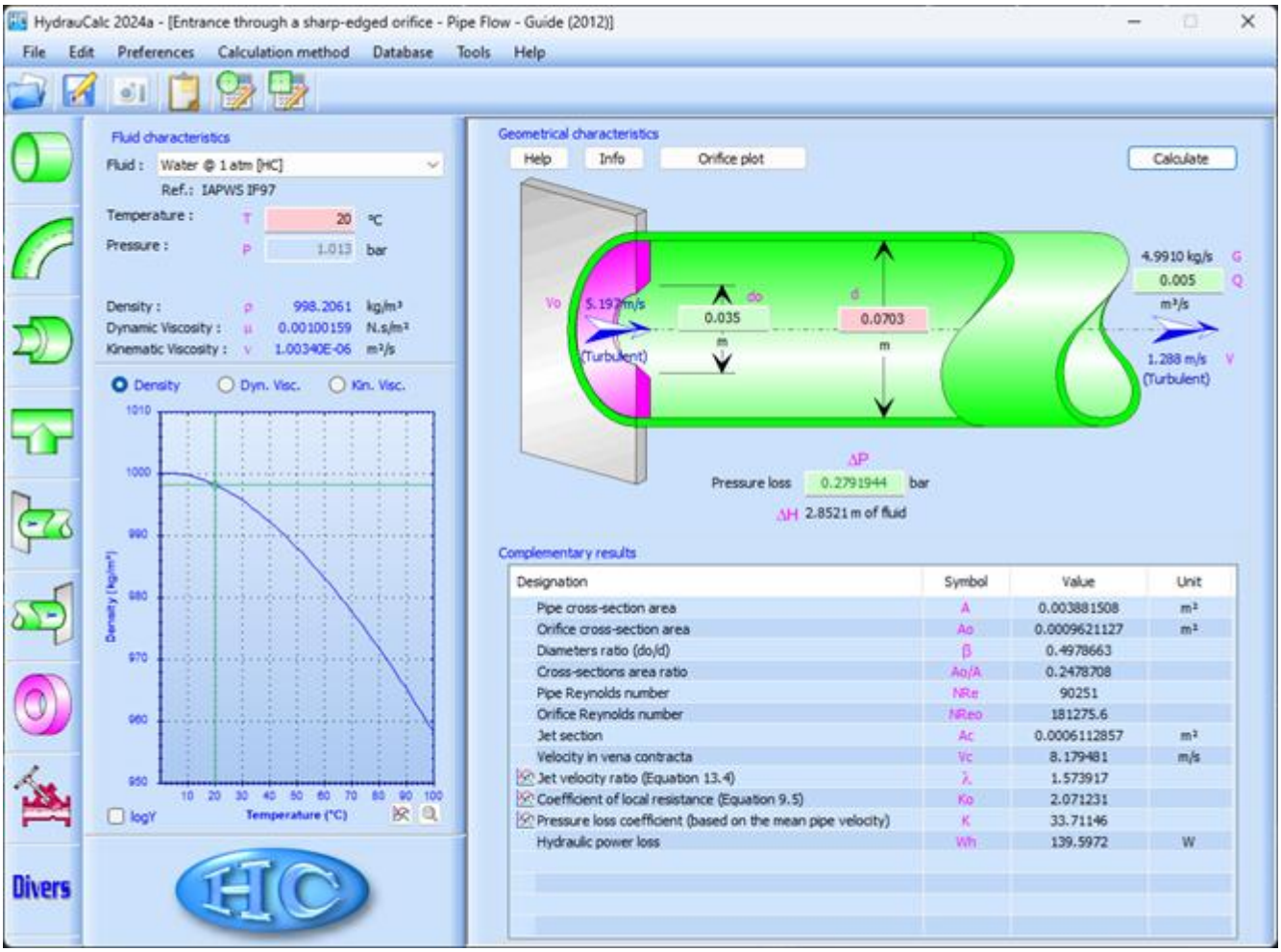
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime in the orifice ($NRe_o \geq 10^4$)

Example of application:

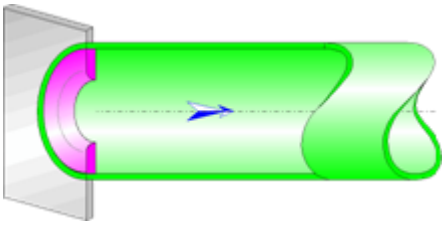


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.5.8 Entrance through a round-edged orifice

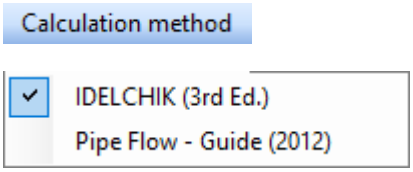
Circular Cross-Section



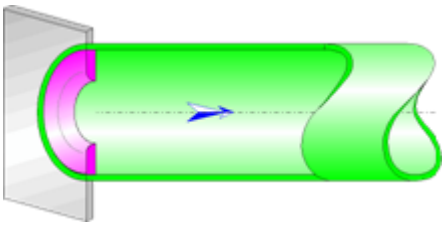
For the calculation of the pressure loss coefficient of a pipe entrance equipped with a round-edged orifice, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.5.8.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe entrance equipped with a round-edged orifice.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Orifice cross-section area (m^2):

$$F_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in orifice (m/s):

$$w_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$Re_0 = \frac{w_0 \cdot D_0}{\nu}$$

Reynolds number in orifice:

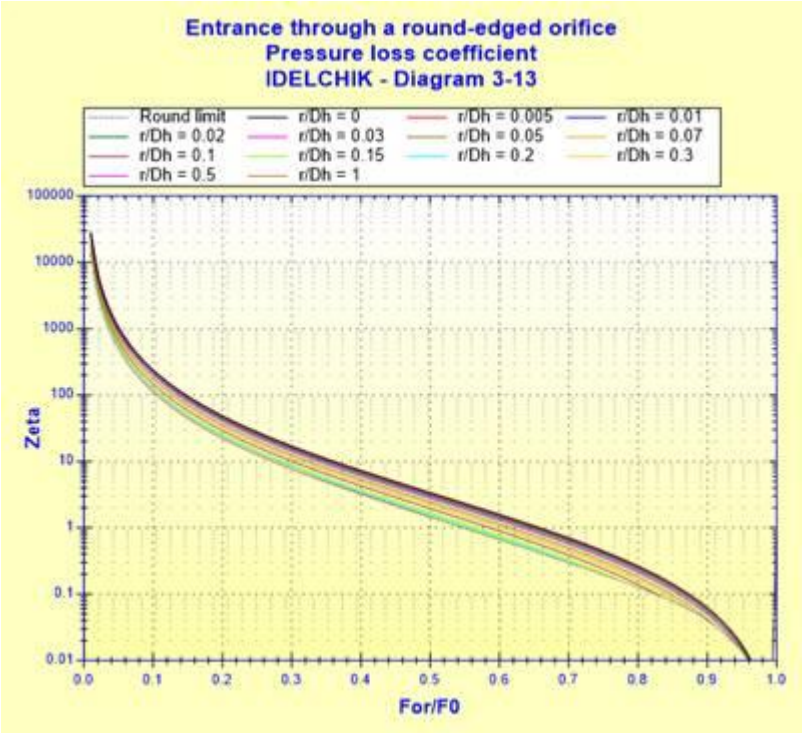
$$Re = \frac{w_{or} \cdot D_{or}}{\nu}$$

Local resistance coefficient (based on the mean pipe velocity):

- $Re \geq 10^5$

$$\zeta = \left[1 + \sqrt{\zeta'} - \frac{F_{or}}{F_0}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-13)

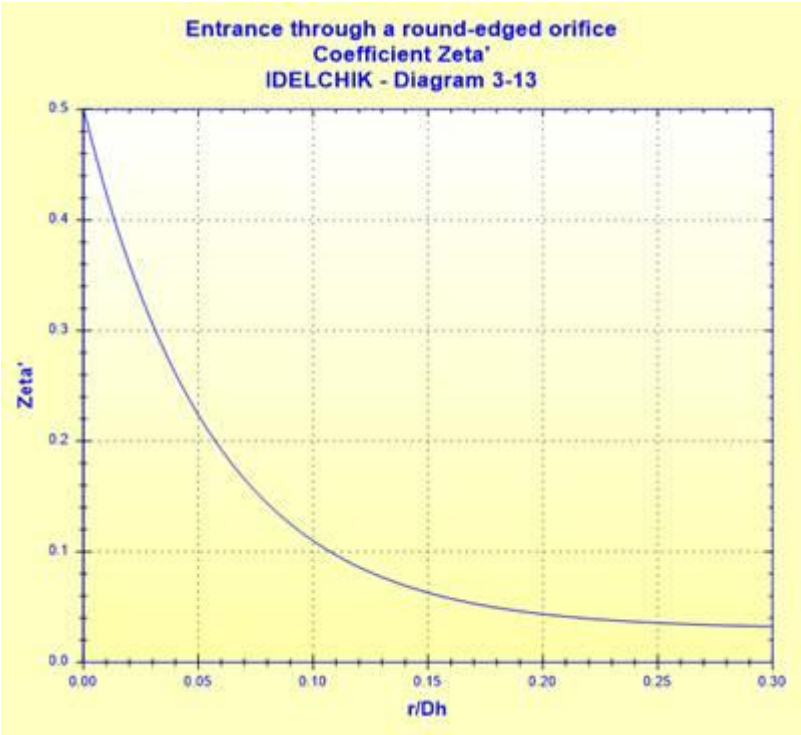


with :

Coefficient of effect of the round:

$$\zeta' = 0.03 + 0.47 \cdot 10^{-7.7 \cdot \frac{r}{D_h}}$$

([1] diagram 3-13)



■ $Re < 10^5$

Quadratic local resistance coefficient:

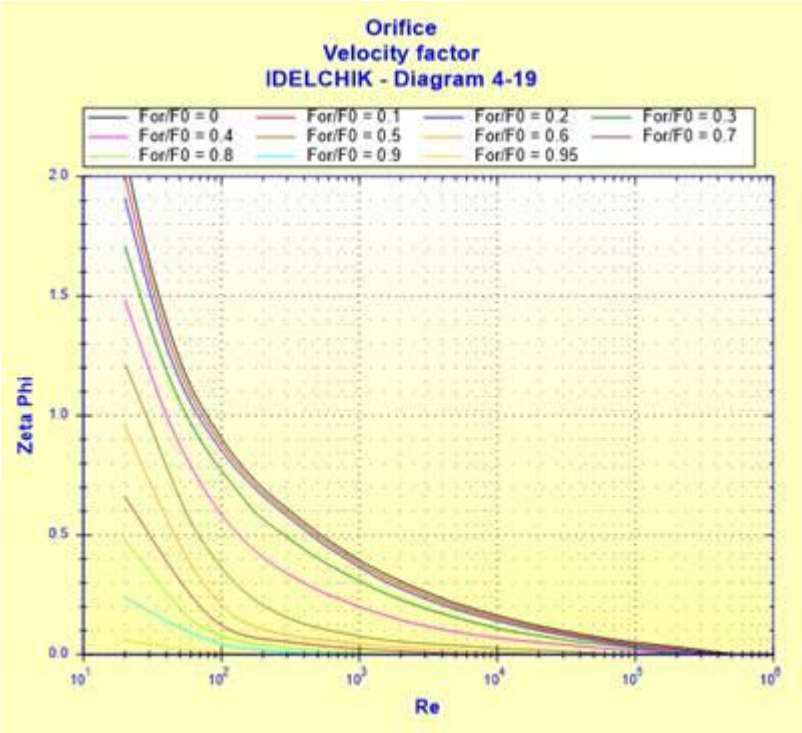
$$\zeta_{quad} = \left[1 + \sqrt{\zeta'} - \frac{F_{or}}{F_0}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-13)

Velocity factor:

$$\zeta_\varphi = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$$

([1] diagram 4-19)

Local resistance coefficient:

- $30 < Re < 10^5$

$$\zeta = \zeta_{\varphi} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $10 < Re \leq 30$

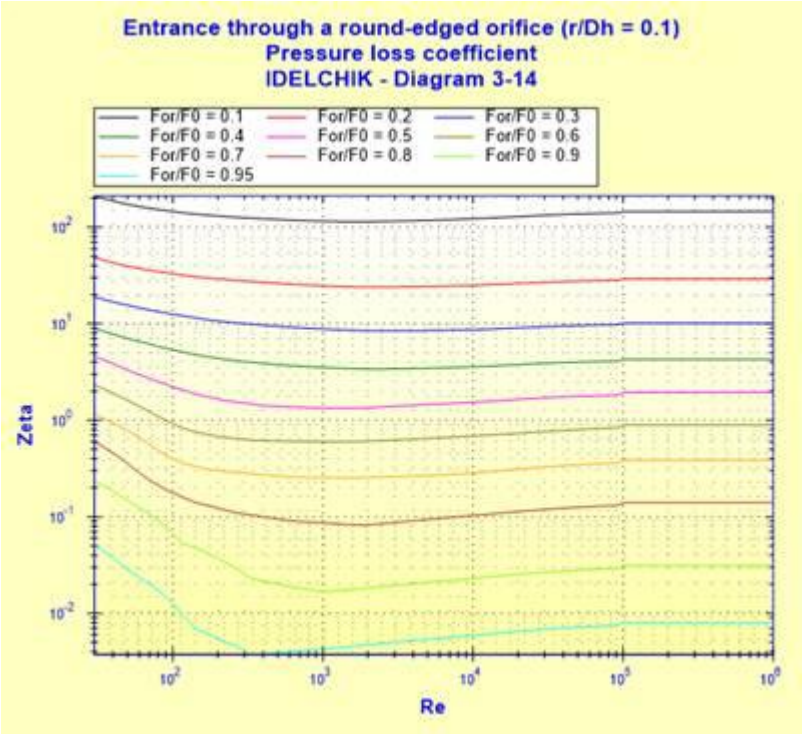
$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $Re \leq 10$

$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2$$

([1] diagram 3-14)



([1] diagram 3-14 with r/Dh = 0.1)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

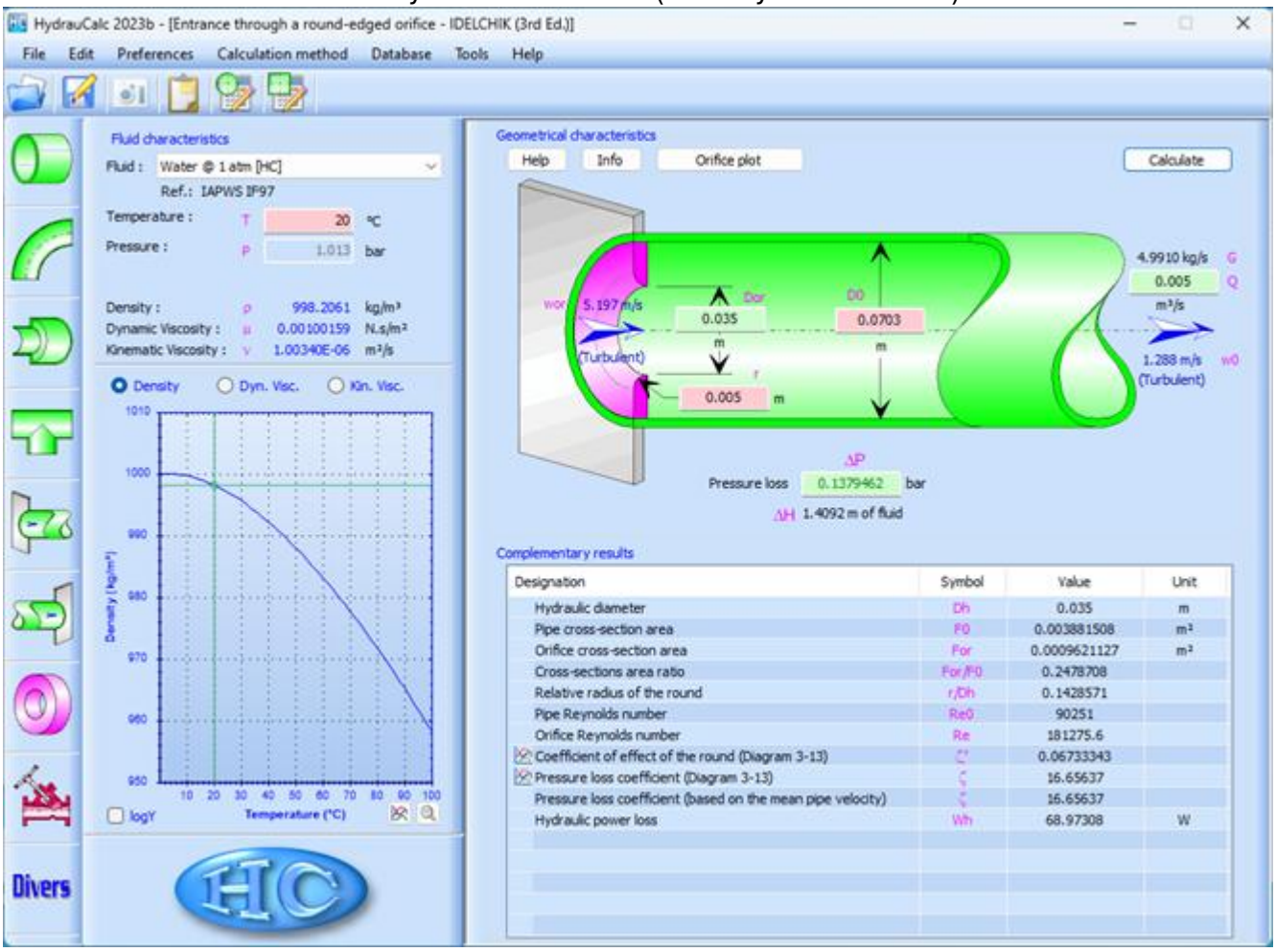
D_h	Hydraulic diameter (m)
D_0	Pipe internal diameter (m)
F_0	Pipe cross-sectional area (m^2)
D_{or}	Orifice diameter (m)

F_{or}	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in pipe (m/s)
w_{or}	Mean velocity in orifice (m/s)
r	Radius of the round (m)
Re_0	Reynolds number in pipe ()
Re	Reynolds number in orifice ()
ζ'	Coefficient of effect of the round ()
ζ_{quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- round radius less than the radius difference ($r < (D_0/2-D_{or}/2)$)

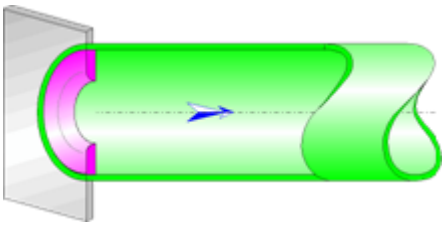
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.5.8.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe entrance equipped with a round-edged orifice.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Ratio of orifice to pipe diameters:

$$\beta = \frac{d_o}{d}$$

Pipe cross-sectional area (m²):

$$A = \pi \cdot \frac{d^2}{4}$$

Orifice cross-sectional area (m²):

$$A_o = \pi \cdot \frac{d_o{}^2}{4}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

Reynolds number in orifice:

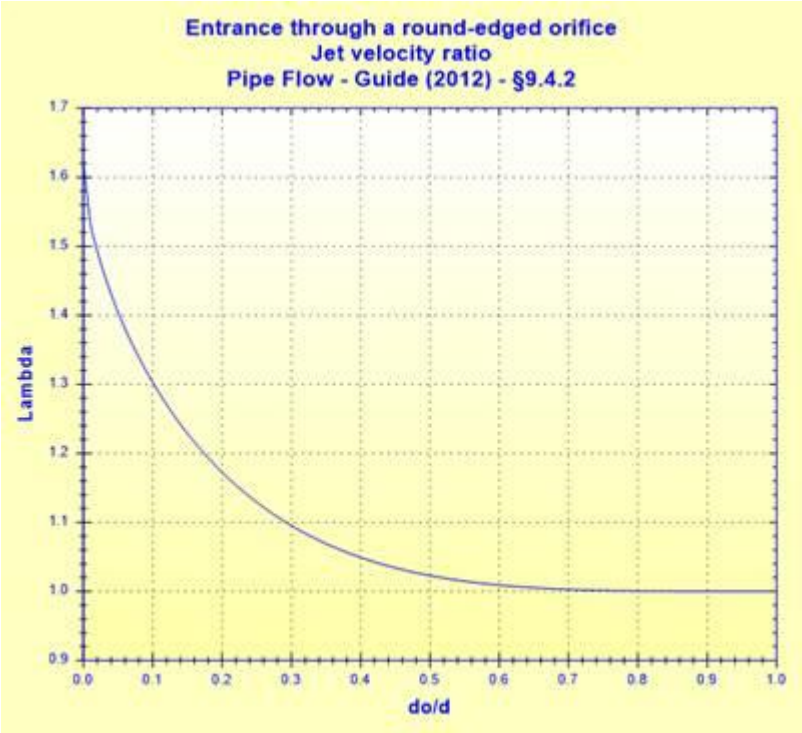
$$N_{Re_O} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

- $r/d_0 \le 1$

$$\lambda = 1 + 0.622 \cdot \left[1 - 0.3 \cdot \sqrt{\frac{r}{d_0}} - 0.7 \cdot \frac{r}{d_0} \right]^4$$

([1] §9.4.2)



- $r/d_0 > 1$

$$\lambda = 1$$ ([1] §9.4.2)

Velocity in vena contracta:

$$V_c = V_0 \cdot \lambda$$

Coefficient of local resistance:

- $r/d_0 \leq 1$

$$K_o = 0.0696 \cdot \left(1 - 0.569 \cdot \frac{r}{d_0}\right) \cdot \lambda^2 + \left(\lambda - \left(\frac{d_o}{d}\right)^2\right)^2$$ ([1] equation 9.6)

■ $r/d_0 > 1$

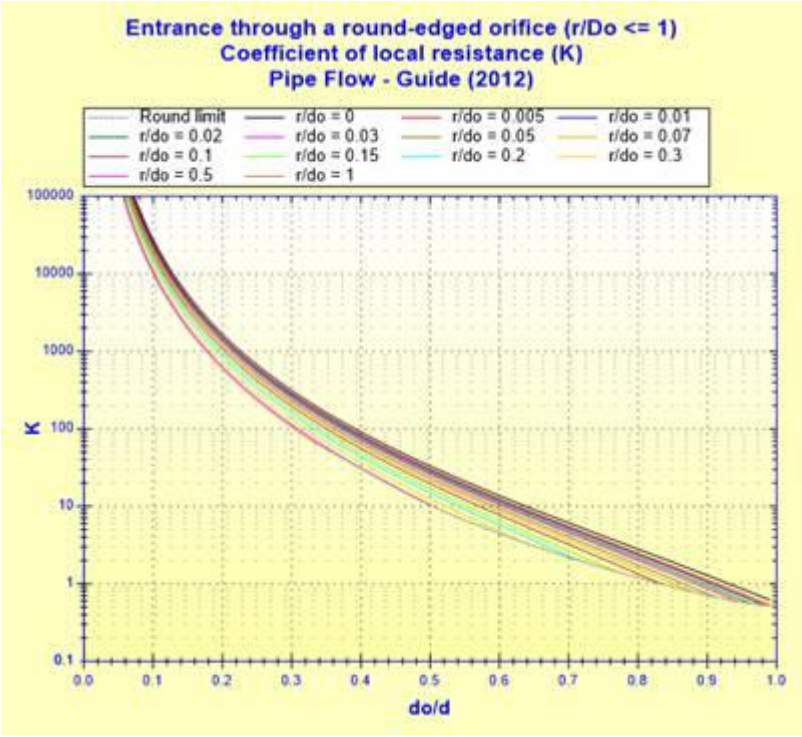
$$K_o = 0.03 + \left(1 - \left(\frac{d_o}{d}\right)^2\right)^2$$

([1] §9.4.2)

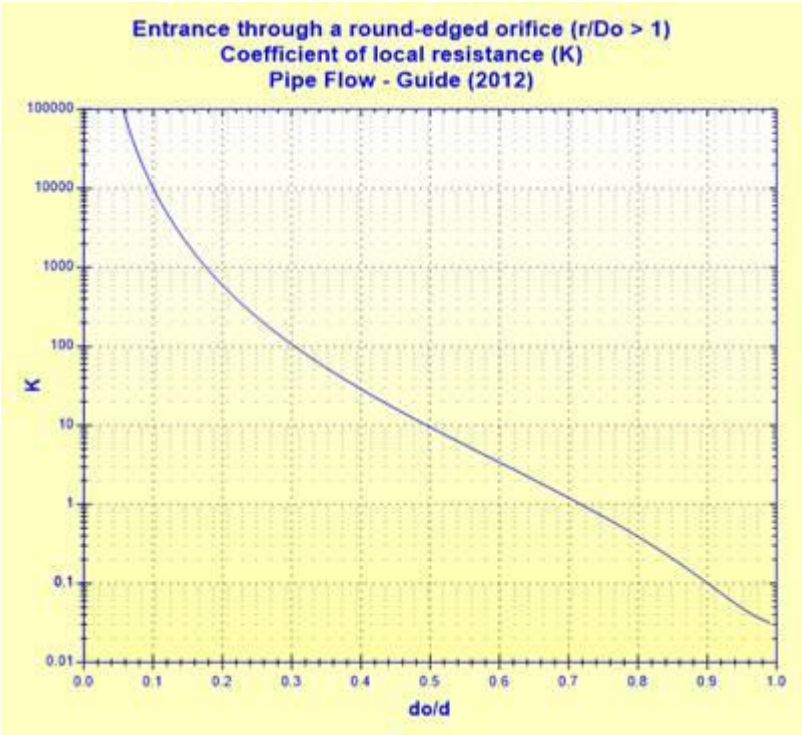
Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_o} \right)^2$$

■ $r/d_0 \leq 1$



■ $r/d_0 > 1$



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_0	Orifice diameter (m)
d	Internal pipe diameter (m)
β	Ratio of orifice to pipe diameters ()
A_o	Orifice cross-sectional area (m^2)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
NRe_o	Reynolds number in orifice ()
NRe	Reynolds number in pipe ()
r	Rounding radius (m)
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
K_o	Coefficient of local resistance ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m³)

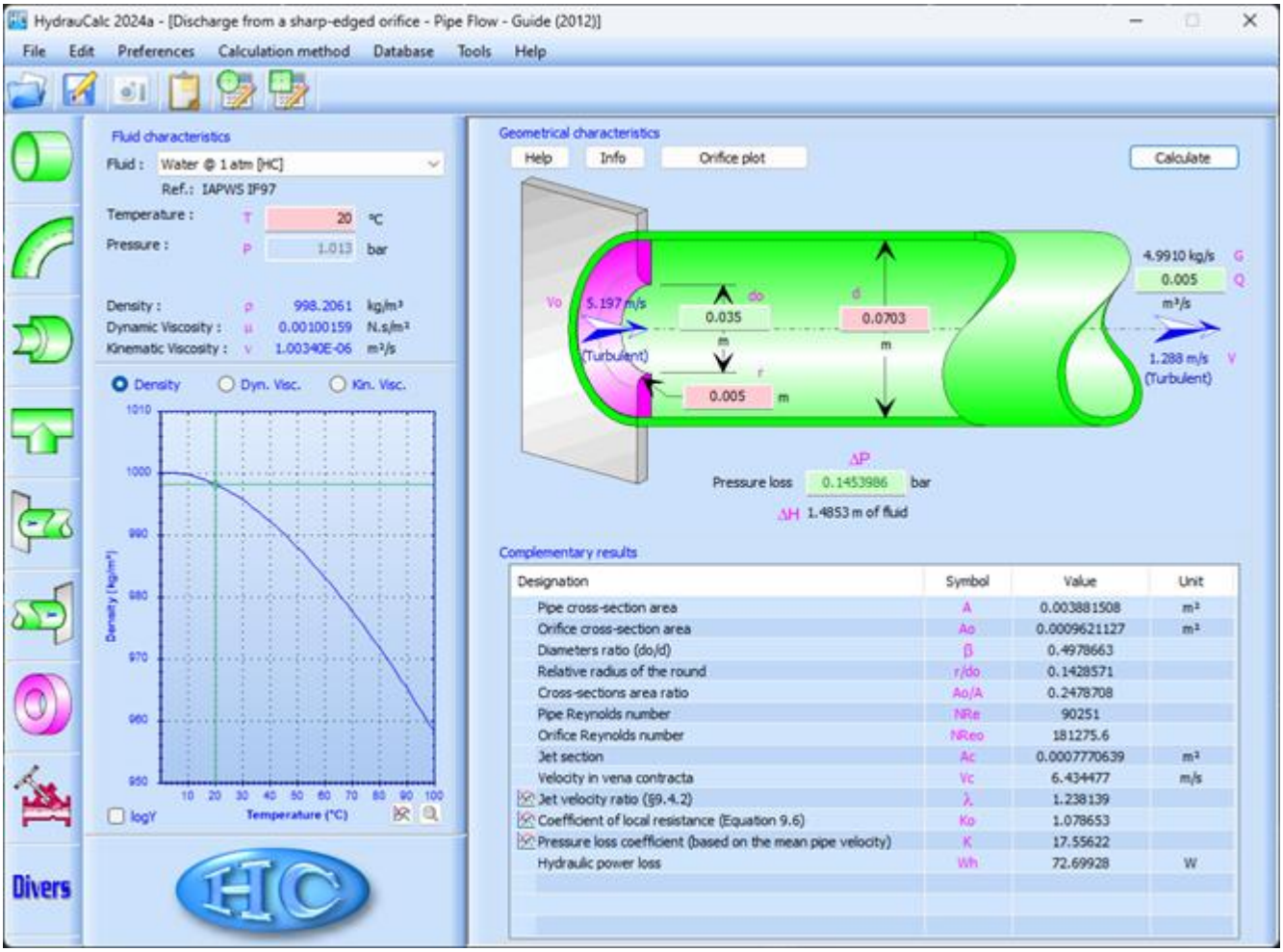
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime in orifice ($NRe_o \geq 10^4$)
- round radius less than the radius difference ($r < (d/2-d_0/2)$)

Example of application:

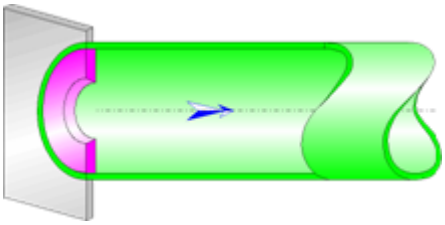


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.5.9 Entrance through a bevel-edged orifice

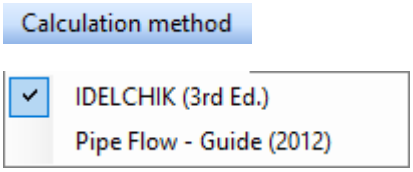
Circular Cross-Section



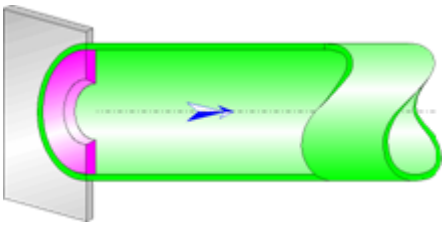
For the calculation of the pressure loss coefficient of a pipe entrance equipped with a bevel-edged orifice, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.5.9.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe entrance equipped with a bevel-edged orifice.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Orifice cross-section area (m^2):

$$F_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in orifice (m/s):

$$w_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$Re_0 = \frac{w_0 \cdot D_0}{\nu}$$

Reynolds number in orifice:

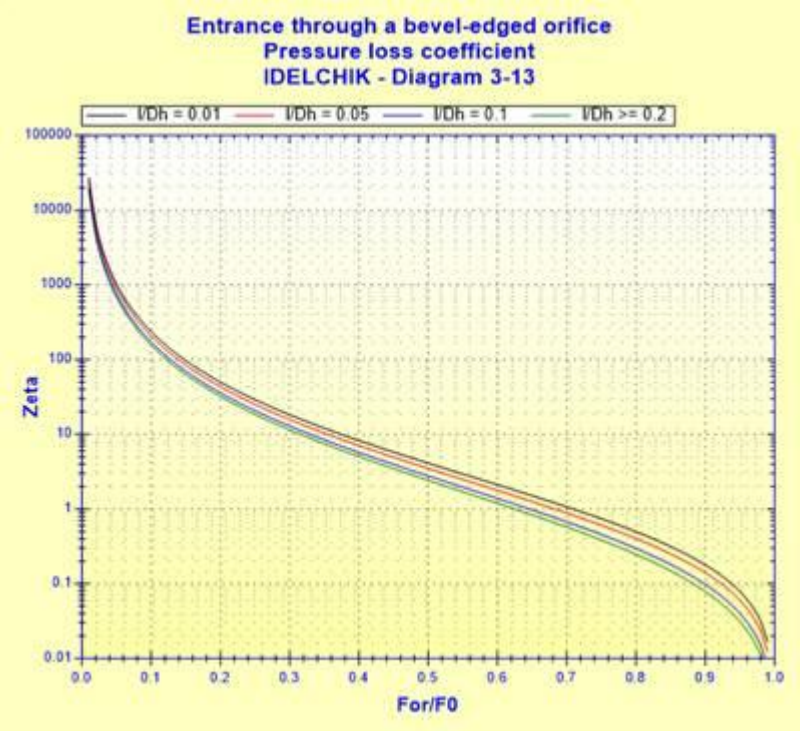
$$Re = \frac{w_{or} \cdot D_{or}}{\nu}$$

Local resistance coefficient (based on the mean pipe velocity):

- $Re \geq 10^5$

$$\zeta = \left[1 + \sqrt{\zeta'} - \frac{F_{or}}{F_0}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-13)

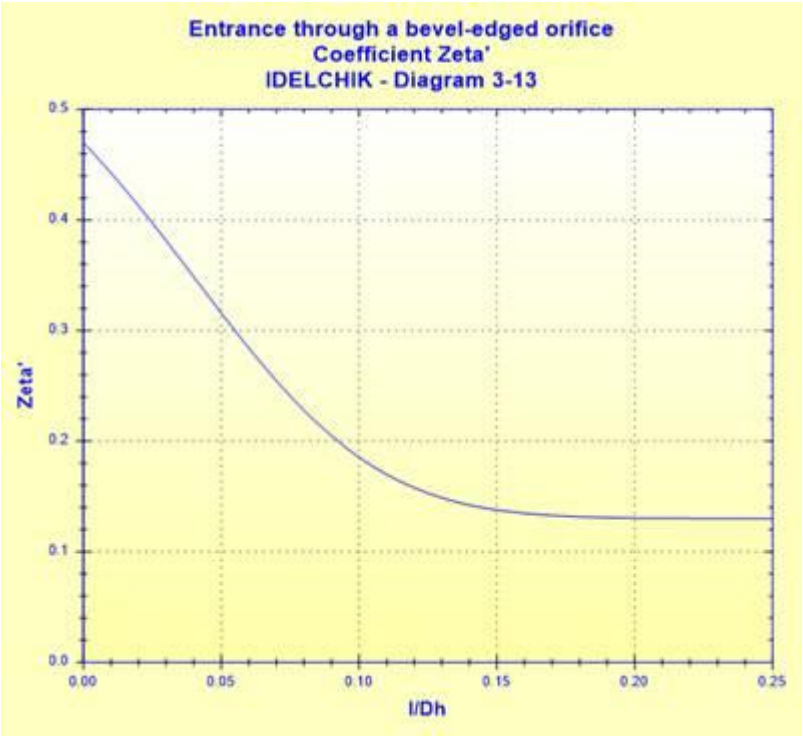


with :

Coefficient of effect of the orifice thickness:

$$\zeta' = 0.13 + 0.34 \cdot 10^{-\left(3.45 \cdot \frac{l}{D_h} + 88.4 \cdot \left(\frac{l}{D_h}\right)^{2.3}\right)}$$

([1] diagram 3-13)



■ $Re < 10^5$

Quadratic local resistance coefficient:

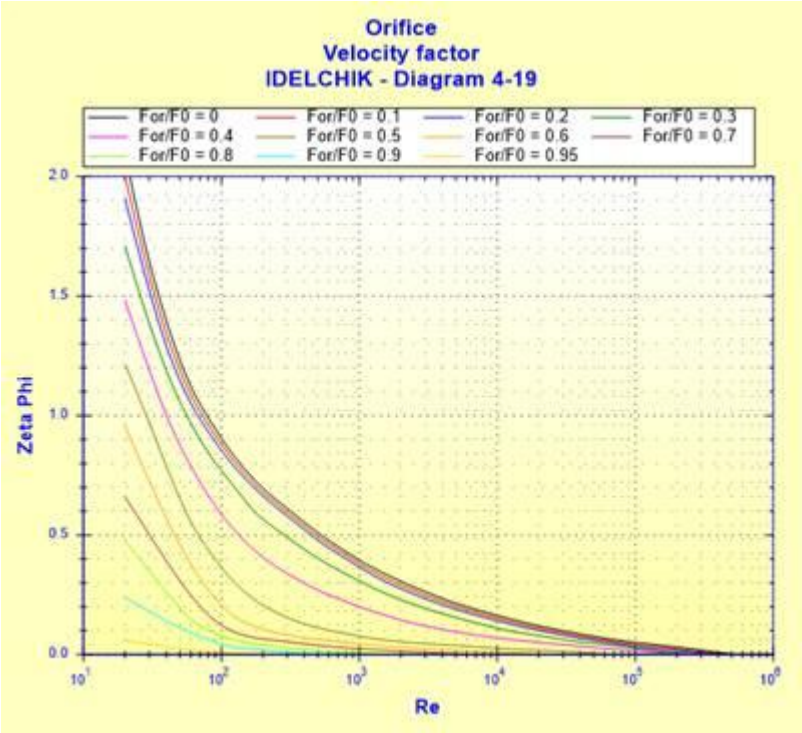
$$\zeta_{quad} = \left[1 + \sqrt{\zeta'} - \frac{F_{or}}{F_0}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-13)

Velocity factor:

$$\zeta_\varphi = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$$

([1] diagram 4-19)

Local resistance coefficient:

- $30 < Re < 10^5$

$$\zeta = \zeta_{\varphi} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $10 < Re \leq 30$

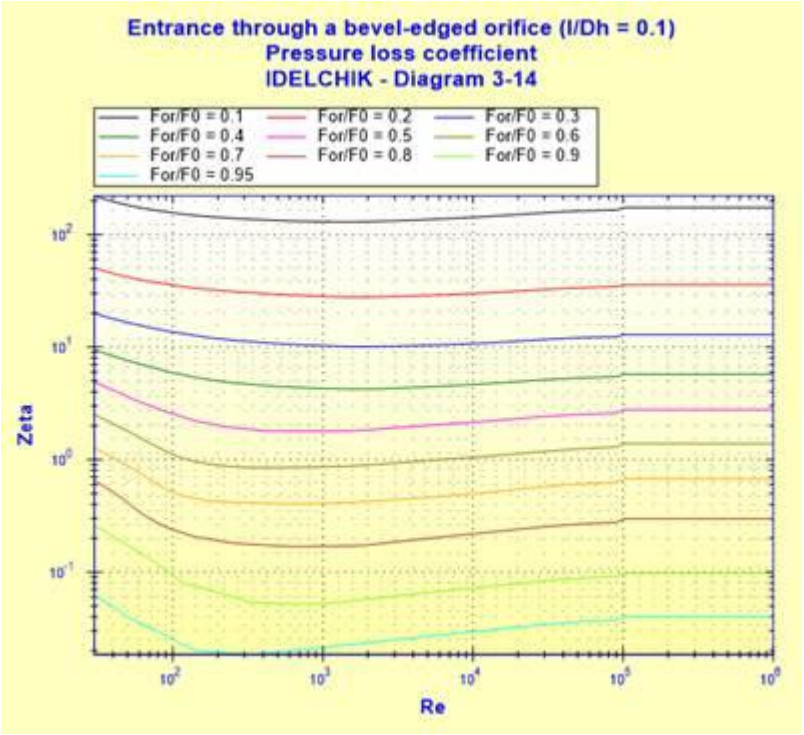
$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $Re \leq 10$

$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2$$

([1] diagram 3-14)



([1] diagram 3-14 with l/Dh = 0.1)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h Hydraulic diameter (m)

D_0 Pipe internal diameter (m)

F_0 Pipe cross-sectional area (m^2)

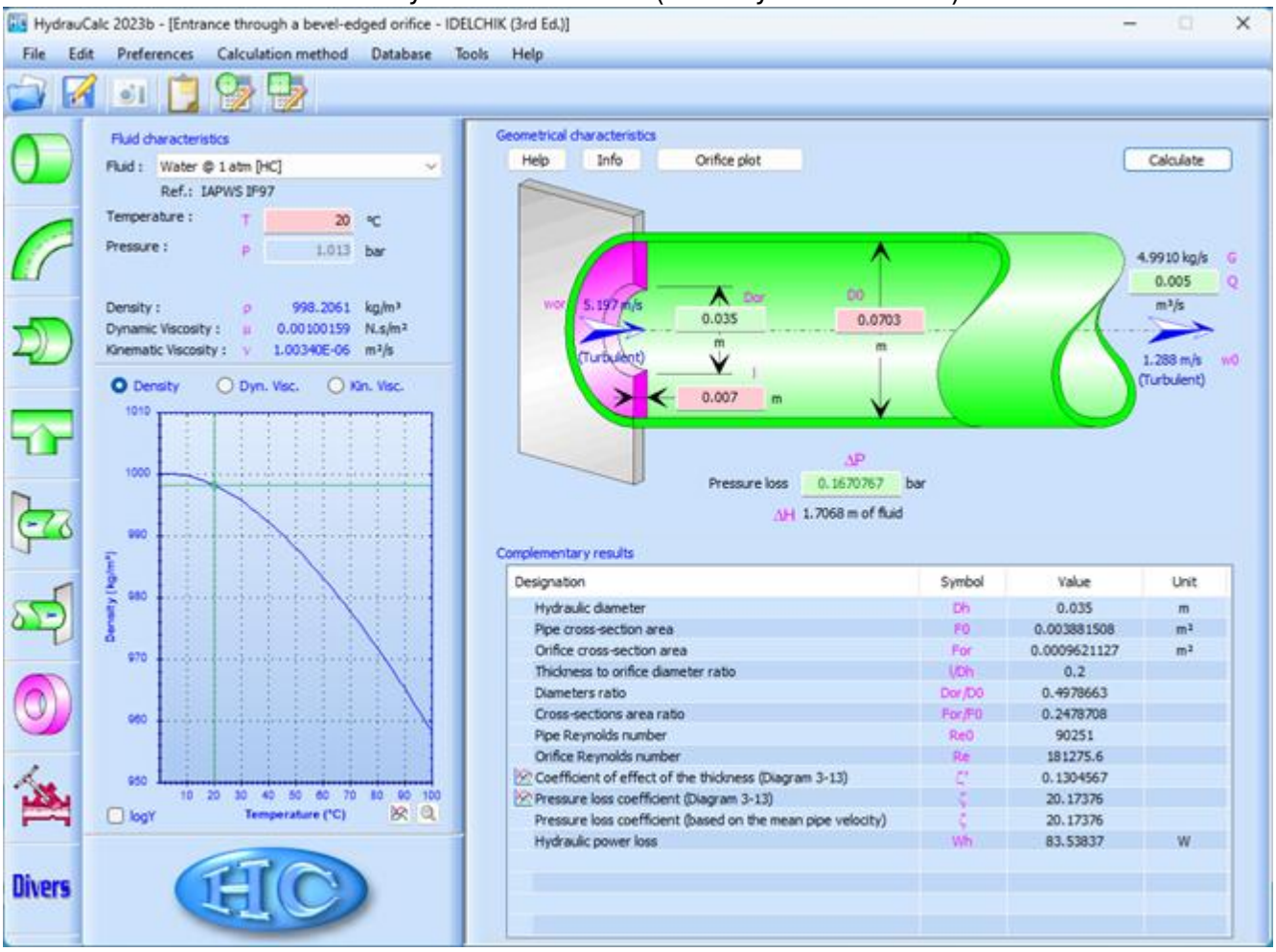
D_{or} Orifice diameter (m)

F_{or}	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in pipe (m/s)
w_{or}	Mean velocity in orifice (m/s)
l	Orifice thickness (m)
Re_0	Reynolds number in pipe ()
Re	Reynolds number in orifice ()
ζ'	Coefficient of effect of the orifice thickness ()
ζ_{quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- angle at the top of the truncated cone between 40 ° and 60 °

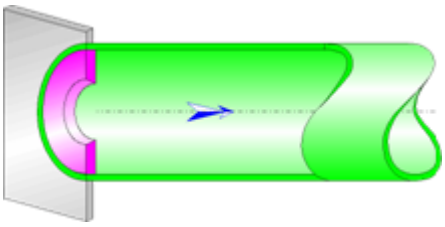
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.5.9.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe entrance equipped with a bevel-edged orifice.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Ratio of orifice to pipe diameters:

$$\beta = \frac{d_o}{d}$$

Pipe cross-sectional area (m²):

$$A = \pi \cdot \frac{d^2}{4}$$

Orifice cross-sectional area (m²):

$$A_o = \pi \cdot \frac{d_o{}^2}{4}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

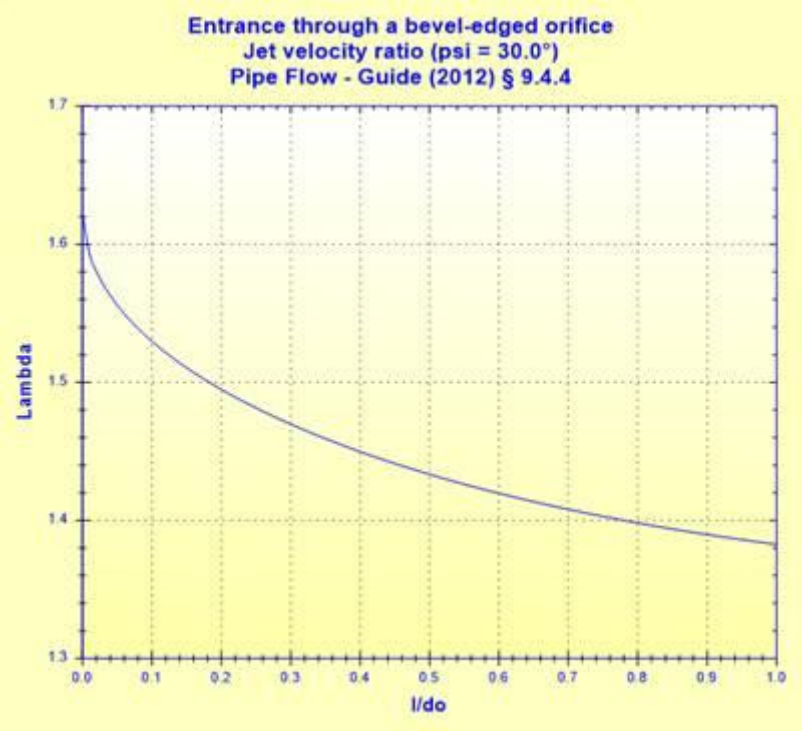
Reynolds number in orifice:

$$N_{Re_O} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left[1 - C_b \cdot \left(\frac{l}{d_0} \right)^{\frac{1-\sqrt[4]{\beta^4 q_0}}{2}} \right]$$

([1] §9.4.4)



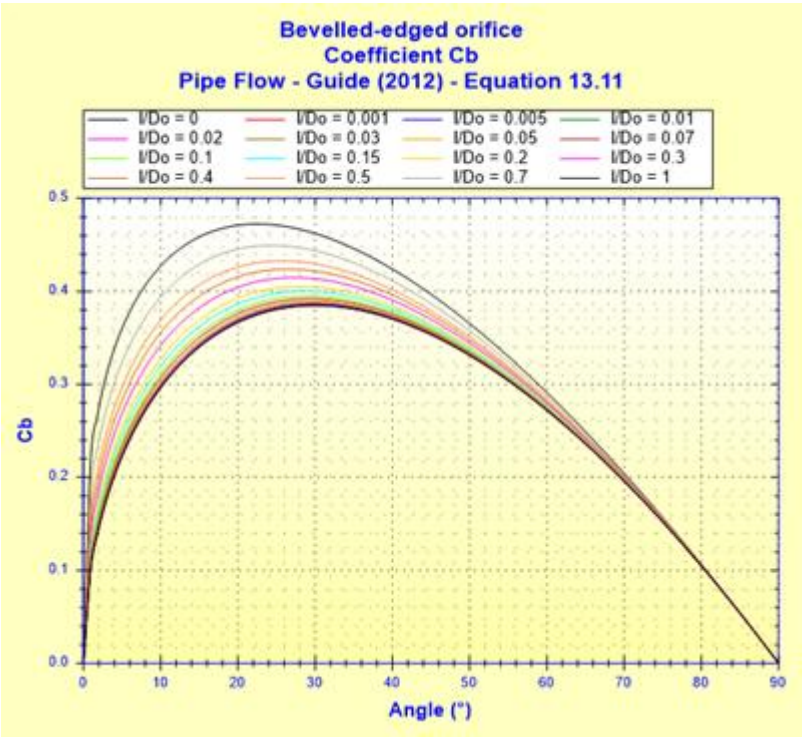
(with ψ = 30°)

with:

Coefficient of effect of the bevel angle:

$$C_b = \left(1 - \frac{\Psi}{90}\right) \cdot \left(\frac{\Psi}{90}\right)^{\frac{1}{1+l/d_0}}$$

([1] §9.4.4)



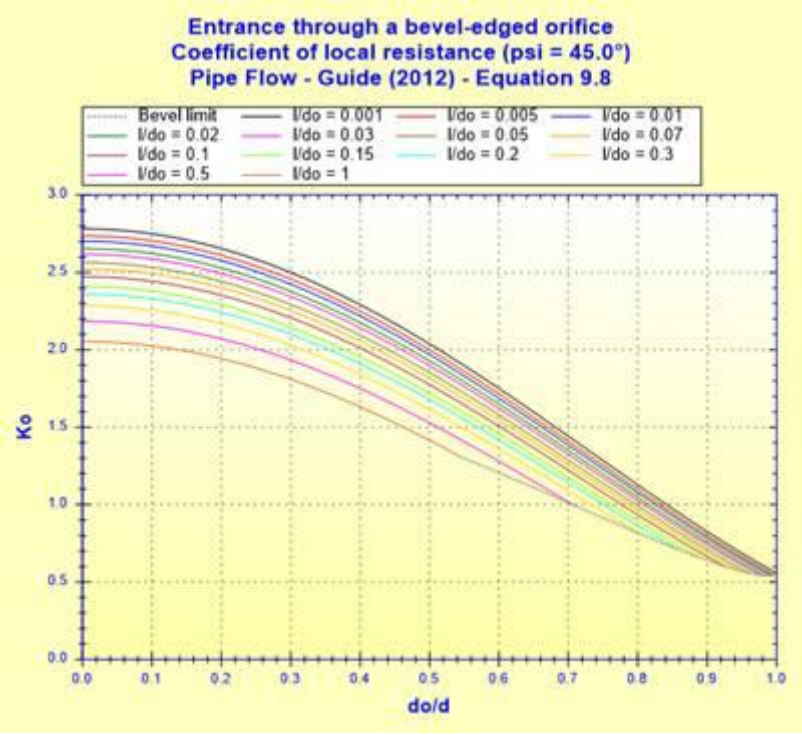
Velocity in vena contracta:

$$V_c = V_0 \cdot \lambda$$

Coefficient of local resistance ($NRe_o \geq 10^4$):

$$K_o = 0.0696 \cdot \left(1 - C_b \cdot \frac{l}{d_0}\right) \cdot \lambda^2 + \left[\lambda - \left(\frac{d_o}{d}\right)^2\right]^2$$

([1] equation 9.8)



(with ψ = 45°)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_o}\right)^2$$

(with ψ = 45°)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

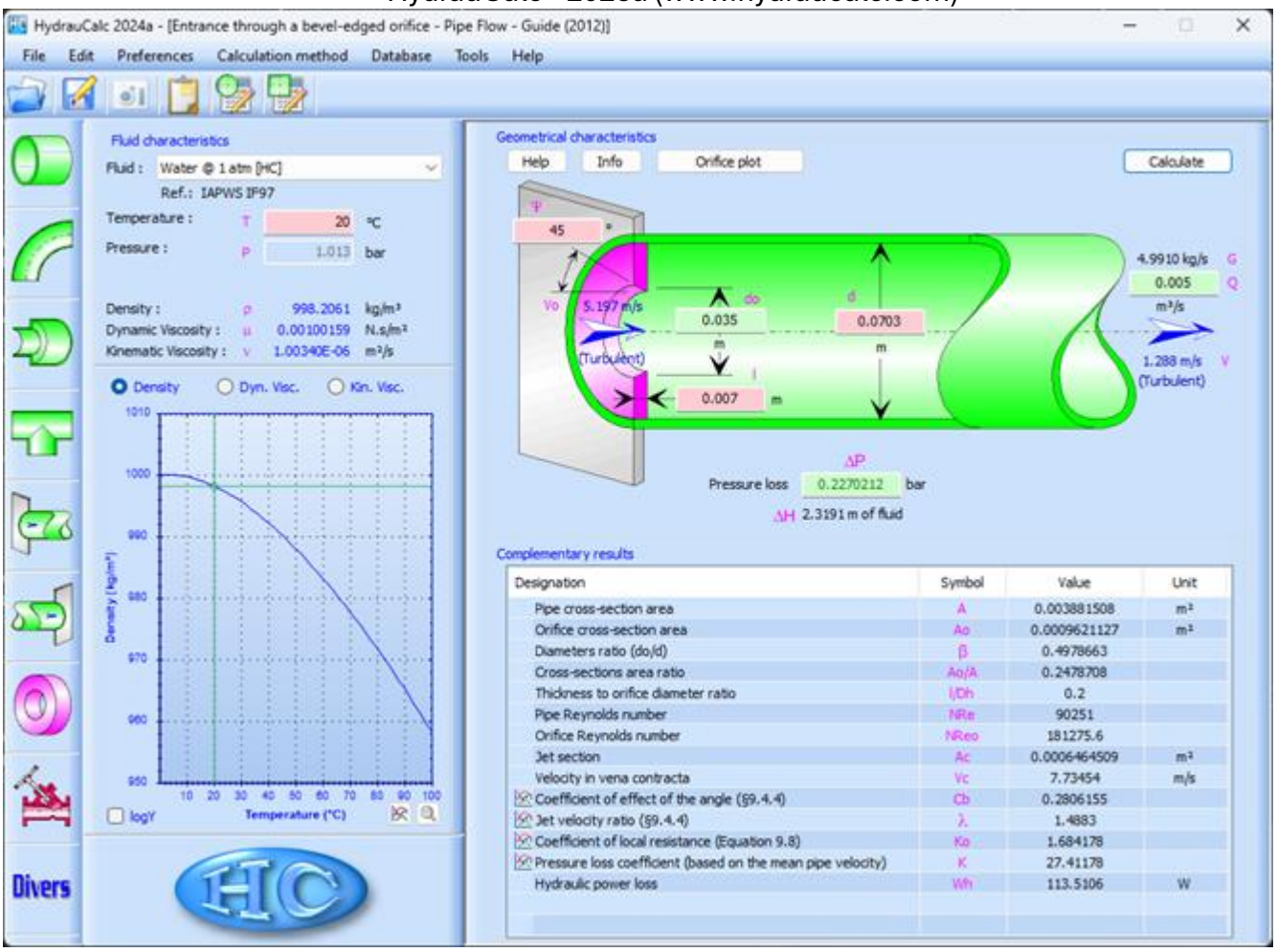
d_0	Orifice diameter (m)
d	Internal pipe diameter (m)
β	Ratio of orifice to pipe diameters ()
A_o	Orifice cross-sectional area (m^2)
A	Pipe cross-sectional area (m^2)

Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
NRe_o	Reynolds number in orifice ()
NRe	Reynolds number in pipe ()
l	Thickness orifice (m)
ψ	Bevel angle (°)
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
C_b	Coefficient of effect of the bevel angle ()
K_o	Coefficient of local resistance ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in orifice ($NRe_o \geq 10^4$)
- bevel angle less than or equal to: $\psi \leq tg^{-1}((d - d_o) / (2\ l))$

Example of application:

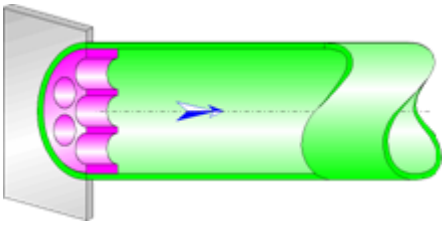


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.5.10 Entrance through a thick-edged grid

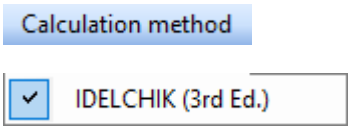
Circular Cross-Section



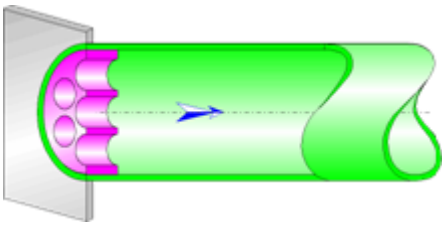
The calculation method used to calculate the pressure loss coefficient of a pipe entrance equipped with a thick-edged grid is described in the following reference document:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

The only calculation method offered appears in the "Calculation method" menu and is activated by default.



2.5.10.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe entrance equipped with a thick-edged grid. Moreover, the head loss due to friction of the fluid on the inner walls of the holes is also taken into account in this component and is calculated with Darcy's formula.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Cross-section area of one hole (m²):

$$f_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Clear cross-sectional area of the grid (m²):

$$F_{or} = f_{or} \cdot N$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in holes (m/s):

$$w_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Reynolds number in holes:

$$\mathrm{Re} = \frac{w_{or} \cdot D_{or}}{\nu}$$

Relative roughness in holes walls:

$$\bar{\Delta} = \frac{\Delta}{D_{or}}$$

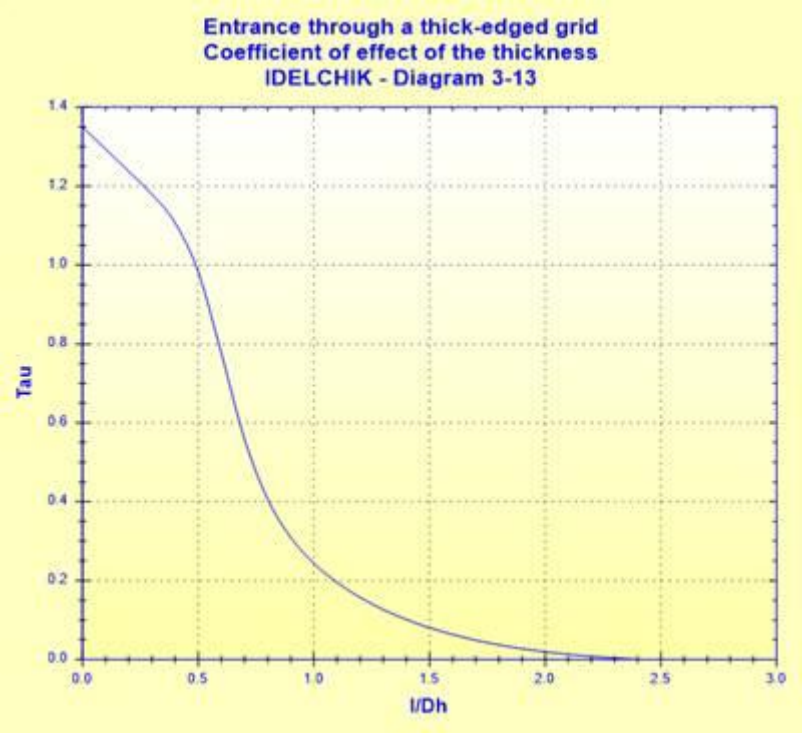
Coefficient of effect of the grid thickness:

$$\tau = \left(2.4 - \frac{l}{D_h}\right) \cdot 10^{-\varphi\left(\frac{l}{D_h}\right)}$$

([1] diagram 3-13)

with:

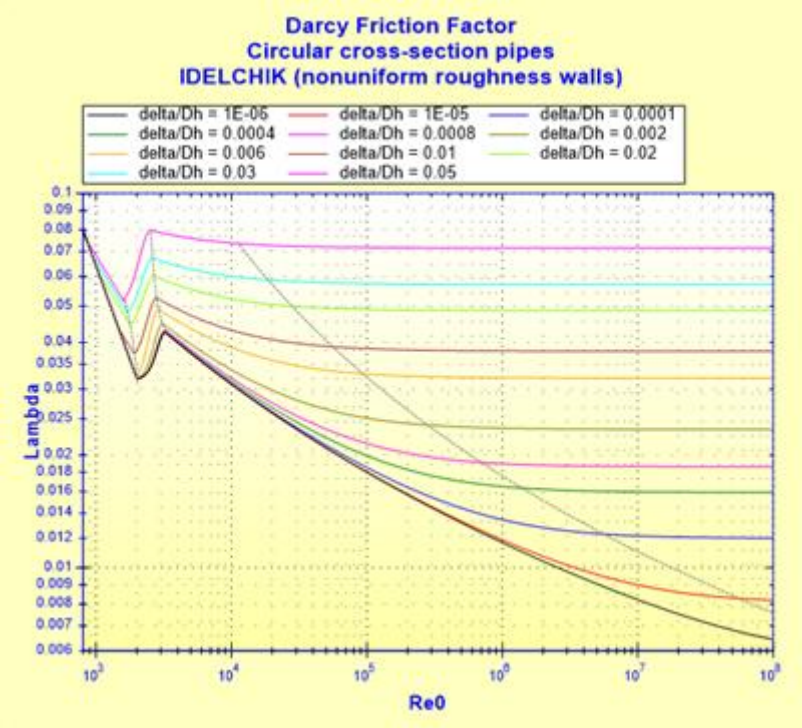
$$\varphi\left(\frac{l}{D_h}\right) = 0.25 + \frac{0.535 \cdot \left(\frac{l}{D_h}\right)^8}{0.05 + \left(\frac{l}{D_h}\right)^7}$$



Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}, \frac{\Delta}{D_h}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)

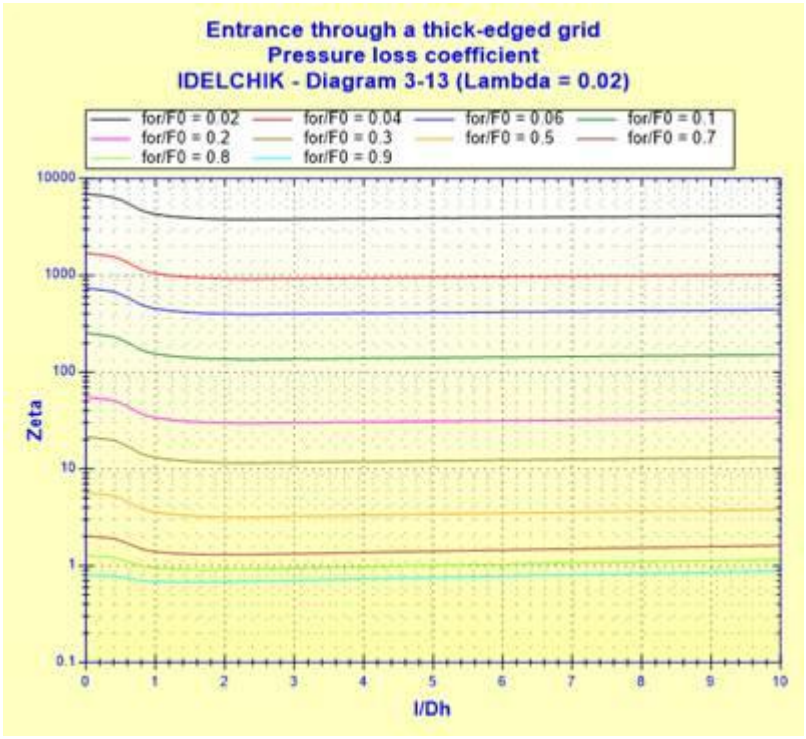


Local resistance coefficient (based on the mean pipe velocity):

- Re ≥ 10^5

$$\zeta = \left[0.5 + \left(1 - \frac{F_{or}}{F_0}\right)^2 + \tau \cdot \left(1 - \frac{F_{or}}{F_0}\right) + \lambda \cdot \frac{l}{D_h}\right] \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-13)



([1] diagram 3-13 with λ = 0.02)

■ $Re < 10^5$

Quadratic local resistance coefficient:

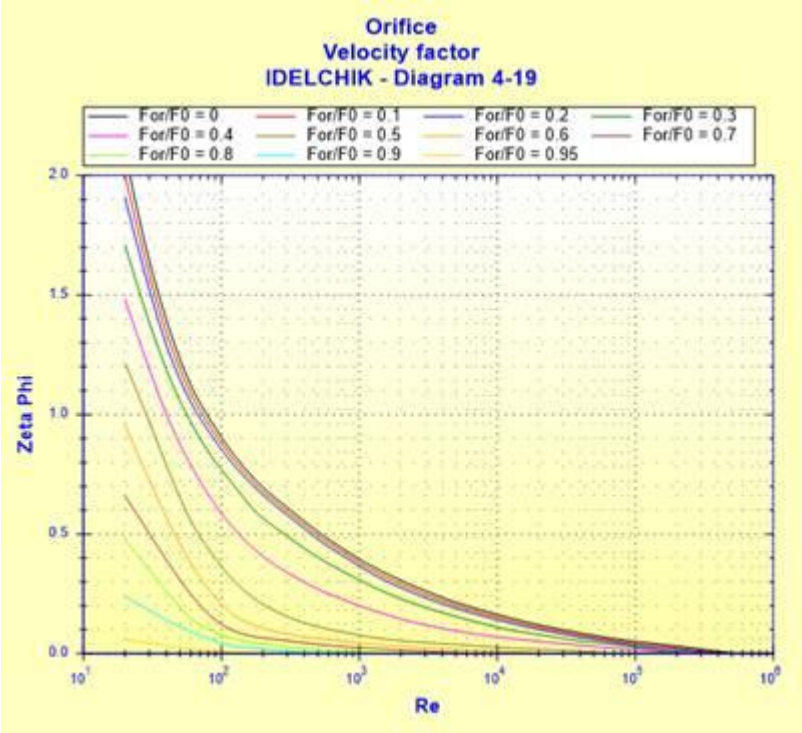
$$\zeta_{quad} = \left[0.5 + \left(1 - \frac{F_{or}}{F_0}\right)^2 + \tau \cdot \left(1 - \frac{F_{or}}{F_0}\right) + \lambda \cdot \frac{l}{D_h}\right] \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-13)

Velocity factor:

$$\zeta_\varphi = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$$

([1] diagram 4-19)

Local resistance coefficient:

- $30 < Re < 10^5$

$$\zeta = \zeta_{\varphi} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $10 < Re \leq 30$

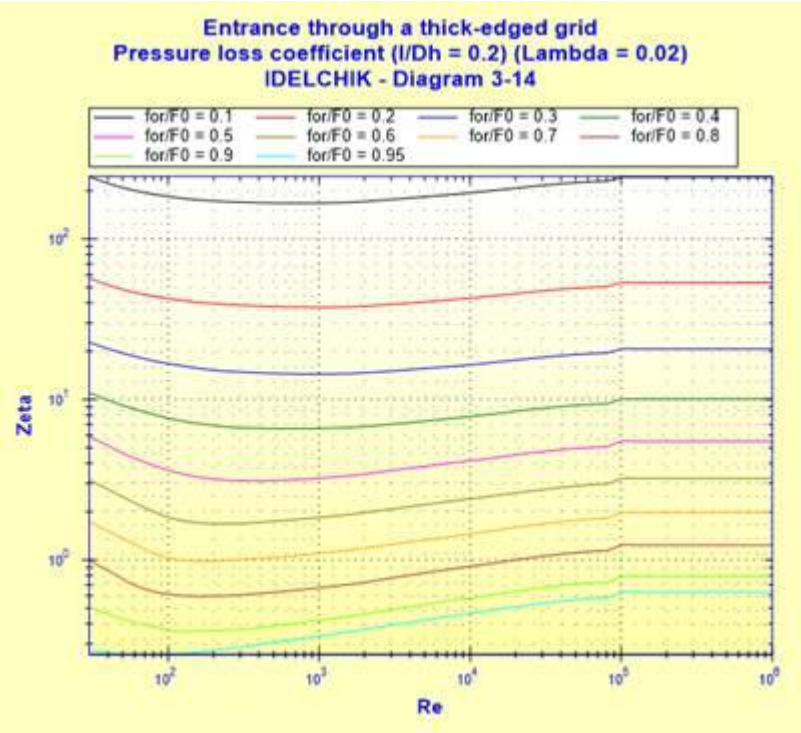
$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $Re \leq 10$

$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2$$

([1] diagram 3-14)



([1] diagram 3-14 with l/Dh = 0.2 and λ = 0.02)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

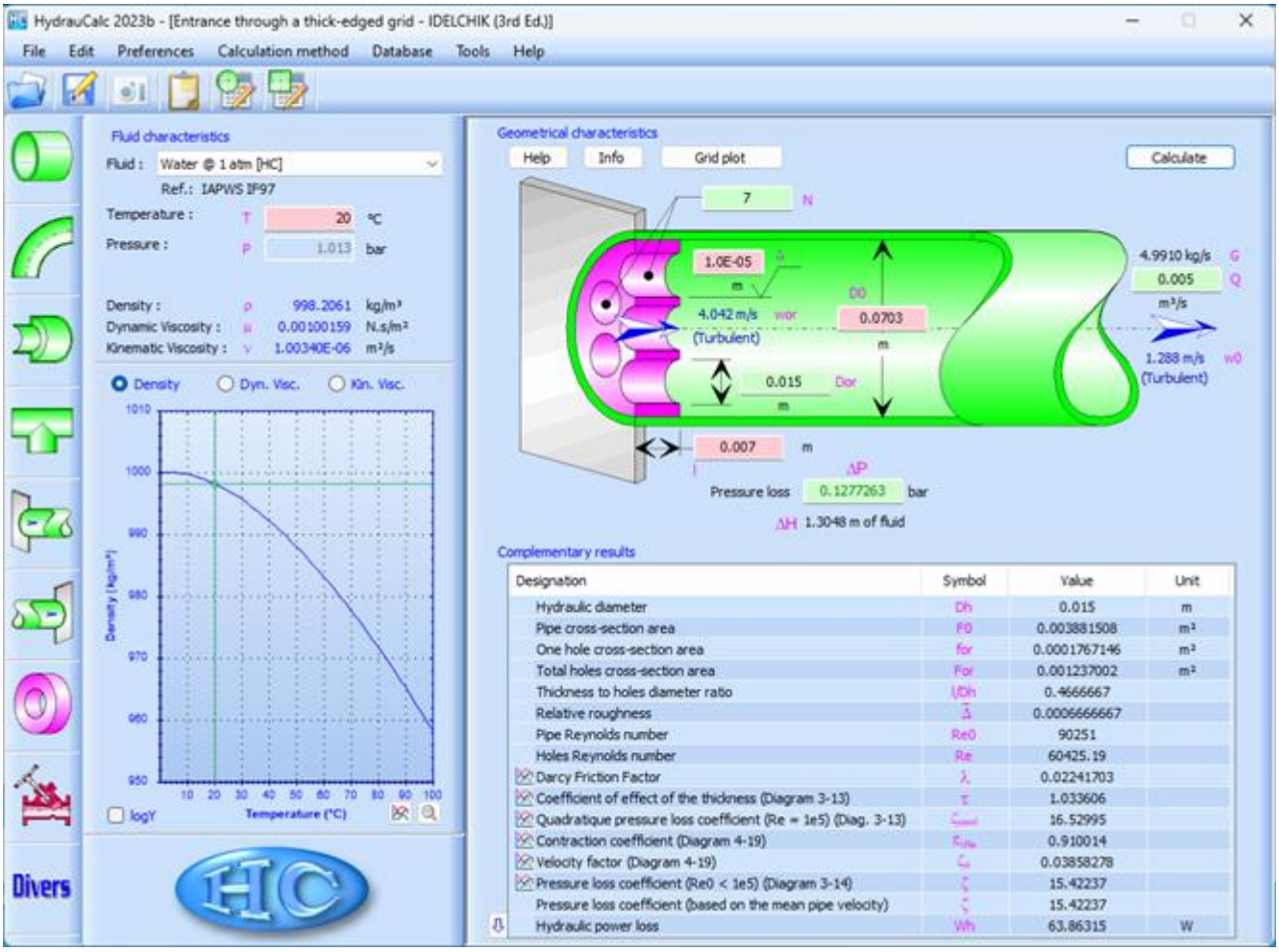
D_h	Hydraulic diameter (m)
D_0	Pipe internal diameter (m)
F_0	Pipe cross-sectional area (m^2)
N	Holes number ()

D_{or}	Holes diameter (m)
f_{or}	Cross-section area of one hole (m^2)
F_{or}	Clear cross-sectional area of the grid (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in pipe (m/s)
w_{or}	Mean velocity in holes (m/s)
Re_0	Reynolds number in pipe ()
Re	Reynolds number in holes ()
Δ	Absolute roughness of holes walls (m)
$\overline{\Delta}$	Relative roughness of holes walls ()
l	Grid thickness (m)
τ	Coefficient of effect of the grid thickness ()
λ	Darcy friction coefficient in holes ()
ζ_{quad}	Quadratic pressure loss coefficient determined as $Re = 10^5$ ()
ζ_φ	Velocity factor ()
$\overline{\varepsilon}_{0Re}$	Contraction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the grid
- thickness to holes diameter ratio (l/D_{or}) greater than 0.015

Example of application:

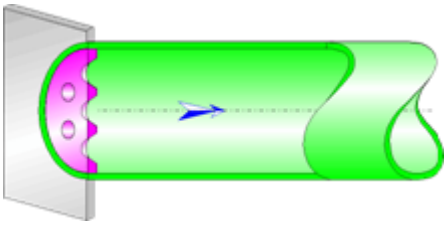


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.5.11 Entrance through a sharp-edged grid

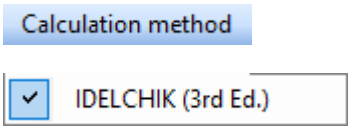
Circular Cross-Section



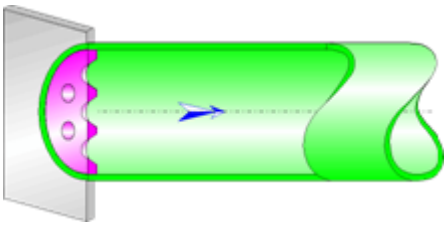
The calculation method used to calculate the pressure loss coefficient of a pipe entrance equipped with a sharp-edged grid is described in the following reference document:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

The only calculation method offered appears in the "Calculation method" menu and is activated by default.



2.5.11.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe entrance equipped with a sharp-edged grid.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Cross-section area of one hole (m²):

$$f_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Clear cross-sectional area of the grid (m²):

$$F_{or} = f_{or} \cdot N$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in holes (m/s):

$$w_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Reynolds number in holes:

$$\mathrm{Re} = \frac{w_{or} \cdot D_{or}}{\nu}$$

Local resistance coefficient (based on the mean pipe velocity):

- $\mathrm{Re} \geq 10^5$

$$\zeta = \left[1.707 - \frac{F_{or}}{F_0}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-12)

■ $Re < 10^5$

Quadratic local resistance coefficient:

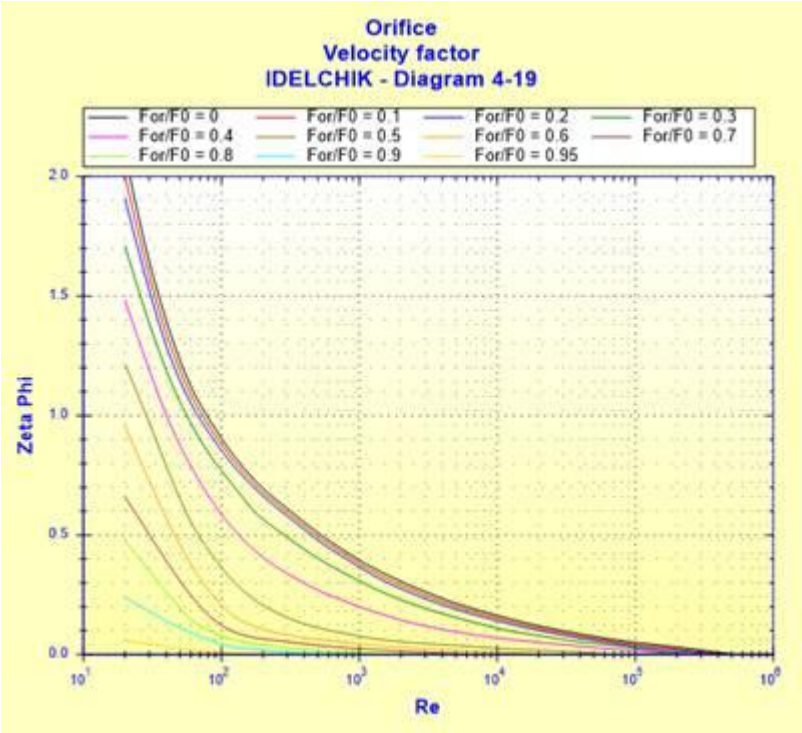
$$\zeta_{quad} = \left[1.707 - \frac{F_{or}}{F_0}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-12)

Velocity factor:

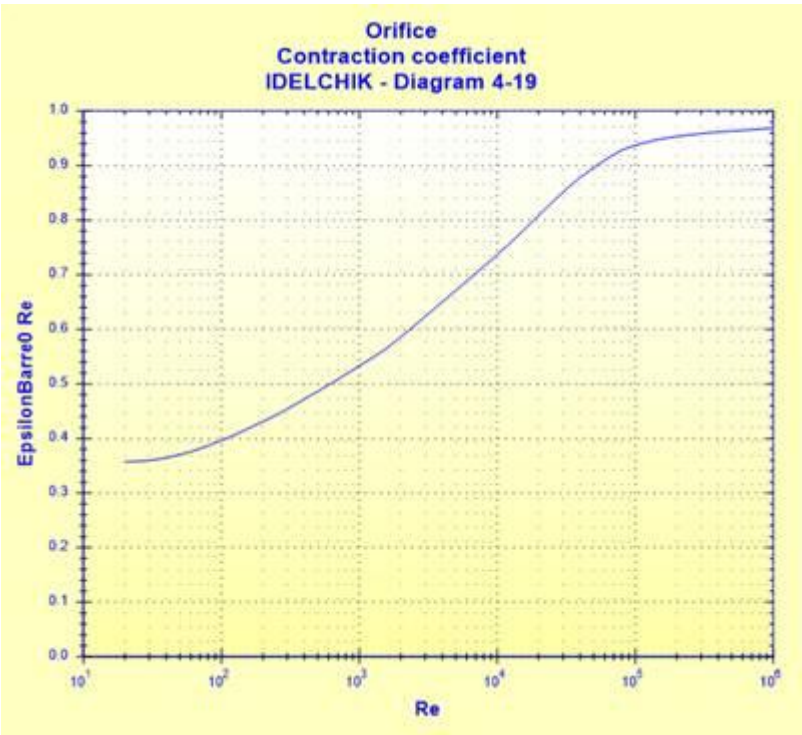
$$\zeta_{\varphi} = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$ ([1] diagram 4-19)



Local resistance coefficient:

- $30 < \mathrm{Re} < 10^5$

$$\zeta = \zeta_{\varphi} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0\mathrm{Re}} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $10 < \mathrm{Re} \leq 30$

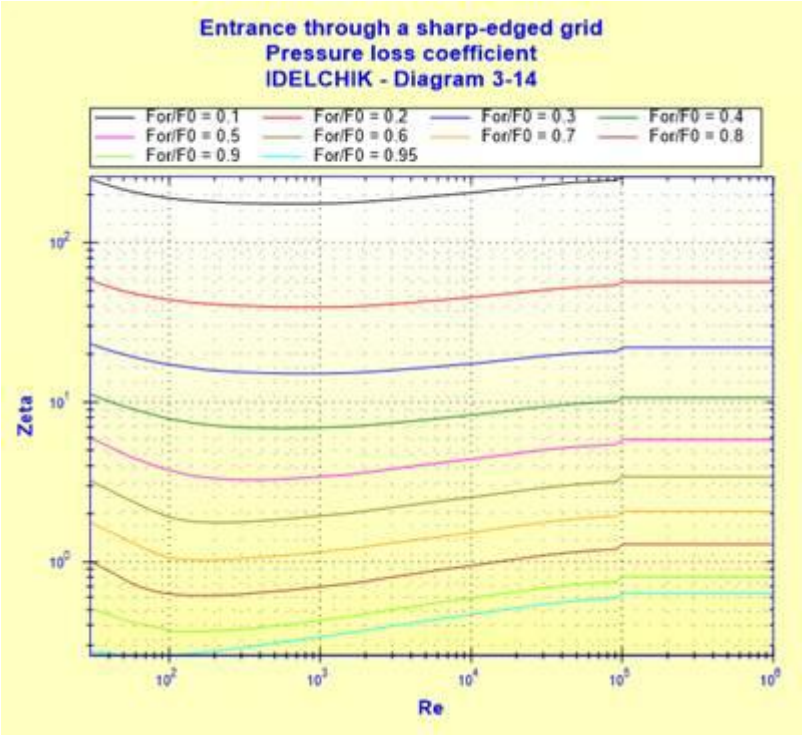
$$\zeta = \frac{33}{\mathrm{Re}} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0\mathrm{Re}} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $\mathrm{Re} \leq 10$

$$\zeta = \frac{33}{\mathrm{Re}} \cdot \left(\frac{F_0}{F_{or}} \right)^2$$

([1] diagram 3-14)



Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_0	Pipe internal diameter (m)
F_0	Pipe cross-sectional area (m^2)
N	Holes number ()
D_{or}	Holes diameter (m)
f_{or}	Cross-section area of one hole (m^2)
F_{or}	Clear cross-sectional area of the grid (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in pipe (m/s)
w_{or}	Mean velocity in holes (m/s)
l	Grid thickness (m)
Re_0	Reynolds number in pipe ()
Re	Reynolds number in holes ()
l	Orifice thickness (m)
ζ_{quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)

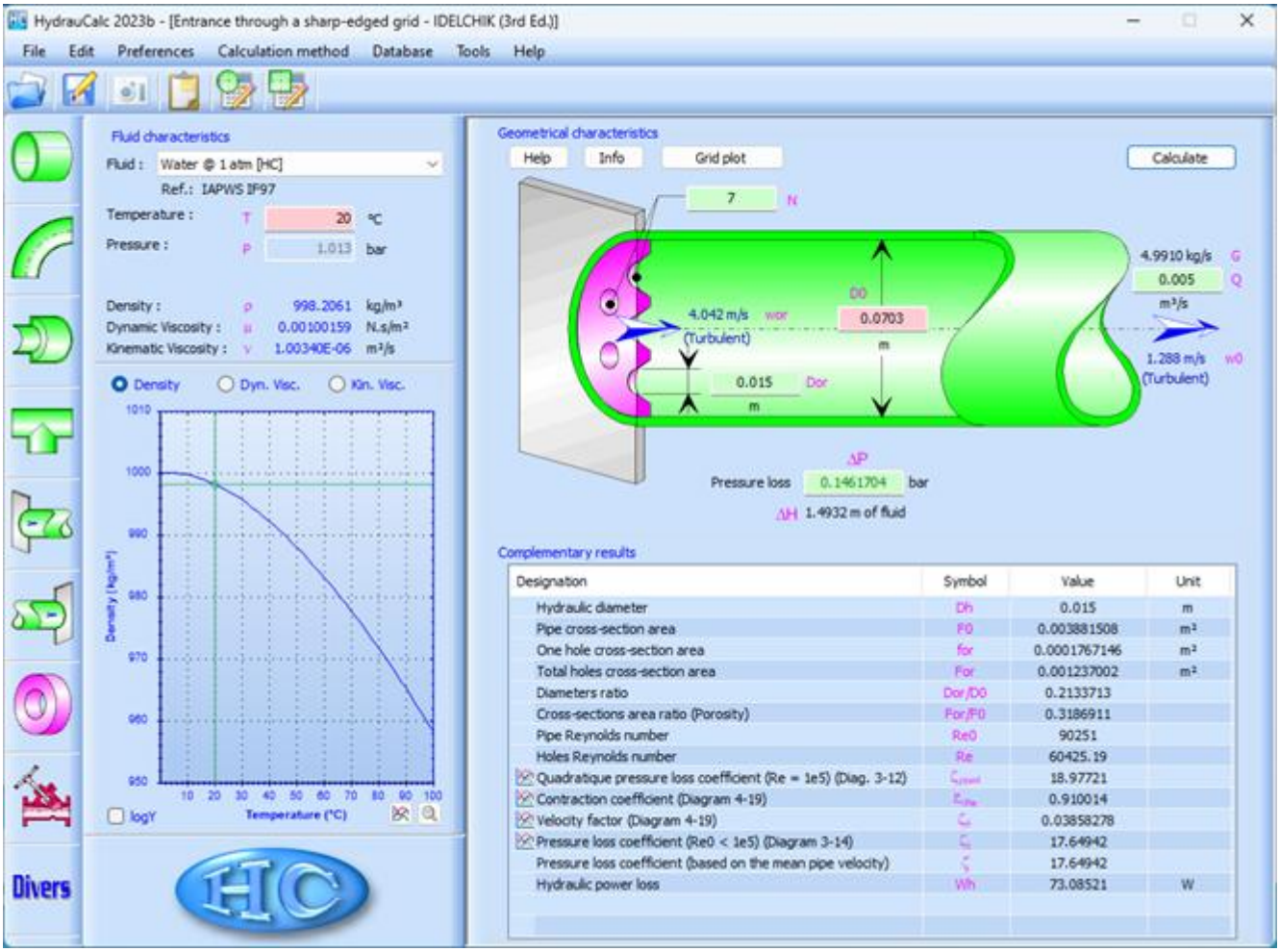
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the grid
- thickness to holes diameter ratio (l/D_{or}) lower than or equal to 0.015

Example of application:

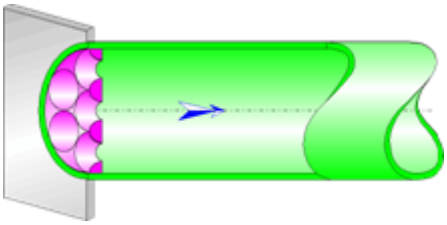


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.5.12 Entrance through a round-edged grid

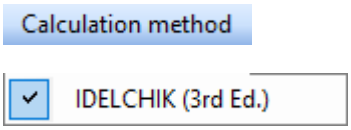
Circular Cross-Section



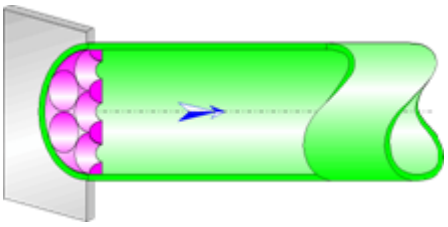
The calculation method used to calculate the pressure loss coefficient of a pipe entrance equipped with a round-edged grid is described in the following reference document:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

The only calculation method offered appears in the "Calculation method" menu and is activated by default.



2.5.12.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe entrance equipped with a round-edged grid.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Cross-section area of one hole (m²):

$$f_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Clear cross-sectional area of the grid (m²):

$$F_{or} = f_{or} \cdot N$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in holes (m/s):

$$w_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Reynolds number in holes:

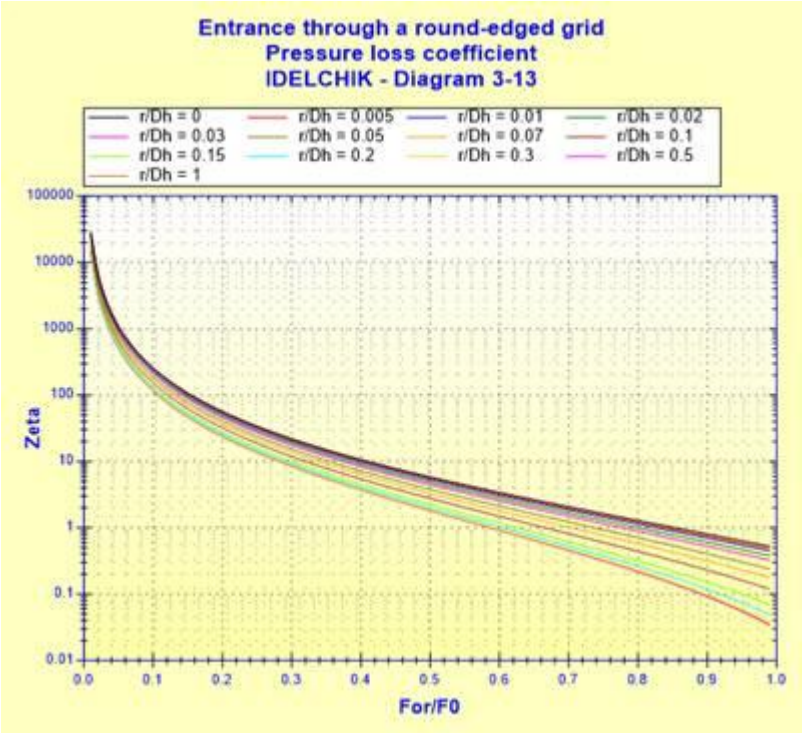
$$\mathrm{Re} = \frac{w_{or} \cdot D_{or}}{\nu}$$

Local resistance coefficient (based on the mean pipe velocity):

- $\mathrm{Re} \geq 10^5$

$$\zeta = \left[1 + \sqrt{\zeta'} - \frac{F_{or}}{F_0}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-13)

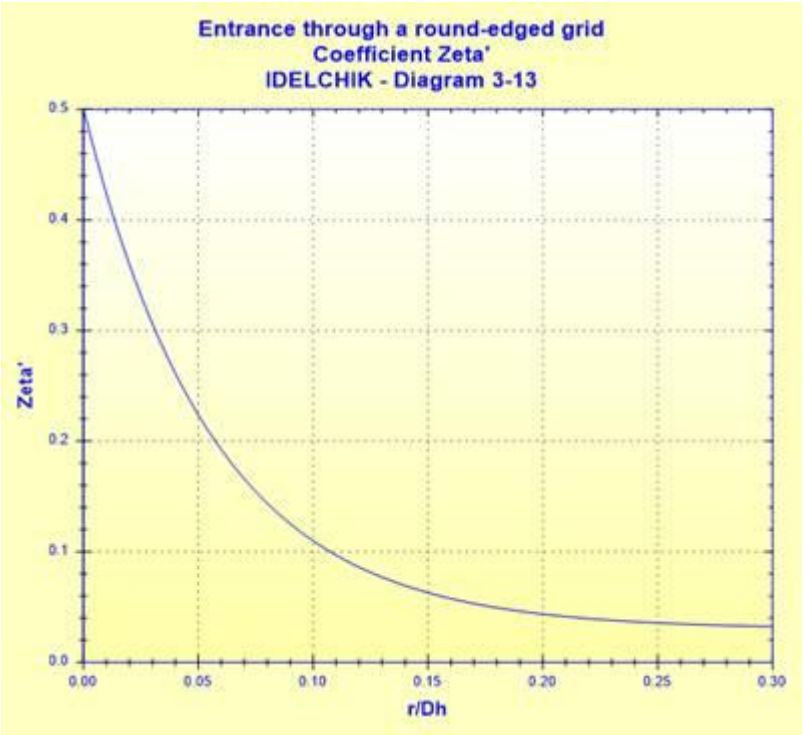


with :

Coefficient of effect of the round:

$$\zeta' = 0.03 + 0.47 \cdot 10^{-7.7 \cdot \frac{r}{D_h}}$$

([1] diagram 3-13)



■ $Re < 10^5$

Quadratic local resistance coefficient:

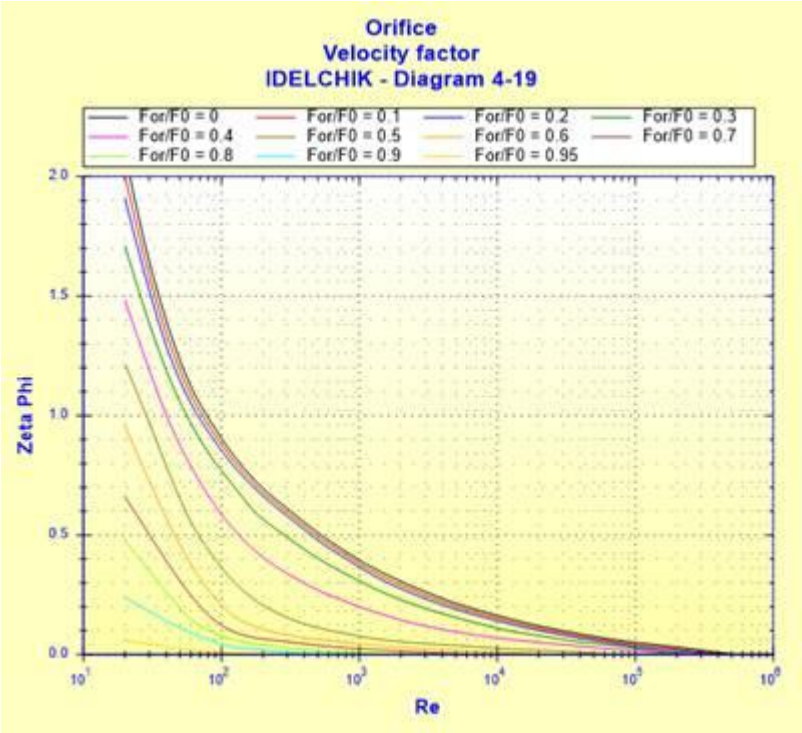
$$\zeta_{quad} = \left[1 + \sqrt{\zeta'} - \frac{F_{or}}{F_0}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-13)

Velocity factor:

$$\zeta_\varphi = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$$

([1] diagram 4-19)

Local resistance coefficient:

- $30 < Re < 10^5$

$$\zeta = \zeta_\varphi \cdot \left(\frac{F_0}{F_{or}}\right)^2 + \bar{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $10 < Re \leq 30$

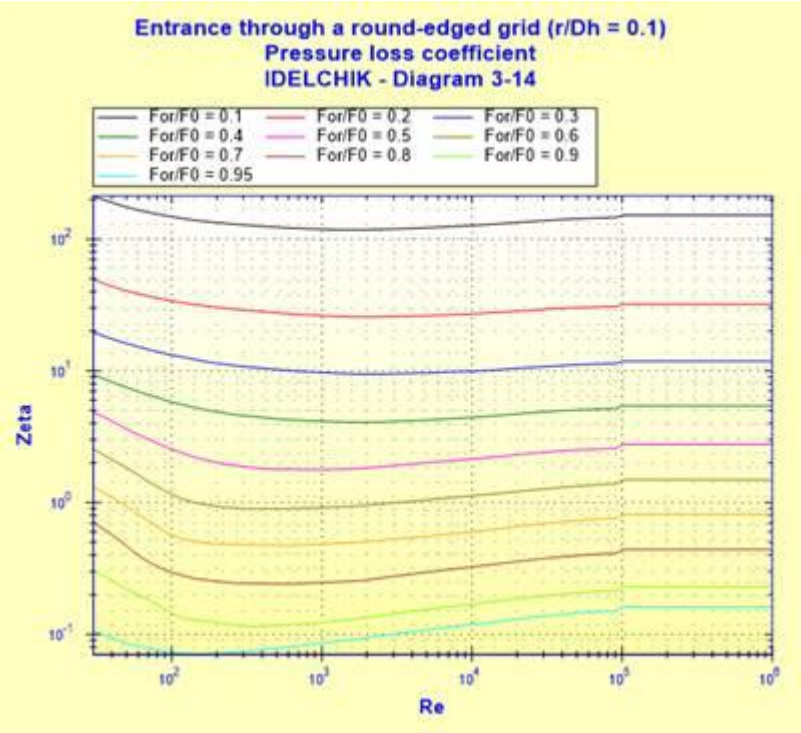
$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}}\right)^2 + \bar{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $Re \leq 10$

$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-14)



([1] diagram 3-14 with r/Dh = 0.1)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_0	Pipe internal diameter (m)
F_0	Pipe cross-sectional area (m^2)
N	Holes number ()

D_{or} Holes diameter (m)

f_{or} Cross-section area of one hole (m^2)

F_{or} Clear cross-sectional area of the grid (m^2)

Q Volume flow rate (m^3/s)

G Mass flow rate (kg/s)

w_0 Mean velocity in pipe (m/s)

w_{or} Mean velocity in holes (m/s)

r Radius of the round (m)

Re_0 Reynolds number in pipe ()

Re Reynolds number in holes ()

ζ' Coefficient of effect of the round ()

ζ_{quad} Quadratic pressure loss coefficient determined as $Re = 10^5$ ()

ζ_{φ} Velocity factor ()

$\bar{\varepsilon}_{0Re}$ Contraction factor ()

ζ Pressure loss coefficient (based on the mean pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m^3)

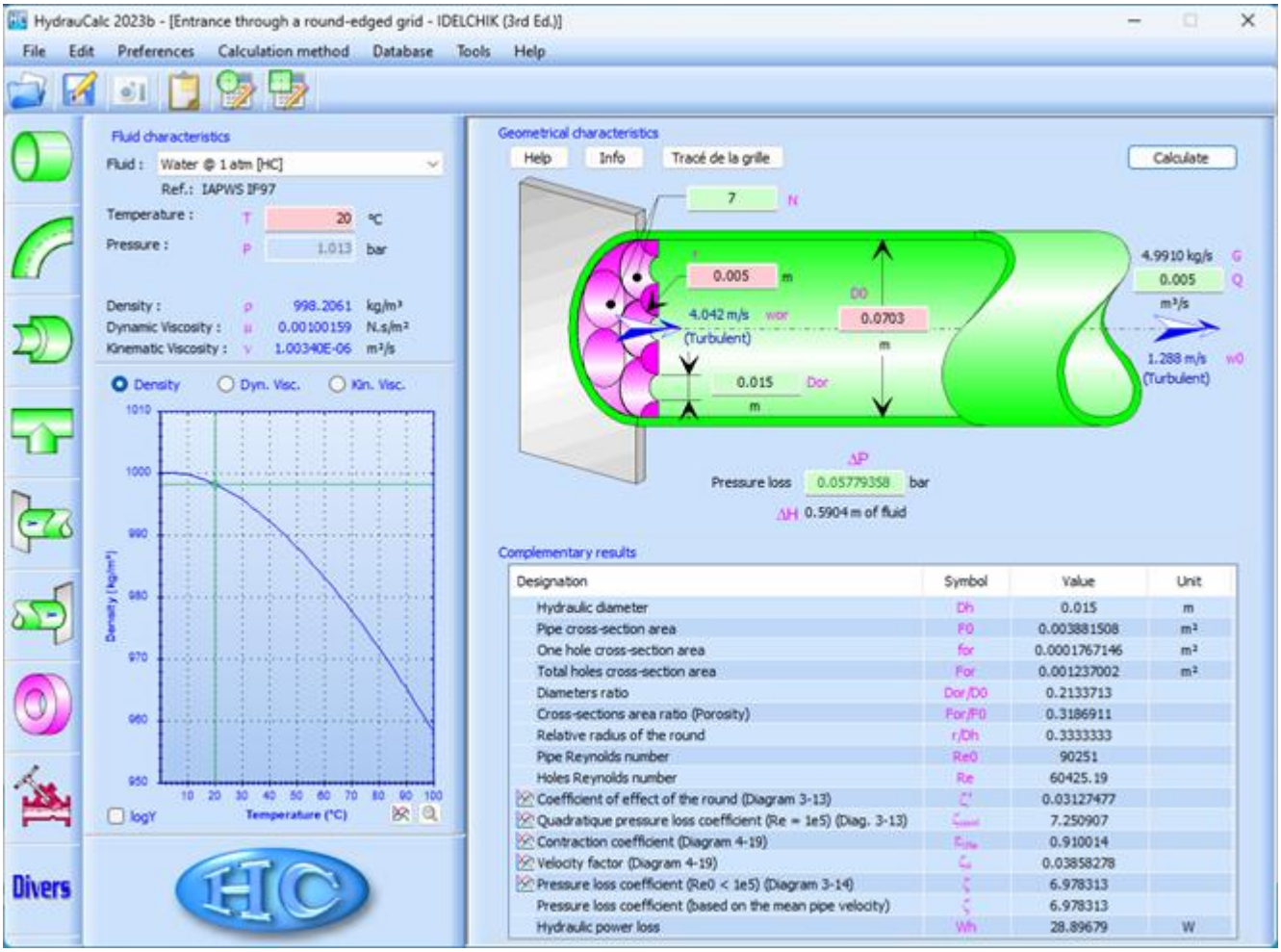
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the grid

Example of application:

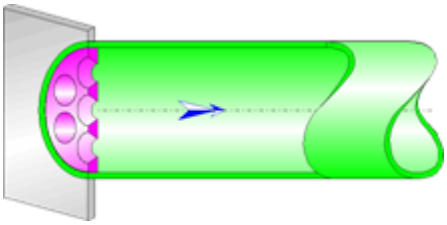


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.5.13 Entrance through a bevel-edged grid

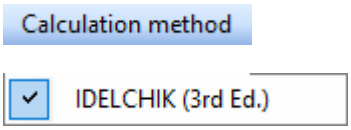
Circular Cross-Section



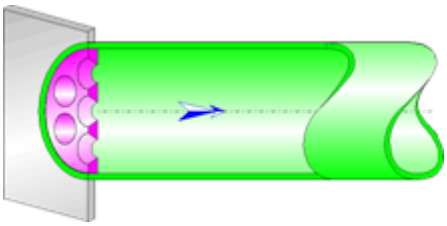
The calculation method used to calculate the pressure loss coefficient of a pipe entrance equipped with a bevel-edged grid is described in the following reference document:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

The only calculation method offered appears in the "Calculation method" menu and is activated by default.



2.5.13.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe entrance equipped with a bevel-edged grid.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Cross-section area of one hole (m²):

$$f_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Clear cross-sectional area of the grid (m²):

$$F_{or} = f_{or} \cdot N$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in holes (m/s):

$$w_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Reynolds number in holes:

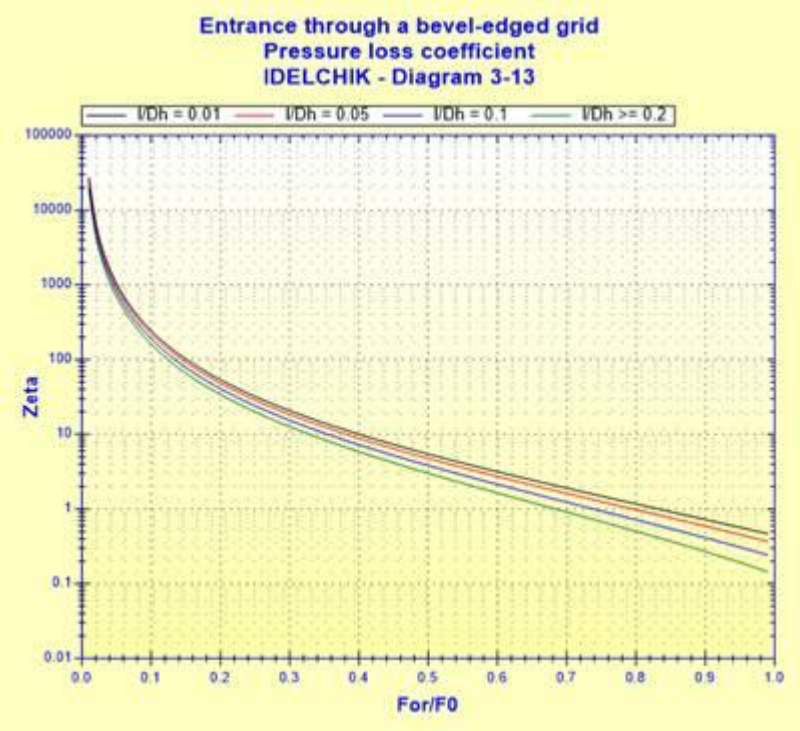
$$\mathrm{Re} = \frac{w_{or} \cdot D_{or}}{\nu}$$

Local resistance coefficient (based on the mean pipe velocity):

- $\mathrm{Re} \geq 10^5$

$$\zeta = \left[1 + \sqrt{\zeta'} - \frac{F_{or}}{F_0}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-13)

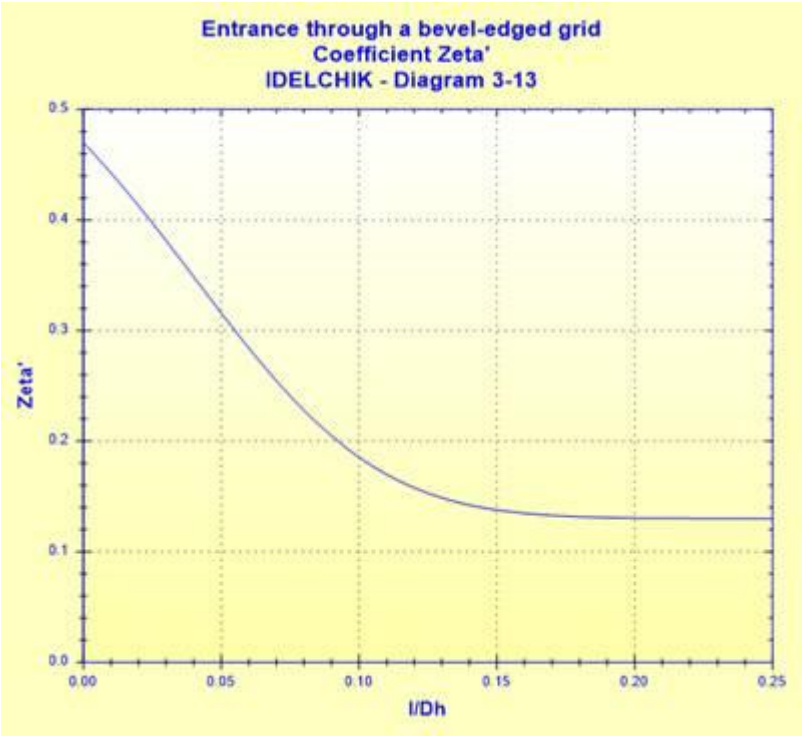


with :

Coefficient of effect of the orifice thickness:

$$\zeta' = 0.13 + 0.34 \cdot 10^{-\left(3.45 \cdot \frac{l}{D_h} + 88.4 \cdot \left(\frac{l}{D_h}\right)^{2.3}\right)}$$

([1] diagram 3-13)



■ $Re < 10^5$

Quadratic local resistance coefficient:

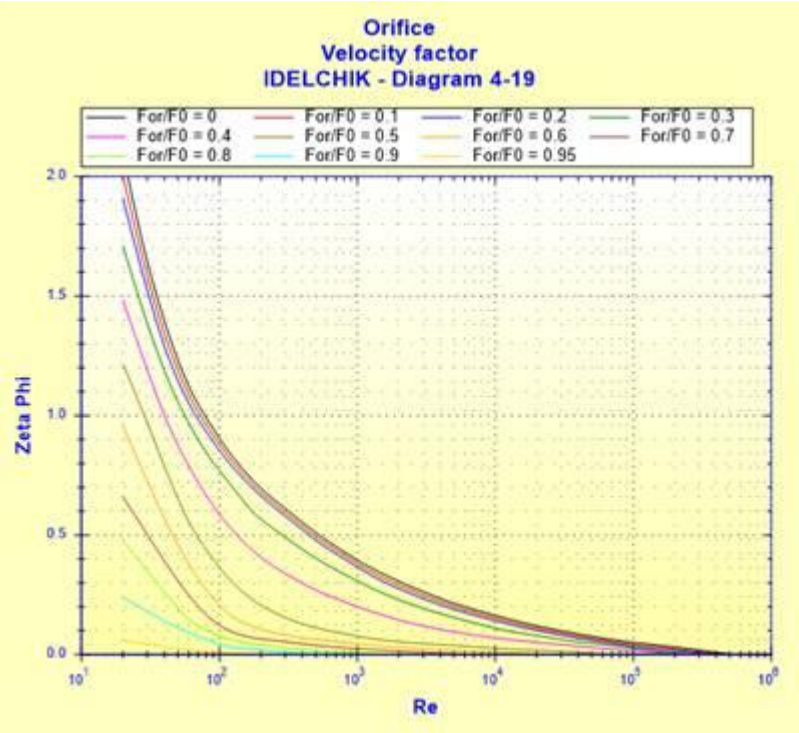
$$\zeta_{quad} = \left[1 + \sqrt{\zeta'} - \frac{F_{or}}{F_0}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 3-13)

Velocity factor:

$$\zeta_\varphi = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$$

([1] diagram 4-19)

Local resistance coefficient:

- $30 < Re < 10^5$

$$\zeta = \zeta_{\varphi} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $10 < Re \leq 30$

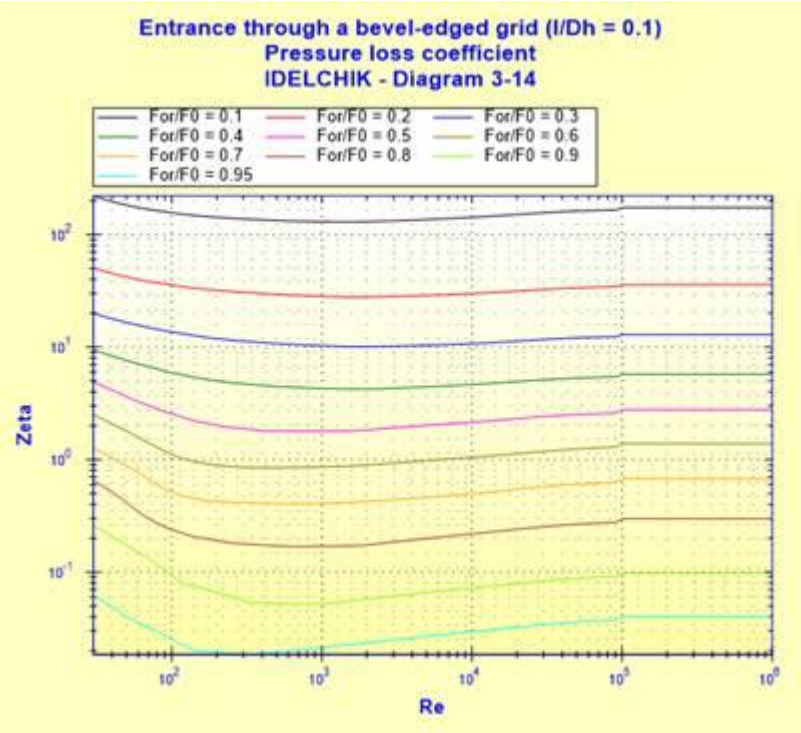
$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 3-14)

- $Re \leq 10$

$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2$$

([1] diagram 3-14)



([1] diagram 3-14 with l/Dh = 0.1)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

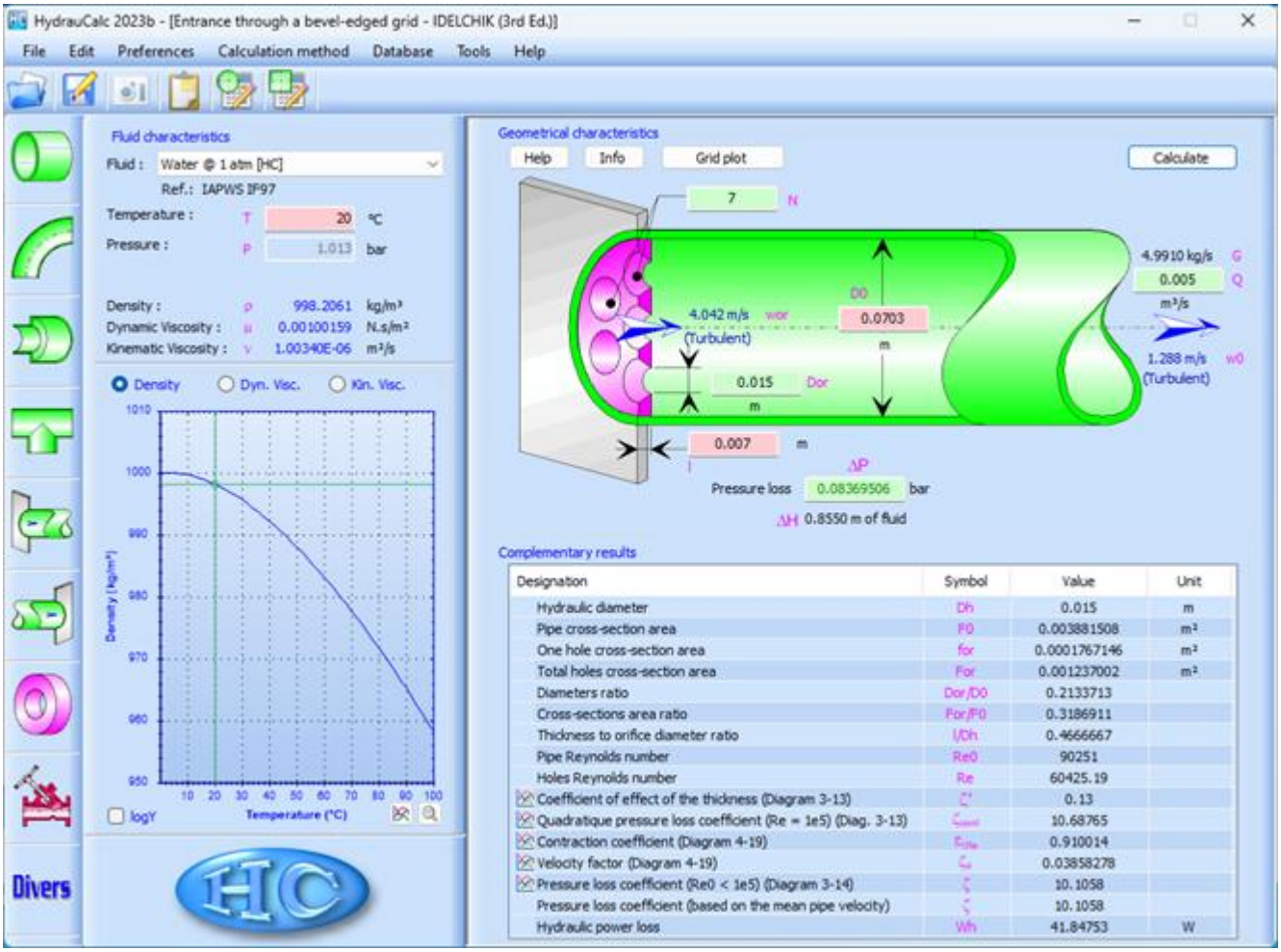
D_h	Hydraulic diameter (m)
D_0	Pipe internal diameter (m)
F_0	Pipe cross-sectional area (m^2)
N	Holes number ()

D_{or}	Holes diameter (m)
f_{or}	Cross-section area of one hole (m^2)
F_{or}	Clear cross-sectional area of the grid (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in pipe (m/s)
w_{or}	Mean velocity in holes (m/s)
l	Grid thickness (m)
Re_0	Reynolds number in pipe ()
Re	Reynolds number in holes ()
ζ'	Coefficient of effect of the orifice thickness ()
ζ_{quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the grid
- angle at the top of the truncated cone between 40 ° and 60 °

Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.6 Discharges

This subsection regroups the set of piping discharges elements that can be modeled and calculated. The types of piping discharge available are:

- Flush-Mounted Sharp-Edged Discharge - Circular Cross-Section

- Flush-Mounted Rounded Discharge - Circular Cross-Section

- Sharp-Edged discharge Mounted at a Distance - Circular Cross-Section

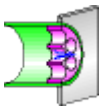
- Discharge from a thick-edged orifice - Circular Cross-Section

- Discharge from a sharp-edged orifice - Circular Cross-Section

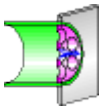
- Discharge from a round-edged orifice - Circular Cross-Section

- Discharge from a bevel-edged orifice - Circular Cross-Section

- Discharge from a thick-edged grid - Circular Cross-Section



- Discharge from a sharp-edged grid - Circular Cross-Section

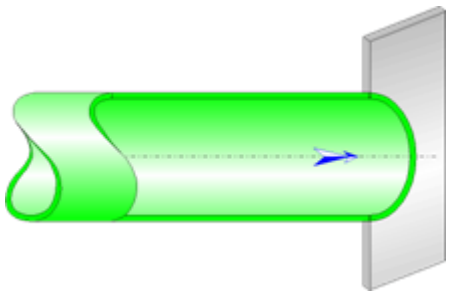


- Discharge from a round-edged grid - Circular Cross-Section

- Discharge from a bevel-edged grid - Circular Cross-Section

2.6.1 Flush-mounted sharp-edged discharge

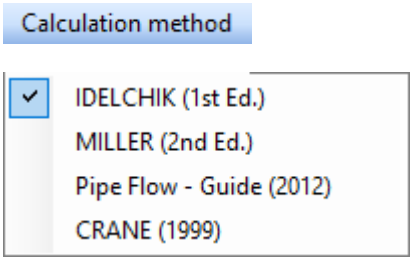
Circular Cross-Section



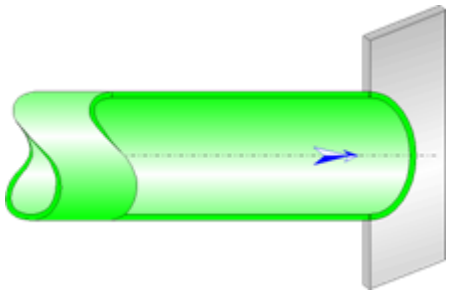
For the calculation of the pressure loss coefficient of flush-mounted sharp-edged discharges of piping, the user can choose from one of the methods described in the following four reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.6.1.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted sharp-edged discharge of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Pipe cross-sectional area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re} = \frac{w_0 \cdot D_0}{\nu}$$

Local resistance coefficient:

$$\zeta_{loc} = 1$$ ([1] diagram 11.1 - Uniform velocity distributions)

Total pressure loss coefficient (based on mean velocity in pipe):

$$\zeta = \zeta_{loc}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot w_0^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{w_0^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

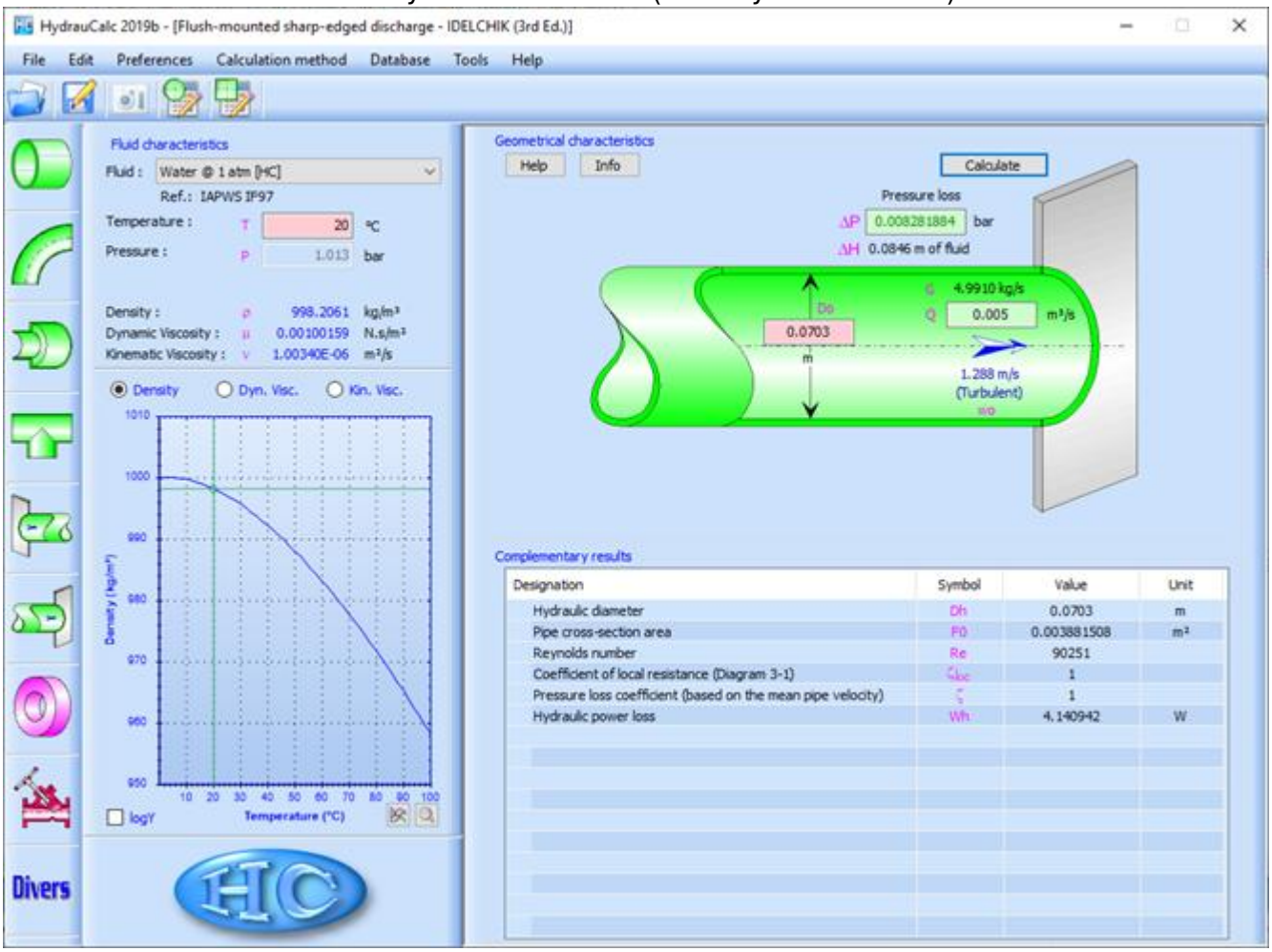
D_h	Hydraulic diameter (m)
D_0	Pipe diameter (m)
F_0	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
w_0	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)

Re	Reynolds number in pipe ()
ζ_{loc}	Local resistance coefficient ()
ζ	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m³)
ν	Fluid kinematic viscosity (m²/s)
g	Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)

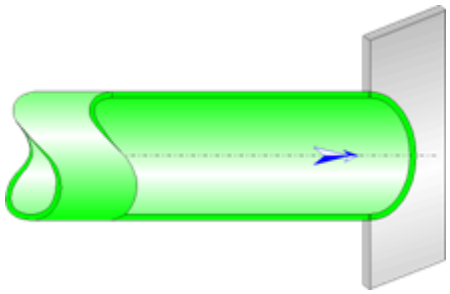
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.6.1.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted sharp-edged discharge of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity in pipe (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

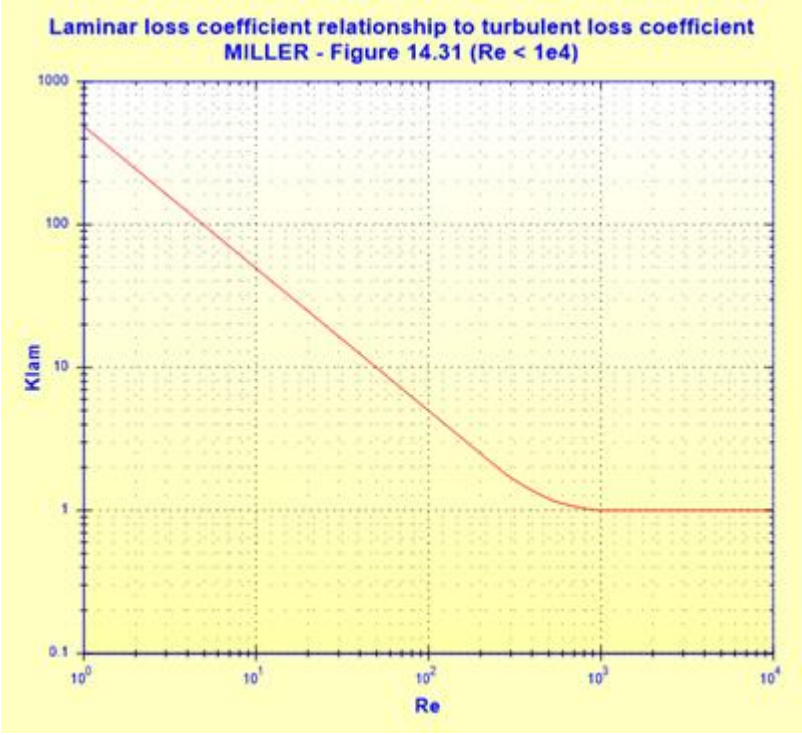
Local resistance coefficient:

- $\mathrm{Re} \geq 10^4$

  $$K_S = 1$$ ([1] figure 14.15 with $A_1/A_2=0$)

- $\mathrm{Re} < 10^4$

  $$K_{lam} = f(\mathrm{Re})$$ ([1] figure 14.31 with $K_{turb} = 1$)



Reynolds Number Correction ($\mathrm{Re} < 10^4$):

$$C_{\mathrm{Re}} = \frac{K_{lam}}{K_s}$$

Total pressure loss coefficient (based on mean velocity in pipe):

- turbulent flow ($Re \geq 10^4$):

$$K = K_s$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in pipe ()
K_s	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

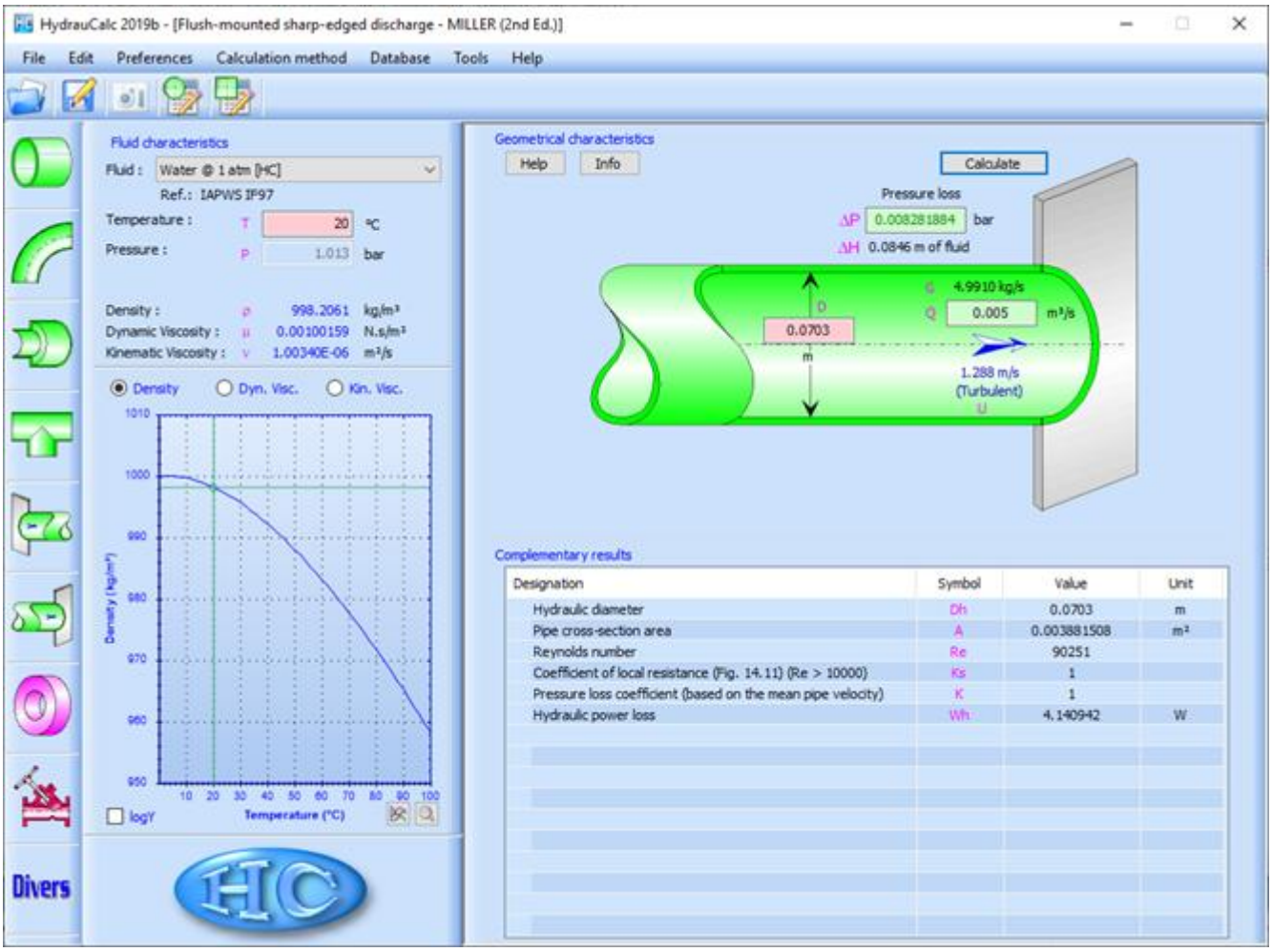
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar and turbulent

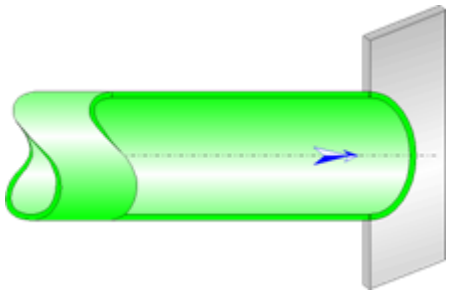
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.6.1.3 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted sharp-edged discharge of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$d_h = d$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity in pipe (m/s):

$$V = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

Local resistance coefficient ($N_{Re} \geq 10^4$):

$$K_2 = 1$$ ([1] §12.1)

Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_2$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot v^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

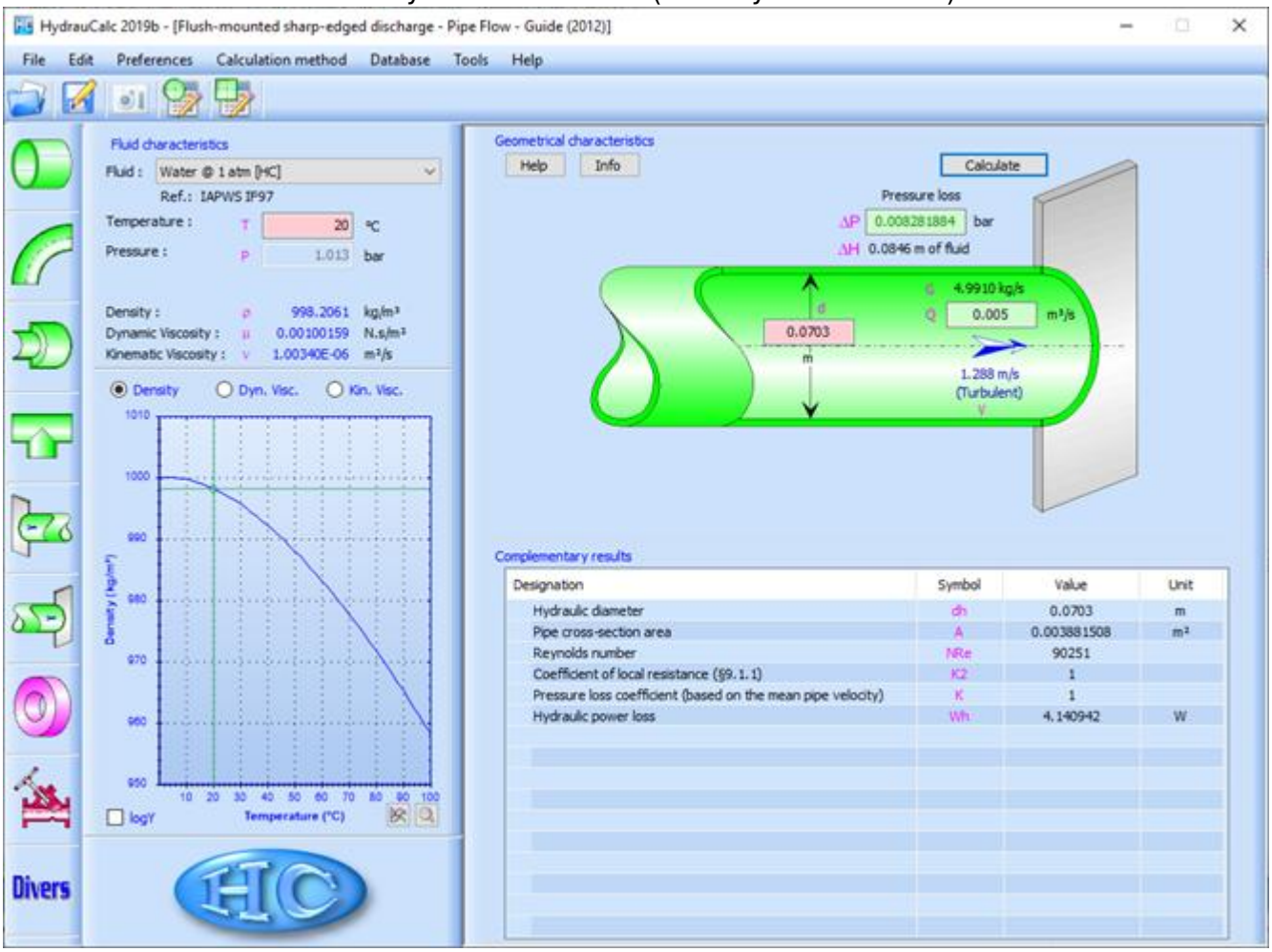
d_h	Hydraulic diameter (m)
d	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)

V	Mean velocity in pipe (m/s)
N_{Re}	Reynolds number in pipe ()
K_2	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in pipe ($N_{Re} \geq 10^4$)

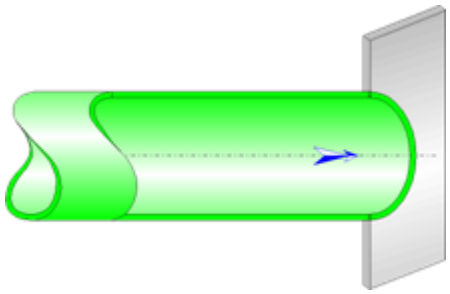
Example of application:



References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.6.1.4 CRANE



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted sharp-edged discharge of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity in pipe (m/s):

$$v = \frac{q}{A}$$

Mass flow rate (kg/s):

$$G = q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re} = \frac{v \cdot D}{\nu}$$

Local resistance coefficient ($\mathrm{Re} \geq 10^4$):

$$K_1 = 1$$ ([1] Appendix A-29)

Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_1$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot v^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot q$$

Symbols, Definitions, SI Units:

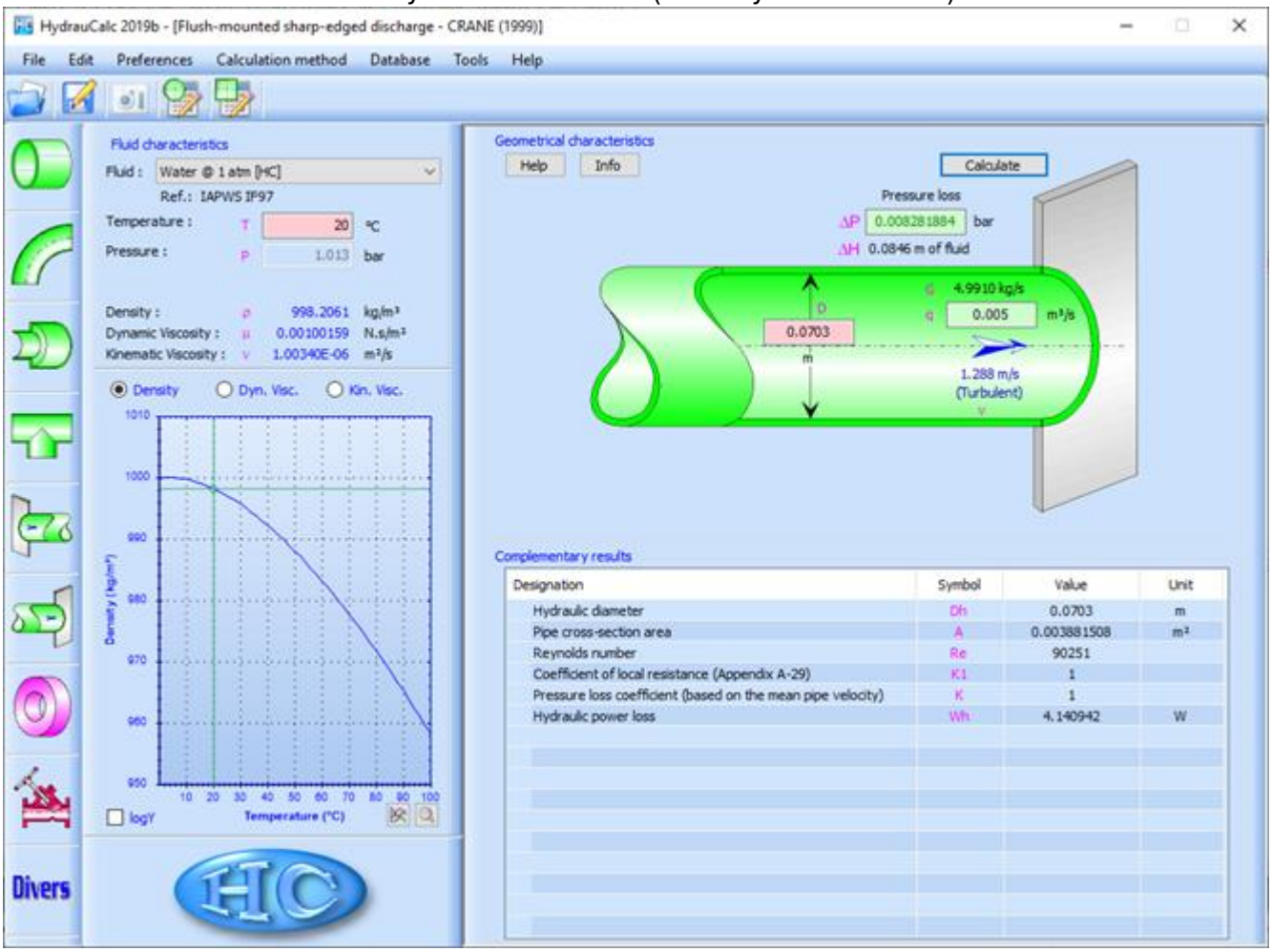
D_h	Hydraulic diameter (m)
D	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
q	Volume flow rate (m^3/s)
v	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)

Re	Reynolds number in pipe ()
K_1	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in pipe ($Re \geq 10^4$)

Example of application:

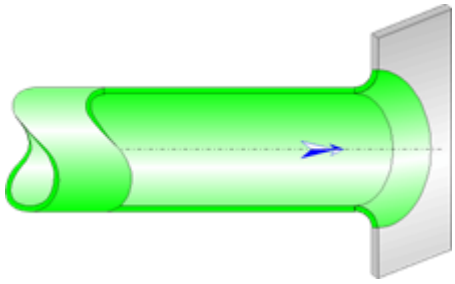


References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 – Edition 1999

2.6.2 Flush-mounted rounded discharge

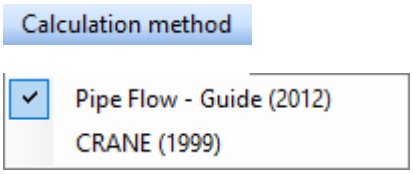
Circular Cross-Section



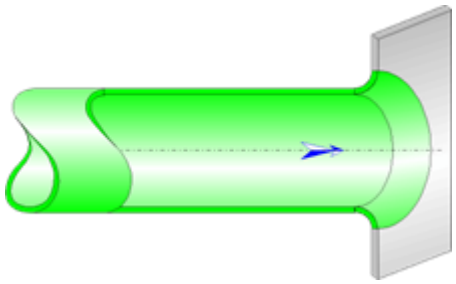
For the calculation of the pressure loss coefficient of flush-mounted rounded discharges of piping, the user can choose from one of the methods described in the following two reference documents:

- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999

The calculation method is selected using the "Calculation method" menu. The default option is "Pipe Flow - Guide (2012)"



2.6.2.1 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted rounded discharge of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$d_h = d$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity in pipe (m/s):

$$V = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

Local resistance coefficient ($N_{Re} \geq 10^4$):

$$K_2 = 1$$ ([1] §12.1)

Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_2$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot v^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

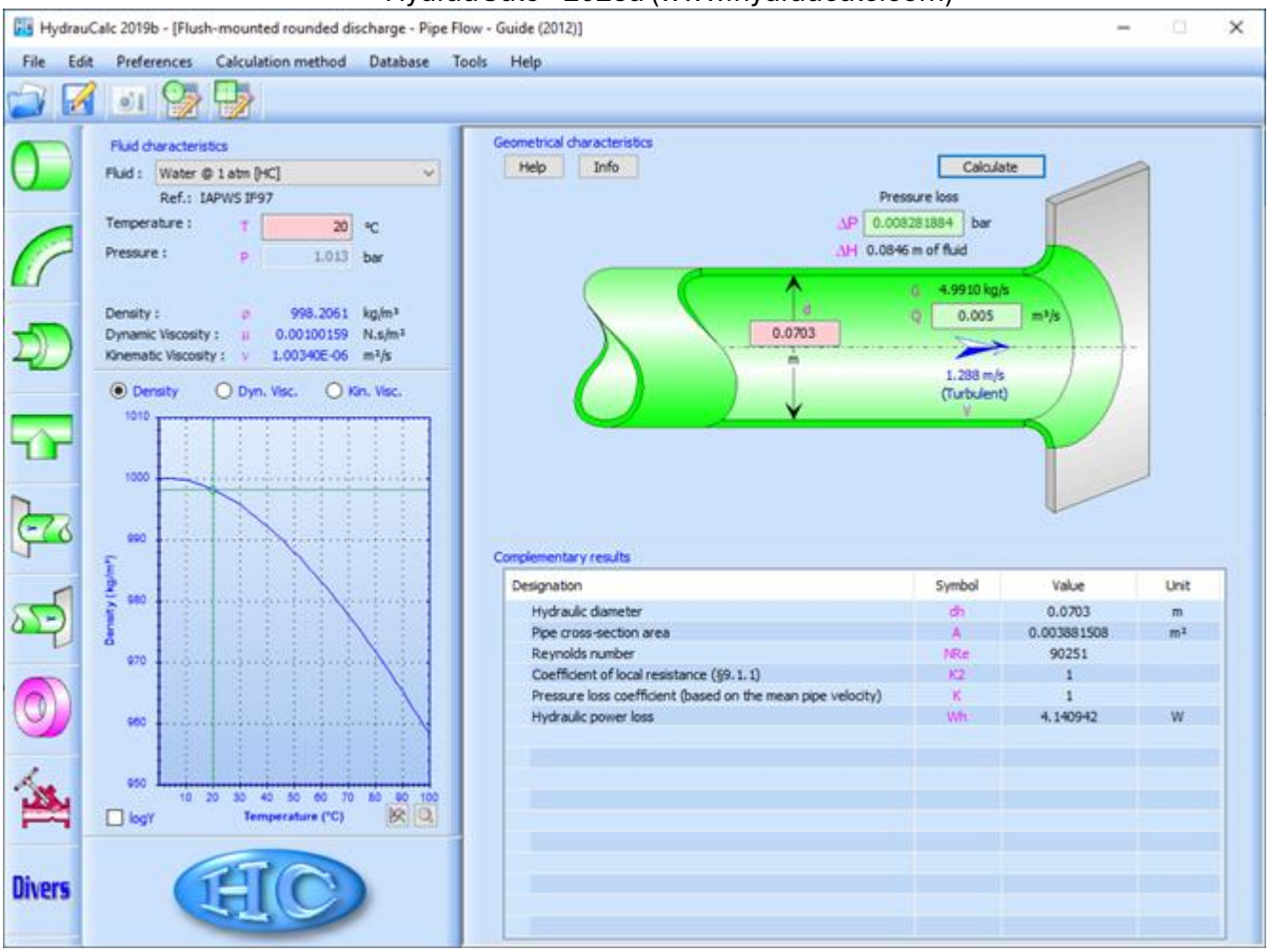
d_h	Hydraulic diameter (m)
d	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)

V	Mean velocity in pipe (m/s)
N_{Re}	Reynolds number in pipe ()
K_2	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in pipe ($N_{Re} \geq 10^4$)

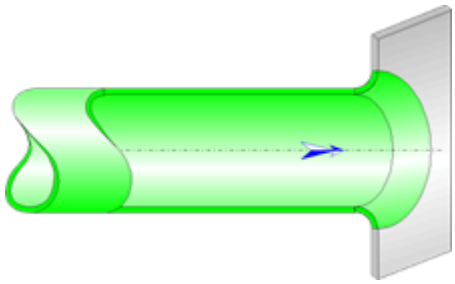
Example of application:



References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.6.2.2 CRANE



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a flush-mounted rounded discharge of piping.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity in pipe (m/s):

$$v = \frac{q}{A}$$

Mass flow rate (kg/s):

$$G = q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re} = \frac{v \cdot D}{\nu}$$

Local resistance coefficient ($\mathrm{Re} \geq 10^4$):

$$K_1 = 1$$ ([1] Appendix A-29)

Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_1$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot v^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot q$$

Symbols, Definitions, SI Units:

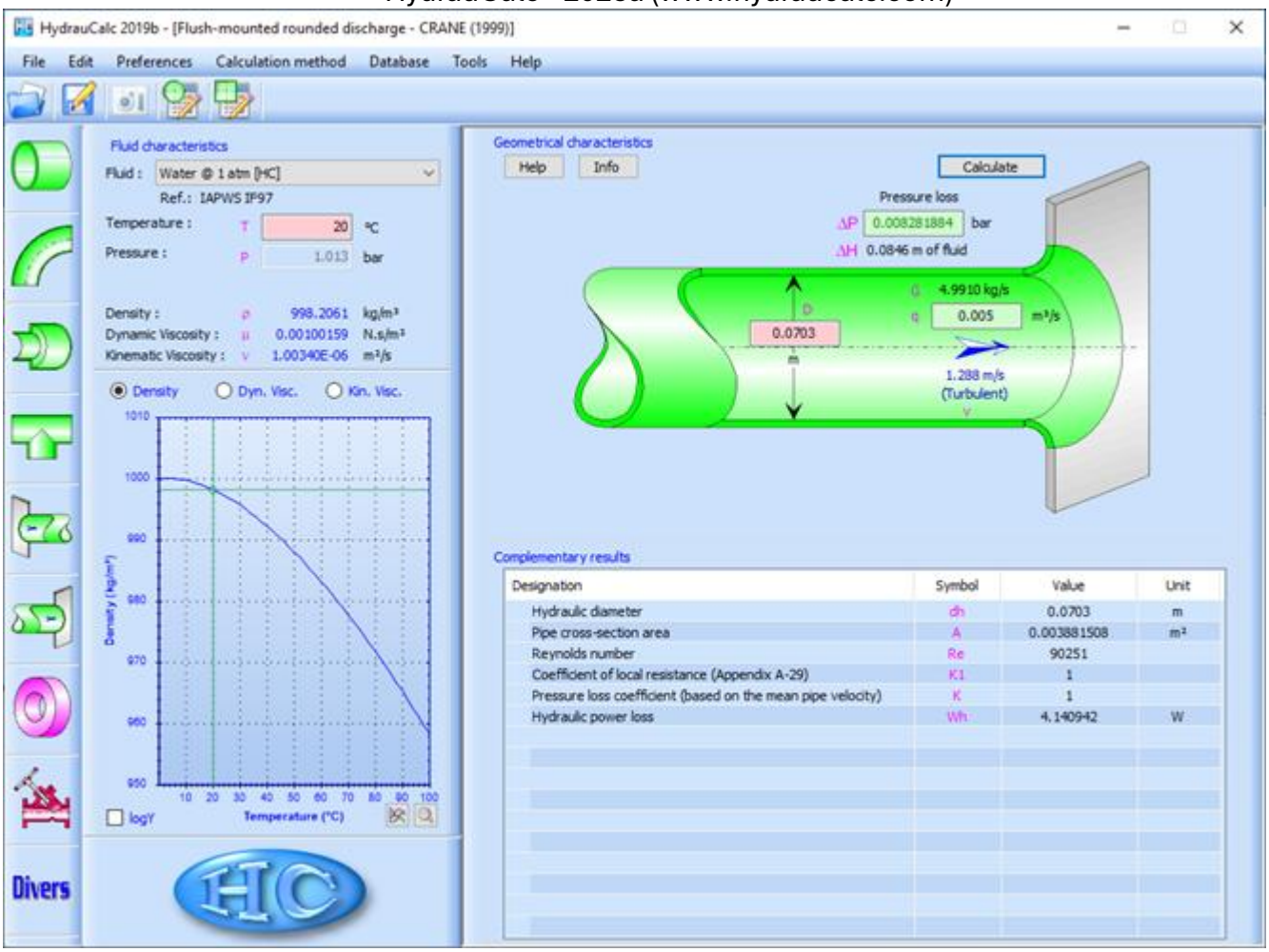
D_h	Hydraulic diameter (m)
D	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
q	Volume flow rate (m^3/s)
v	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)

Re	Reynolds number in pipe ()
K_1	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in pipe ($Re \geq 10^4$)

Example of application:

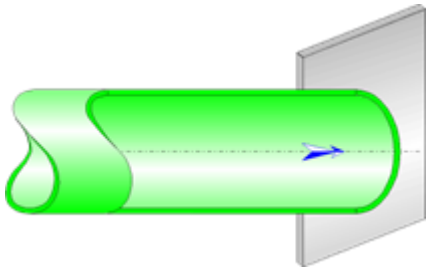


References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 – Edition 1999

2.6.3 Sharp-edged discharge mounted at a distance

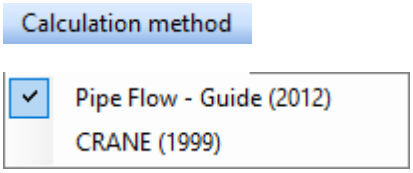
Circular Cross-Section



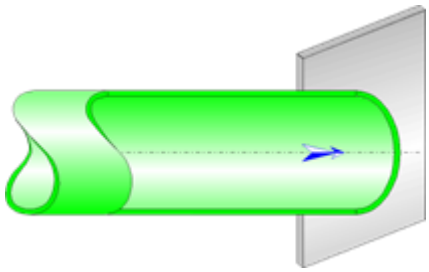
For the calculation of the pressure loss coefficient of Sharp-edged discharges of piping mounted at a distance, the user can choose from one of the methods described in the following two reference documents:

- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999

The calculation method is selected using the "Calculation method" menu. The default option is "Pipe Flow - Guide (2012)"



2.6.3.1 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sharp-edged discharge of piping mounted at a distance.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$d_h = d$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity in pipe (m/s):

$$V = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

Local resistance coefficient ($N_{Re} \geq 10^4$):

$$K_2 = 1$$ ([1] §12.1)

Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_2$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot v^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

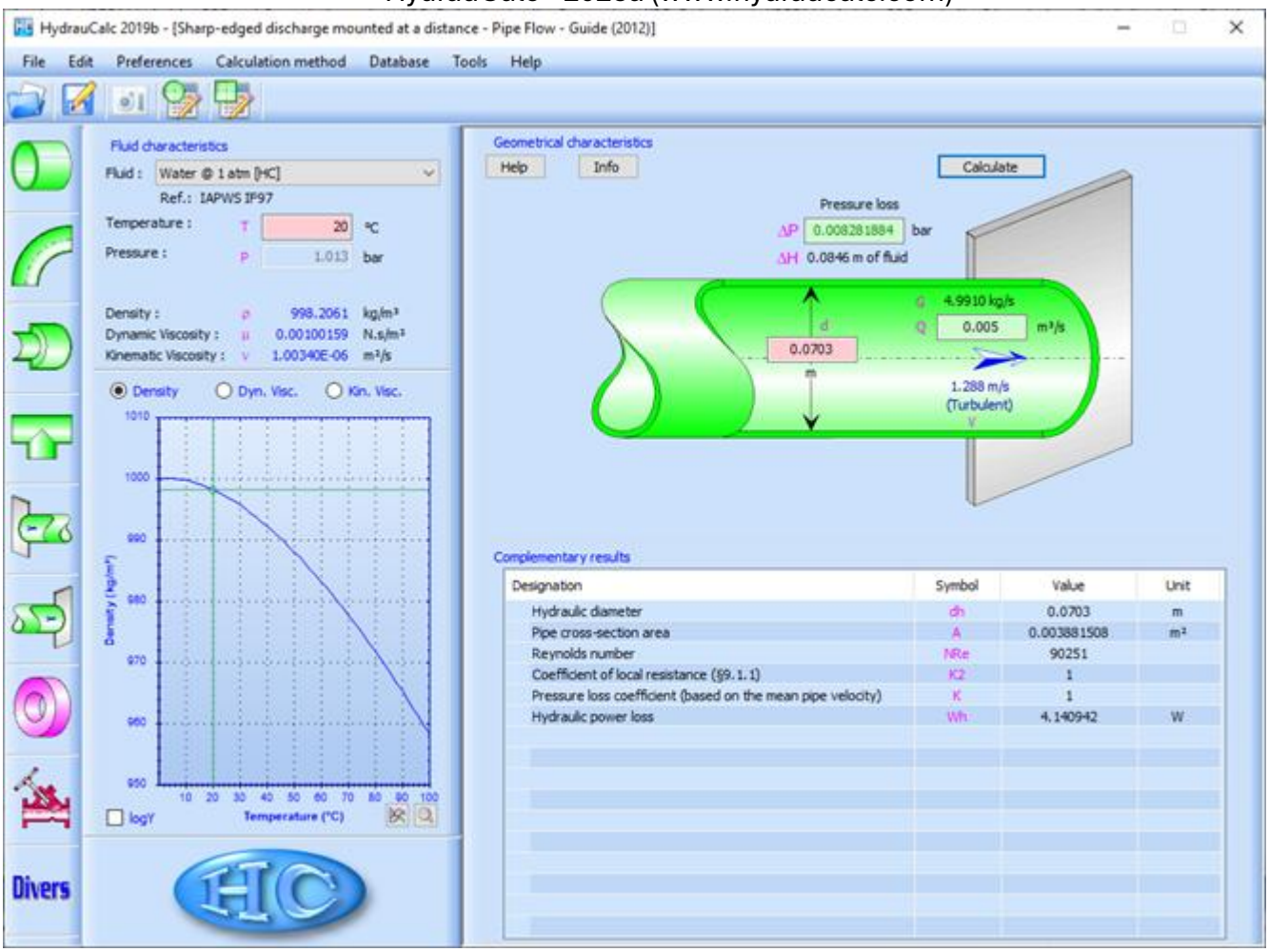
d_h	Hydraulic diameter (m)
d	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)

V	Mean velocity in pipe (m/s)
N_{Re}	Reynolds number in pipe ()
K_2	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in pipe ($N_{Re} \geq 10^4$)

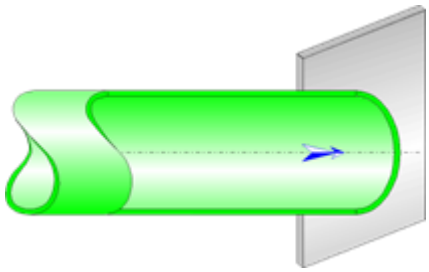
Example of application:



References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.6.3.2 CRANE



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sharp-edged discharge of piping mounted at a distance.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D$$

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity in pipe (m/s):

$$v = \frac{q}{A}$$

Mass flow rate (kg/s):

$$G = q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re} = \frac{v \cdot D}{\nu}$$

Local resistance coefficient ($\mathrm{Re} \geq 10^4$):

$$K_1 = 1$$ ([1] Appendix A-29)

Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_1$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot v^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot q$$

Symbols, Definitions, SI Units:

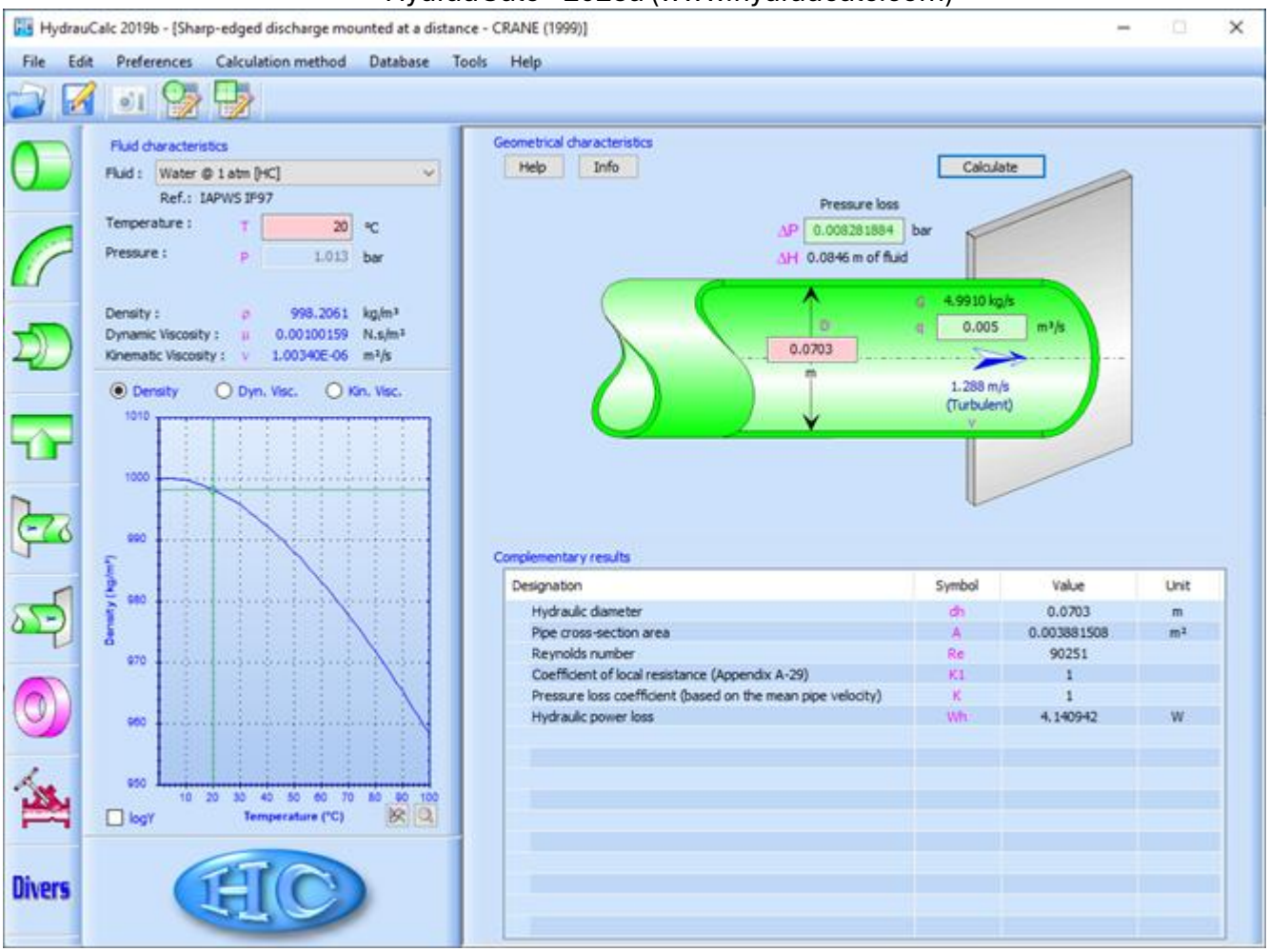
D_h	Hydraulic diameter (m)
D	Pipe diameter (m)
A	Pipe cross-sectional area (m^2)
q	Volume flow rate (m^3/s)
v	Mean velocity in pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in pipe ()

K_1	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in pipe ($Re \geq 10^4$)

Example of application:

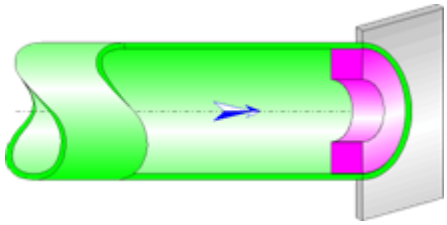


References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 – Edition 1999

2.6.4 Discharge from a thick-edged orifice

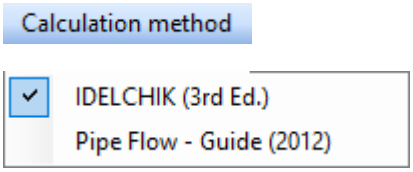
Circular Cross-Section



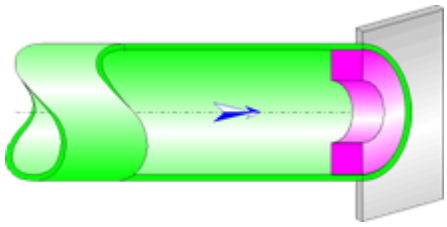
For the calculation of the pressure loss coefficient of a pipe discharge equipped with a thick-edged orifice, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.6.4.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe discharge equipped with a thick-edged orifice. Moreover, the head loss due to friction of the fluid on the inner walls of the holes is also taken into account in this component and is calculated with Darcy's formula.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Orifice cross-section area (m²):

$$F_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Mean velocity in pipe (m/s):

$$W_0 = \frac{Q}{F_0}$$

Mean velocity in orifice (m/s):

$$W_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_0 = \frac{W_0 \cdot D_0}{\nu}$$

Reynolds number in orifice:

$$\mathrm{Re} = \frac{W_{or} \cdot D_{or}}{\nu}$$

Relative roughness in orifice walls:

$$\bar{\Delta} = \frac{\Delta}{D_{or}}$$

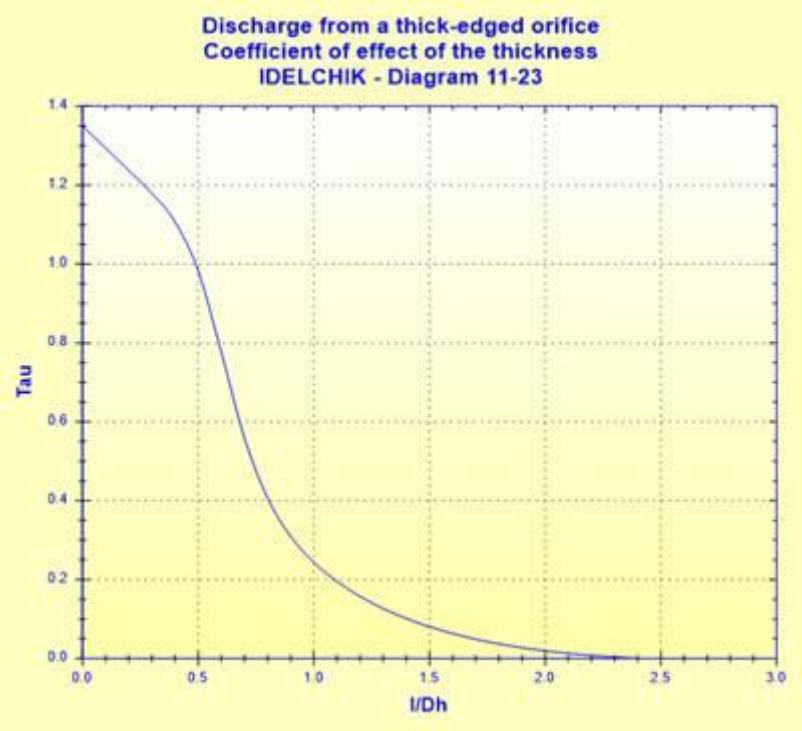
Coefficient of effect of the orifice thickness:

$$\tau = \left(2.4 - \frac{l}{D_h}\right) \cdot 10^{-\varphi\left(\frac{l}{D_h}\right)}$$

([1] diagram 11-23 and 3-13)

with:

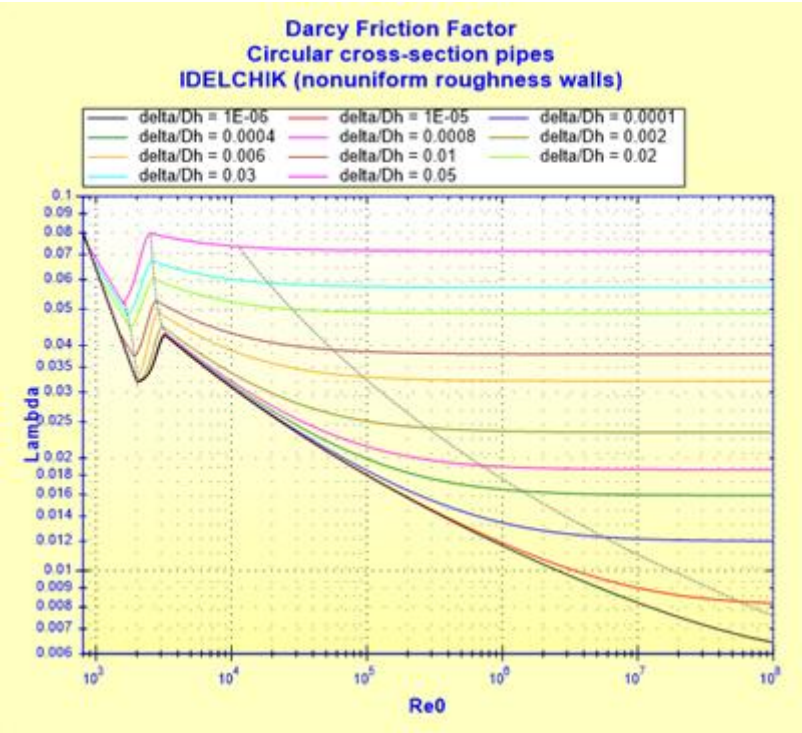
$$\varphi\left(\frac{l}{D_h}\right) = 0.25 + \frac{0.535 \cdot \left(\frac{l}{D_h}\right)^8}{0.05 + \left(\frac{l}{D_h}\right)^7}$$



Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}, \frac{\Delta}{D_h}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)

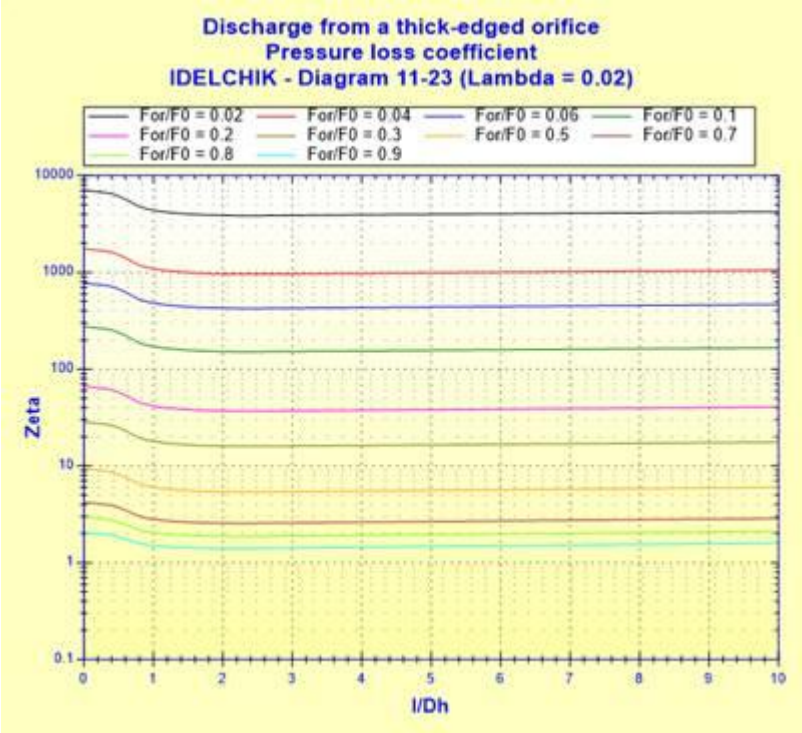


Local resistance coefficient (based on the mean pipe velocity):

■ $Re \geq 10^5$

$$\zeta = \left[1 + 0.5 \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.75} + \tau \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.375} + \lambda \cdot \frac{l}{D_h}\right] \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 11-23)



([1] diagram 11-23 with λ = 0.02)

■ $Re < 10^5$

Quadratic local resistance coefficient:

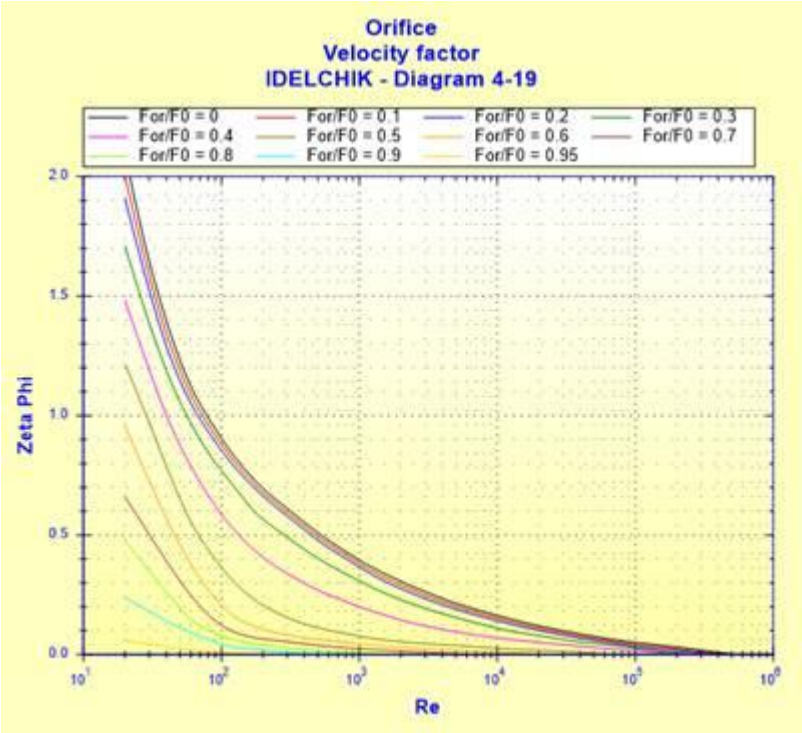
$$\zeta_{quad} = \left[1 + 0.5 \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.75} + \tau \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.375} + \lambda \cdot \frac{l}{D_h}\right] \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 11-23)

Velocity factor:

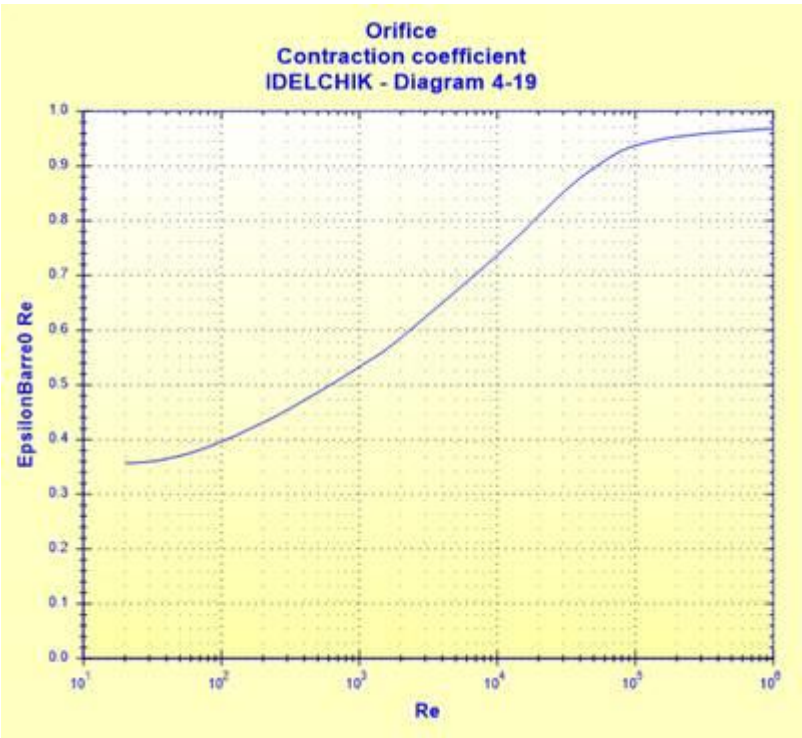
$$\zeta_\varphi = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$ ([1] diagram 4-19)



Local resistance coefficient:

- $30 < \mathrm{Re} < 10^5$

$$\zeta = \zeta_{\varphi} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0\mathrm{Re}} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $10 < \mathrm{Re} \leq 30$

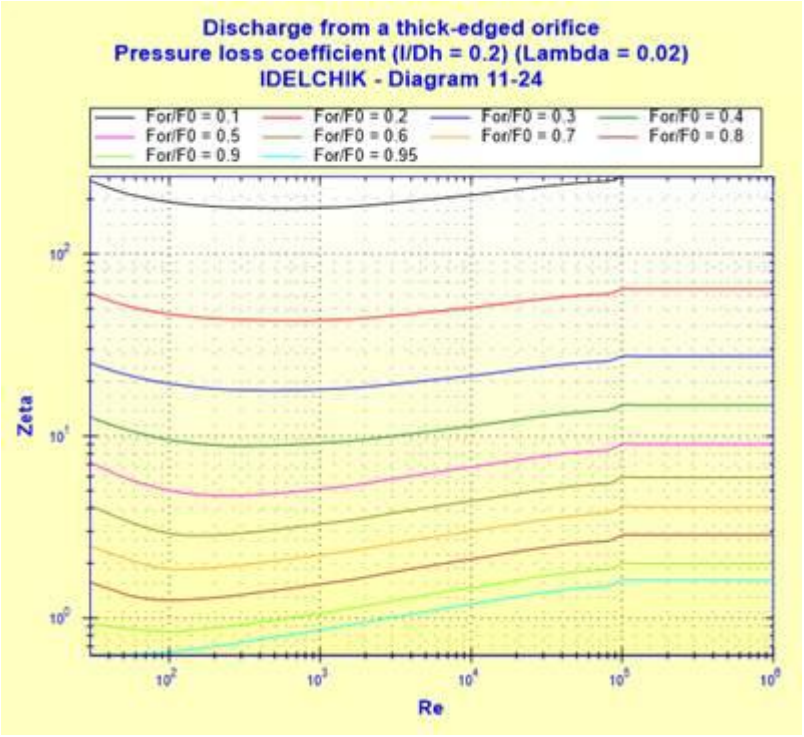
$$\zeta = \frac{33}{\mathrm{Re}} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0\mathrm{Re}} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $\mathrm{Re} \leq 10$

$$\zeta = \frac{33}{\mathrm{Re}} \cdot \left(\frac{F_0}{F_{or}} \right)^2$$

([1] diagram 11-24)



([1] diagram 11-24 with l/Dh = 0.2 and λ = 0.02)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_0	Pipe internal diameter (m)
F_0	Pipe cross-sectional area (m^2)
D_{or}	Orifice diameter (m)
F_{or}	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in pipe (m/s)
w_{or}	Mean velocity in orifice (m/s)
Re_0	Reynolds number in pipe ()
Re	Reynolds number in orifice ()
Δ	Absolute roughness of orifice walls (m)
$\bar{\Delta}$	Relative roughness of orifice walls ()
l	Orifice thickness (m)
τ	Coefficient of effect of the orifice thickness ()
λ	Darcy friction coefficient in orifice ()
ζ_{quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)

ρ Fluid density (kg/m³)

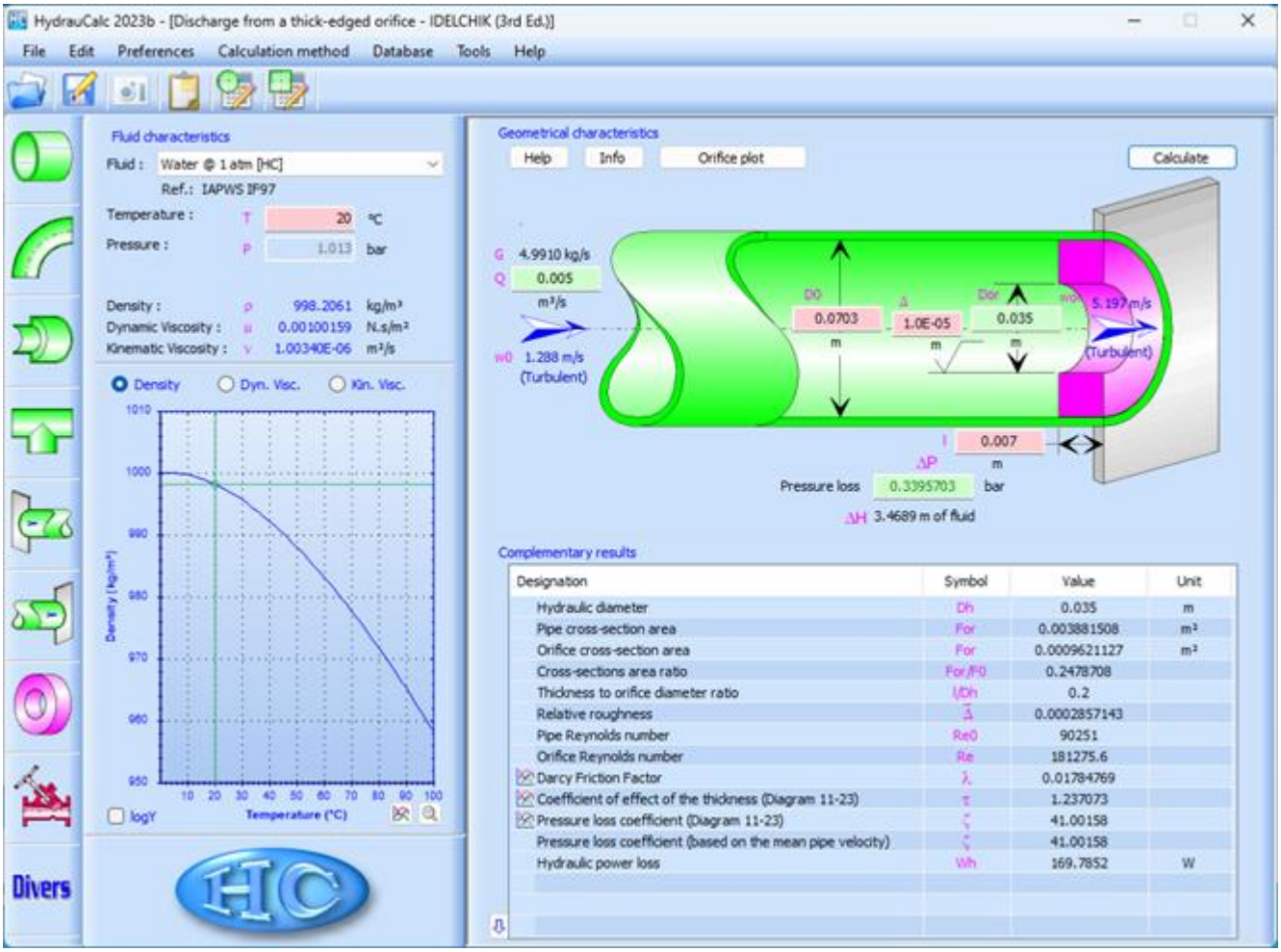
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- thickness to orifice diameter ratio (l/D_{or}) greater than 0.015

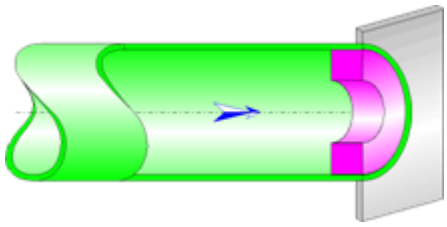
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.6.4.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe discharge equipped with a thick-edged orifice. Moreover, when the thickness of the orifice is greater than 1.4 times the diameter of the orifice, the head loss due to friction in the orifice is also taken into account because it becomes significant.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Ratio of orifice to pipe diameters:

$$\beta = \frac{d_o}{d}$$

Pipe cross-sectional area (m²):

$$A = \pi \cdot \frac{d^2}{4}$$

Orifice cross-sectional area (m²):

$$A_o = \pi \cdot \frac{{d_o}^2}{4}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

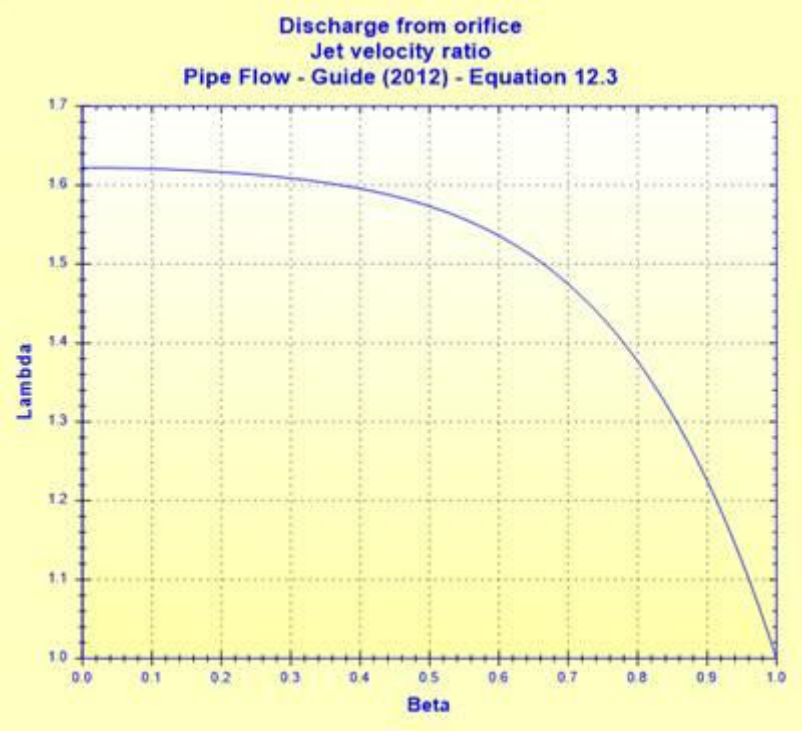
$$N_{Re} = \frac{V \cdot d}{\nu}$$

Reynolds number in orifice:

$$N_{Re_O} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left(1 - 0.215\beta^2 - 0.785\beta^5\right)$$ ([1] equation 12.3)



Velocity in vena contracta:

$$V_c = V_0 \cdot \lambda$$

Coefficient of local resistance ($NRe_o \geq 10^4$):

- Thickness to orifice diameter ratio (t/d_o) ≤ 1.4:

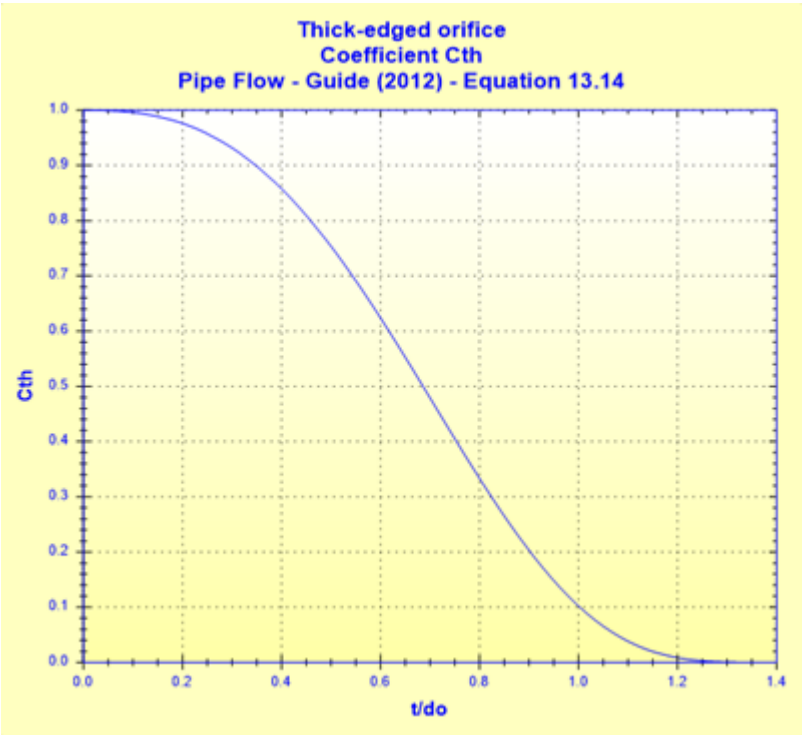
$$K_o = 0.0696 \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + C_{th} \cdot \lambda^2 + \left(1 - C_{th}\right) \cdot \left[\left(\lambda - 1\right)^2 + 1\right]$$

([1] equation 12.5)

with :

$$C_{th} = \left[1 - 0.50 \cdot \left(\frac{t}{1.4 d_o}\right)^{2.5} - 0.50 \cdot \left(\frac{t}{1.4 d_o}\right)^{3}\right]^{4.5}$$

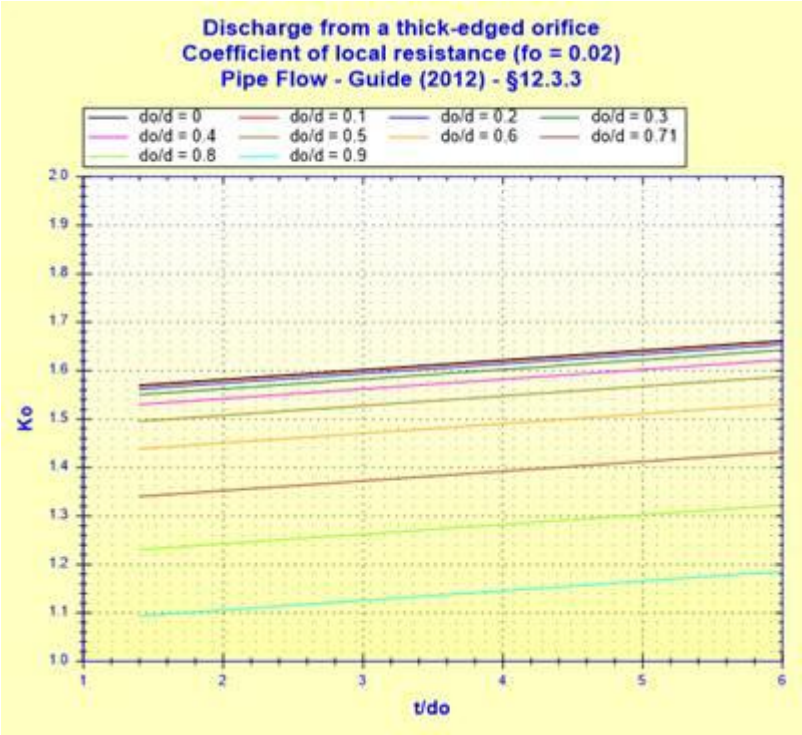
([1] equation 13.14)



■ Thickness to orifice diameter ratio (t/d_o) > 1.4:

$$K_o = 0.0696 \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + (\lambda - 1)^2 + 1 + f_o \cdot \left[\frac{t}{d_o} - 1.4\right]$$

([1] §12.3.3)

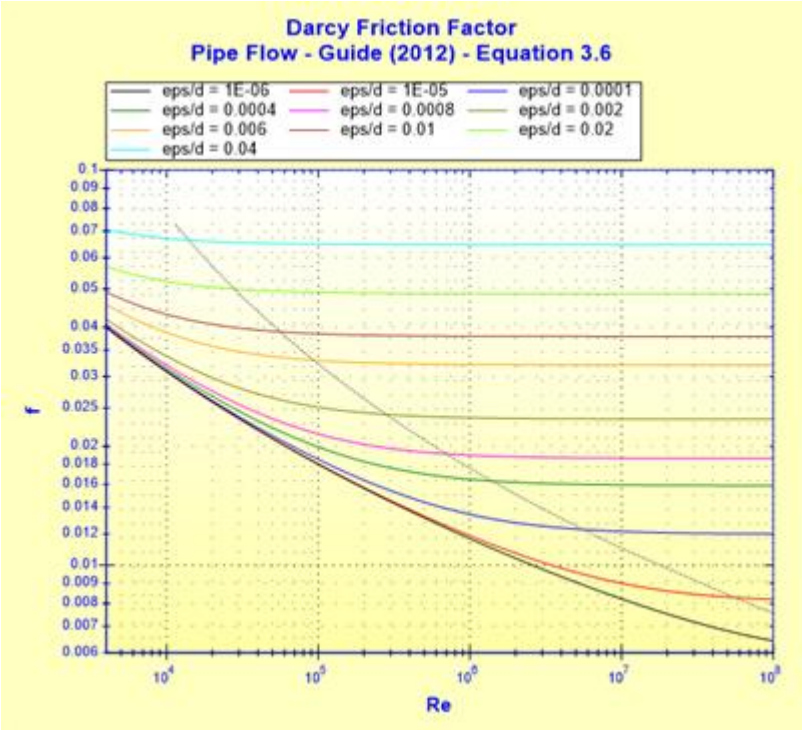


([1] §12.3.3 with fo = 0,02)

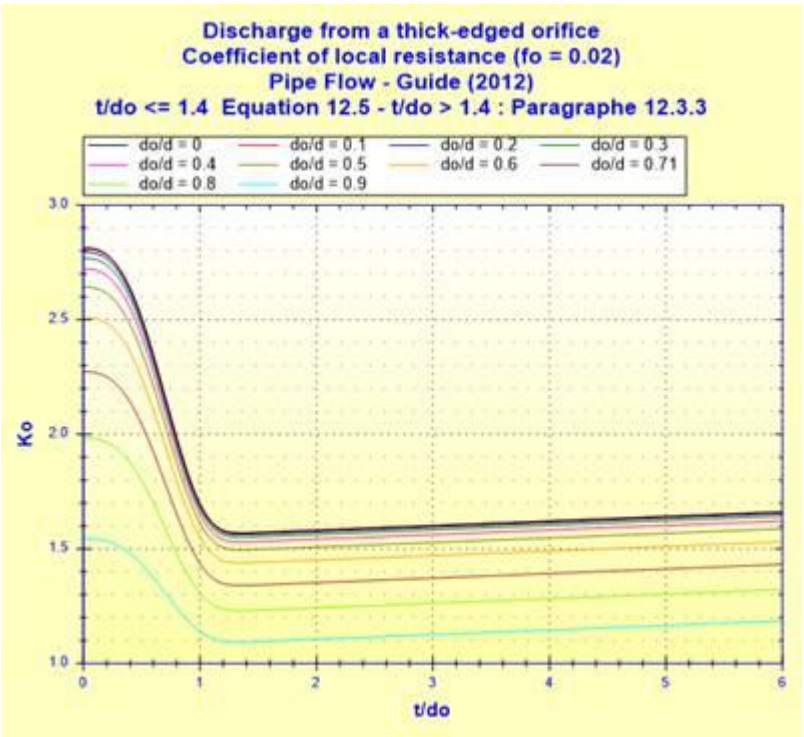
with :

$$f_o = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d_o} + \frac{2.51}{NRe_0 \cdot \sqrt{f_o}}\right)\right]^2}$$

Colebrook-White equation ([1] equation 3.6)



- All thickness to orifice diameter ratios (t/d_o):



([1] equation 12.5 and §12.3.3 with fo = 0,02)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_o} \right)^2$$

(with fo = 0.02)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

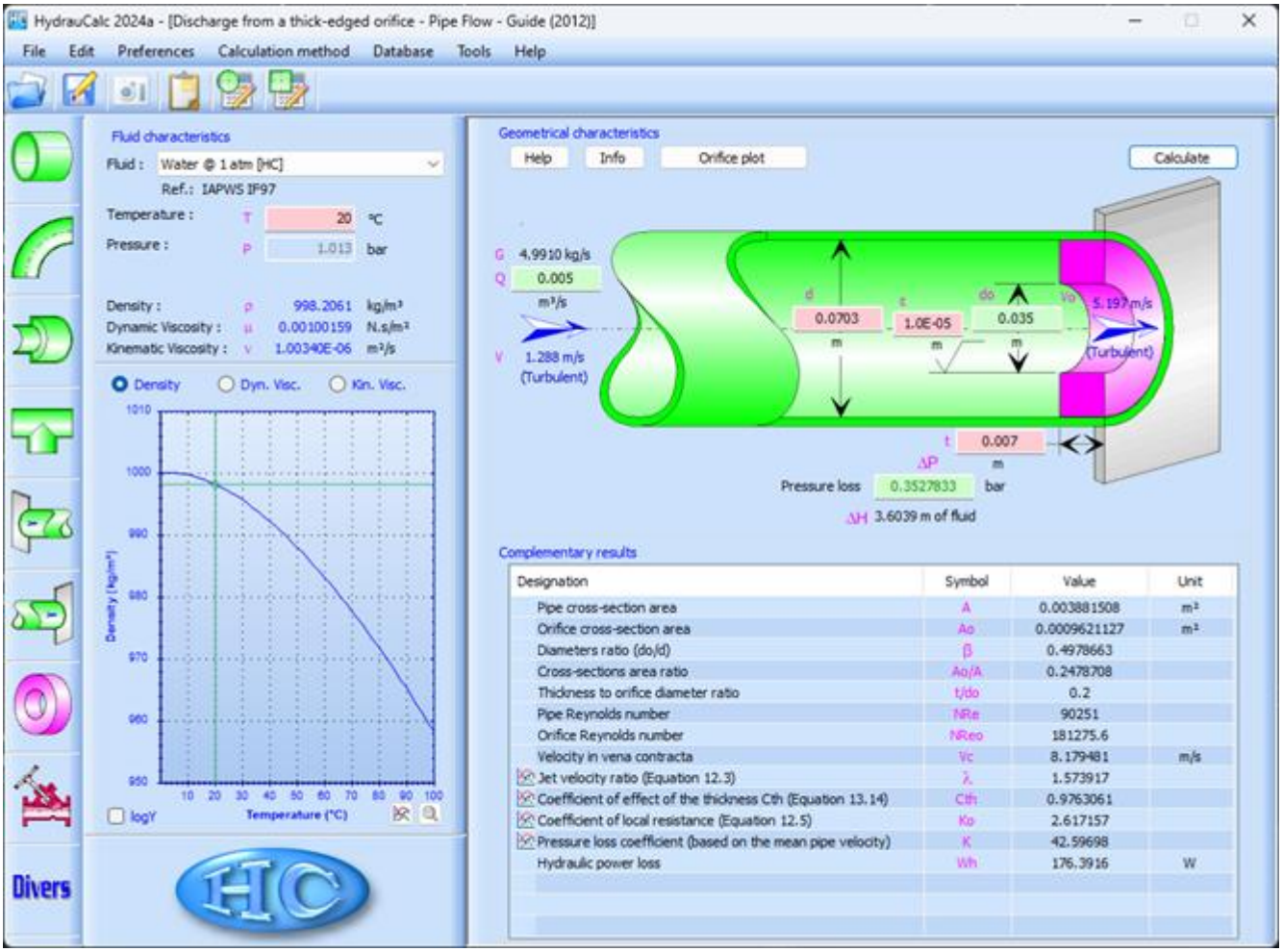
d_0	Orifice diameter (m)
d	Internal pipe diameter (m)
β	Ratio of orifice to pipe diameters ()

A_o	Orifice cross-sectional area (m^2)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
NRe_o	Reynolds number in orifice ()
NRe	Reynolds number in pipe ()
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
t	Thickness orifice (m)
K_o	Coefficient of local resistance ()
Cth	Coefficient of effect of the orifice thickness ()
ε	Absolute roughness of orifice walls (m)
f_o	Friction factor ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in orifice ($NRe_o \geq 10^4$)
- stabilized flow upstream of the orifice

Example of application:

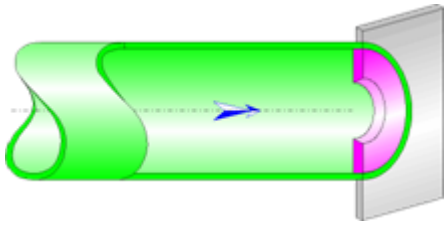


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.6.5 Discharge from a sharp-edged orifice

Circular Cross-Section

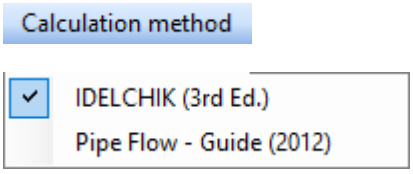


For the calculation of the pressure loss coefficient of a pipe discharge equipped with a sharp-edged orifice, the user can choose from one of the methods described in the following two reference documents:

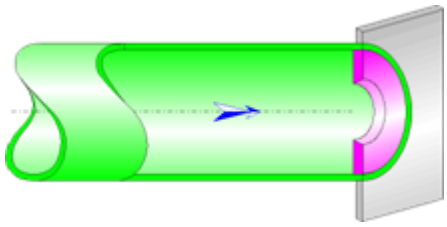
- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)".



2.6.5.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe discharge equipped with a sharp-edged orifice.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Orifice cross-section area (m^2):

$$F_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Mean velocity in pipe (m/s):

$$W_0 = \frac{Q}{F_0}$$

Mean velocity in orifice (m/s):

$$W_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_0 = \frac{W_0 \cdot D_0}{\nu}$$

Reynolds number in orifice:

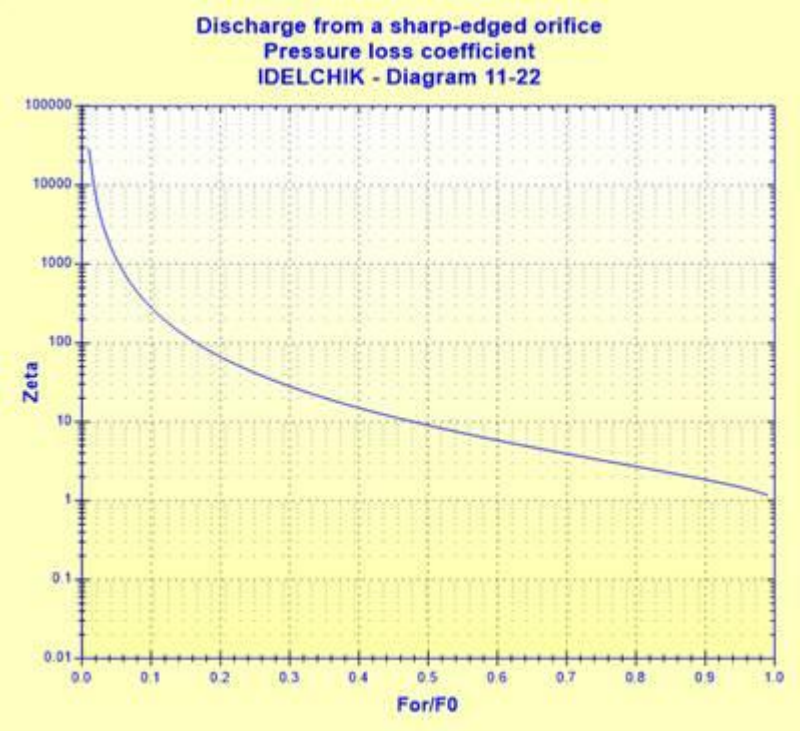
$$\mathrm{Re} = \frac{W_{or} \cdot D_{or}}{\nu}$$

Local resistance coefficient (based on the mean pipe velocity):

- $\mathrm{Re} \geq 10^5$

$$\zeta = \left[1 + 0.707 \cdot \sqrt{\left(1 - \frac{F_{or}}{F_0}\right)}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 11-22)



■ $Re < 10^5$

Quadratic local resistance coefficient:

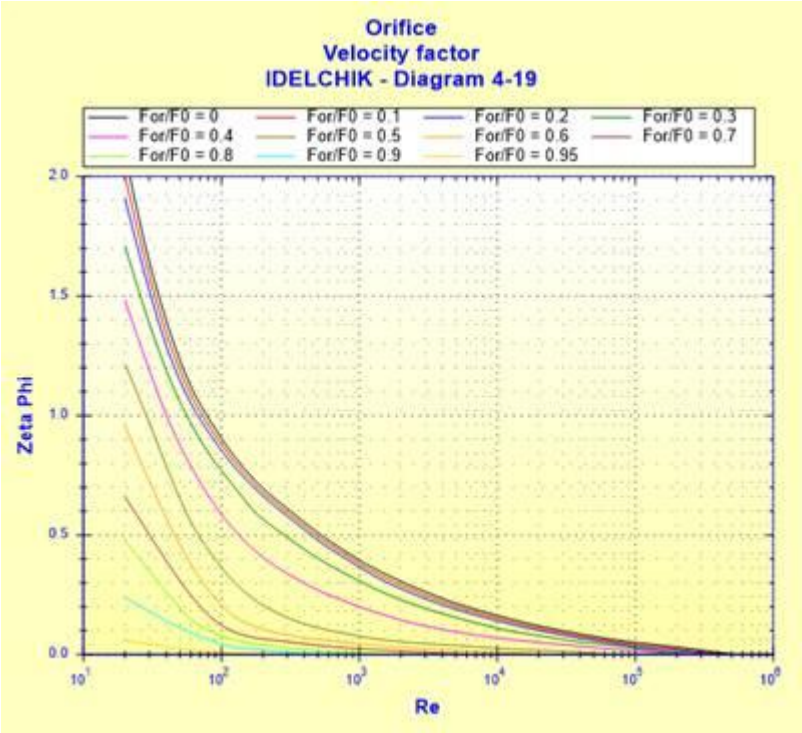
$$\zeta_{quad} = \left[1 + 0.707 \cdot \sqrt{\left(1 - \frac{F_{or}}{F_0}\right)}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 11-22)

Velocity factor:

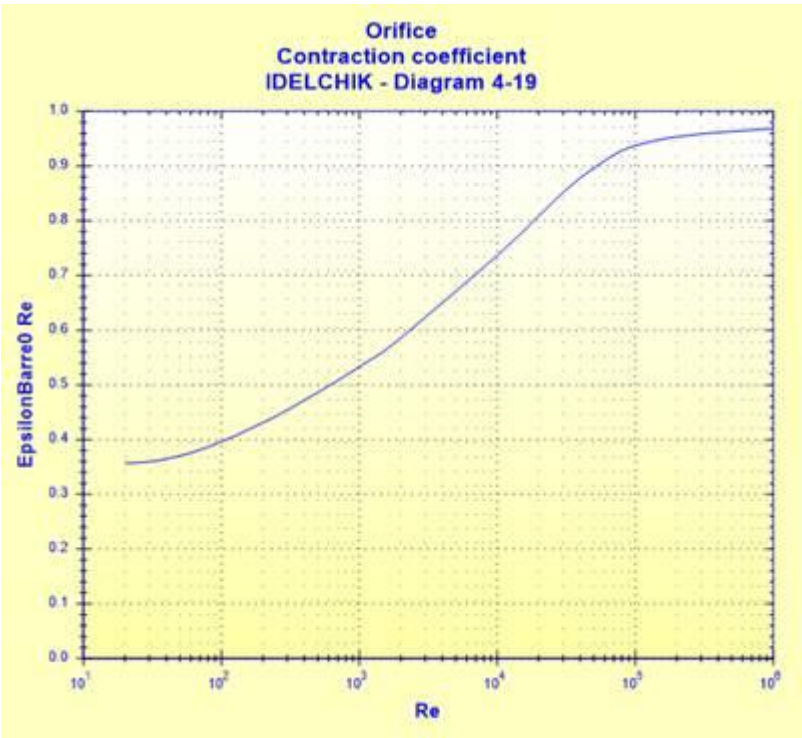
$$\zeta_\varphi = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$ ([1] diagram 4-19)



Local resistance coefficient:

- $30 < \mathrm{Re} < 10^5$

$$\zeta = \zeta_{\varphi} \cdot \left(\frac{F_0}{F_{or}}\right)^2 + \overline{\varepsilon}_{0\mathrm{Re}} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $10 < \mathrm{Re} \leq 30$

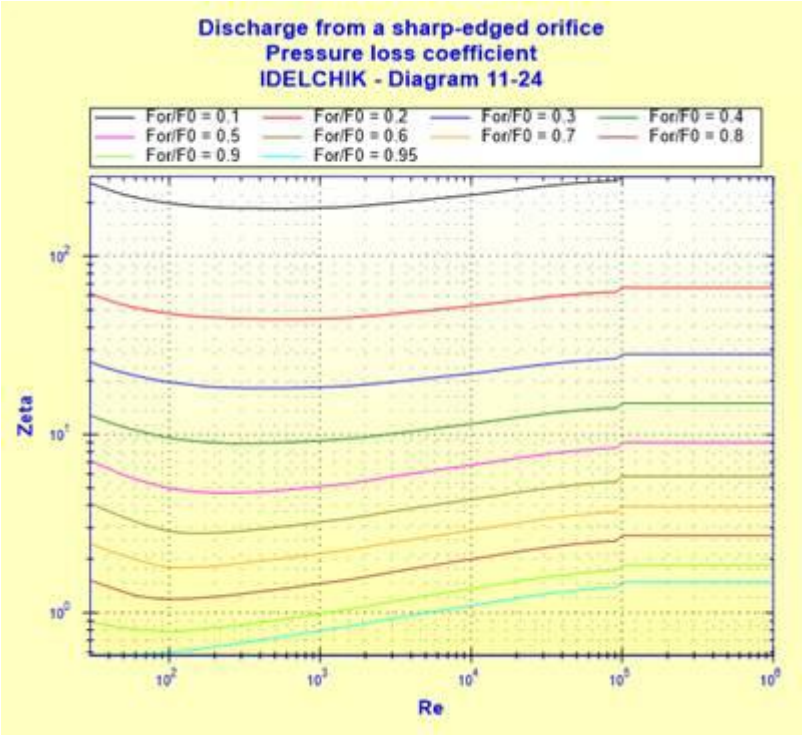
$$\zeta = \frac{33}{\mathrm{Re}} \cdot \left(\frac{F_0}{F_{or}}\right)^2 + \overline{\varepsilon}_{0\mathrm{Re}} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $\mathrm{Re} \leq 10$

$$\zeta = \frac{33}{\mathrm{Re}} \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 11-24)



Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

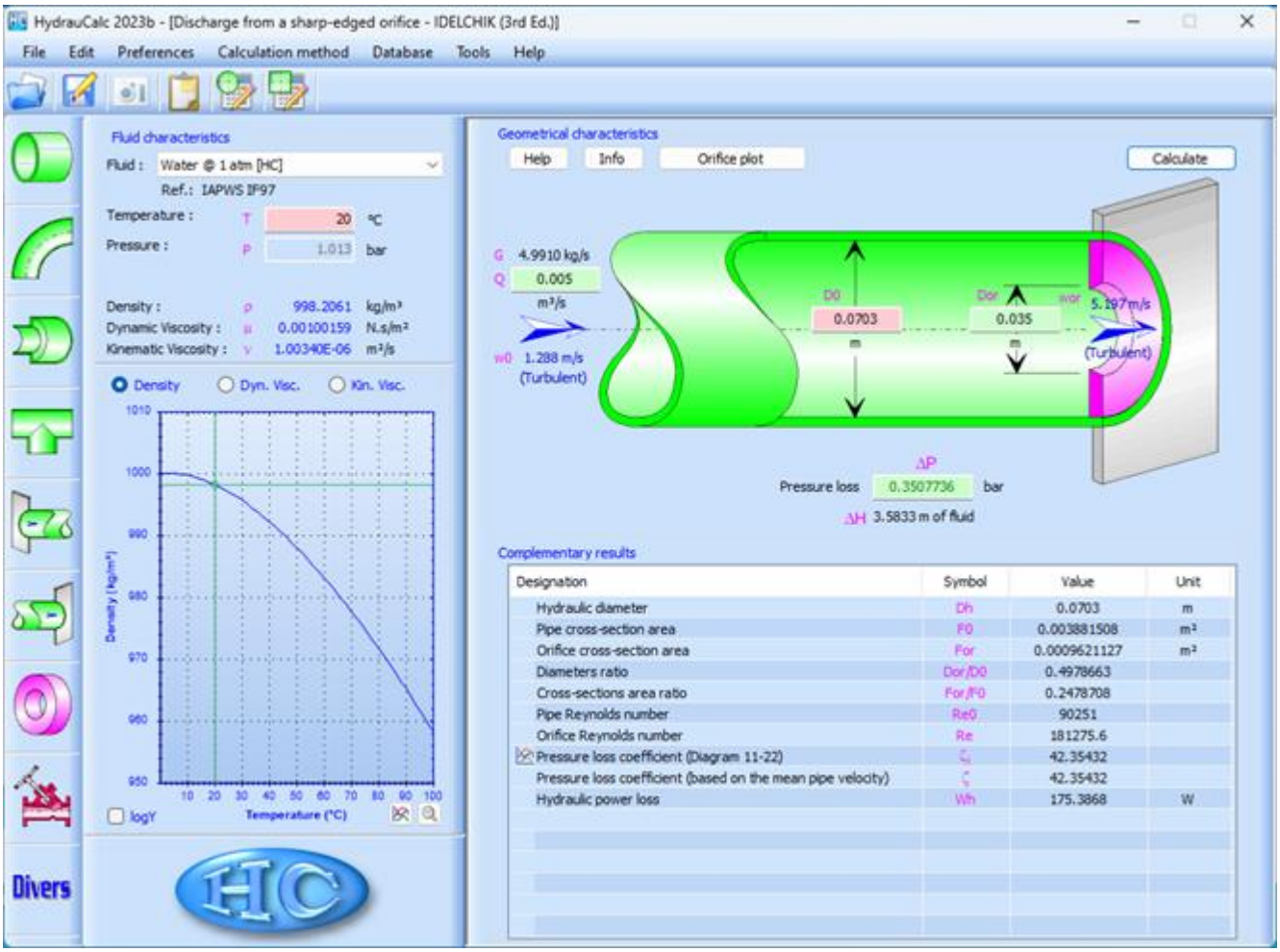
Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_0	Pipe internal diameter (m)
F_0	Pipe cross-sectional area (m^2)
D_{or}	Orifice diameter (m)
F_{or}	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in pipe (m/s)
w_{or}	Mean velocity in orifice (m/s)
Re_0	Reynolds number in pipe ()
Re	Reynolds number in orifice ()
ζ_{quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- chamfer angle about 45°
- thickness to orifice diameter ratio (l/D_{or}) lower than or equal to 0.015

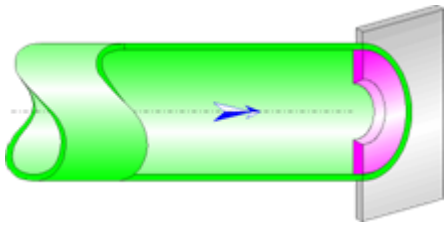
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.6.5.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe discharge equipped with a sharp-edged orifice.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Ratio of orifice to pipe diameter:

$$\beta = \frac{d_o}{d}$$

Pipe cross-sectional area (m²):

$$A = \pi \cdot \frac{d^2}{4}$$

Orifice cross-sectional area (m²):

$$A_o = \pi \cdot \frac{d_o^2}{4}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

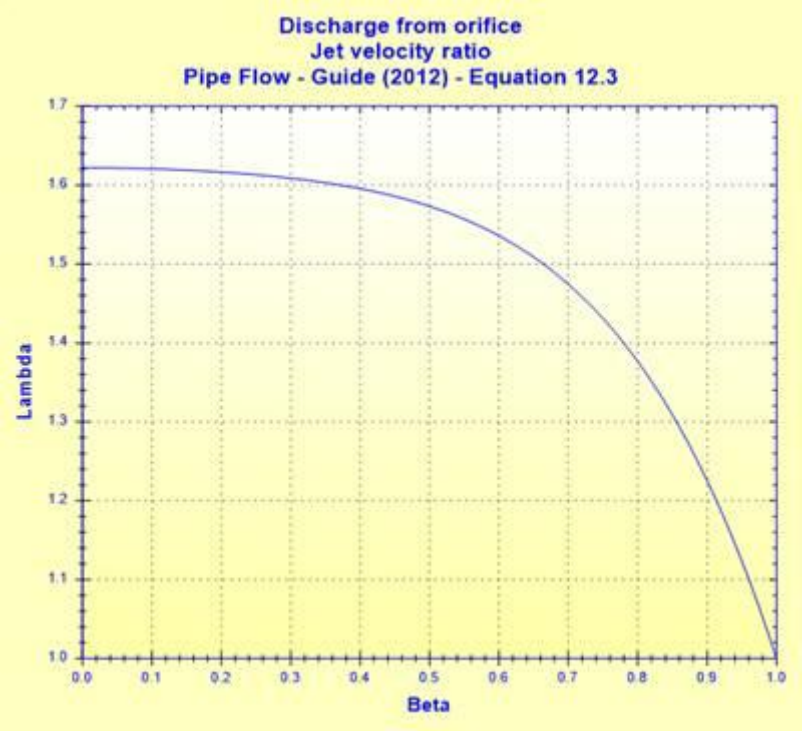
$$N_{Re} = \frac{V \cdot d}{\nu}$$

Reynolds number in orifice:

$$N_{Re_O} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left(1 - 0.215\beta^2 - 0.785\beta^5\right)$$ ([1] equation 12.3)



Velocity in vena contracta (m/s):

$$V_c = V_o \cdot \lambda$$

Vena contracta cross-sectional area (m^2):

$$A_c = \frac{Q}{V_c}$$

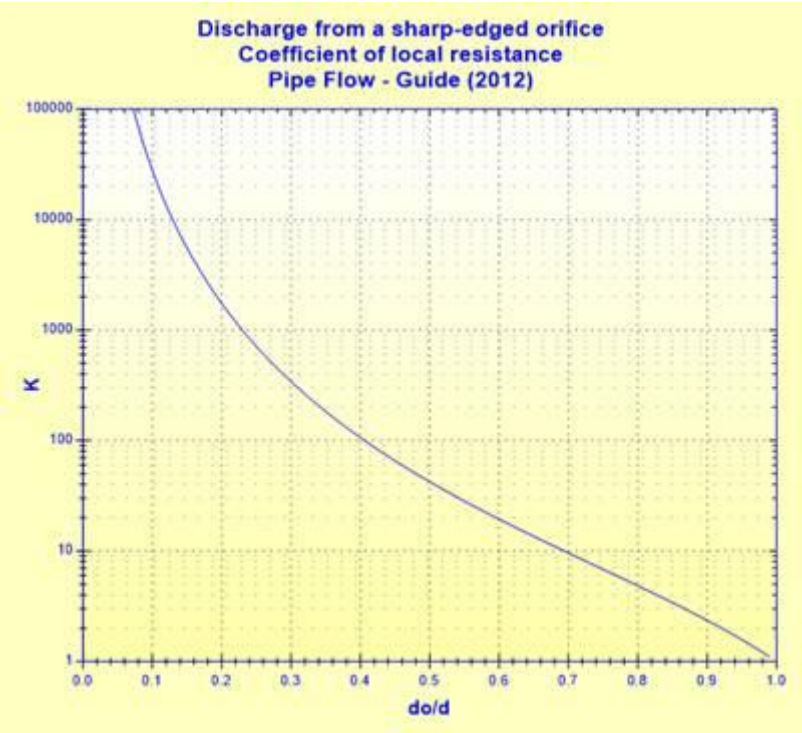
Coefficient of local resistance ($NRe_o \geq 10^4$):

$$K_o = 0.0696 \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + \lambda^2$$

([1] equation 12.2)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_o} \right)^2$$



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_0	Orifice diameter (m)
d	Internal pipe diameter (m)
β	Ratio of orifice to pipe diameter ()
A_o	Orifice cross-sectional area (m^2)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in orifice diameter (m/s)
V	Mean velocity in pipe diameter (m/s)
NRe_o	Reynolds number in orifice ()
NRe	Reynolds number in pipe ()
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
K_o	Coefficient of local resistance ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m³)

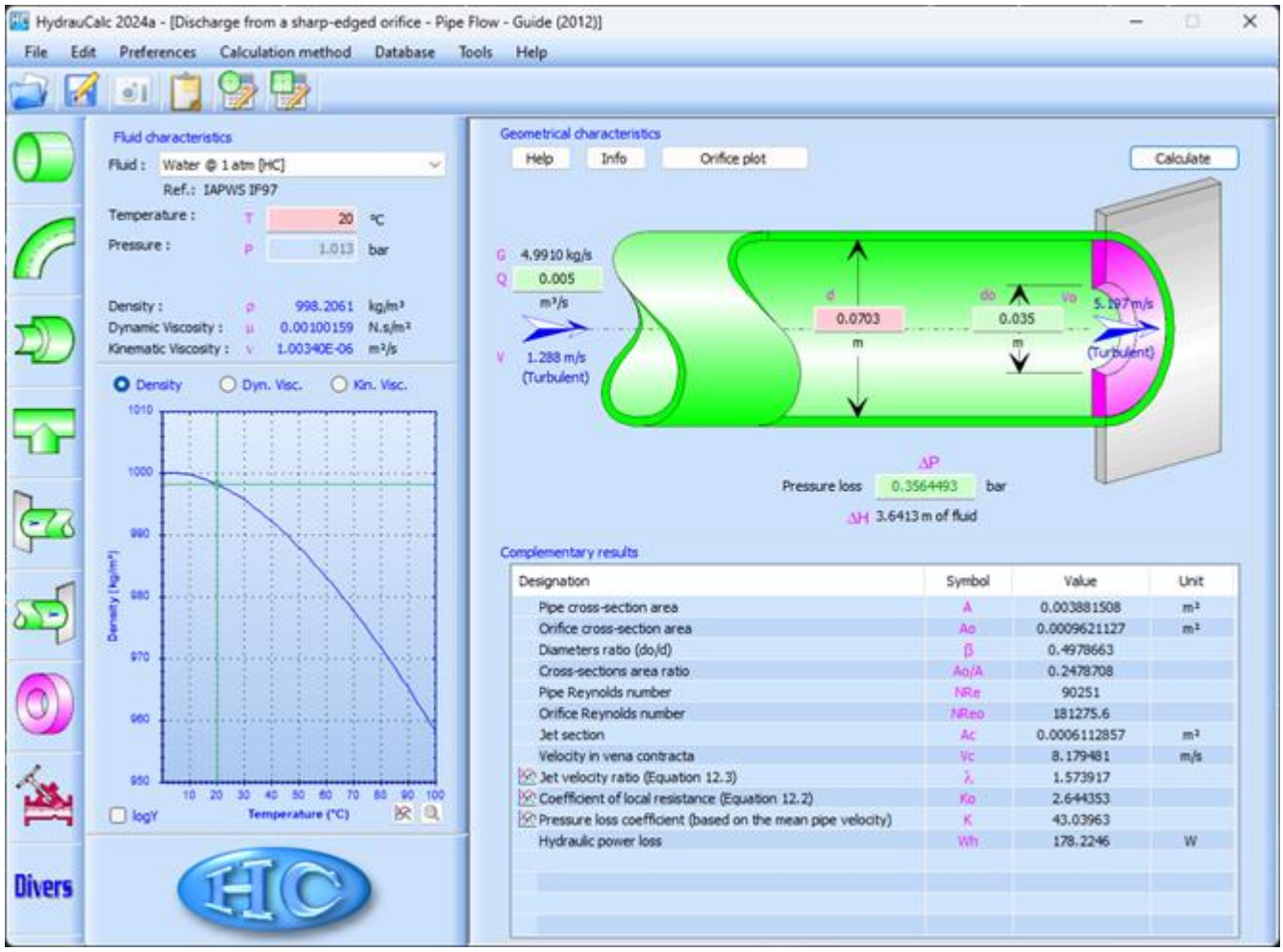
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime in the orifice ($NRe_o \geq 10^4$)
- stabilized flow upstream of the orifice

Example of application:

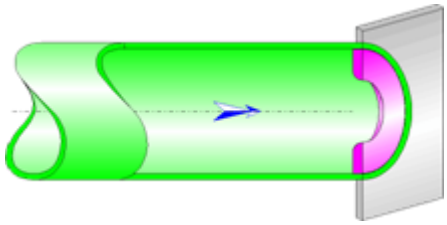


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.6.6 Discharge from a round-edged orifice

Circular Cross-Section

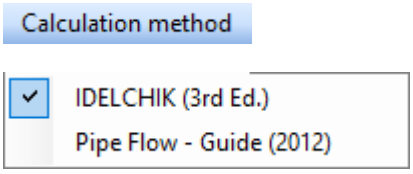


For the calculation of the pressure loss coefficient of a pipe discharge equipped with a round-edged orifice, the user can choose from one of the methods described in the following two reference documents:

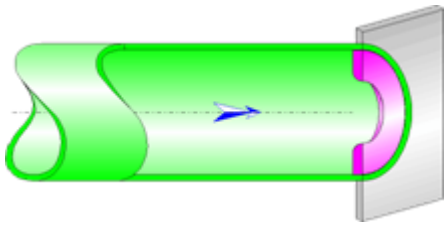
- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)".



2.6.6.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe discharge equipped with a round-edged orifice.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Orifice cross-section area (m^2):

$$F_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Mean velocity in pipe (m/s):

$$W_0 = \frac{Q}{F_0}$$

Mean velocity in orifice (m/s):

$$W_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$Re_0 = \frac{W_0 \cdot D_0}{\nu}$$

Reynolds number in orifice:

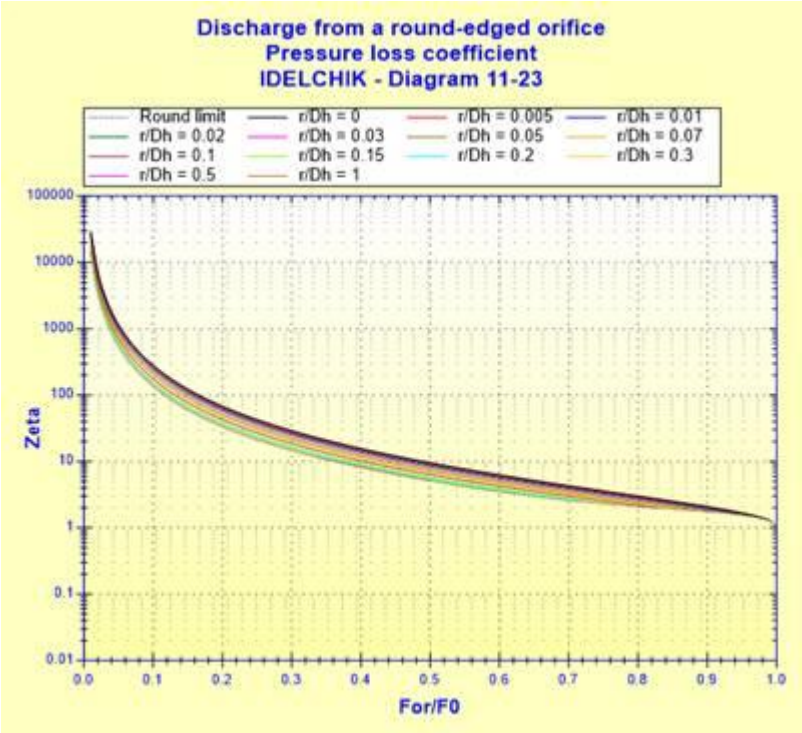
$$Re = \frac{W_{or} \cdot D_{or}}{\nu}$$

Local resistance coefficient (based on the mean pipe velocity):

- $Re \geq 10^5$

$$\zeta = \left[1 + \zeta' \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.75} + 2 \cdot \sqrt{\zeta'} \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.375}\right] \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 11-23)

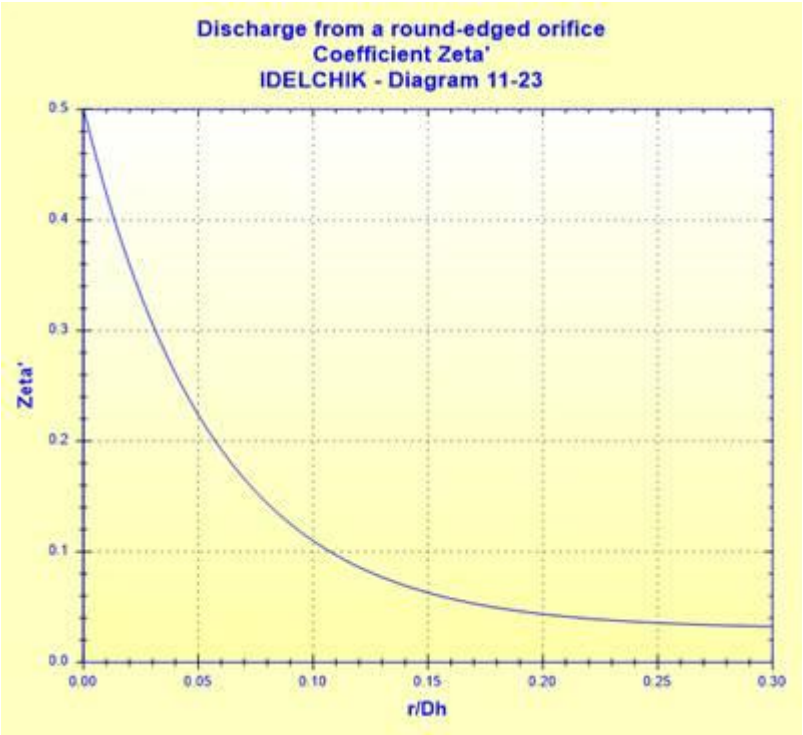


with :

Coefficient of effect of the round:

$$\zeta' = 0.03 + 0.47 \cdot 10^{-7.7 \cdot \frac{r}{D_h}}$$

([1] diagram 11-23 and 3-13)



■ $Re < 10^5$

Quadratic local resistance coefficient:

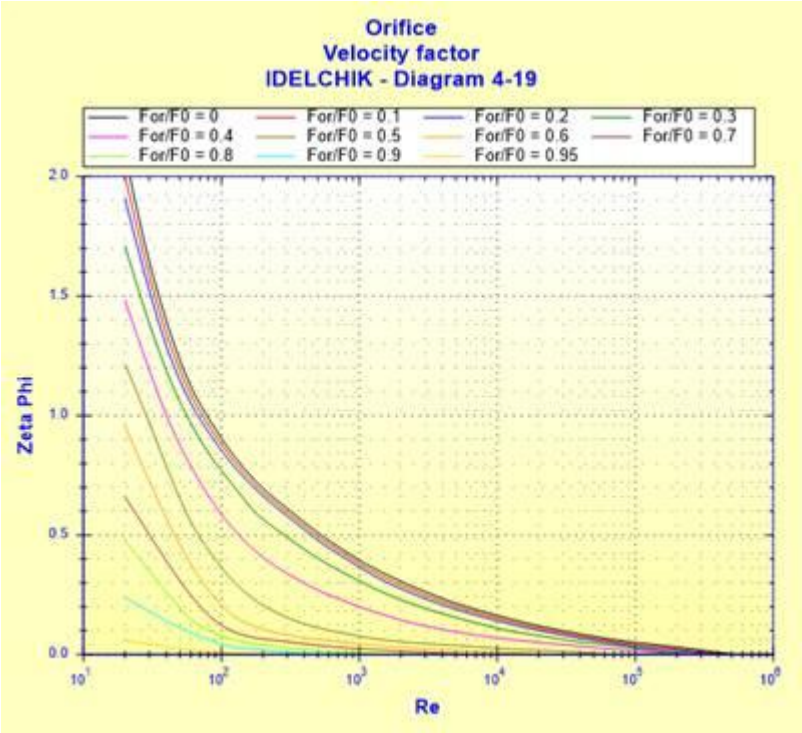
$$\zeta_{quad} = \left[1 + \zeta' \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.75} + 2 \cdot \sqrt{\zeta'} \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.375}\right] \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 11-23)

Velocity factor:

$$\zeta_\varphi = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$$

([1] diagram 4-19)

Local resistance coefficient:

- $30 < Re < 10^5$

$$\zeta = \zeta_{\varphi} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $10 < Re \leq 30$

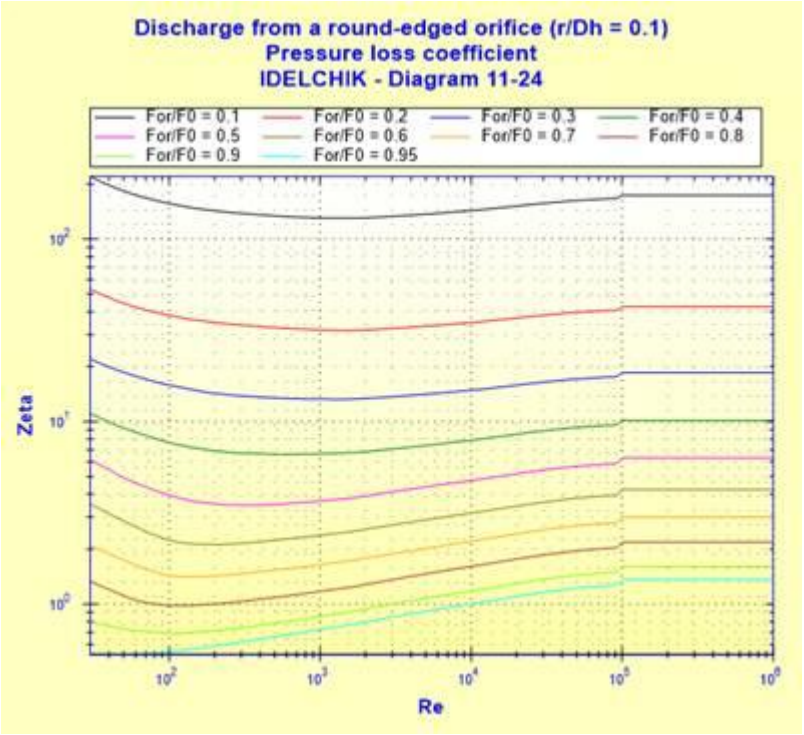
$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $Re \leq 10$

$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2$$

([1] diagram 11-24)



([1] diagram 11-24 with r/Dh = 0.1)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h Hydraulic diameter (m)

D_0 Pipe internal diameter (m)

F_0 Pipe cross-sectional area (m^2)

D_{or} Orifice diameter (m)

F_{or} Orifice cross-sectional area (m^2)

Q Volume flow rate (m^3/s)

G Mass flow rate (kg/s)

w_0 Mean velocity in pipe (m/s)

w_{or} Mean velocity in orifice (m/s)

Re_0 Reynolds number in pipe ()

Re Reynolds number in orifice ()

ζ' Coefficient of effect of the round ()

r Radius of the round (m)

ζ_{quad} Quadratic pressure loss coefficient determined as Re = 10^5 ()

ζ_{φ} Velocity factor ()

$\bar{\varepsilon}_{0Re}$ Contraction factor ()

ζ Pressure loss coefficient (based on the mean pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m^3)

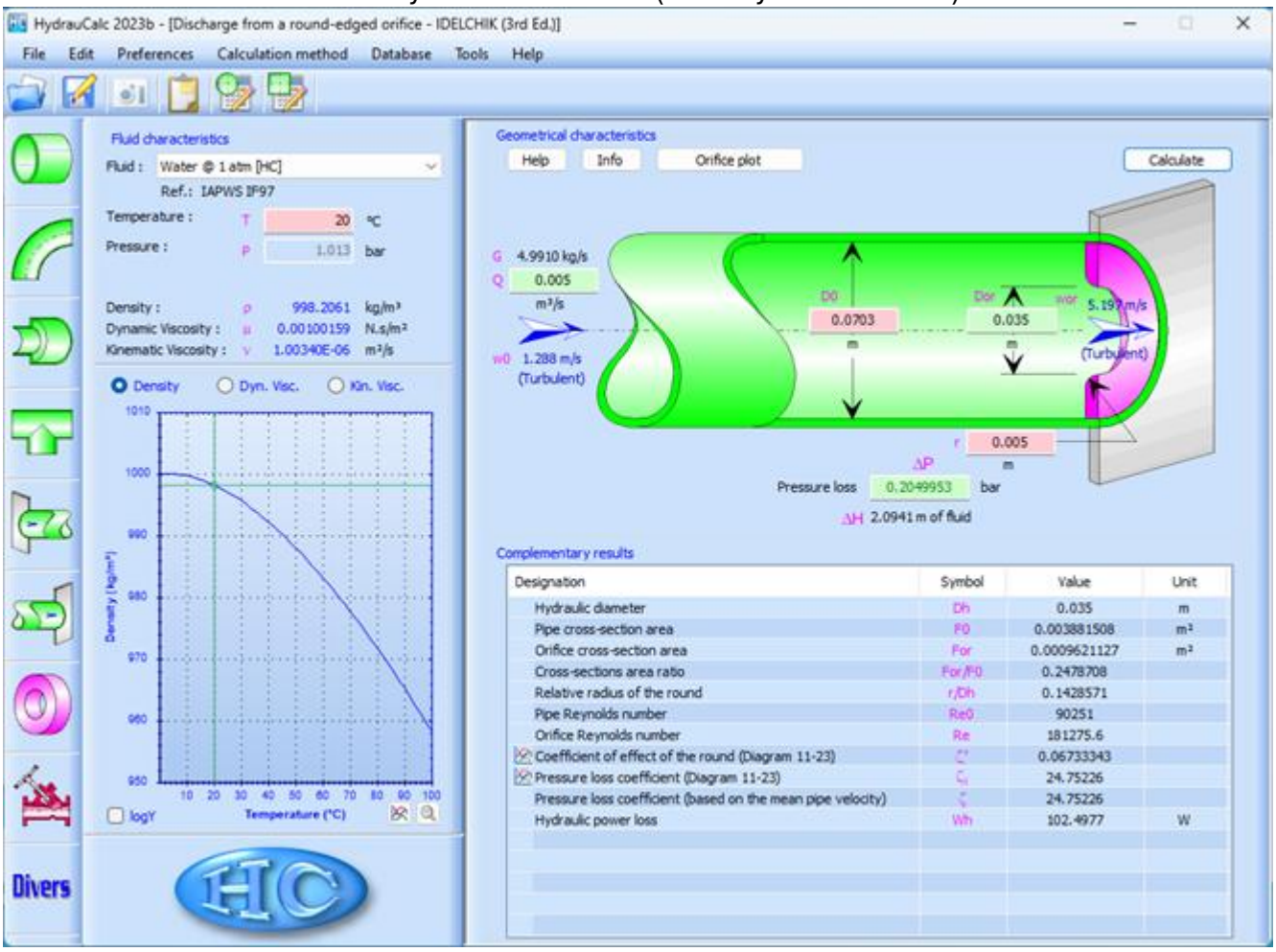
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- round radius less than the radius difference ($r < (D_0/2-D_{or}/2)$)

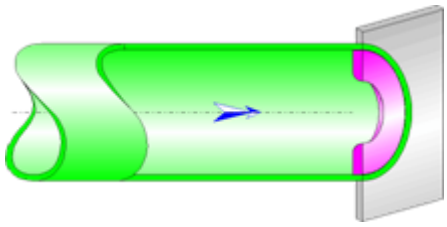
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.6.6.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe discharge equipped with a round-edged orifice.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Ratio of orifice to pipe diameters:

$$\beta = \frac{d_o}{d}$$

Pipe cross-sectional area (m²):

$$A = \pi \cdot \frac{d^2}{4}$$

Orifice cross-sectional area (m²):

$$A_o = \pi \cdot \frac{d_o{}^2}{4}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

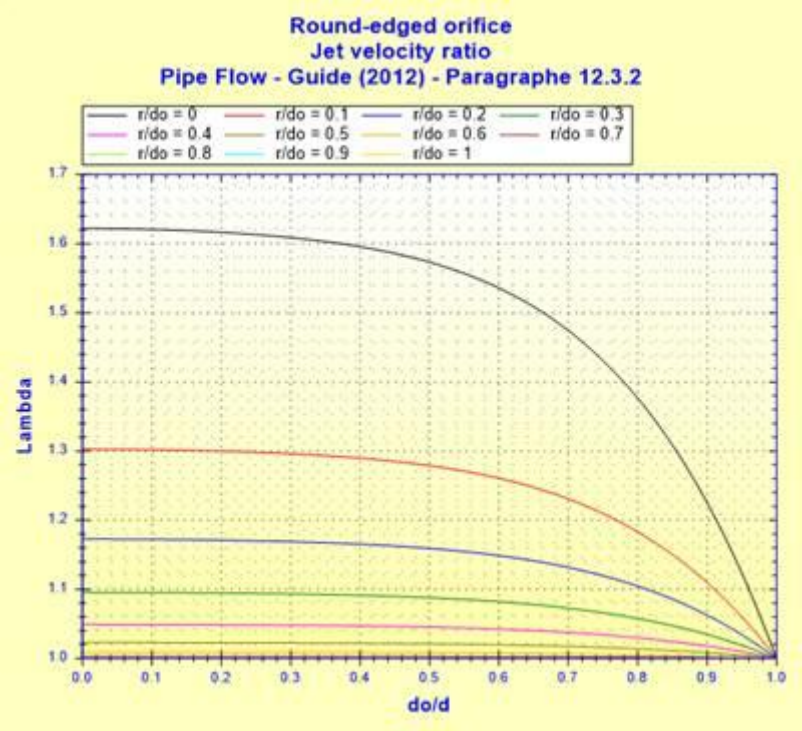
Reynolds number in orifice:

$$N_{Re_O} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left[1 - 0.3 \cdot \sqrt{\frac{r}{d_0}} - 0.7 \cdot \frac{r}{d_0} \right]^4 \cdot \left(1 - 0.215 \cdot \beta^2 - 0.785 \cdot \beta^5 \right)$$

([1] §12.3.2)



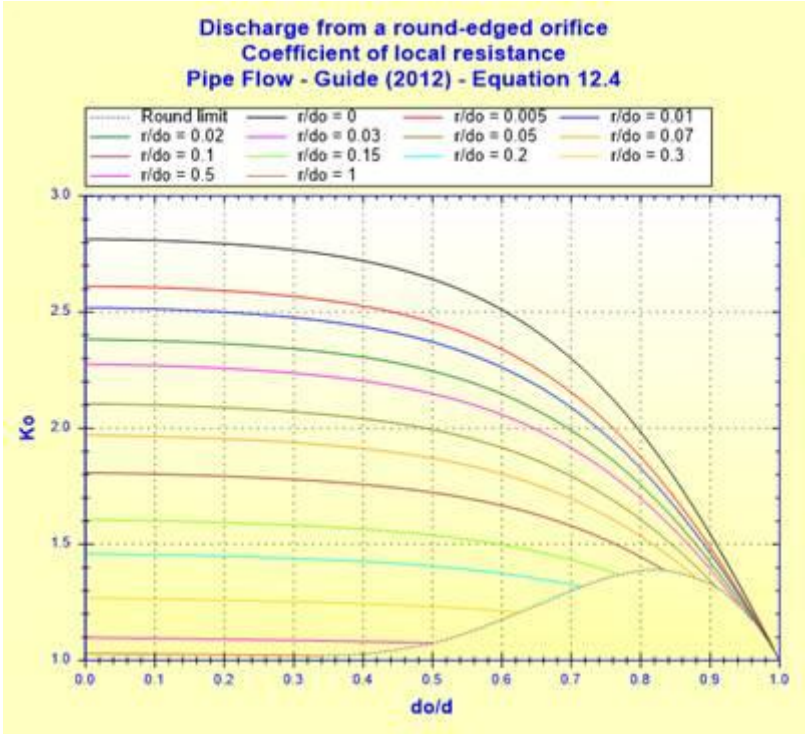
Velocity in vena contracta:

$$V_C = V_0 \cdot \lambda$$

Coefficient of local resistance:

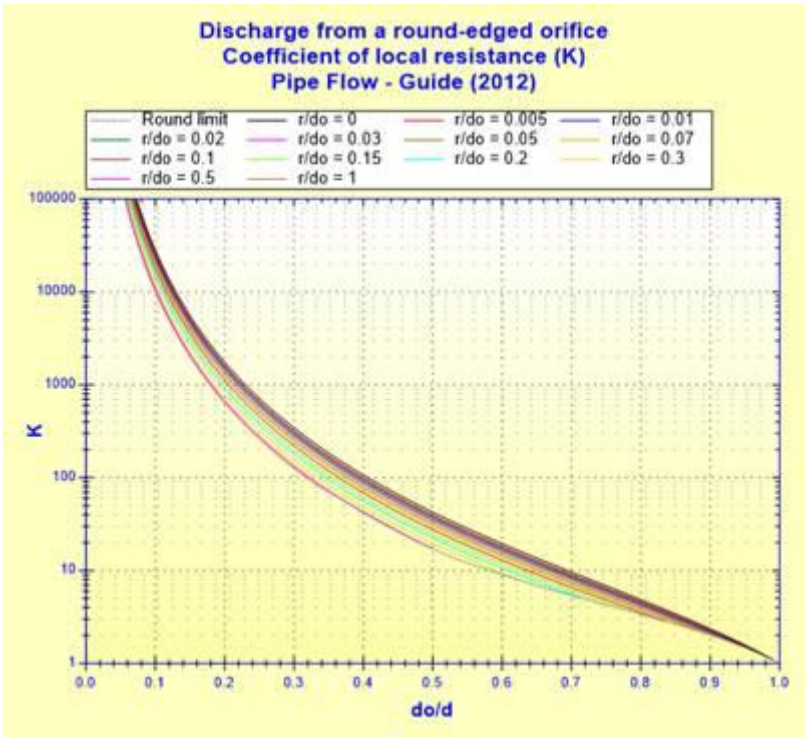
$$K_o = 0.0696 \cdot \left(1 - 0.569 \cdot \frac{r}{d_0}\right) \cdot \left(1 - \sqrt{\frac{r}{d_0}} \cdot \beta\right) \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + \lambda^2$$

([1] equation 12.4)



Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_o} \right)^2$$



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_0	Orifice diameter (m)
d	Internal pipe diameter (m)
β	Ratio of orifice to pipe diameters ()
A_o	Orifice cross-sectional area (m^2)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
NRe_o	Reynolds number in orifice ()
NRe	Reynolds number in pipe ()
r	Rounding radius (m)
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
K_o	Coefficient of local resistance ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m³)

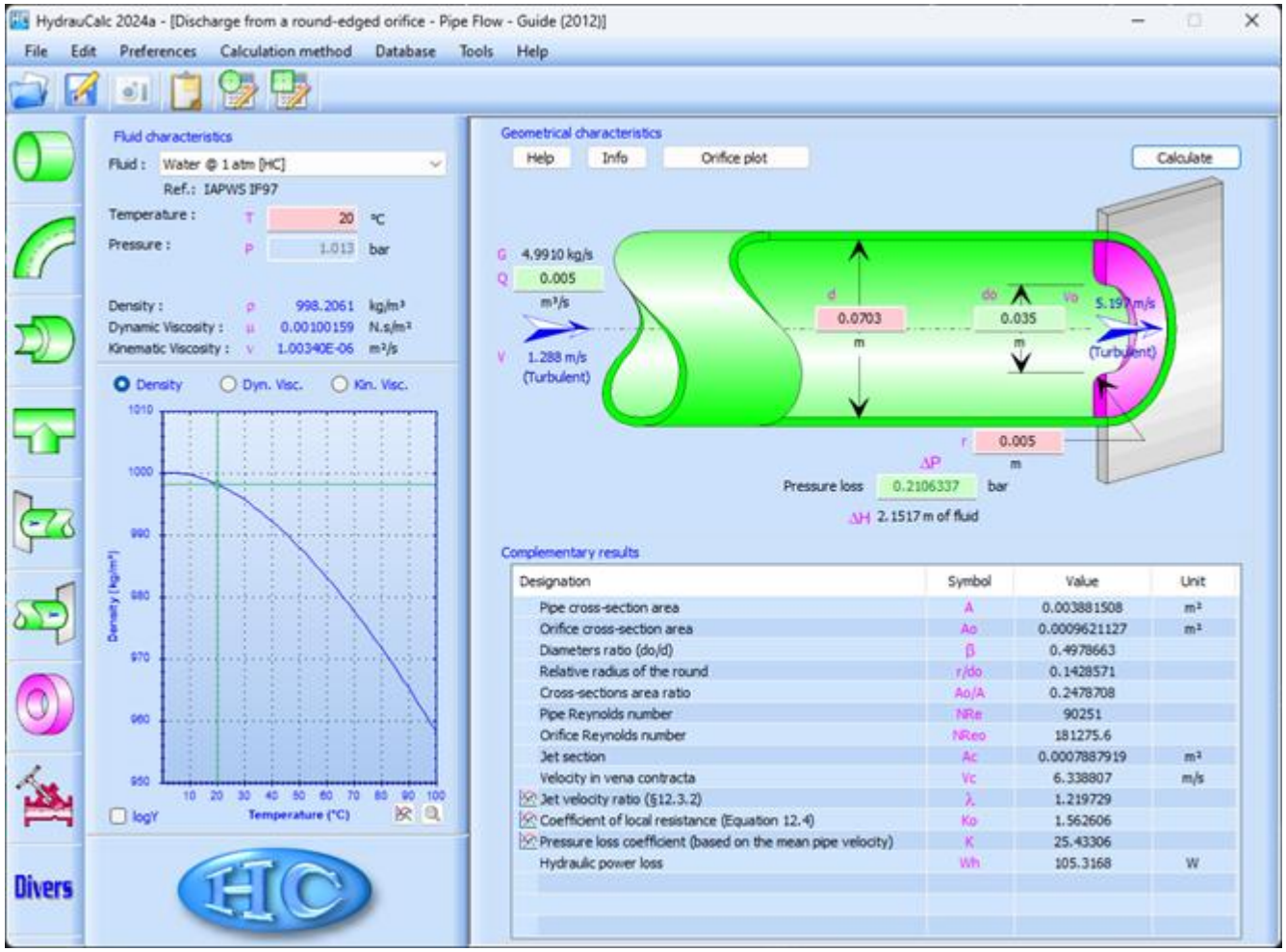
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime in orifice ($NRe_o \geq 10^4$)
- stabilized flow upstream of the orifice
- round radius less than the radius difference ($r < (d/2-d_0/2)$)

Example of application:

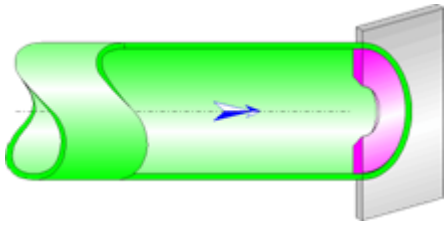


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.6.7 Discharge from a bevel-edged orifice

Circular Cross-Section

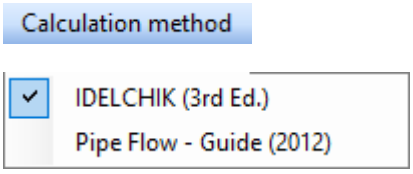


For the calculation of the pressure loss coefficient of a pipe discharge equipped with a bevel-edged orifice, the user can choose from one of the methods described in the following two reference documents:

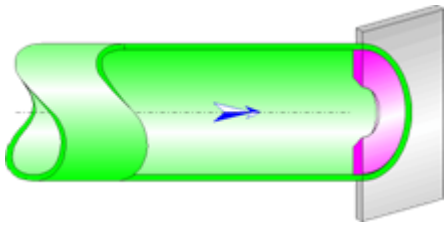
- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)".



2.6.7.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe discharge equipped with a bevel-edged orifice.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Orifice cross-section area (m^2):

$$F_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Mean velocity in pipe (m/s):

$$W_0 = \frac{Q}{F_0}$$

Mean velocity in orifice (m/s):

$$W_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$Re_0 = \frac{W_0 \cdot D_0}{\nu}$$

Reynolds number in orifice:

$$Re = \frac{W_{or} \cdot D_{or}}{\nu}$$

Local resistance coefficient (based on the mean pipe velocity):

- $Re \geq 10^5$

$$\zeta = \left[1 + \zeta' \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.75} + 2 \cdot \sqrt{\zeta'} \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.375}\right] \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

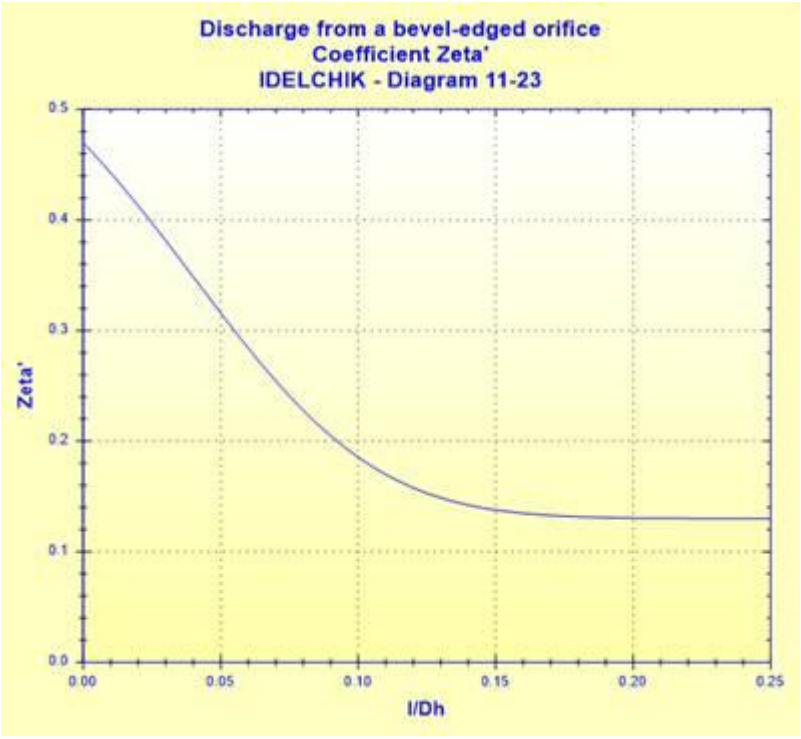
([1] diagram 11-23)

with :

Coefficient of effect of the orifice thickness:

$$\zeta' = 0.13 + 0.34 \cdot 10^{-\left(3.45 \cdot \frac{l}{D_h} + 88.4 \cdot \left(\frac{l}{D_h}\right)^{2.3}\right)}$$

([1] diagram 11-23 and 3-13)



■ Re < 10^5

Quadratic local resistance coefficient:

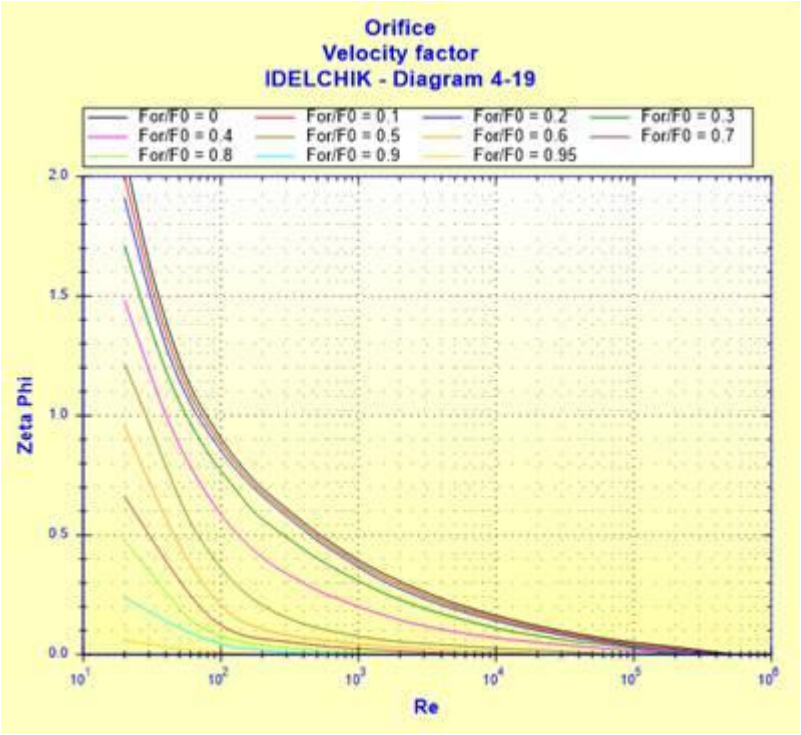
$$\zeta_{quad} = \left[1 + \zeta' \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.75} + 2 \cdot \sqrt{\zeta'} \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.375}\right] \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 11-23)

Velocity factor:

$$\zeta_\varphi = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$$

([1] diagram 4-19)

Local resistance coefficient:

- $30 < Re < 10^5$

$$\zeta = \zeta_{\varphi} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $10 < Re \leq 30$

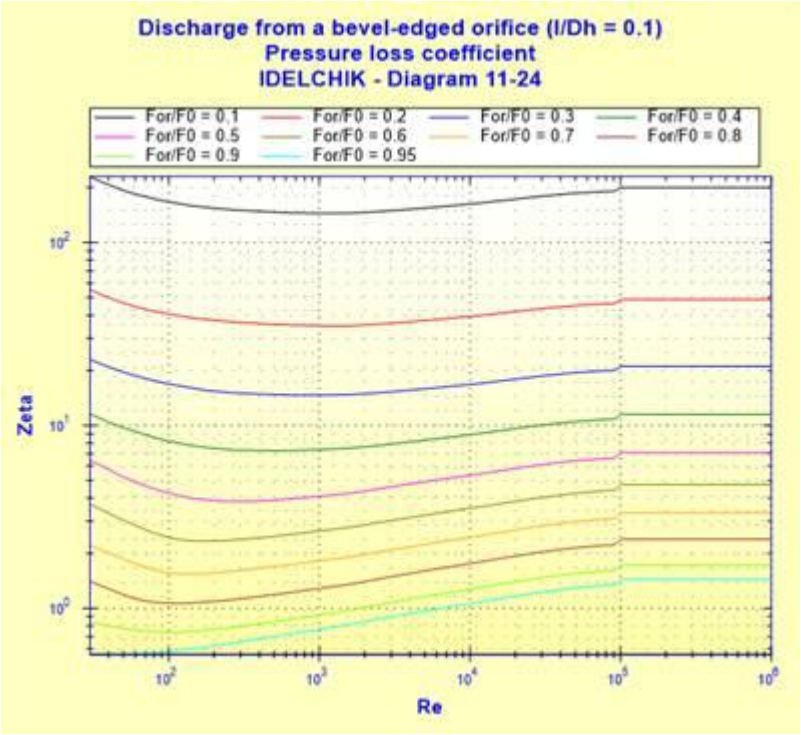
$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $Re \leq 10$

$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2$$

([1] diagram 11-24)



([1] diagram 11-24 with l/Dh = 0.1)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

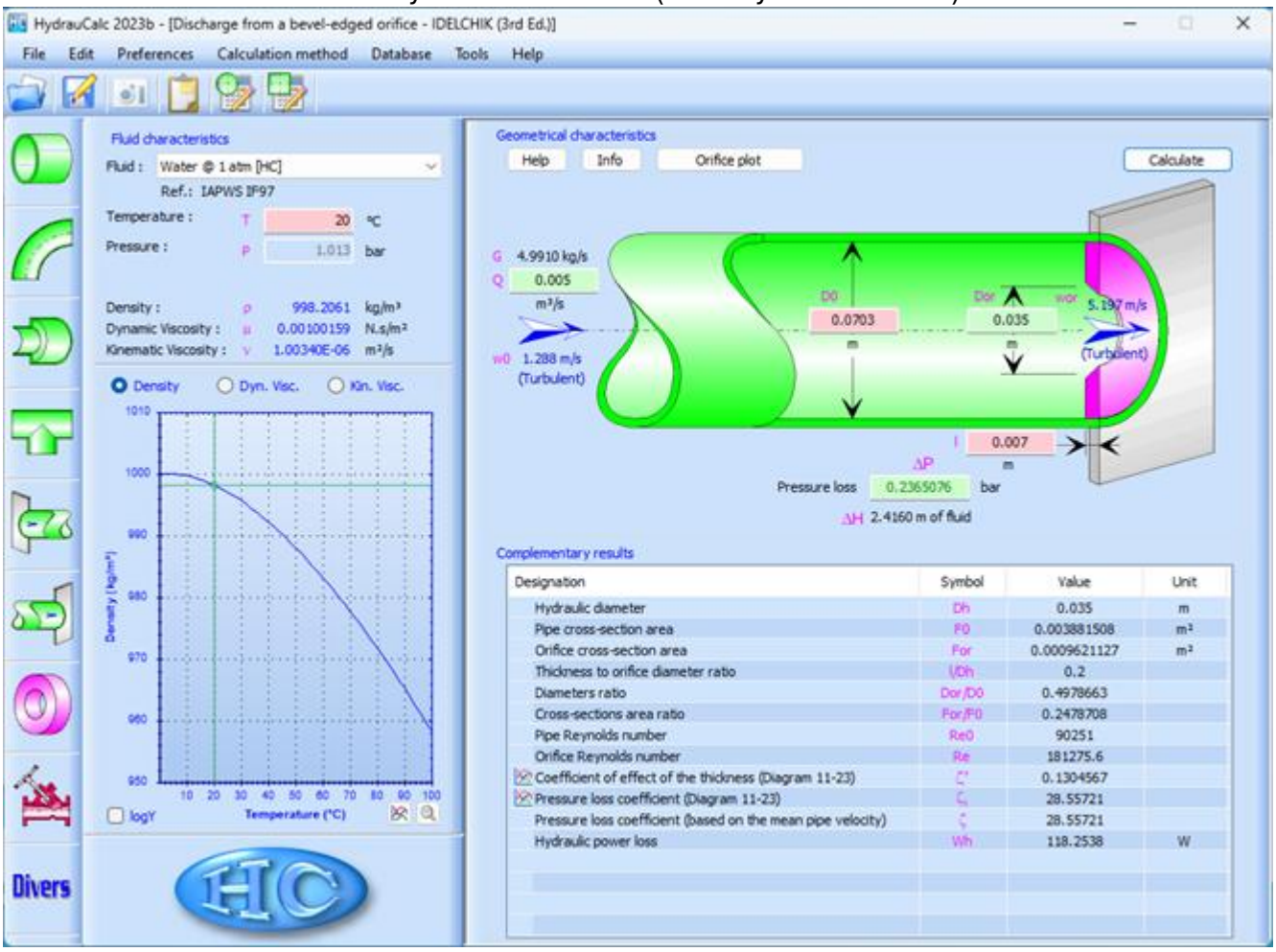
D_h	Hydraulic diameter (m)
D_0	Pipe internal diameter (m)
F_0	Pipe cross-sectional area (m^2)
D_{or}	Orifice diameter (m)

F_{or}	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in pipe (m/s)
w_{or}	Mean velocity in orifice (m/s)
Re_0	Reynolds number in pipe ()
Re	Reynolds number in orifice ()
ζ'	Coefficient of effect of the orifice thickness ()
l	Orifice thickness (m)
ζ_{quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- angle at the top of the truncated cone between 40 ° and 60 °

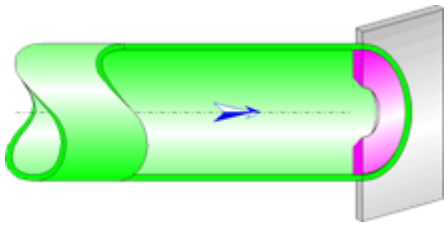
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.6.7.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a discharge from a bevel-edged orifice.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Ratio of orifice to pipe diameters:

$$\beta = \frac{d_o}{d}$$

Pipe cross-sectional area (m²):

$$A = \pi \cdot \frac{d^2}{4}$$

Orifice cross-sectional area (m²):

$$A_o = \pi \cdot \frac{d_o{}^2}{4}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

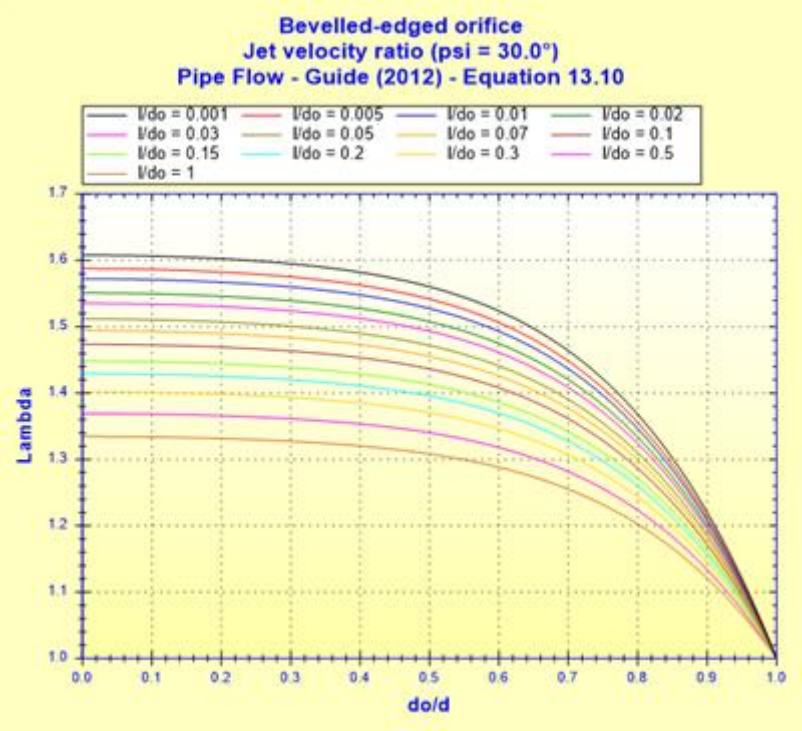
Reynolds number in orifice:

$$N_{Re_O} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left[1 - C_b \cdot \left(\frac{l}{d_0} \right)^{\frac{1-\sqrt[4]{\beta^5}}{2}} \right] \cdot \left(1 - 0.215 \cdot \beta^2 - 0.785 \cdot \beta^5 \right)$$

([1] equation 13.10)

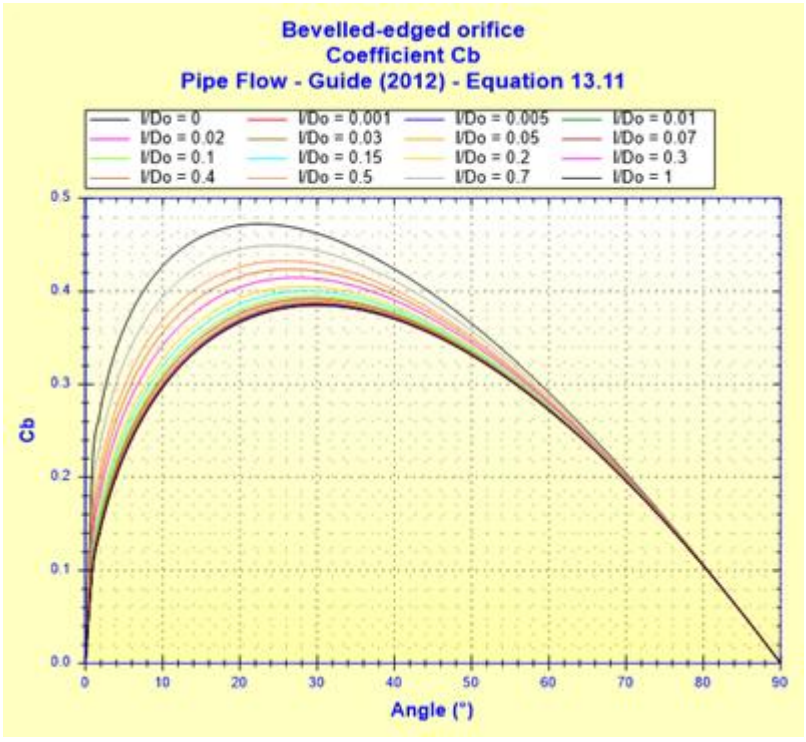


with:

Coefficient of effect of the bevel angle:

$$C_b = \left(1 - \frac{\Psi}{90}\right) \cdot \left(\frac{\Psi}{90}\right)^{\frac{1}{2 + l/d_o}}$$

([1] equation 13.11)



(with ψ = 30°)

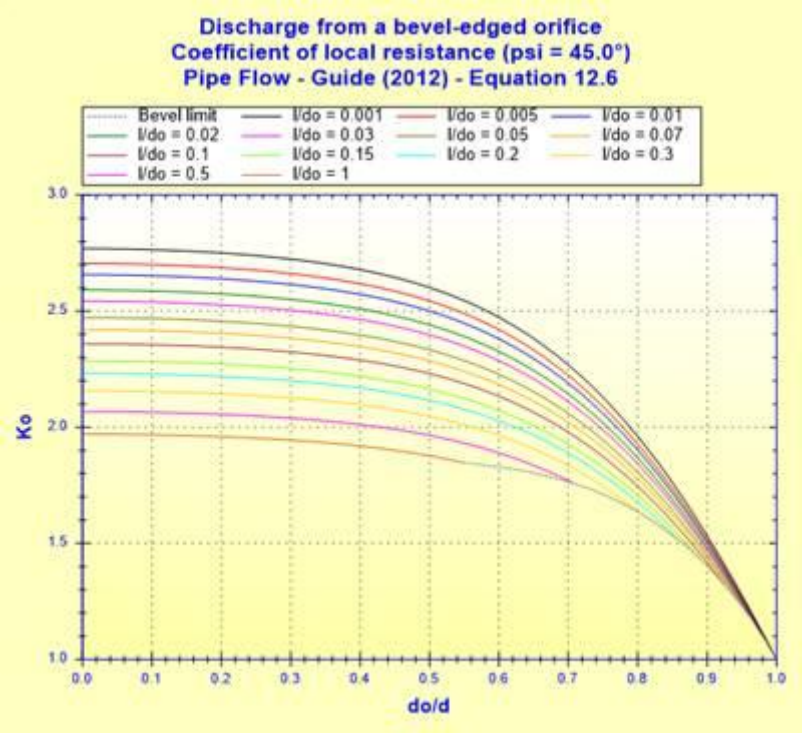
Velocity in vena contracta:

$$V_c = V_0 \cdot \lambda$$

Coefficient of local resistance ($NRe_o \geq 10^4$):

$$K_o = 0.0696 \cdot \left(1 - C_b \cdot \frac{l}{d_0}\right) \cdot \left(1 - 0.42 \cdot \sqrt{\frac{l}{d_0}} \cdot \beta^2\right) \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + \lambda^2$$

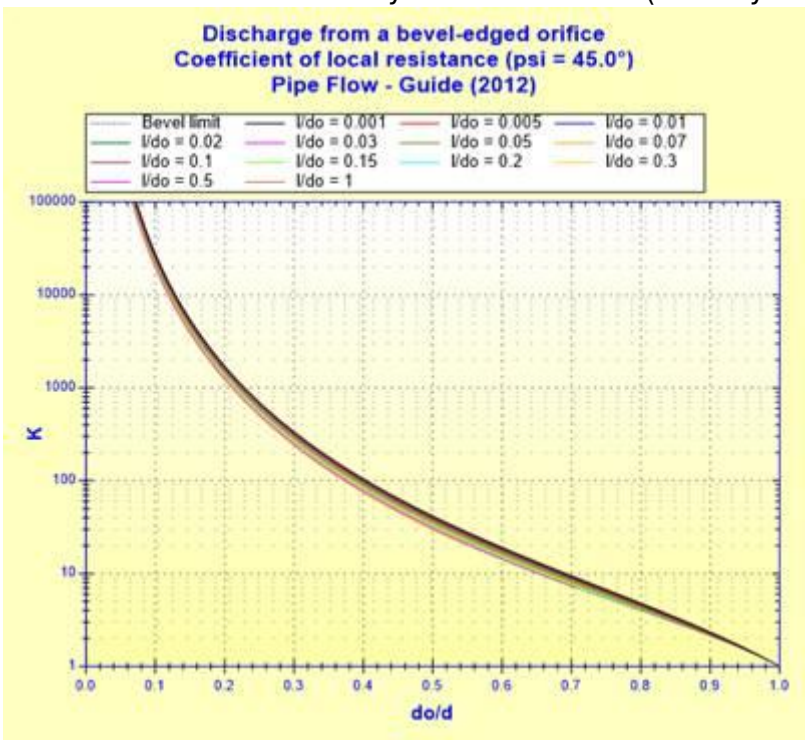
([1] equation 12.6)



(with ψ = 45°)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_o}\right)^2$$



(with ψ = 45°)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

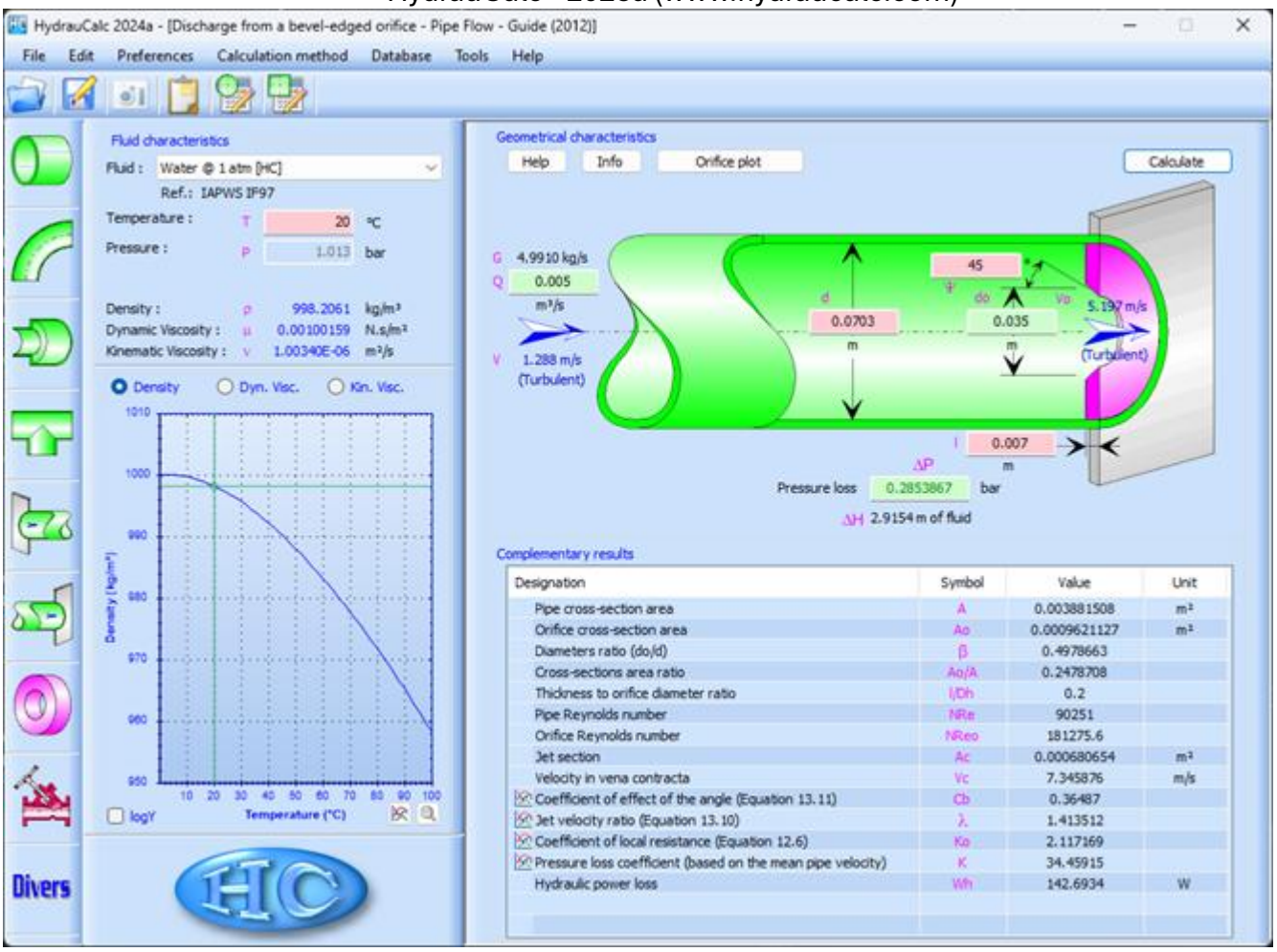
d_0	Orifice diameter (m)
d	Internal pipe diameter (m)
β	Ratio of orifice to pipe diameters ()
A_o	Orifice cross-sectional area (m^2)
A	Pipe cross-sectional area (m^2)

Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
NRe_o	Reynolds number in orifice ()
NRe	Reynolds number in pipe ()
l	Thickness orifice (m)
ψ	Bevel angle (°)
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
C_b	Coefficient of effect of the bevel angle ()
K_o	Coefficient of local resistance ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in orifice ($NRe_o \geq 10^4$)
- stabilized flow upstream of the orifice
- bevel angle less than or equal to: $\psi \leq tg^{-1}((d - d_o) / (2\ l))$

Example of application:

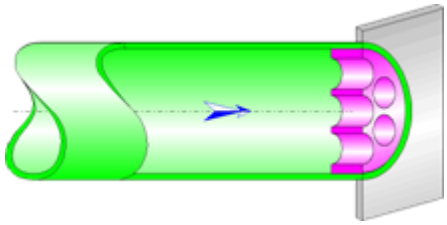


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.6.8 Discharge from a thick-edged grid

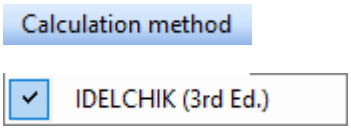
Circular Cross-Section



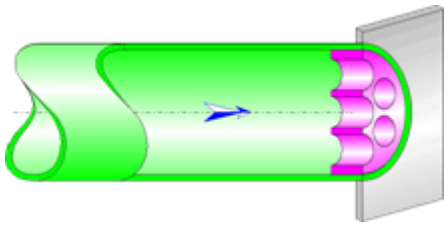
The calculation method used to calculate the pressure loss coefficient of a pipe discharge equipped with a thick-edged grid is described in the following reference document:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

The only calculation method offered appears in the "Calculation method" menu and is activated by default.



2.6.8.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe discharge equipped with a thick-edged grid. Moreover, the head loss due to friction of the fluid on the inner walls of the holes is also taken into account in this component and is calculated with Darcy's formula.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Cross-section area of one hole (m²):

$$f_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Clear cross-sectional area of the grid (m²):

$$F_{or} = f_{or} \cdot N$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in holes (m/s):

$$w_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Reynolds number in holes:

$$\mathrm{Re} = \frac{w_{or} \cdot D_{or}}{\nu}$$

Relative roughness in holes walls:

$$\bar{\Delta} = \frac{\Delta}{D_{or}}$$

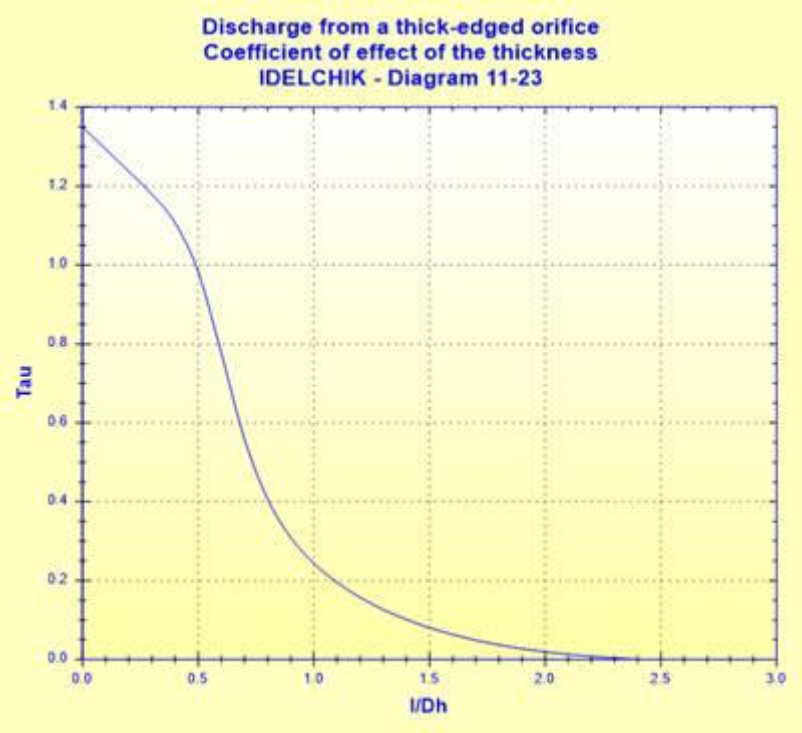
Coefficient of effect of the grid thickness:

$$\tau = \left(2.4 - \frac{l}{D_h}\right) \cdot 10^{-\varphi\left(\frac{l}{D_h}\right)}$$

([1] diagram 11-23 and 3-13)

with:

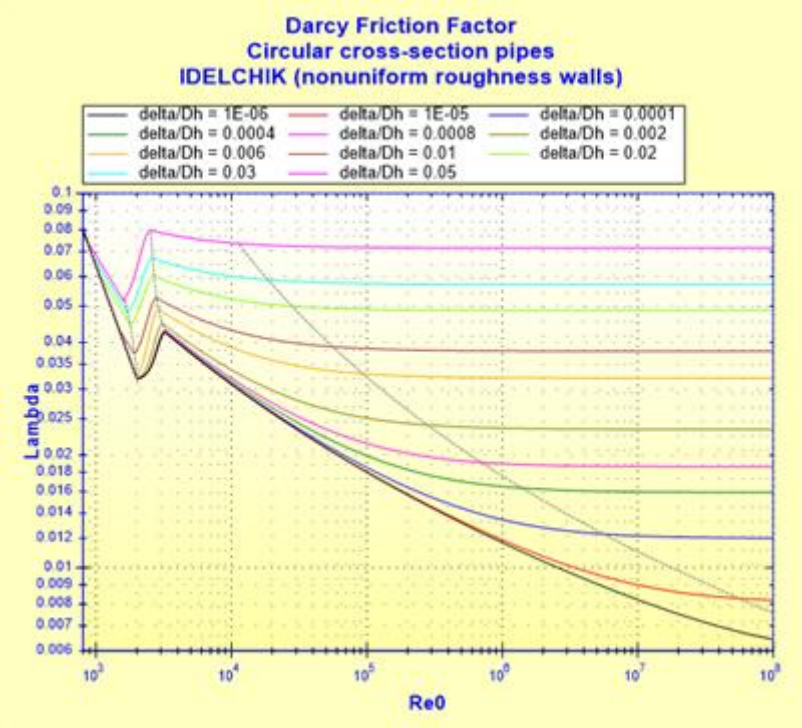
$$\varphi\left(\frac{l}{D_h}\right) = 0.25 + \frac{0.535 \cdot \left(\frac{l}{D_h}\right)^8}{0.05 + \left(\frac{l}{D_h}\right)^7}$$



Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}, \frac{\Delta}{D_h}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)

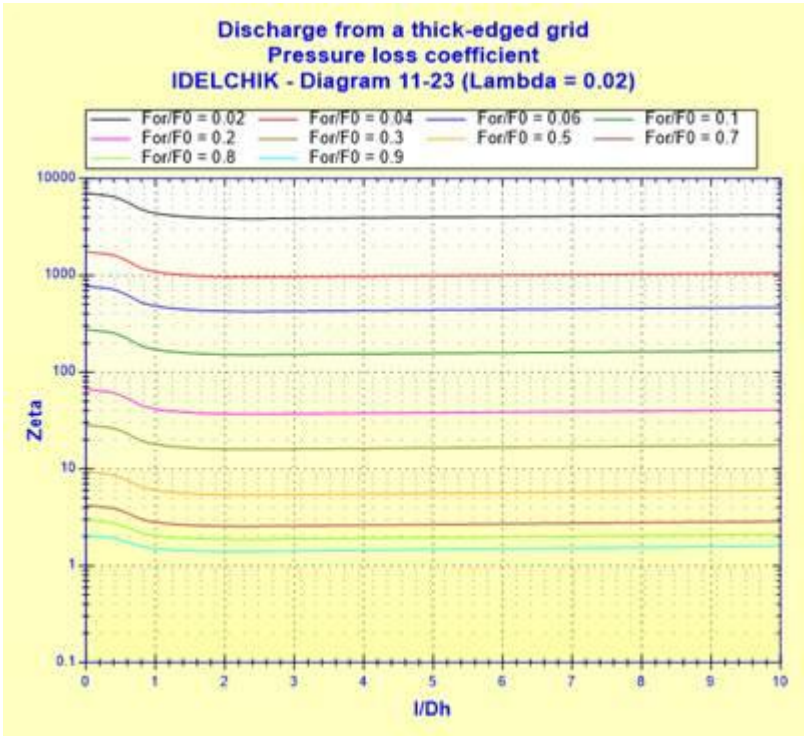


Local resistance coefficient (based on the mean pipe velocity):

- Re ≥ 10^5

$$\zeta = \left[1 + 0.5 \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.75} + \tau \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.375} + \lambda \cdot \frac{l}{D_h}\right] \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 11-23)



([1] diagram 11-23 with λ = 0.02)

■ $Re < 10^5$

Quadratic local resistance coefficient:

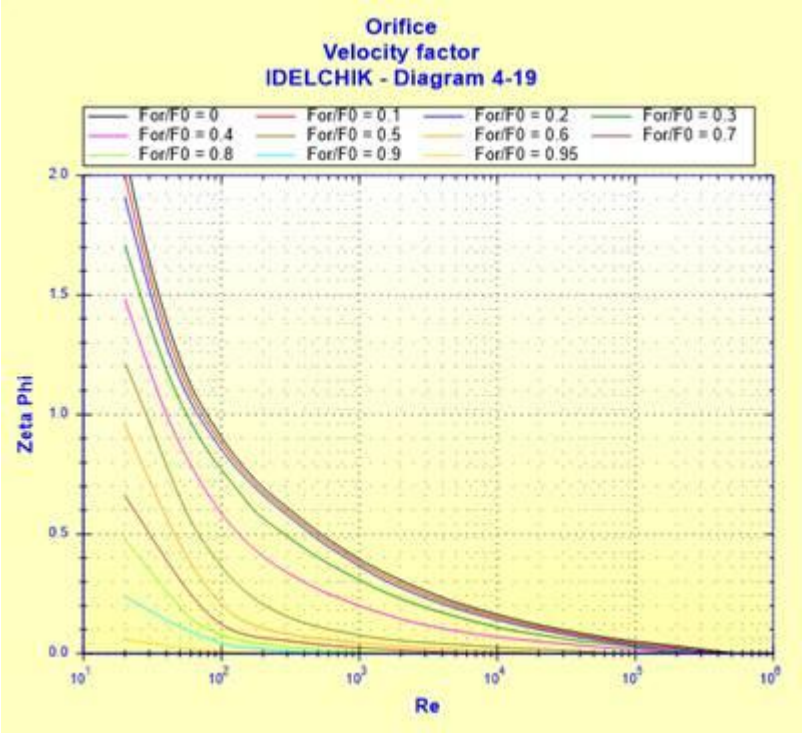
$$\zeta_{quad} = \left[1 + 0.5 \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.75} + \tau \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.375} + \lambda \cdot \frac{l}{D_h}\right] \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 11-23)

Velocity factor:

$$\zeta_\varphi = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$$

([1] diagram 4-19)

Local resistance coefficient:

- $30 < Re < 10^5$

$$\zeta = \zeta_{\varphi} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $10 < Re \leq 30$

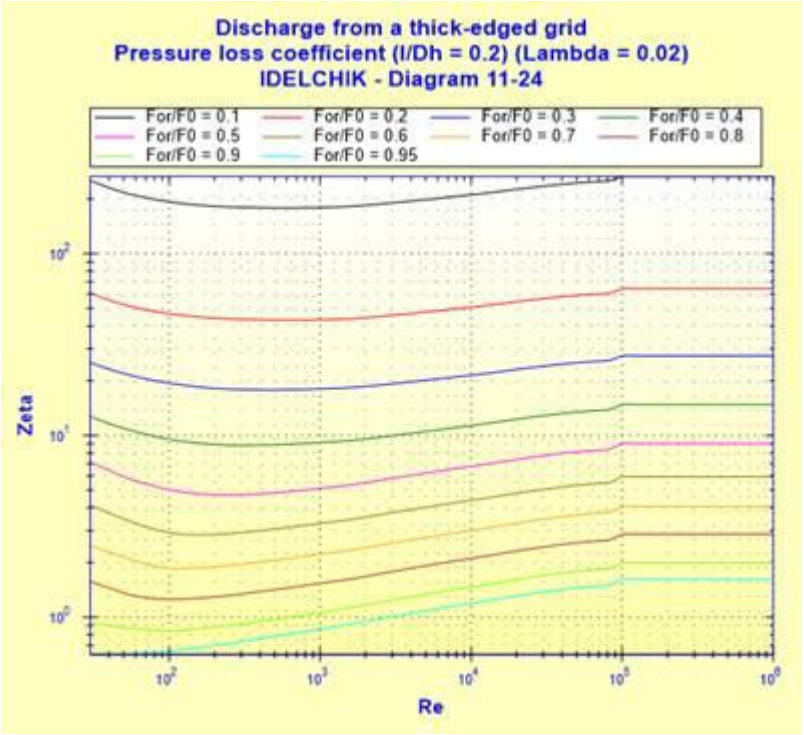
$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $Re \leq 10$

$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2$$

([1] diagram 11-24)



([1] diagram 11-24 with l/Dh = 0.2 and λ = 0.02)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

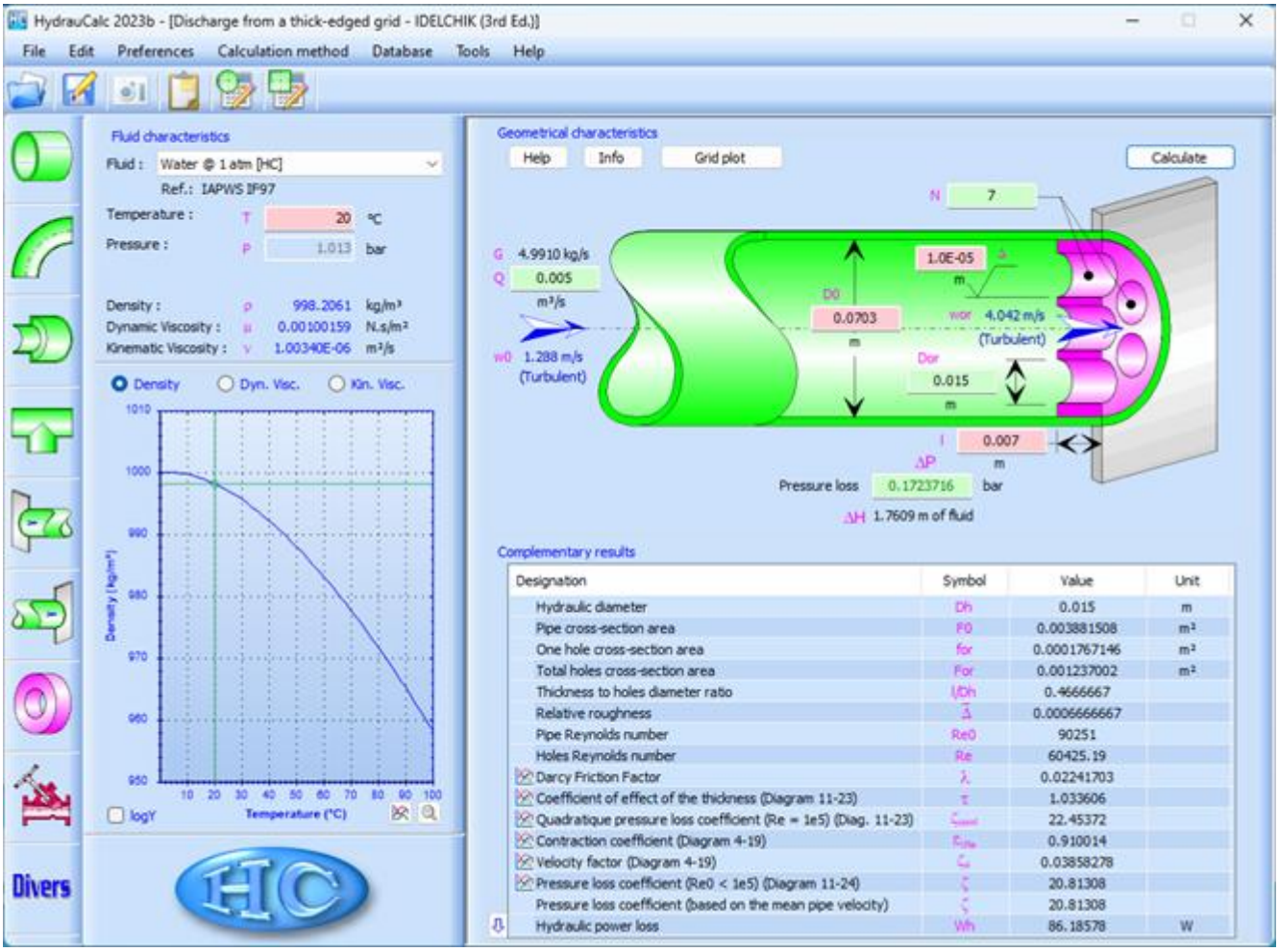
D_h	Hydraulic diameter (m)
D_0	Pipe internal diameter (m)
F_0	Pipe cross-sectional area (m^2)
N	Holes number ()

D_{or}	Holes diameter (m)
f_{or}	Cross-section area of one hole (m^2)
F_{or}	Clear cross-sectional area of the grid (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in pipe (m/s)
w_{or}	Mean velocity in holes (m/s)
Re_0	Reynolds number in pipe ()
Re	Reynolds number in holes ()
Δ	Absolute roughness of holes walls (m)
$\bar{\Delta}$	Relative roughness of holes walls ()
l	Grid thickness (m)
τ	Coefficient of effect of the grid thickness ()
λ	Darcy friction coefficient in holes ()
ζ_{quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the grid
- thickness to holes diameter ratio (l/D_{or}) greater than 0.015

Example of application:

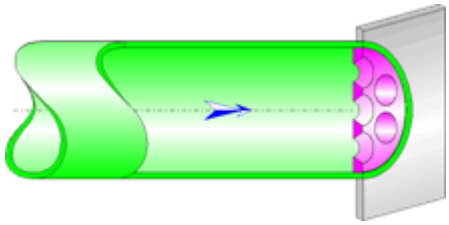


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.6.9 Discharge from a sharp-edged grid

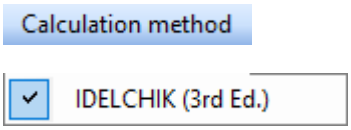
Circular Cross-Section



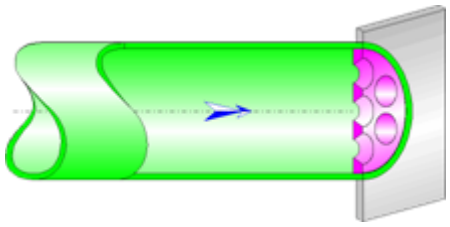
The calculation method used to calculate the pressure loss coefficient of a pipe discharge equipped with a sharp-edged grid is described in the following reference document:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

The only calculation method offered appears in the "Calculation method" menu and is activated by default.



2.6.9.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe discharge equipped with a sharp-edged grid.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Cross-section area of one hole (m²):

$$f_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Clear cross-sectional area of the grid (m²):

$$F_{or} = f_{or} \cdot N$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in holes (m/s):

$$w_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Reynolds number in holes:

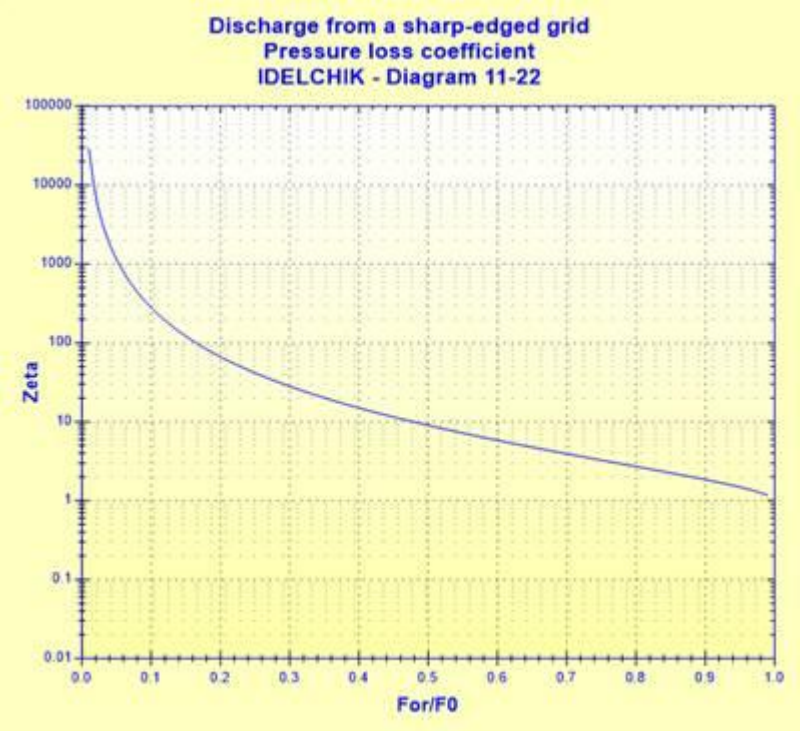
$$\mathrm{Re} = \frac{w_{or} \cdot D_{or}}{\nu}$$

Local resistance coefficient (based on the mean pipe velocity):

- $\mathrm{Re} \geq 10^5$

$$\zeta = \left[1 + 0.707 \cdot \sqrt{\left(1 - \frac{F_{or}}{F_0}\right)}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 11-22)



■ $Re < 10^5$

Quadratic local resistance coefficient:

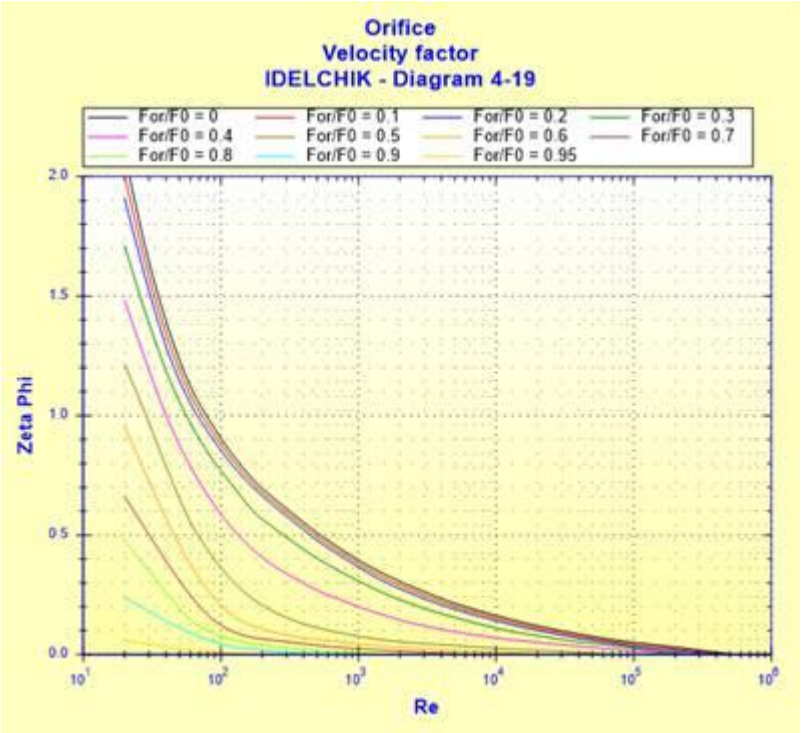
$$\zeta_{quad} = \left[1 + 0.707 \cdot \sqrt{\left(1 - \frac{F_{or}}{F_0}\right)}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 11-22)

Velocity factor:

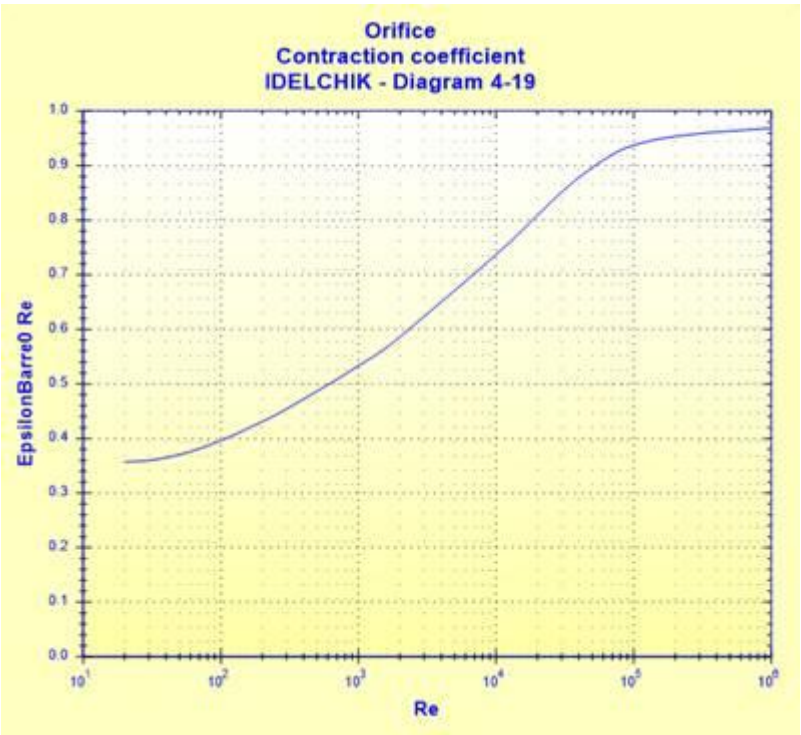
$$\zeta_\varphi = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$ ([1] diagram 4-19)



Local resistance coefficient:

- $30 < \mathrm{Re} < 10^5$

$$\zeta = \zeta_{\varphi} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0\mathrm{Re}} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $10 < \mathrm{Re} \leq 30$

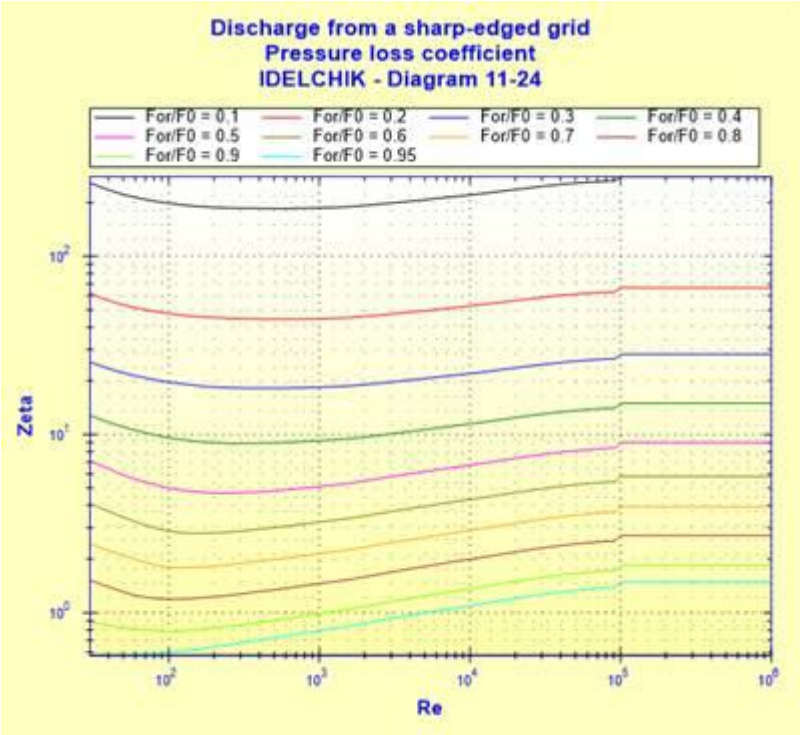
$$\zeta = \frac{33}{\mathrm{Re}} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0\mathrm{Re}} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $\mathrm{Re} \leq 10$

$$\zeta = \frac{33}{\mathrm{Re}} \cdot \left(\frac{F_0}{F_{or}} \right)^2$$

([1] diagram 11-24)



Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

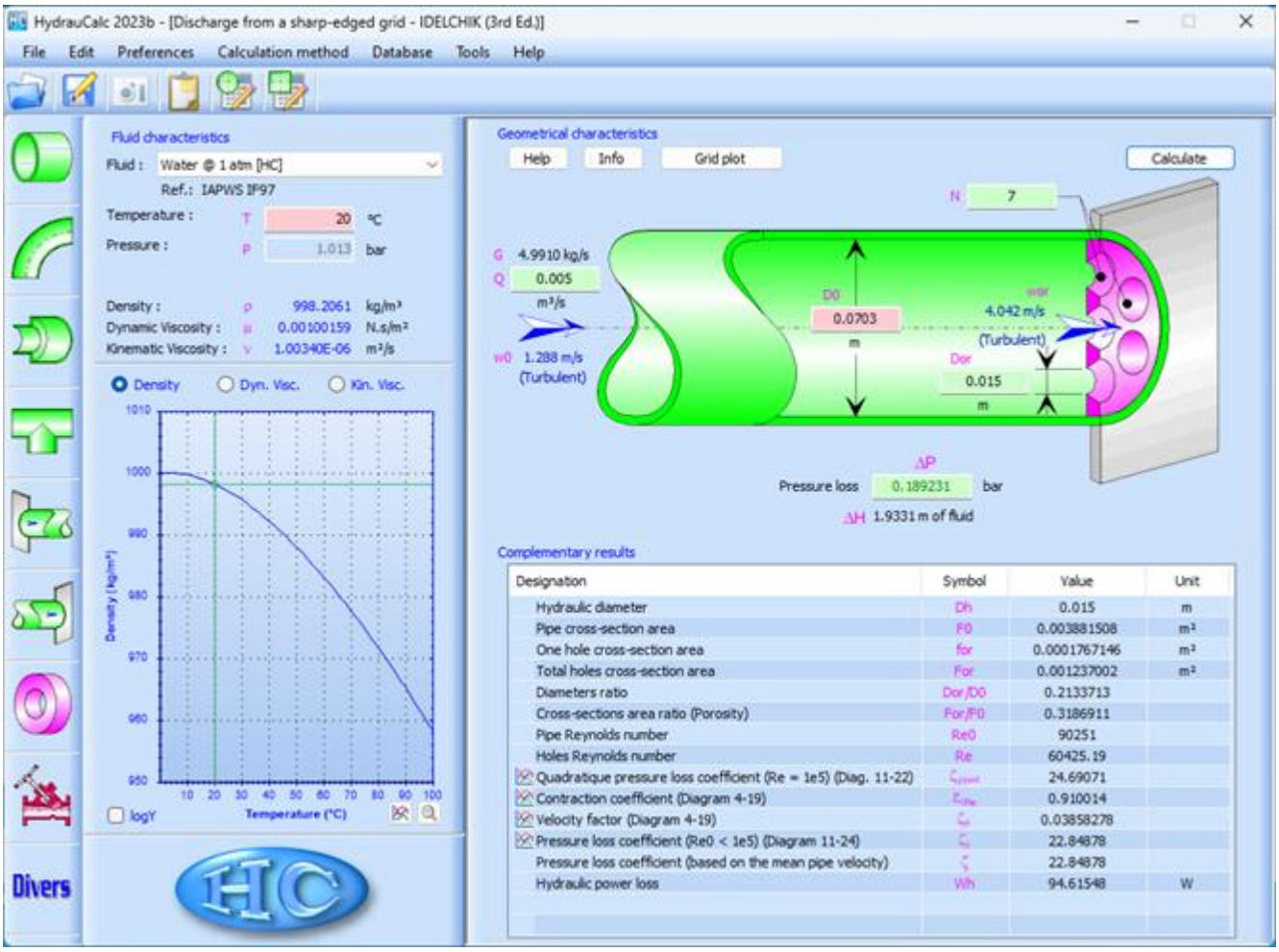
D_h	Hydraulic diameter (m)
D_0	Pipe internal diameter (m)
F_0	Pipe cross-sectional area (m^2)
N	Holes number ()
D_{or}	Holes diameter (m)
f_{or}	Cross-section area of one hole (m^2)
F_{or}	Clear cross-sectional area of the grid (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in pipe (m/s)
w_{or}	Mean velocity in holes (m/s)
l	Grid thickness (m)
Re_0	Reynolds number in pipe ()
Re	Reynolds number in holes ()
ζ_{quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the grid
- thickness to holes diameter ratio (l/D_{or}) lower than or equal to 0.015

Example of application:

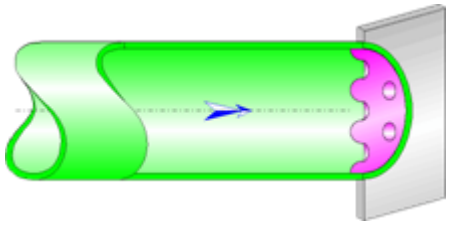


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.6.10 Discharge from a round-edged grid

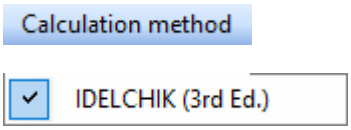
Circular Cross-Section



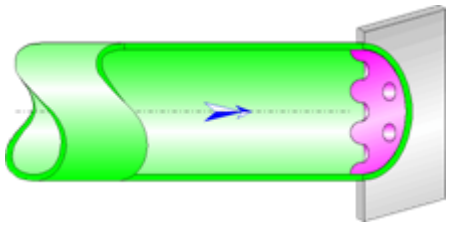
The calculation method used to calculate the pressure loss coefficient of a pipe discharge equipped with a round-edged grid is described in the following reference document:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

The only calculation method offered appears in the "Calculation method" menu and is activated by default.



2.6.10.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe discharge equipped with a round-edged grid.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Cross-section area of one hole (m²):

$$f_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Clear cross-sectional area of the grid (m²):

$$F_{or} = f_{or} \cdot N$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in holes (m/s):

$$w_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Reynolds number in holes:

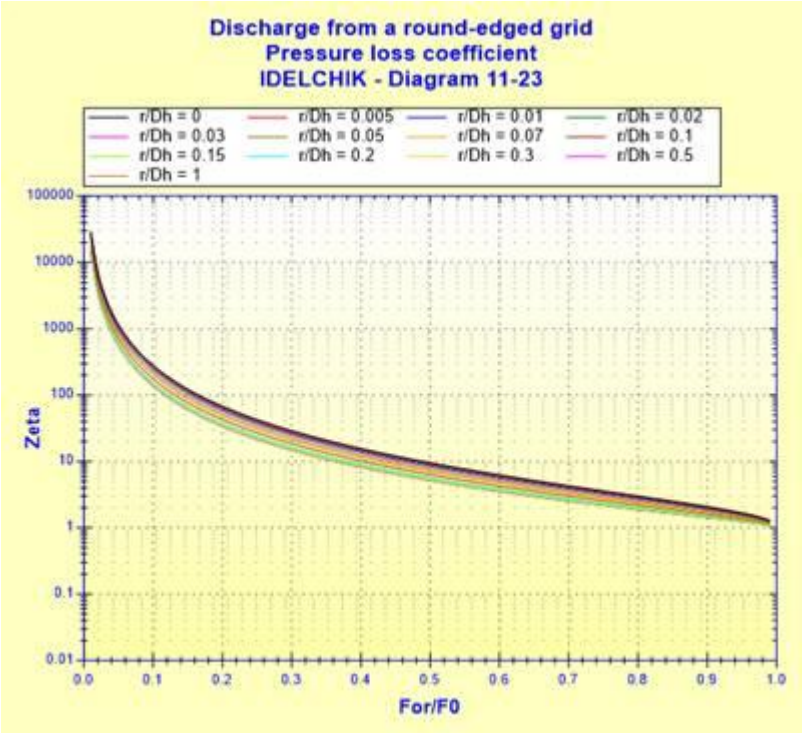
$$\mathrm{Re} = \frac{w_{or} \cdot D_{or}}{\nu}$$

Local resistance coefficient (based on the mean pipe velocity):

- $\mathrm{Re} \geq 10^5$

$$\zeta = \left[1 + \zeta' \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.75} + 2 \cdot \sqrt{\zeta'} \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.375}\right] \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 11-23)



with :

Coefficient of effect of the round:

$$\zeta' = 0.03 + 0.47 \cdot 10^{-7.7 \cdot \frac{r}{D_h}}$$

([1] diagram 11-23 and 3-13)

■ $Re < 10^5$

Quadratic local resistance coefficient:

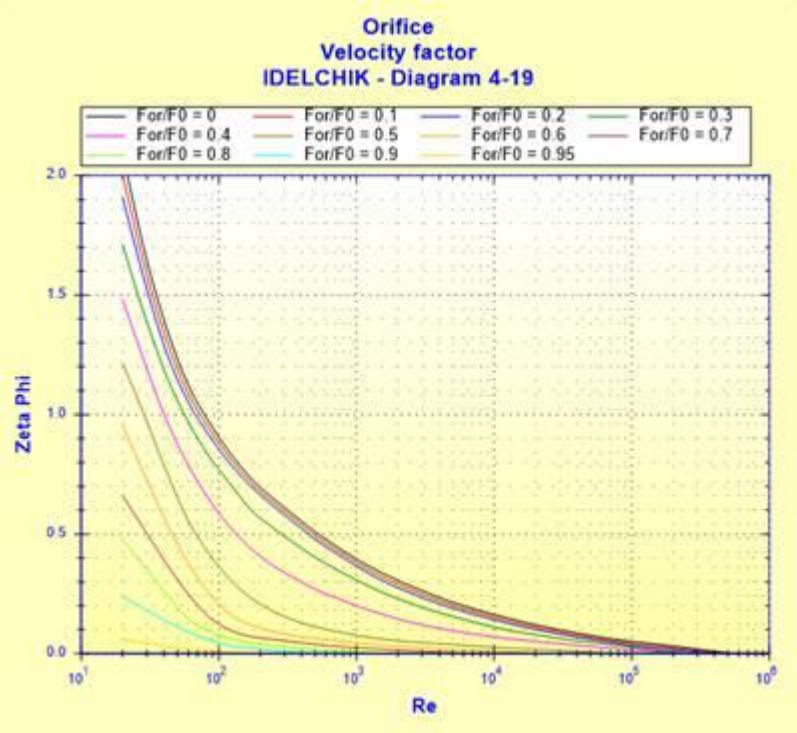
$$\zeta_{quad} = \left[1 + 0.707 - \sqrt{\left(1 - \frac{F_{or}}{F_0}\right)}\right]^2 \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 11-23)

Velocity factor:

$$\zeta_{\varphi} = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$$

([1] diagram 4-19)

Local resistance coefficient:

- $30 < Re < 10^5$

$$\zeta = \zeta_{\varphi} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \bar{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $10 < Re \leq 30$

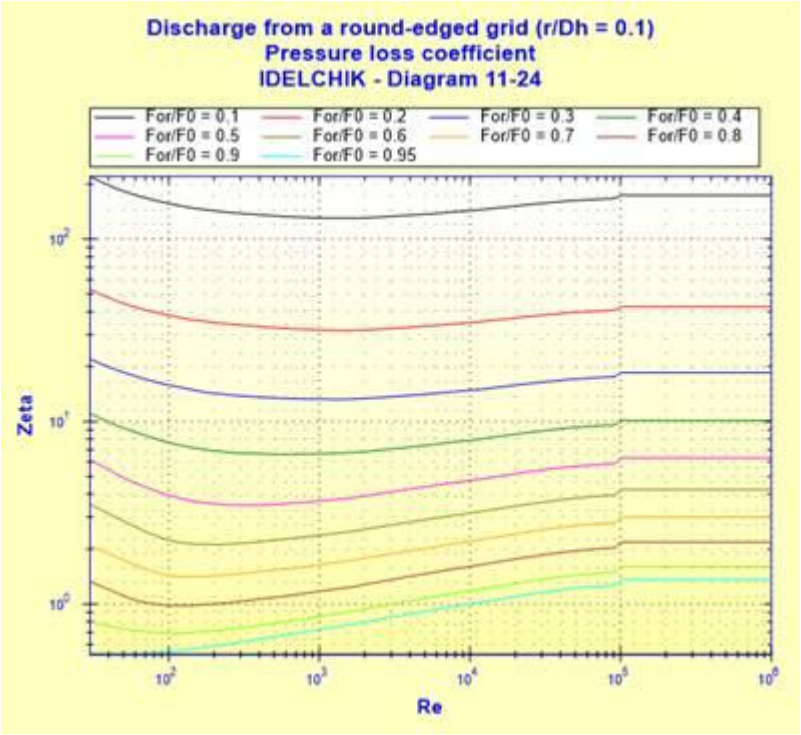
$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \bar{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $Re \leq 10$

$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2$$

([1] diagram 11-24)



([1] diagram 3-14 with r/Dh = 0.1)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_0	Pipe internal diameter (m)
F_0	Pipe cross-sectional area (m^2)
N	Holes number ()

D_{or} Holes diameter (m)

f_{or} Cross-section area of one hole (m^2)

F_{or} Clear cross-sectional area of the grid (m^2)

Q Volume flow rate (m^3/s)

G Mass flow rate (kg/s)

w_0 Mean velocity in pipe (m/s)

w_{or} Mean velocity in holes (m/s)

Re_0 Reynolds number in pipe ()

Re Reynolds number in holes ()

ζ' Coefficient of effect of the round ()

r Radius of the round (m)

ζ_{quad} Quadratic pressure loss coefficient determined as $Re = 10^5$ ()

ζ_{φ} Velocity factor ()

$\bar{\varepsilon}_{0Re}$ Contraction factor ()

ζ Pressure loss coefficient (based on the mean pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m^3)

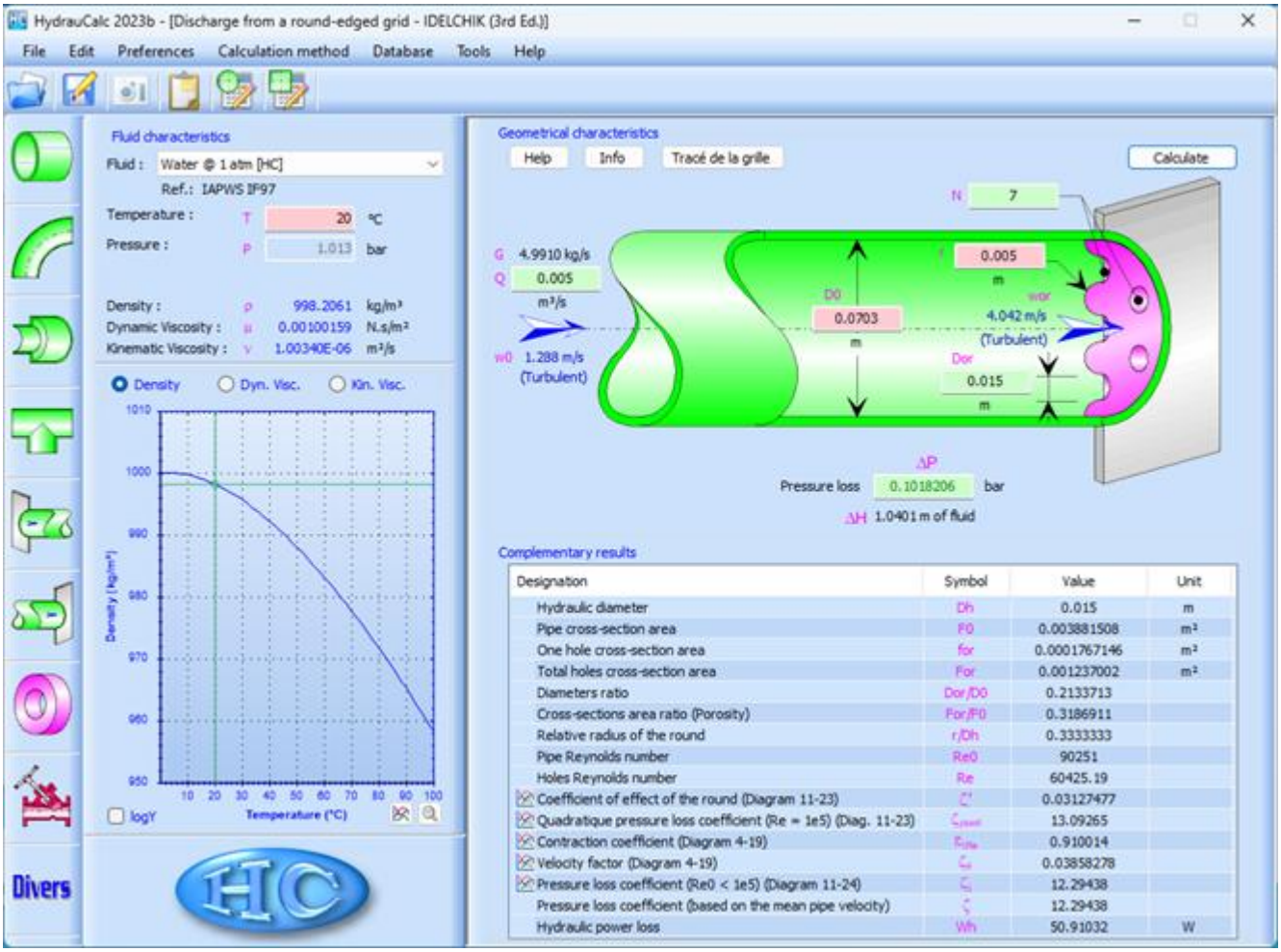
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the grid

Example of application:

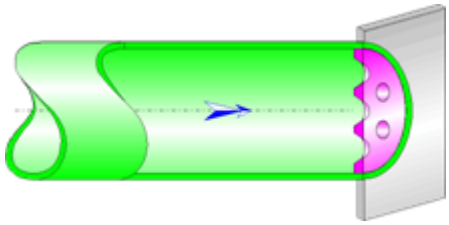


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.6.11 Discharge from a bevel-edged grid

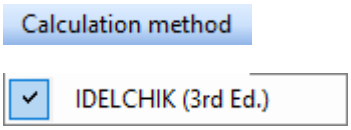
Circular Cross-Section



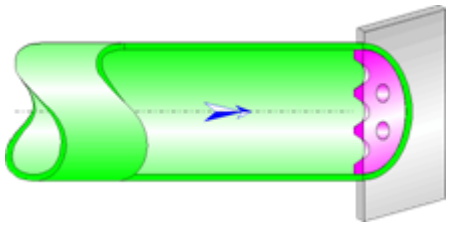
The calculation method used to calculate the pressure loss coefficient of a pipe discharge equipped with a bevel-edged grid is described in the following reference document:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

The only calculation method offered appears in the "Calculation method" menu and is activated by default.



2.6.11.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a pipe discharge equipped with a bevel-edged grid.

The head loss by friction in the piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_{or}$$

Pipe cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Cross-section area of one hole (m²):

$$f_{or} = \pi \cdot \frac{D_{or}^2}{4}$$

Clear cross-sectional area of the grid (m²):

$$F_{or} = f_{or} \cdot N$$

Mean velocity in pipe (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mean velocity in holes (m/s):

$$w_{or} = \frac{Q}{F_{or}}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Reynolds number in holes:

$$\mathrm{Re} = \frac{w_{or} \cdot D_{or}}{\nu}$$

Local resistance coefficient (based on the mean pipe velocity):

- $\mathrm{Re} \geq 10^5$

$$\zeta = \left[1 + \zeta' \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.75} + 2 \cdot \sqrt{\zeta'} \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.375}\right] \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

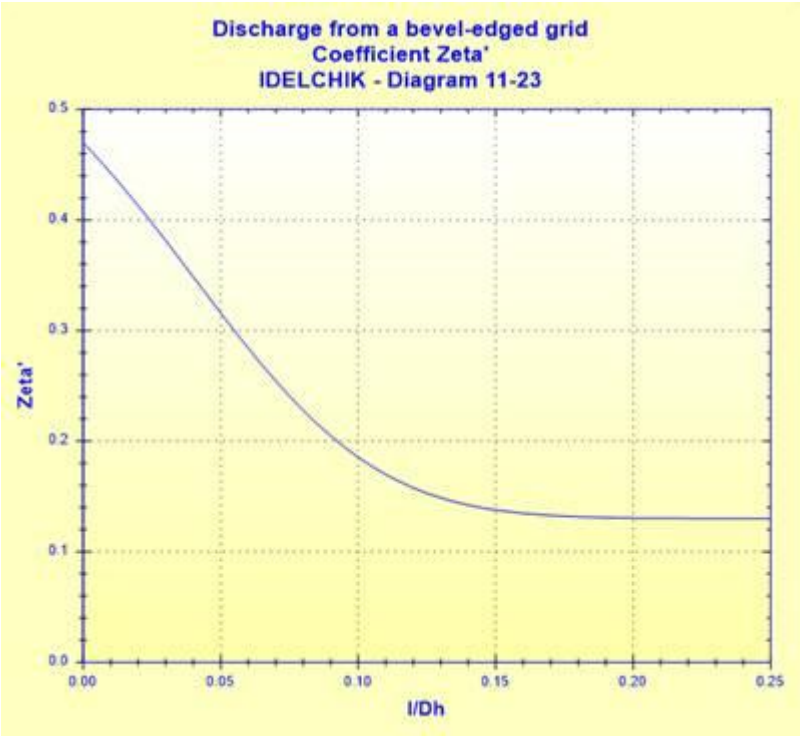
([1] diagram 11-23)

with :

Coefficient of effect of the grid thickness:

$$\zeta' = 0.13 + 0.34 \cdot 10^{-\left(3.45 \cdot \frac{l}{D_h} + 88.4 \cdot \left(\frac{l}{D_h}\right)^{2.3}\right)}$$

([1] diagram 11-23 and 3-13)



■ Re < 10^5

Quadratic local resistance coefficient:

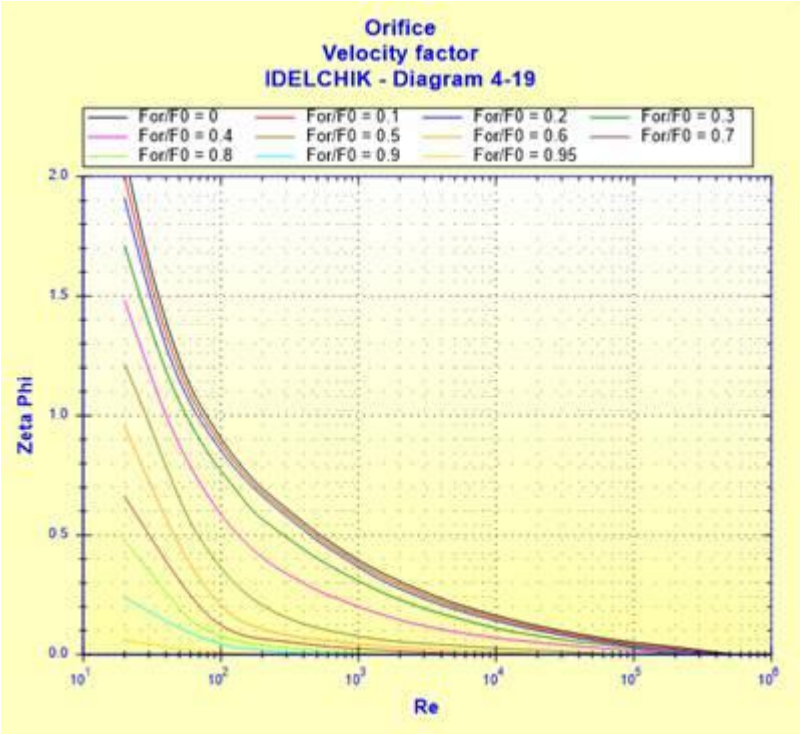
$$\zeta_{quad} = \left[1 + \zeta' \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.75} + 2 \cdot \sqrt{\zeta'} \cdot \left(1 - \frac{F_{or}}{F_0}\right)^{0.375}\right] \cdot \left(\frac{F_0}{F_{or}}\right)^2$$

([1] diagram 11-23)

Velocity factor:

$$\zeta_\varphi = f\left(\mathrm{Re}, \frac{F_{or}}{F_0}\right)$$

([1] diagram 4-19)



Contraction factor:

$$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re})$$

([1] diagram 4-19)

Local resistance coefficient:

- $30 < Re < 10^5$

$$\zeta = \zeta_{\varphi} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $10 < Re \leq 30$

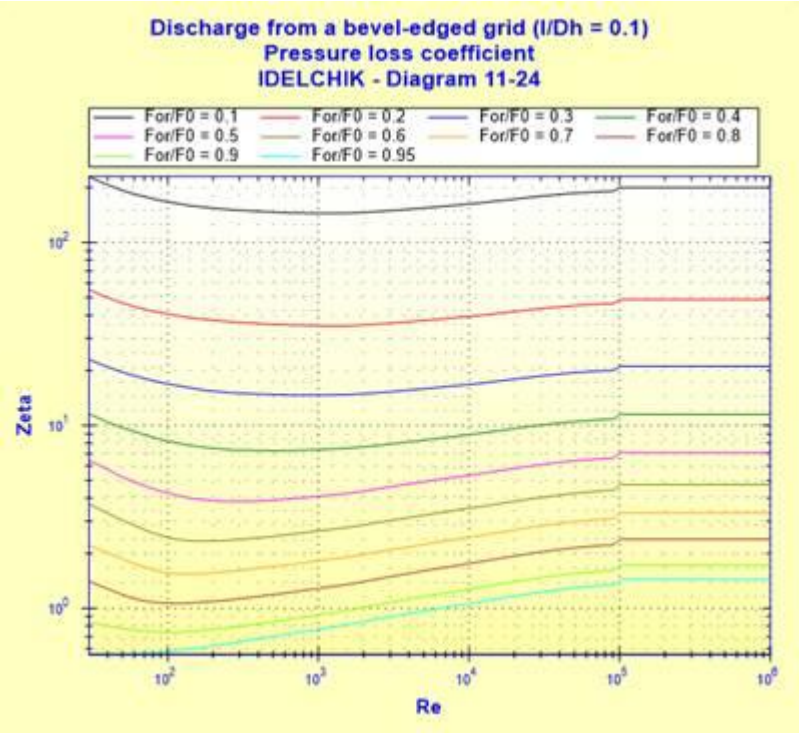
$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{quad}$$

([1] diagram 11-24)

- $Re \leq 10$

$$\zeta = \frac{33}{Re} \cdot \left(\frac{F_0}{F_{or}} \right)^2$$

([1] diagram 11-24)



([1] diagram 11-24 with l/Dh = 0.1)

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_0^{\,2}}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_0^{\,2}}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

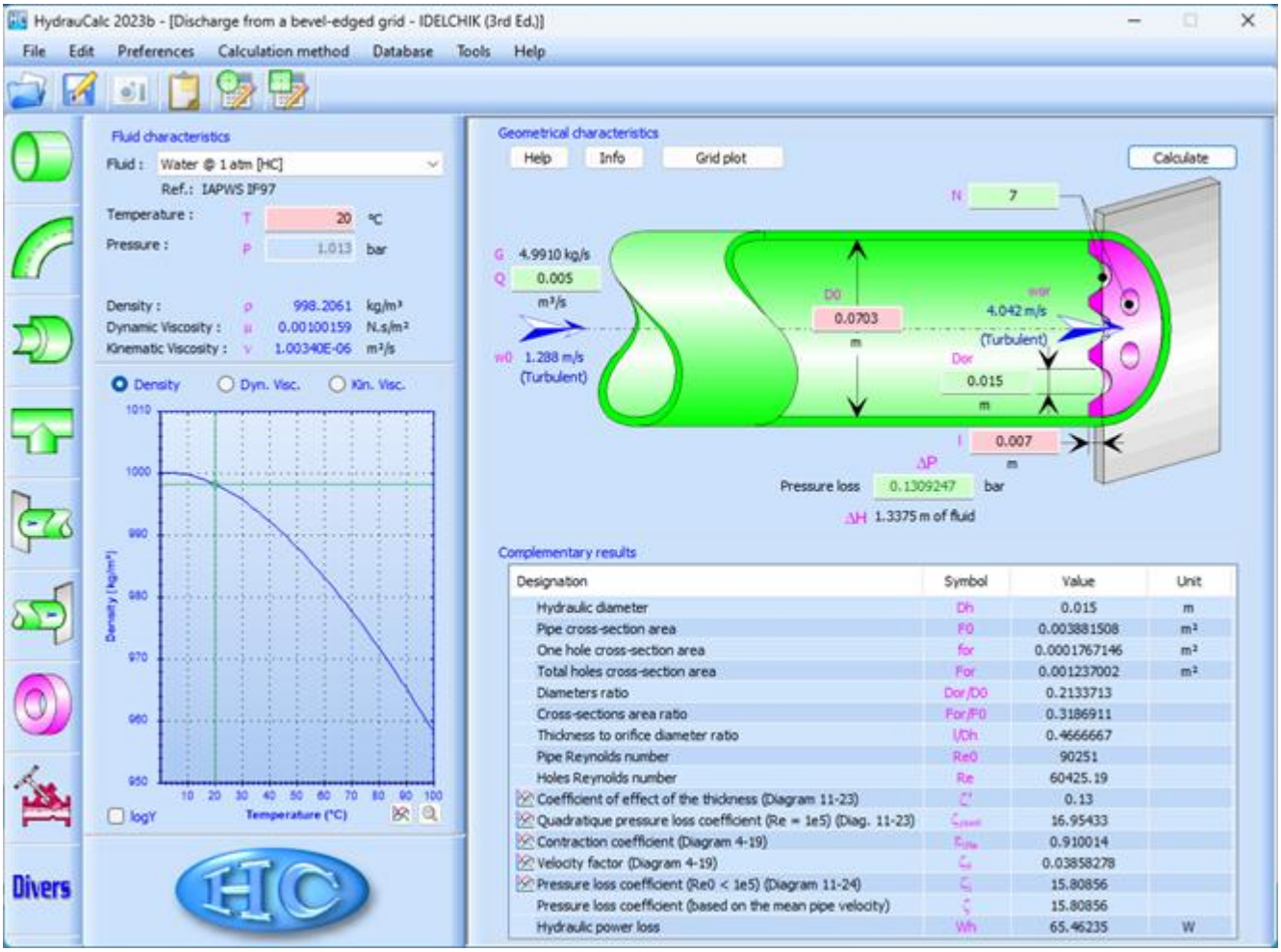
D_h	Hydraulic diameter (m)
D_0	Pipe internal diameter (m)
F_0	Pipe cross-sectional area (m^2)
N	Holes number ()

D_{or}	Holes diameter (m)
f_{or}	Cross-section area of one hole (m^2)
F_{or}	Clear cross-sectional area of the grid (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_0	Mean velocity in pipe (m/s)
w_{or}	Mean velocity in holes (m/s)
l	Grid thickness (m)
Re_0	Reynolds number in pipe ()
Re	Reynolds number in holes ()
ζ'	Coefficient of effect of the grid thickness ()
ζ_{quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the grid

Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.7 Restriction orifices

This subsection regroups the set of restriction orifices that can be modeled and calculated. The types of restriction orifice available are:

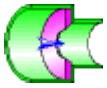
- Thick-edged orifice

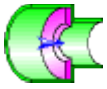
- Sharp-edged orifice

- Round-edged orifice

- Bevel-edged orifice

- Thick-edged Orifice (with pipe contraction)

- Sharp-edged orifice (with pipe contraction)

- Round-edged orifice (with pipe contraction)

- Bevel-edged orifice (with pipe contraction)

- Thick-edged Orifice (with pipe expansion)

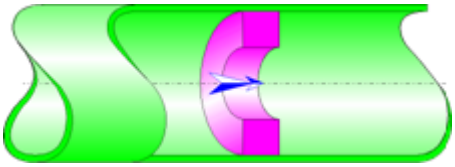
- Sharp-edged orifice (with pipe expansion)

- Round-edged orifice (with pipe expansion)

- Bevel-edged orifice (with pipe expansion)

2.7.1 Thick-edged orifice

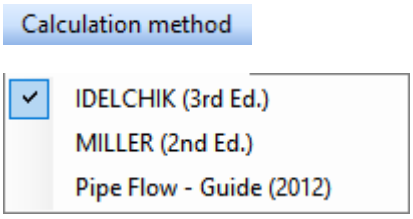
Circular Cross-Section



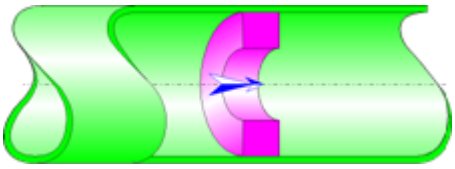
For the calculation of the pressure loss coefficient of thick-edged orifices, the user can choose from one of the methods described in the following three reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.7.1.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a thick-edged orifice installed in a straight pipe. Moreover, the head loss due to friction of the fluid on the inner walls of the orifice is also taken into account in this component and is calculated with Darcy's formula.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Pipe cross-section area (m²):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Orifice cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity in pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in orifice (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in orifice:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Relative roughness in orifice walls:

$$\bar{\Delta} = \frac{\Delta}{D_0}$$

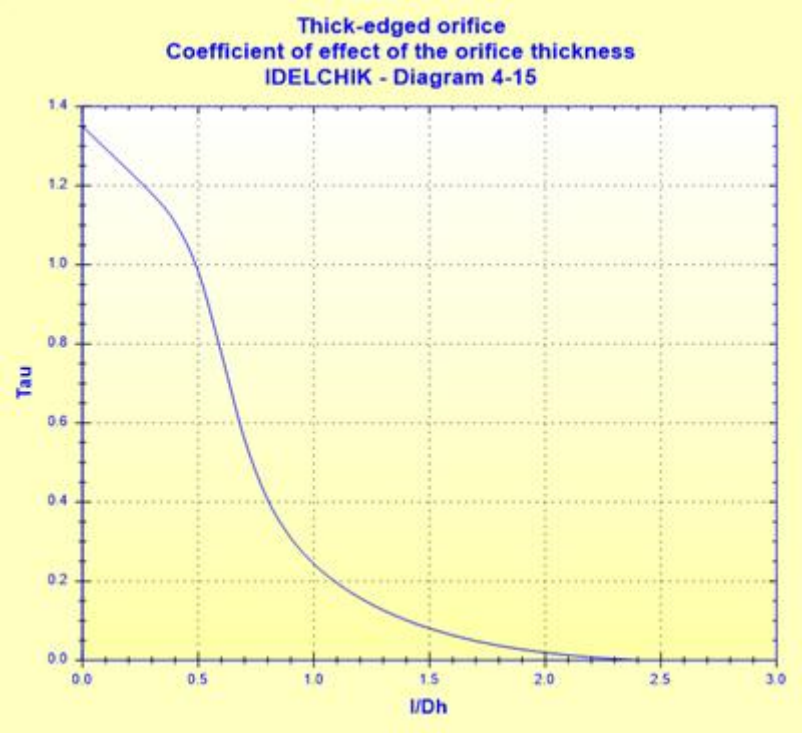
Coefficient of effect of the orifice thickness:

$$\tau = \left(2.4 - \frac{l}{D_h}\right) \cdot 10^{-\varphi\left(\frac{l}{D_h}\right)}$$

([2] diagram 4-15)

with:

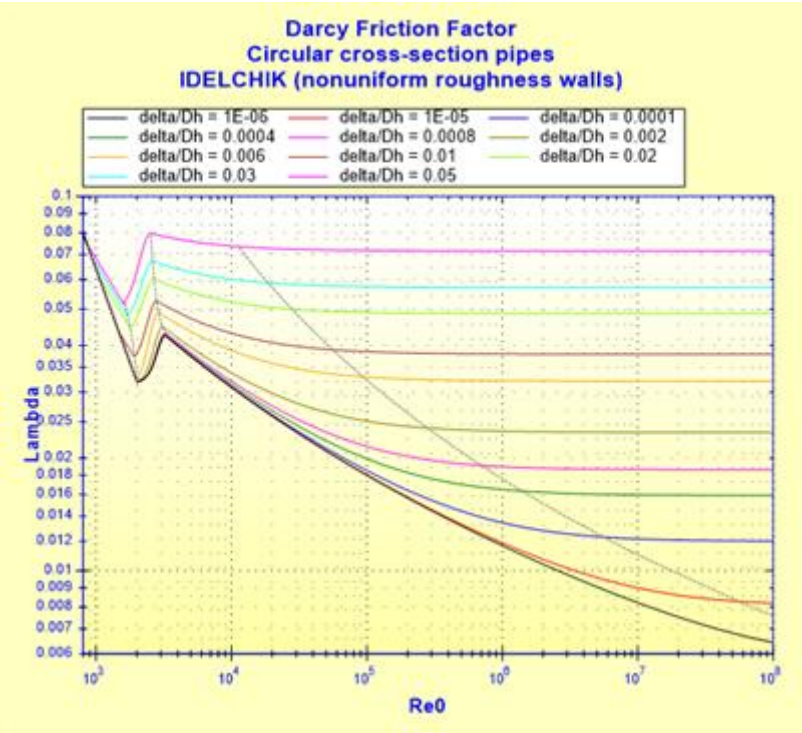
$$\varphi\left(\frac{l}{D_h}\right) = 0.25 + \frac{0.535 \cdot \left(\frac{l}{D_h}\right)^8}{0.05 + \left(\frac{l}{D_h}\right)^7}$$



Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}_0, \frac{\Delta}{D_h}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)

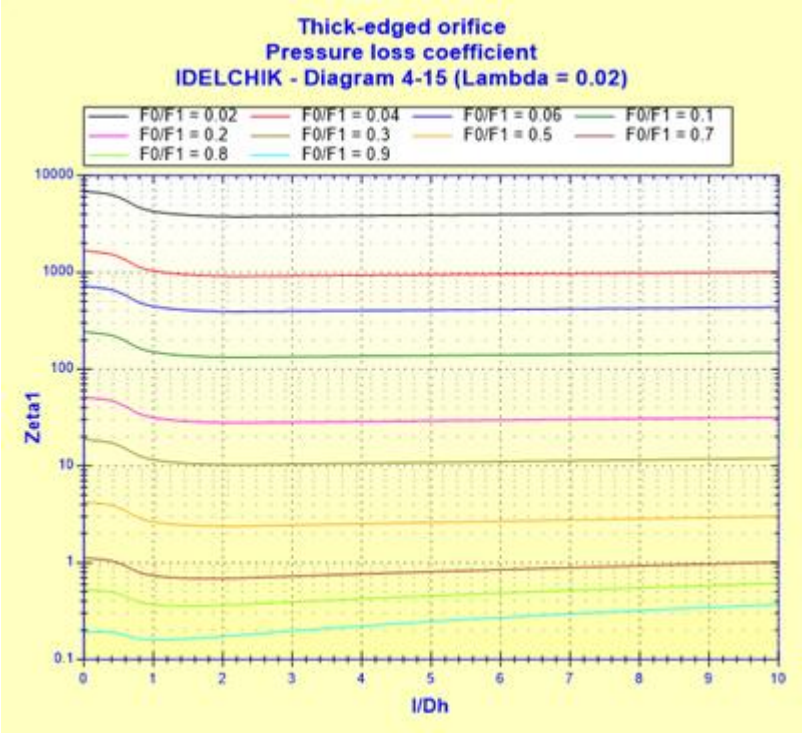


Local resistance coefficient:

■ $Re_0 \geq 10^5$

$$\zeta_1 = \left[0.5 \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \tau \cdot \left(1 - \frac{F_0}{F_1}\right)^{1.375} + \left(1 - \frac{F_0}{F_1}\right)^2 + \lambda \cdot \frac{l}{D_h}\right] \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-15)



([1] diagram 4-15 with $\lambda = 0.02$)

■ $Re_0 < 10^5$

Quadratic local resistance coefficient:

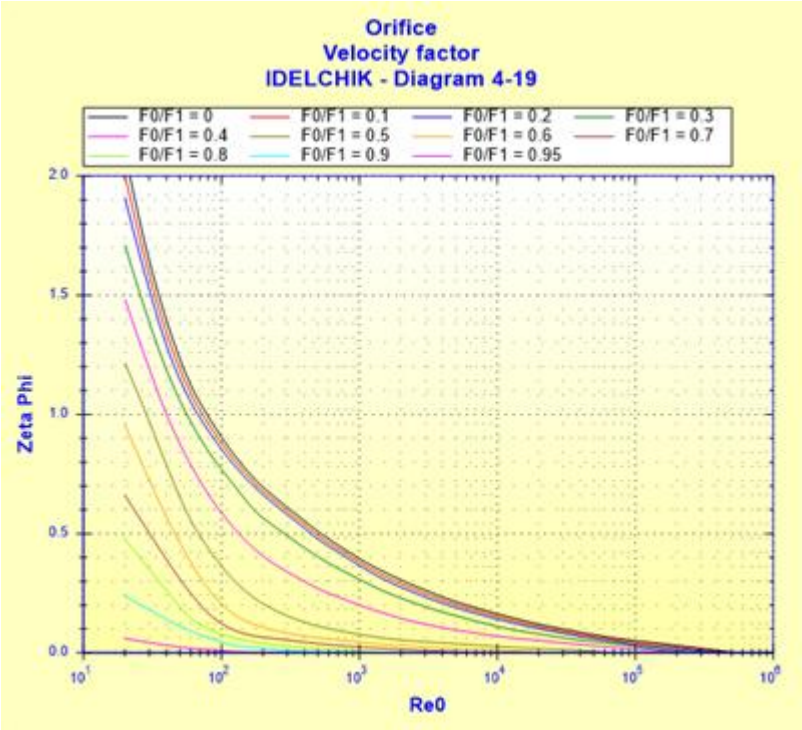
$$\zeta_{1quad} = \left[0.5 \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \tau \cdot \left(1 - \frac{F_0}{F_1}\right)^{1.375} + \left(1 - \frac{F_0}{F_1}\right)^2 + \lambda \cdot \frac{l}{D_h}\right] \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-15)

Velocity factor:

$$\zeta_\varphi = f\left(Re_0, \frac{F_0}{F_1}\right)$$

([1] diagram 4-19)



Contraction factor:

$\bar{\varepsilon}_{0Re} = f(Re_0)$ ([1] diagram 4-19)

Local resistance coefficient:

- $30 < Re_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $10 < Re_0 \leq 30$

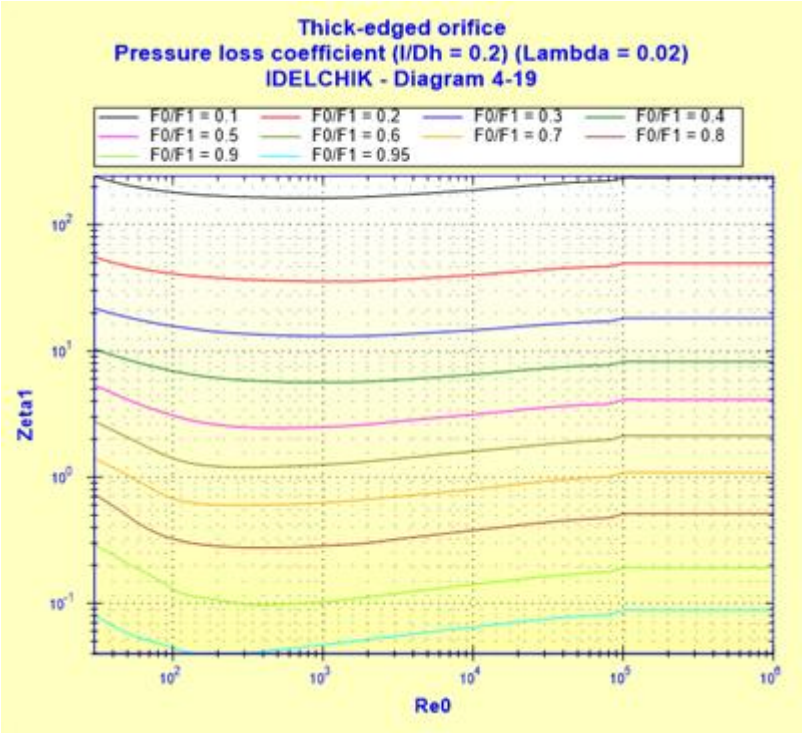
$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-19)



([1] diagram 4-19 with l/Dh = 0.2 and λ = 0.02)

Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \zeta_1$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{w_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_1	Pipe internal diameter (m)
D_0	Orifice diameter (m)
F_1	Pipe cross-sectional area (m^2)
F_0	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_1	Mean velocity in pipe (m/s)
w_0	Mean velocity in orifice (m/s)
l	Orifice thickness (m)
Re_1	Reynolds number in pipe ()
Re_0	Reynolds number in orifice ()
Δ	Absolute roughness of orifice walls (m)
$\bar{\Delta}$	Relative roughness of orifice walls ()
τ	Coefficient of effect of the orifice thickness ()
λ	Darcy friction coefficient in orifice ()
ζ_{1quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ_1	Local resistance coefficient ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

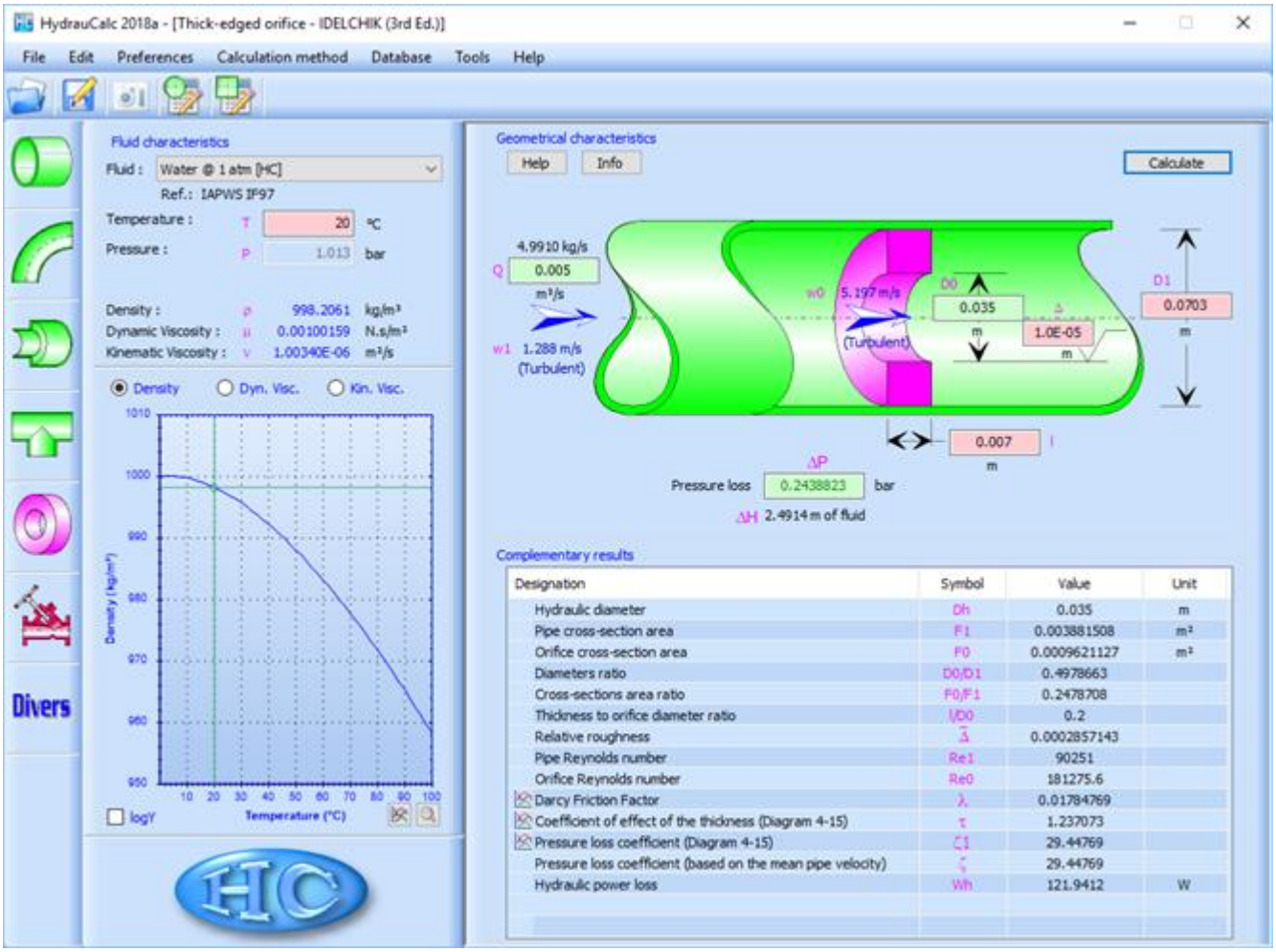
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- thickness to orifice diameter ratio (l/D_0) greater than 0.015

Example of application:



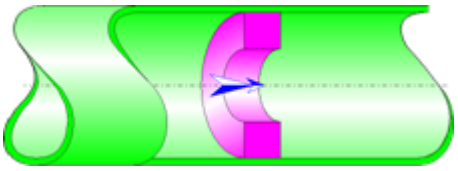
References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

[2] Идельчик.И.Е.Справочник по гидравлическим сопротивлениям.1992 (original document in Russian language)

Note: The formulation used for the calculation of the coefficient $\varphi\left(\frac{l}{D_h}\right)$ is that of the original reference document [2] which differs from that of the translated document [1]

2.7.1.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a thick-edged orifice installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Pipe cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{D^2}{4}$$

Orifice cross-sectional area (m^2):

$$A_2 = \pi \cdot \frac{d^2}{4}$$

Mean velocity in pipe (m/s):

$$U = \frac{Q}{A_1}$$

Mean velocity in orifice (m/s):

$$u = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

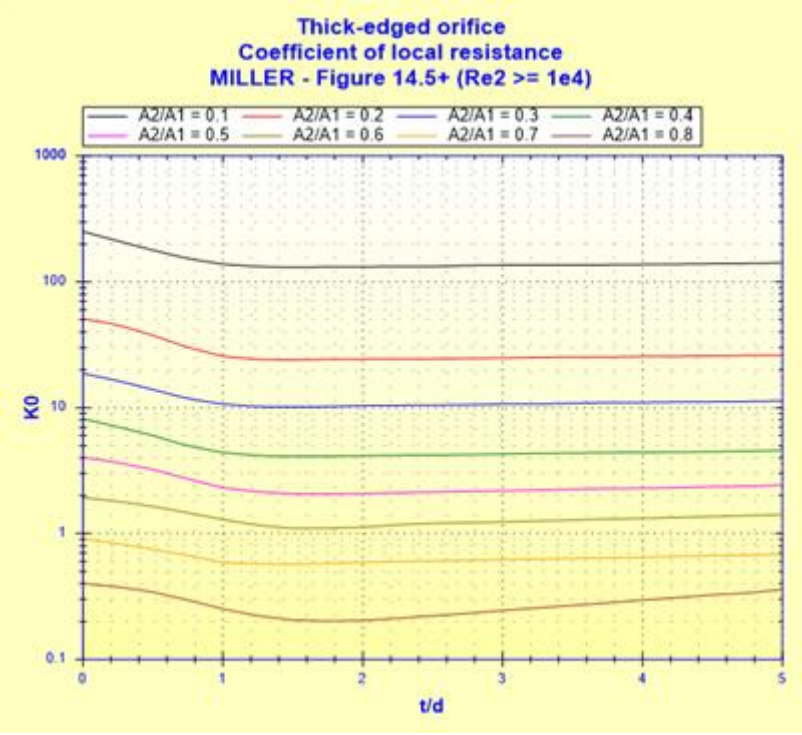
$$Re_1 = \frac{U \cdot D}{\nu}$$

Reynolds number in orifice:

$$Re_2 = \frac{u \cdot d}{\nu}$$

Local resistance coefficient:

$$K_0 = f\left(\frac{t}{d}, \frac{A_2}{A_1}\right)$$ ([1] figure 14.5+)



Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_0$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Pipe internal diameter (m)
d	Orifice diameter (m)
A_1	Pipe cross-sectional area (m^2)
A_2	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity in pipe (m/s)
u	Mean velocity in orifice (m/s)
Re_1	Reynolds number in pipe ()
Re_2	Reynolds number in orifice ()
t	Orifice thickness (m)
K_0	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

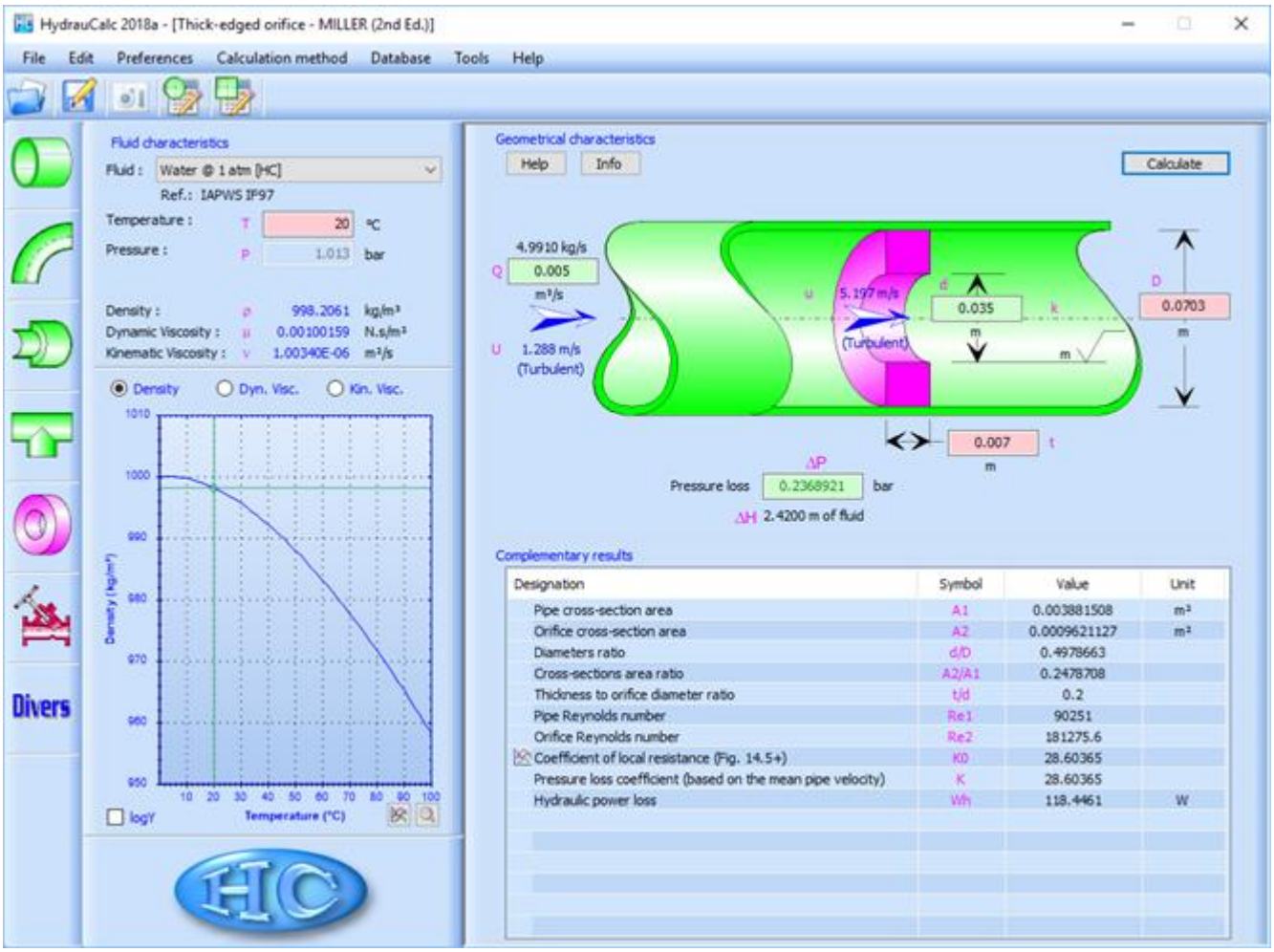
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime in orifice ($Re_2 \geq 10^4$)
- stabilized flow upstream of the orifice

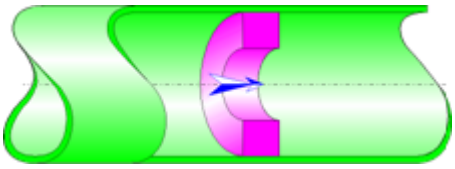
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.7.1.3 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a thick-edged orifice installed in a straight pipe. Moreover, when the thickness of the orifice is greater than 1.4 times the diameter of the orifice, the head loss due to friction in the orifice is also taken into account because it becomes significant.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of orifice to pipe diameters:

$$\beta = \frac{d_o}{d}$$

Pipe cross-sectional area (m²):

$$A = \pi \cdot \frac{d^2}{4}$$

Orifice cross-sectional area (m²):

$$A_o = \pi \cdot \frac{{d_o}^2}{4}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

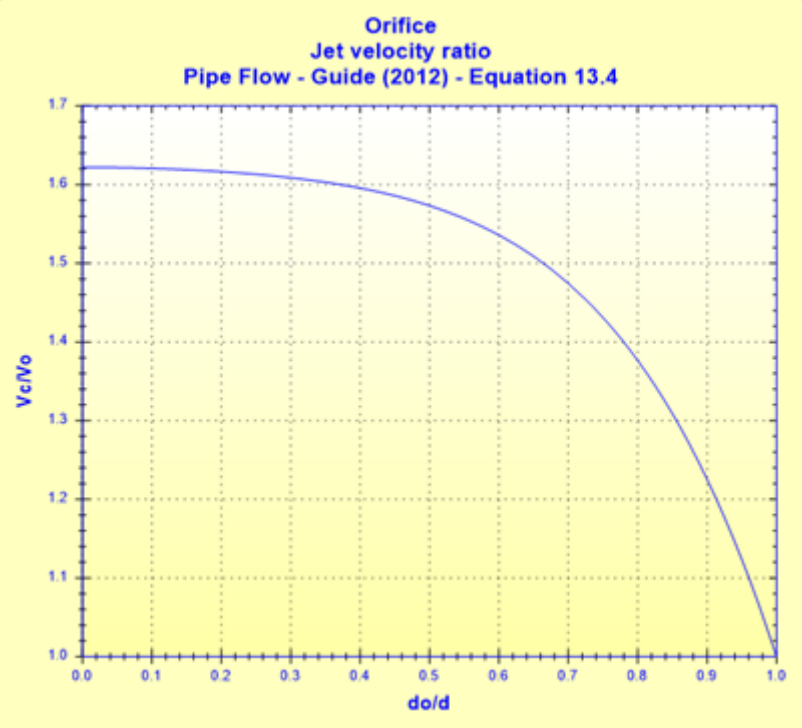
$$N_{Re} = \frac{V \cdot d}{\nu}$$

Reynolds number in orifice:

$$N_{Re_O} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left(1 - 0.215\beta^2 - 0.785\beta^5\right)$$ ([1] equation 13.4)



Velocity in vena contracta:

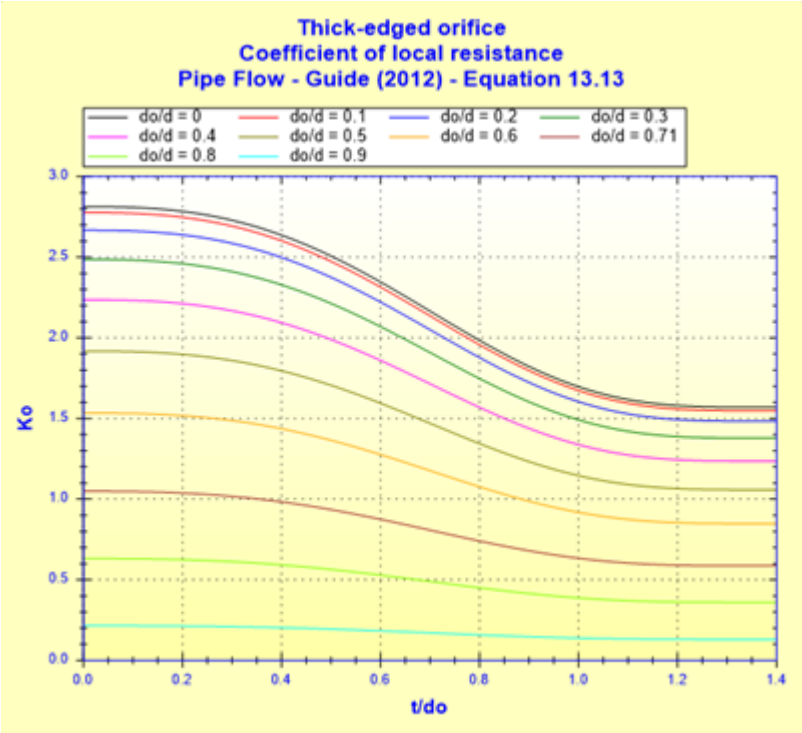
$$V_C = V_0 \cdot \lambda$$

Coefficient of local resistance ($NRe_o \geq 10^4$):

- Thickness to orifice diameter ratio (t/d_o) ≤ 1.4:

$$K_o = 0.0696 \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + C_{th} \cdot \left(\lambda - \beta^2\right)^2 + \left(1 - C_{th}\right) \cdot \left[\left(\lambda - 1\right)^2 + \left(1 - \beta^2\right)^2\right]$$

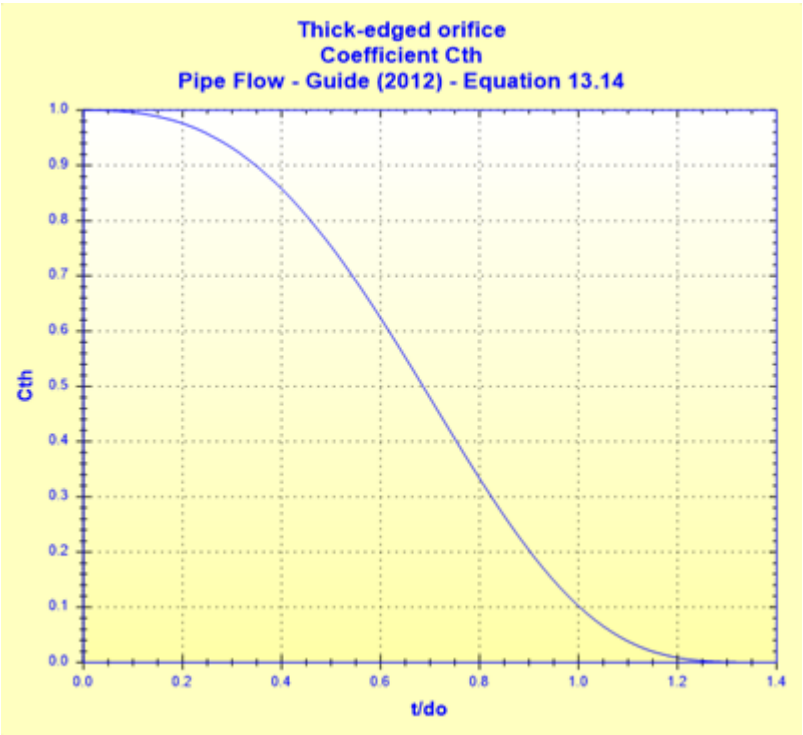
([1] equation 13.13)



with :

$$C_{th} = \left[1 - 0.50 \cdot \left(\frac{t}{1.4 d_o}\right)^{2.5} - 0.50 \cdot \left(\frac{t}{1.4 d_o}\right)^{3}\right]^{4.5}$$

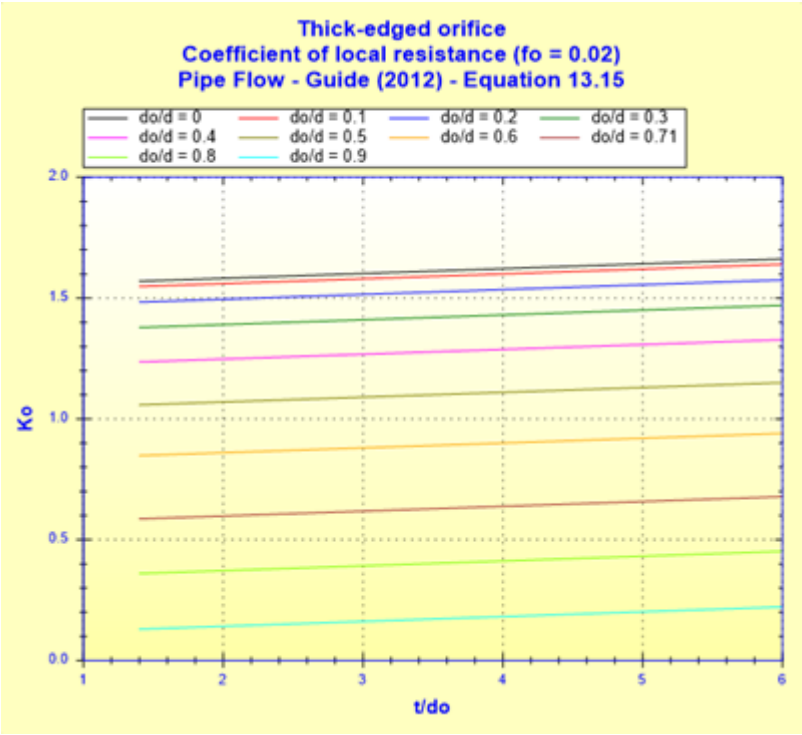
([1] equation 13.14)



■ Thickness to orifice diameter ratio (t/d_o) > 1.4:

$$K_o = 0.0696 \cdot \left(1-\beta^5\right) \cdot \lambda^2 + (\lambda-1)^2 + \left(1-\beta^2\right)^2 + f_o \cdot \left(\frac{t}{d_o} - 1.4\right)$$

([1] equation 13.15)

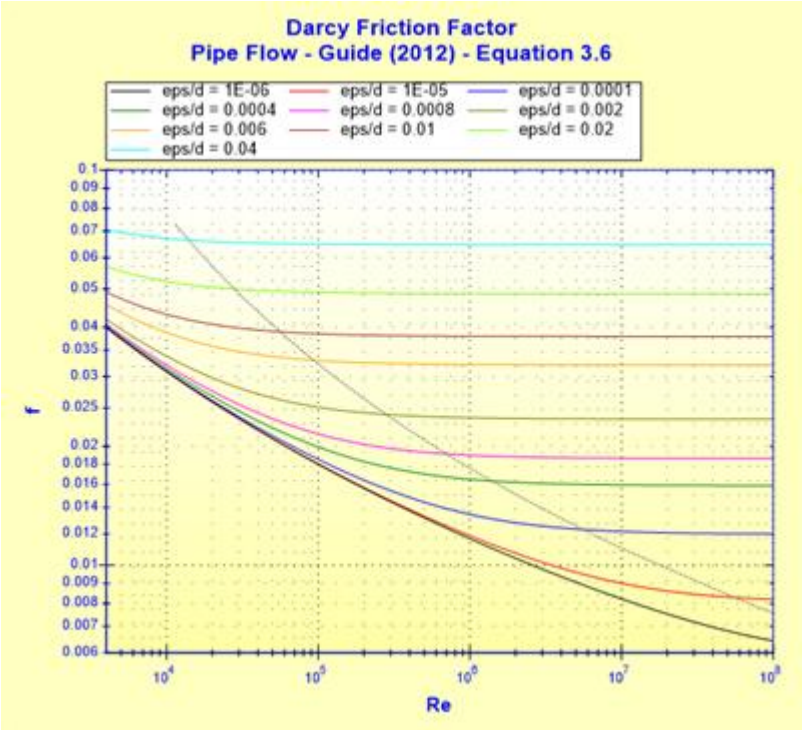


([1] equation 13.15 with fo = 0,02)

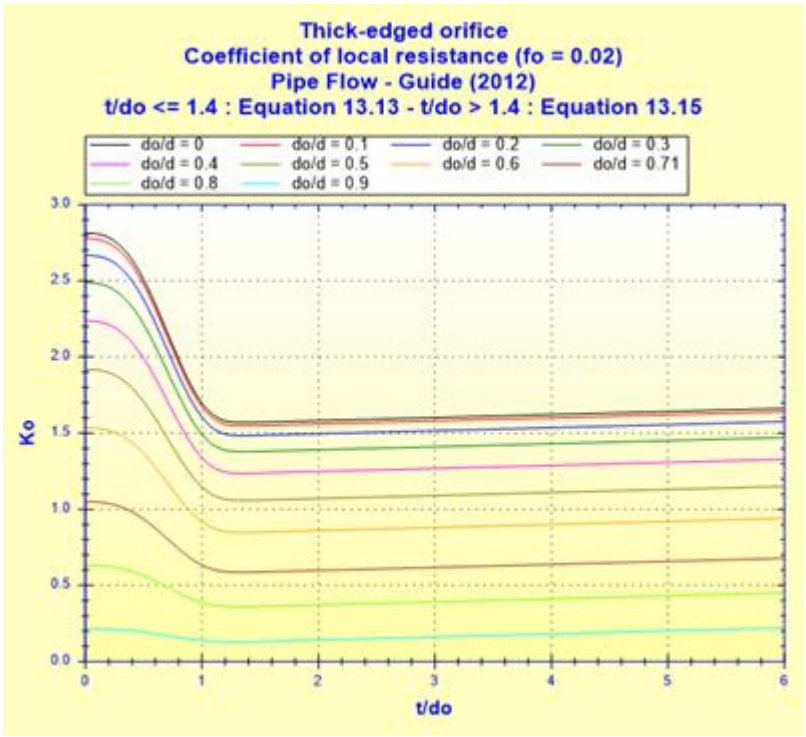
with :

$$f_o = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d_o} + \frac{2.51}{N\mathrm{Re}_0 \cdot \sqrt{f_o}}\right)\right]^2}$$

Colebrook-White equation ([1] equation 3.6)



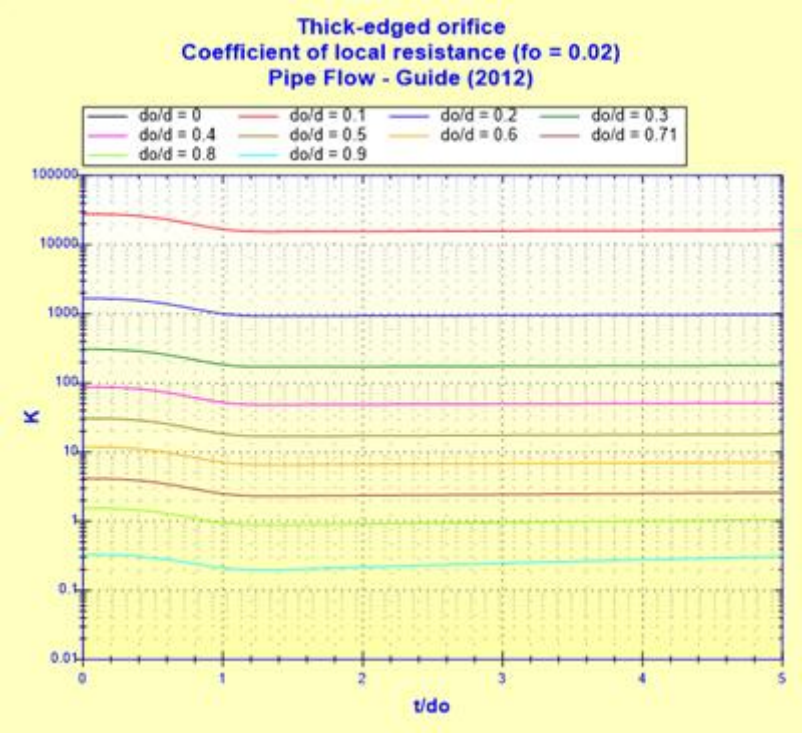
■ All thickness to orifice diameter ratios (t/d_o):



([1] equations 13.13 and 13.15 with fo = 0.02)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_o} \right)^2$$



(with fo = 0.02)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

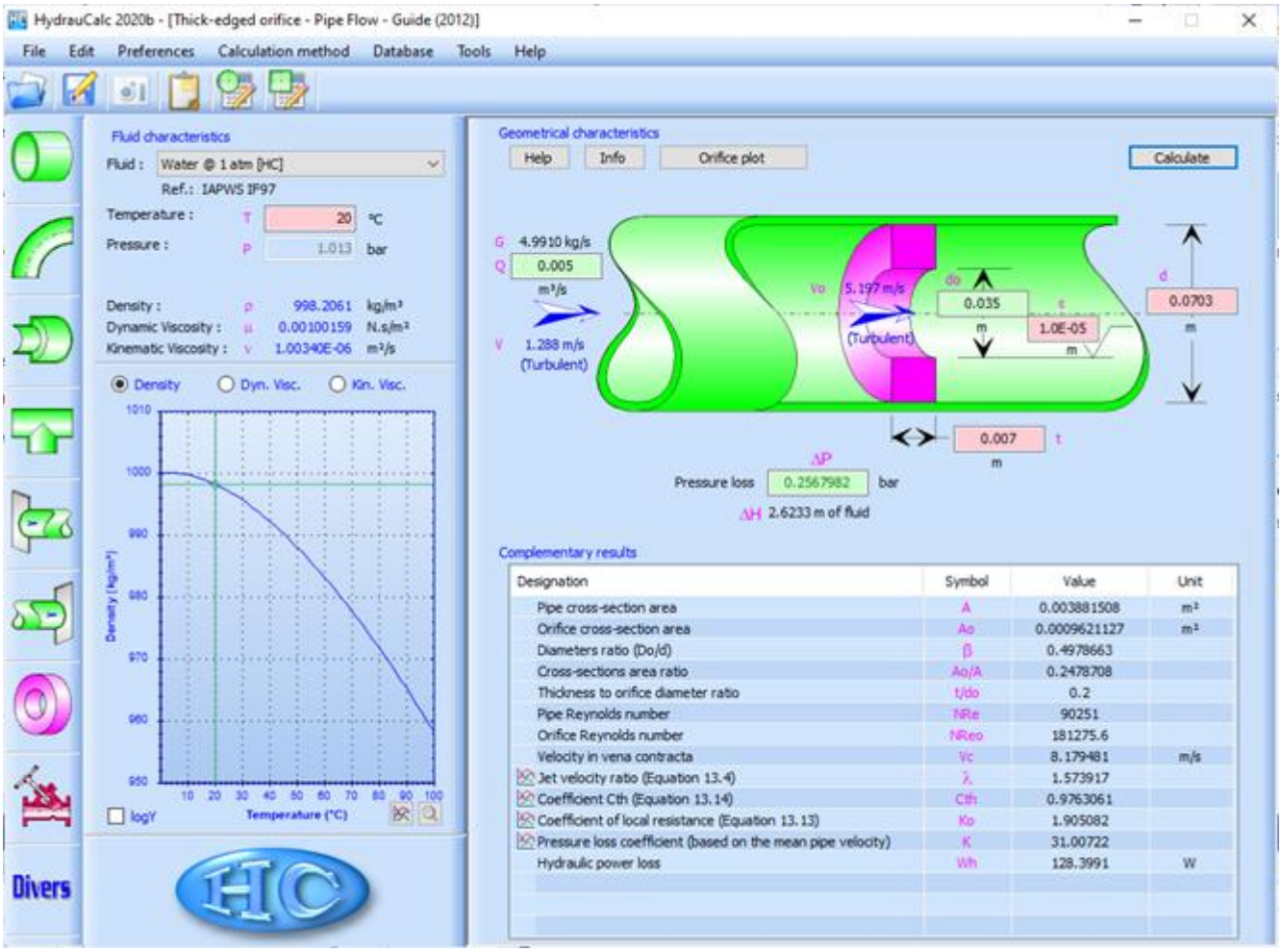
d_0	Orifice diameter (m)
d	Internal pipe diameter (m)
β	Ratio of orifice to pipe diameters ()

A_o	Orifice cross-sectional area (m^2)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
NRe_o	Reynolds number in orifice ()
NRe	Reynolds number in pipe ()
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
t	Thickness orifice (m)
K_o	Coefficient of local resistance ()
Cth	Coefficient ()
ε	Absolute roughness of orifice walls (m)
f_o	Friction factor ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in orifice ($NRe_o \geq 10^4$)
- stabilized flow upstream of the orifice

Example of application:

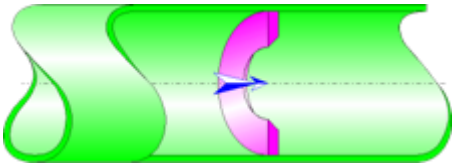


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.7.2 Sharp-edged orifice

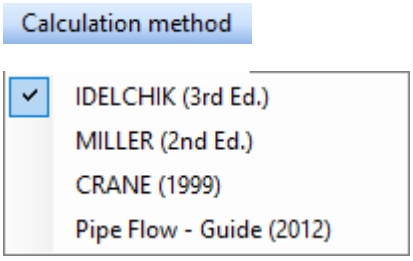
Circular Cross-Section



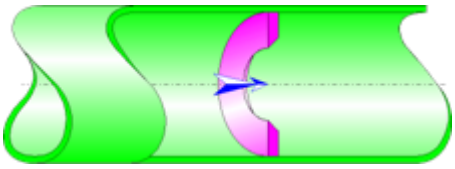
For the calculation of the pressure loss coefficient of sharp-edged orifices, the user can choose from one of the methods described in the following four reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.7.2.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sharp-edged orifice installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Pipe cross-section area (m^2):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Orifice cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity in pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in orifice (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in orifice:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Local resistance coefficient:

- $\mathrm{Re}_0 \geq 10^5$

$$\zeta_1 = \left[\left(1 - \frac{F_0}{F_1}\right) + 0.707 \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375}\right]^2 \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-14)

■ $Re_0 \le 10^5$

Quadratic local resistance coefficient:

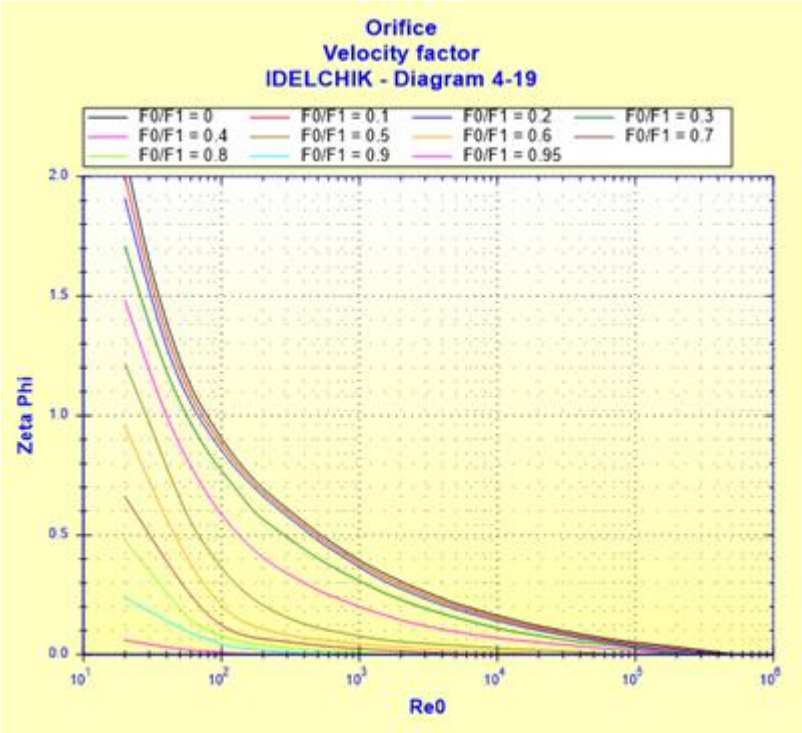
$$\zeta_{1quad} = \left[\left(1-\frac{F_0}{F_1}\right)+0.707\cdot\left(1-\frac{F_0}{F_1}\right)^{0.375}\right]^2\cdot\left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-14)

Velocity factor:

$$\zeta_\varphi = f\left(Re_0, \frac{F_0}{F_1}\right)$$

([1] diagram 4-19)



Contraction factor:

$\bar{\varepsilon}_{0\,\mathrm{Re}} = f(\mathrm{Re}_0)$ ([1] diagram 4-19)

Local resistance coefficient:

- $30 < \mathrm{Re}_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $10 < Re_0 \leq 30$

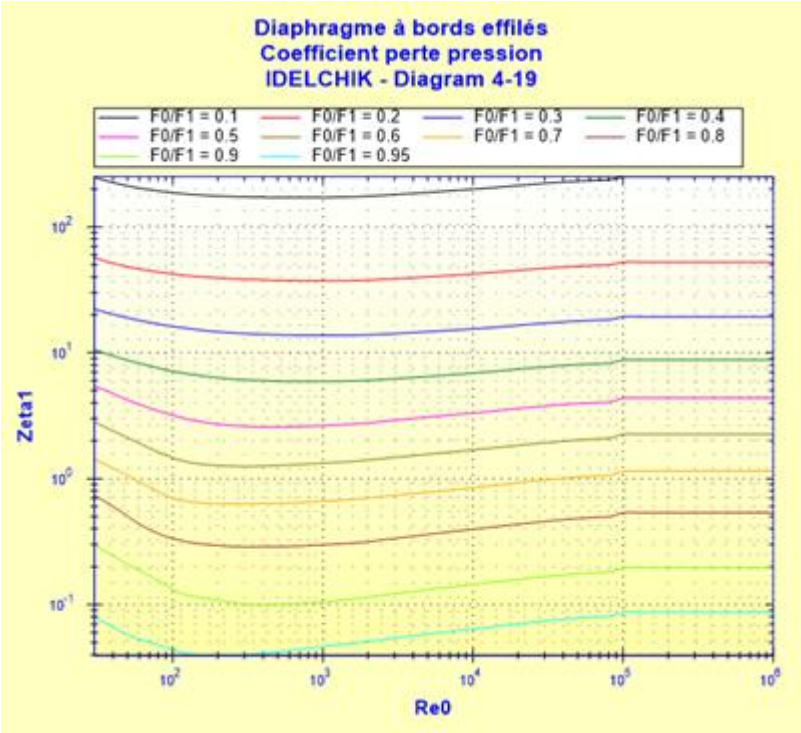
$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-19)



([1] diagramme 4-19)

Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \zeta_1$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{w_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_1	Pipe internal diameter (m)
F_1	Pipe cross-sectional area (m^2)
D_0	Orifice diameter (m)
F_0	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_1	Mean velocity in pipe (m/s)
w_0	Mean velocity in orifice (m/s)
Re_1	Reynolds number in pipe ()
Re_0	Reynolds number in orifice ()
ζ_{1quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ_1	Local resistance coefficient ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

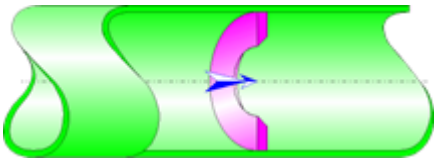
- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice

Example of application:

References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.7.2.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sharp-edged orifice installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Pipe cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{D^2}{4}$$

Orifice cross-sectional area (m^2):

$$A_2 = \pi \cdot \frac{d^2}{4}$$

Mean velocity in pipe (m/s):

$$U = \frac{Q}{A_1}$$

Mean velocity in orifice (m/s):

$$u = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$Re_1 = \frac{U \cdot D}{\nu}$$

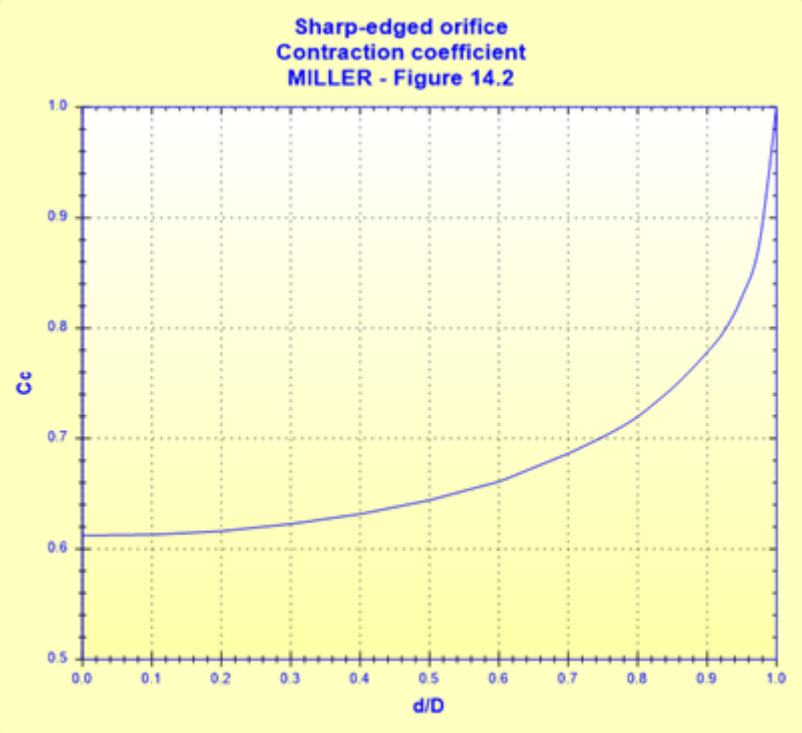
Reynolds number in orifice:

$$Re_2 = \frac{u \cdot d}{\nu}$$

Contraction coefficient:

$$C_c = f\left(\frac{d}{D}\right)$$

([1] figure 14.2)



Vena contracta cross-sectional area (m²):

$$A_c = d \cdot \left(\frac{d}{D}\right)^2 \cdot C_c$$

Mean velocity in vena contracta (m/s):

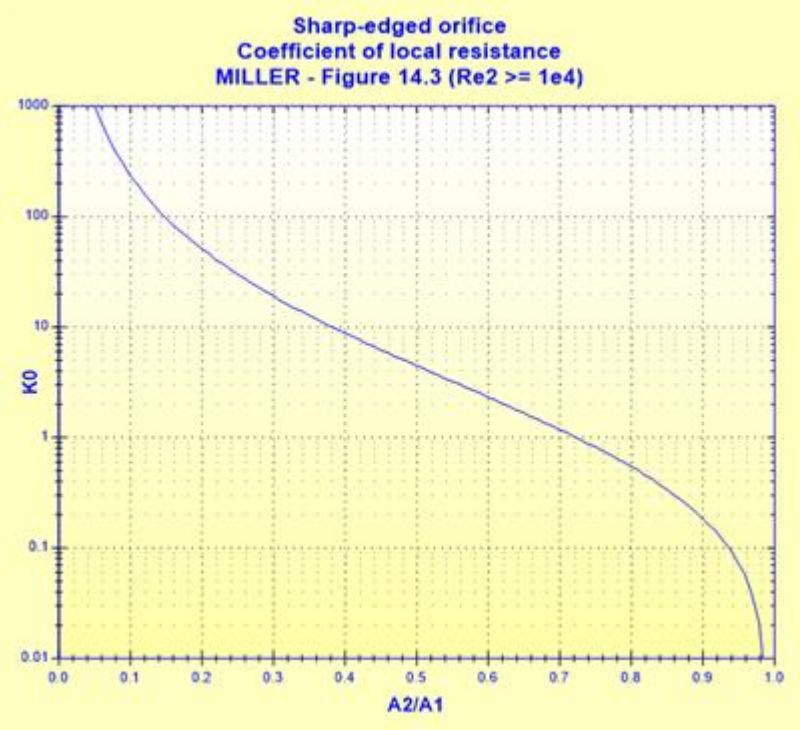
$$U_c = \frac{Q}{A_c}$$

Local resistance Coefficient:

- $Re_2 \geq 10^4$

$$K_0 = f\left(\frac{A_2}{A_1}\right)$$

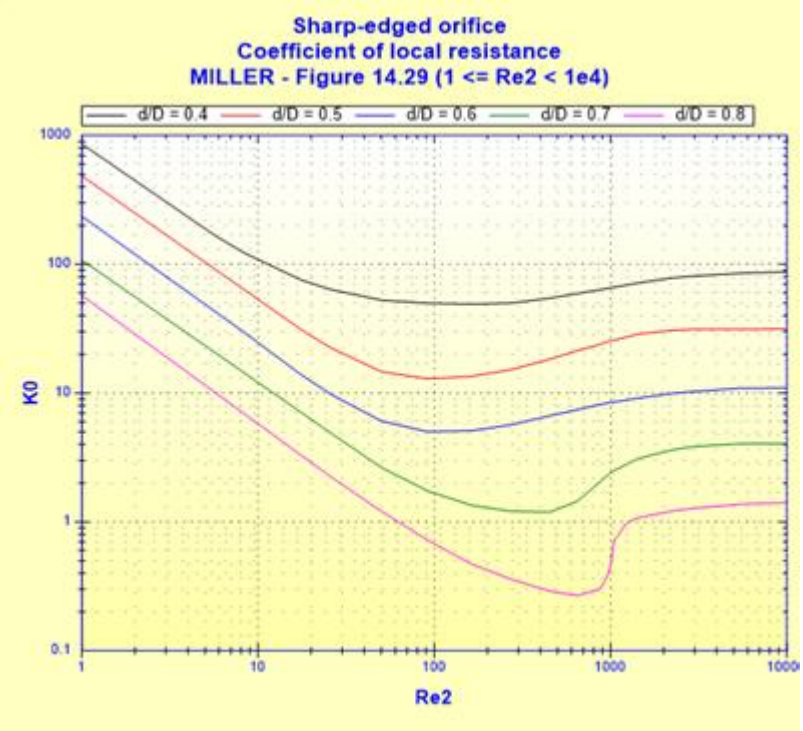
([1] figure 14.3)



- $Re_2 < 10^4$

$$K_0 = f\left(Re_2, \frac{d}{D}\right)$$

([1] figure 14.29)



Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_0$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D Pipe internal diameter (m)

d Orifice diameter (m)

A_1	Pipe cross-sectional area (m^2)
A_2	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity in pipe (m/s)
u	Mean velocity in orifice (m/s)
Re_1	Reynolds number in pipe ()
Re_2	Reynolds number in orifice ()
C_c	Contraction coefficient ()
A_c	Vena contracta cross-sectional area (m^2)
U_c	Mean velocity in vena contracta (m/s)
K_0	Coefficient of local resistance ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice

note: 1) for diameters ratios "d/D" lower than 0.4 or greater than 0.8 and when the Reynolds number in the orifice "Re_2" is lower than 10^4, the local resistance coefficient "K_0" is extrapolated

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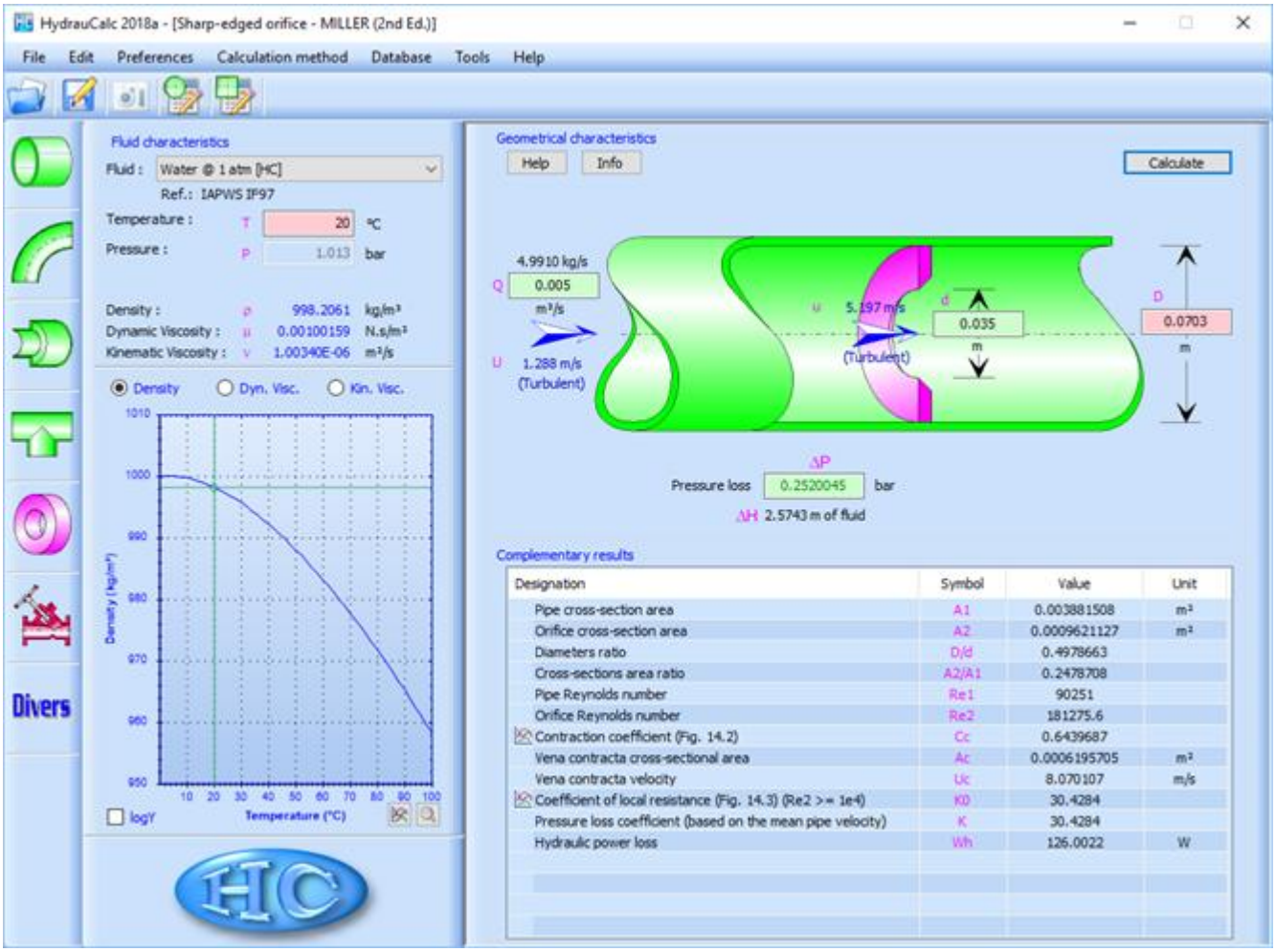
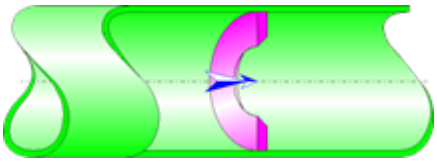
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.7.2.3 CRANE



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a square-edged orifice installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Diameter ratio:

$$\beta = \frac{D_1}{D_2}$$

Orifice cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Pipe cross-sectional area (m^2):

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity in orifice (m/s):

$$v_1 = \frac{q}{A_1}$$

Mean velocity in pipe (m/s):

$$v_2 = \frac{q}{A_2}$$

Mass flow rate (kg/s):

$$w = q \cdot \rho$$

Reynolds number in orifice:

$$\mathrm{Re}_1 = \frac{v_1 \cdot D_1}{\nu}$$

Reynolds number in pipe:

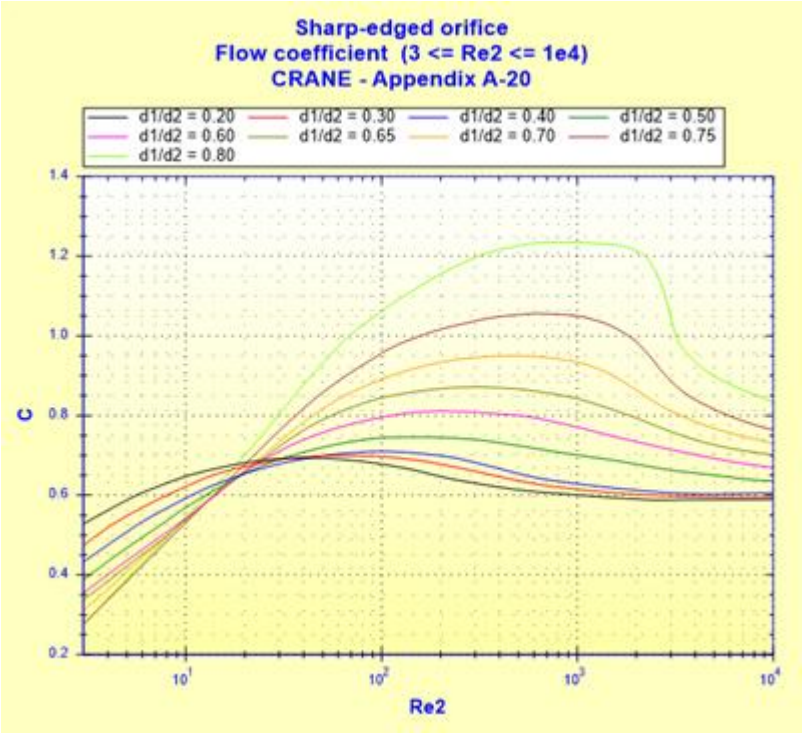
$$\mathrm{Re}_2 = \frac{v_2 \cdot D_2}{\nu}$$

Flow coefficient:

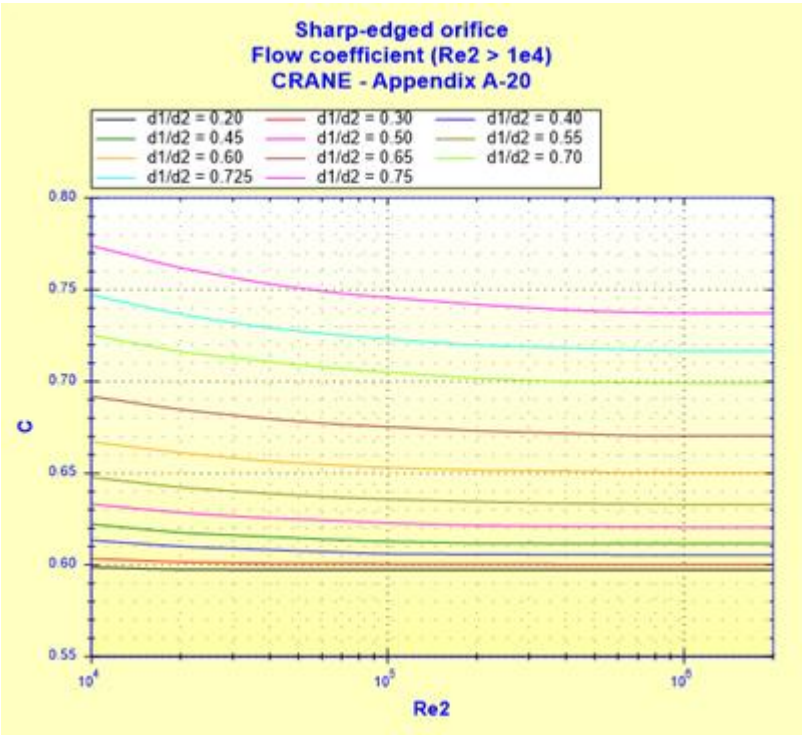
$$C = f\left(\mathrm{Re}_2, \frac{d_1}{d_2}\right)$$

([1] appendix A-20)

- $3 \leq \mathrm{Re}_2 \leq 10^4$



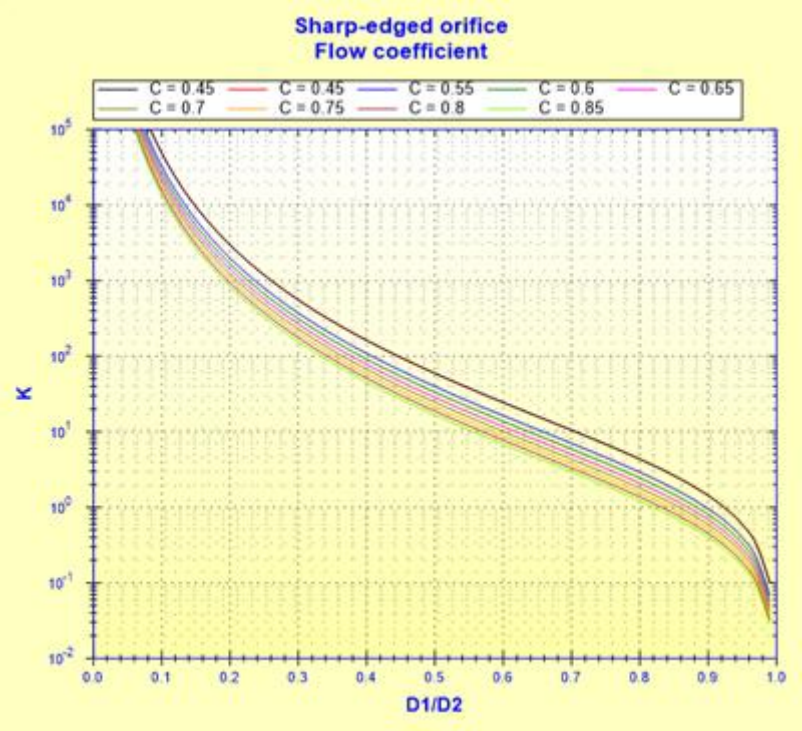
■ $Re_2 > 10^4$



Resistance coefficient of orifice:

$$K_o = \frac{1-\beta^2}{C^2 \cdot \beta^4}$$

([1] appendix A-20)



Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_o$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot v_2^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{v_2^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_1 Orifice diameter (m)

D_2 Pipe diameter (m)

β	Diameter ratio ()
A_1	Orifice cross-sectional area (m^2)
A_2	Pipe cross-sectional area (m^2)
q	Volume flow rate (m^3/s)
w	Mass flow rate (kg/s)
v_1	Mean velocity in orifice (m/s)
v_2	Mean velocity in pipe (m/s)
Re_1	Reynolds number in orifice ()
Re_2	Reynolds number in pipe ()
C	Flow coefficient ()
K_o	Resistance coefficient of orifice ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

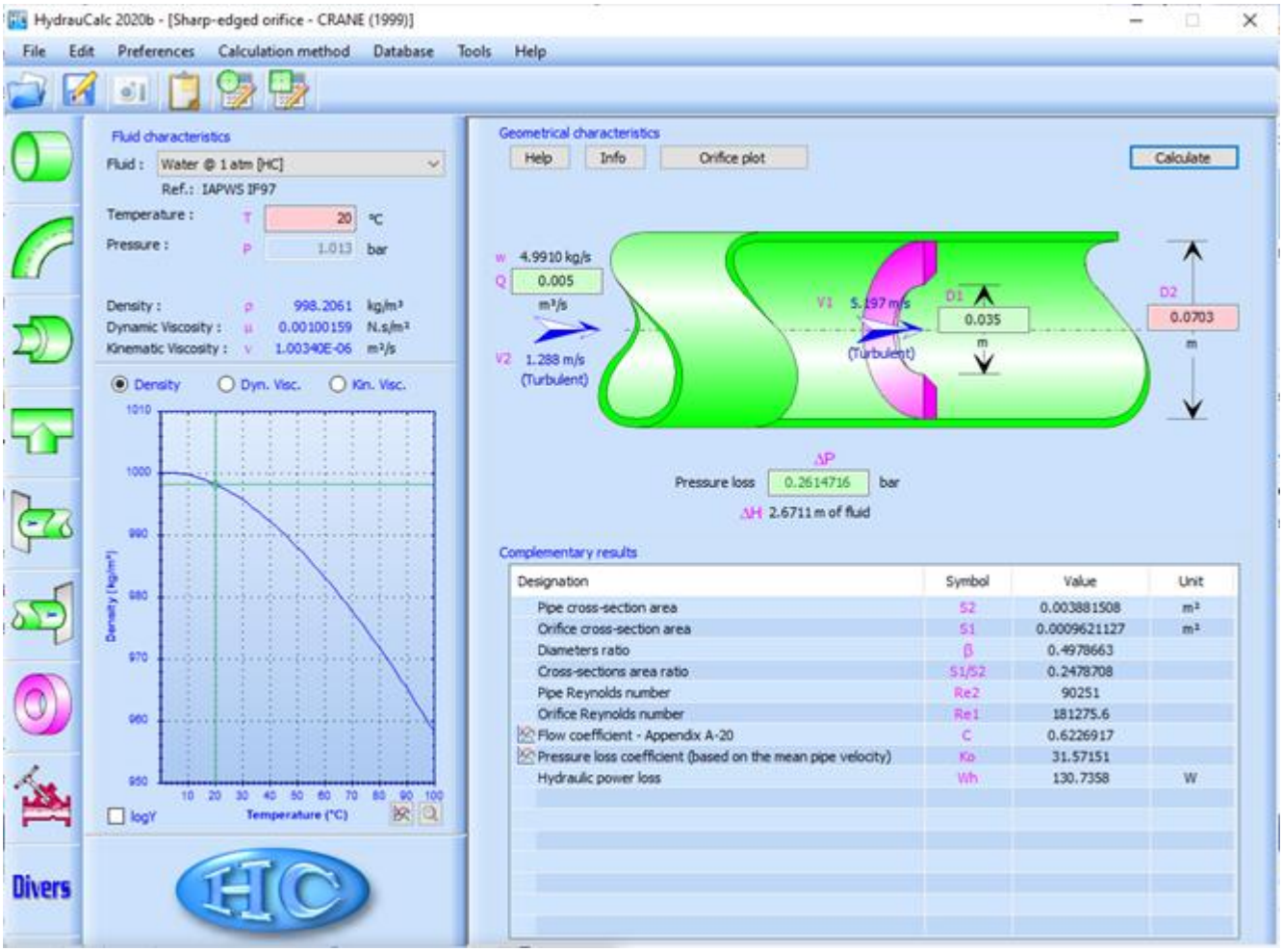
- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice

note: 1) for Reynolds number "Re_2" between 3 and 10^4, and diameter ratio "D_1/D_2" lower than 0.2 or greater than 0.8, the flow coefficient "C" is extrapolated

2) for Reynolds number "Re_2" between 10^4 and 2.10^6, and diameter ratio "D_1/D_2" lower than 0.2 or greater than 0.75, the flow coefficient "C" is extrapolated

---

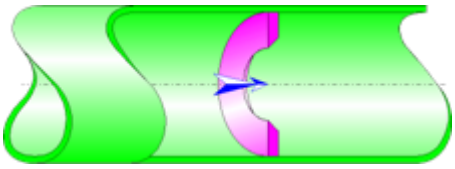
Example of application:



References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 – Edition 1999

2.7.2.4 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sharp-edged orifice installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of orifice to pipe diameter:

$$\beta = \frac{d_o}{d}$$

Pipe cross-sectional area (m²):

$$A = \pi \cdot \frac{d^2}{4}$$

Orifice cross-sectional area (m²):

$$A_o = \pi \cdot \frac{d_o^{\,2}}{4}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

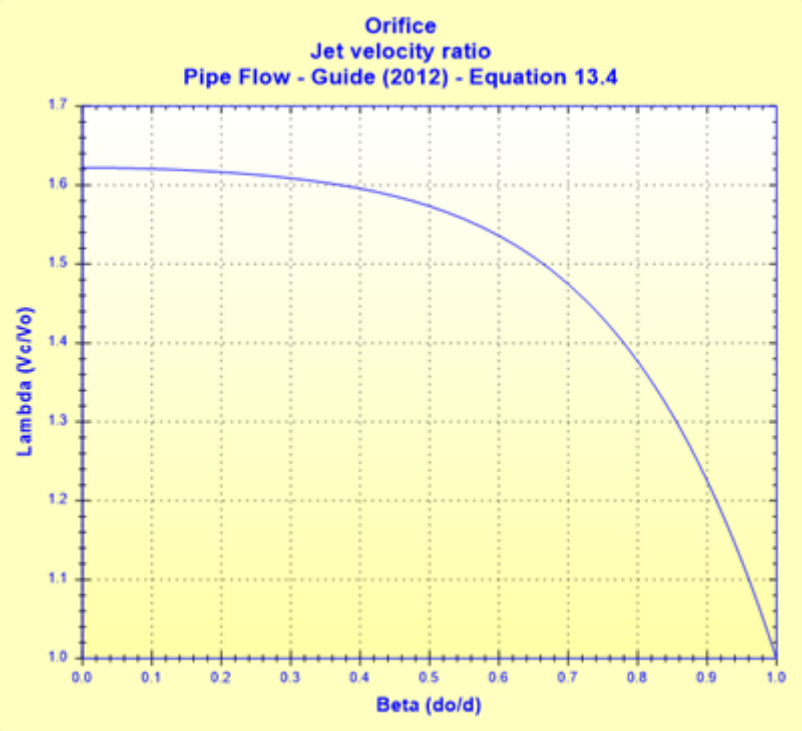
$$N_{Re} = \frac{V \cdot d}{\nu}$$

Reynolds number in orifice:

$$N_{Re_O} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left(1 - 0.215\beta^2 - 0.785\beta^5\right)$$ ([1] equation 13.4)



Velocity in vena contracta (m/s):

$$V_C = V_O \cdot \lambda$$

Vena contracta cross-sectional area (m^2):

$$A_C = \frac{Q}{V_C}$$

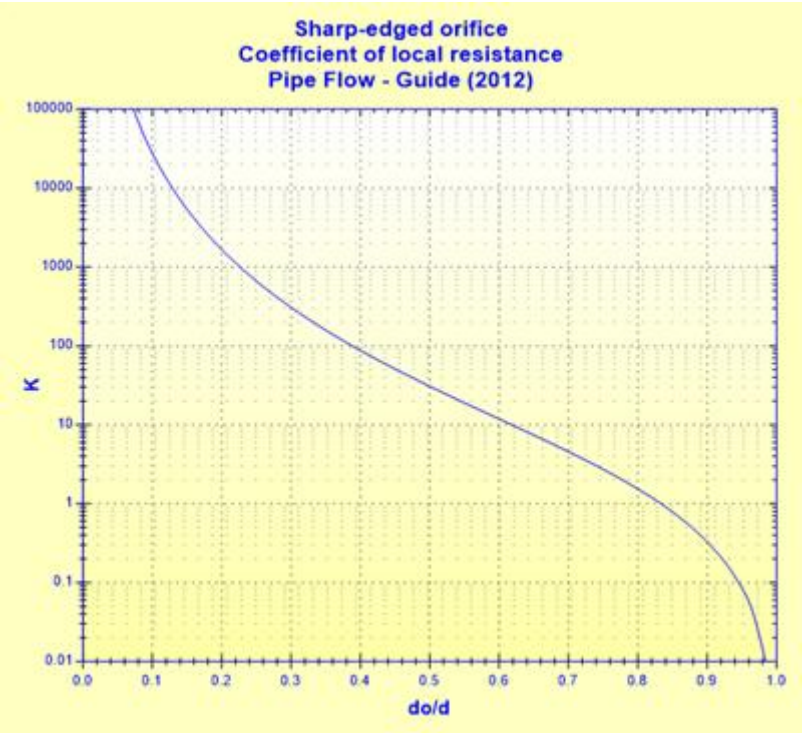
Coefficient of local resistance ($NRe_o \geq 10^4$):

$$K_o = 0.0696 \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + \left(\lambda - \beta^2\right)^2$$

([1] equation 13.3)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_o} \right)^2$$



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_0	Orifice diameter (m)
d	Internal pipe diameter (m)
β	Ratio of orifice to pipe diameter ()
A_o	Orifice cross-sectional area (m^2)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in orifice diameter (m/s)
V	Mean velocity in pipe diameter (m/s)
NRe_o	Reynolds number in orifice ()
NRe	Reynolds number in pipe ()
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
K_o	Coefficient of local resistance ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m³)

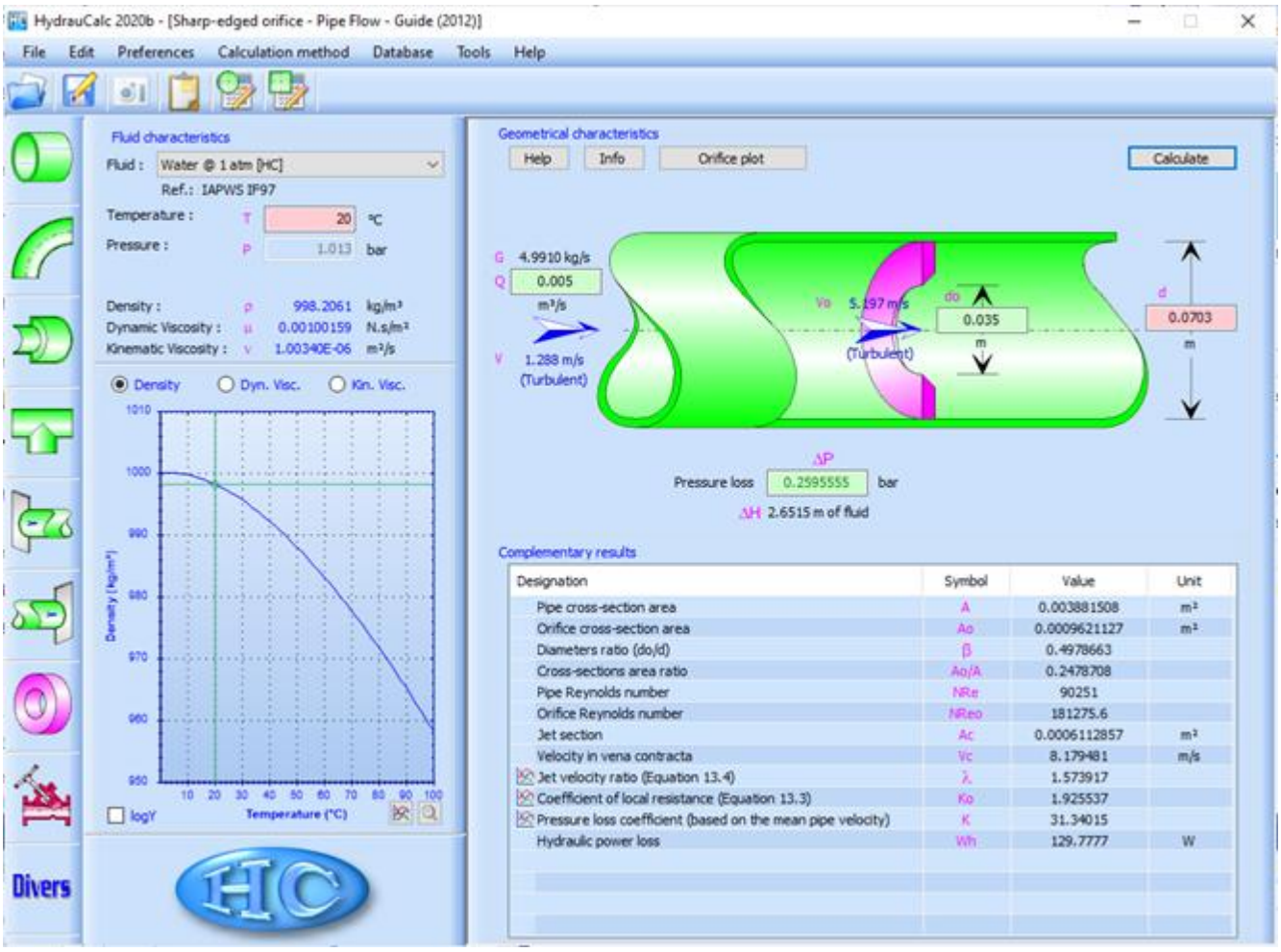
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime in the orifice ($NRe_o \geq 10^4$)
- stabilized flow upstream of the orifice

Example of application:

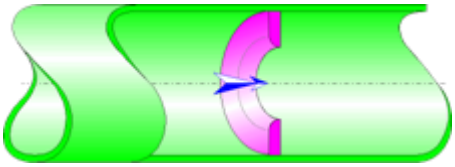


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.7.3 Round-edged orifice

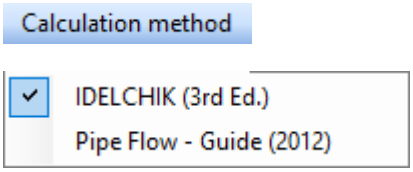
Circular Cross-Section



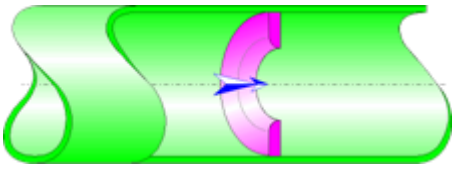
For the calculation of the pressure loss coefficient in round-edged orifices, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.7.3.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a round-edged orifice installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Pipe cross-section area (m^2):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Orifice cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity in pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in orifice (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in orifice:

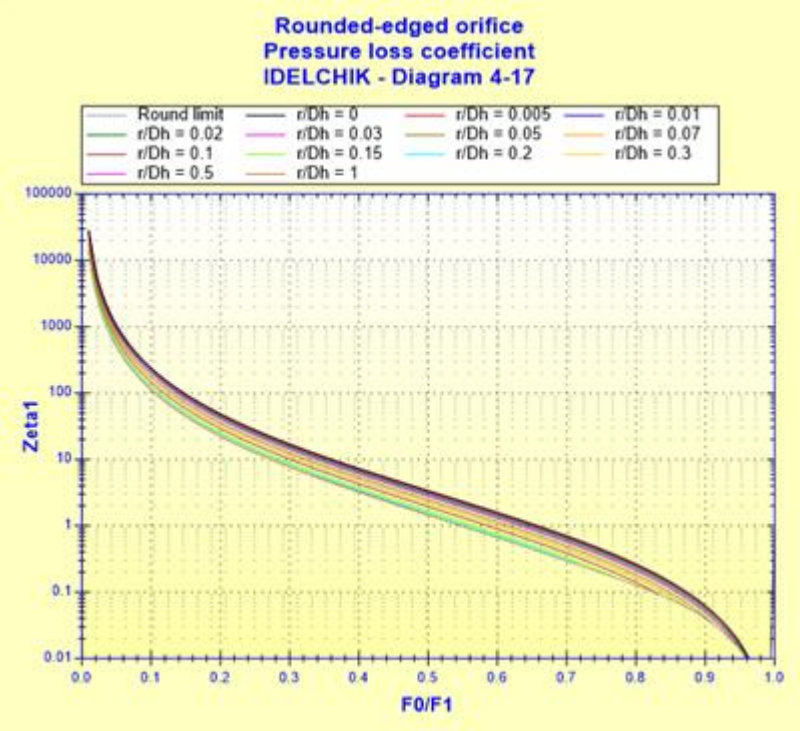
$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Local resistance coefficient:

- $\mathrm{Re}_0 \geq 10^5$

$$\zeta_1 = \left[1 - \frac{F_0}{F_1} + \sqrt{\zeta'} \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75}\right]^2 \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-17)

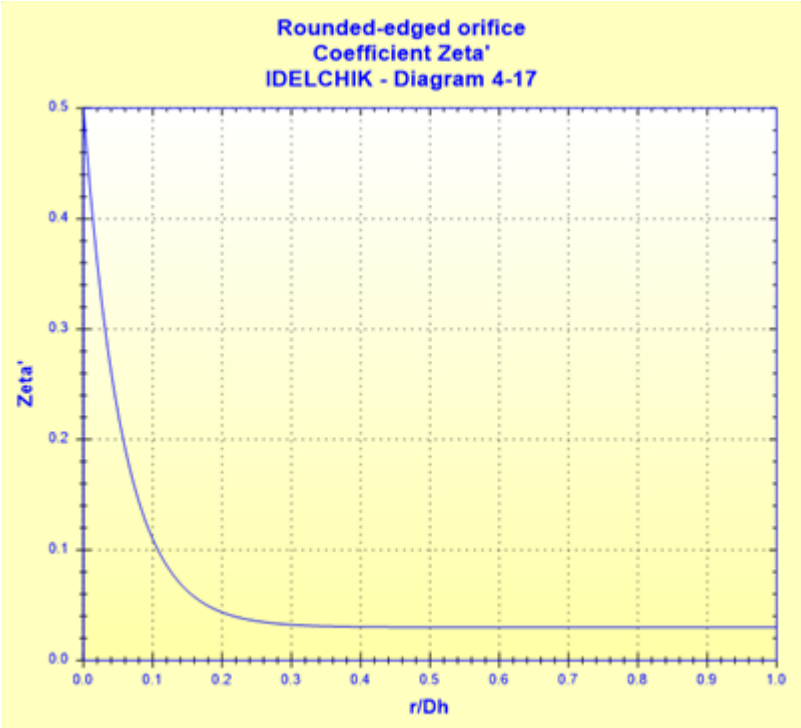


with :

Coefficient of effect of the round:

$$\zeta' = 0.03 + 0.47 \cdot 10^{-7.7 \cdot \frac{r}{D_h}}$$

([1] diagram 4-17)



■ $Re_0 \leq 10^5$

Quadratic local resistance coefficient:

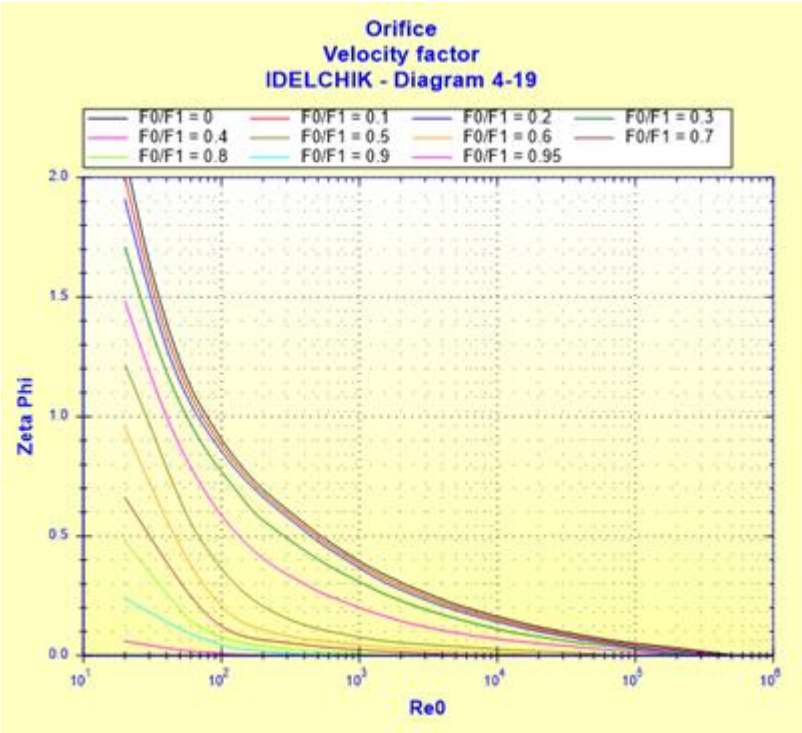
$$\zeta_{1quad} = \left[1 - \frac{F_0}{F_1} + \sqrt{\zeta'} \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75}\right]^2 \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-17)

Velocity factor:

$$\zeta_\varphi = f\left(\mathrm{Re}_0, \frac{F_0}{F_1}\right)$$

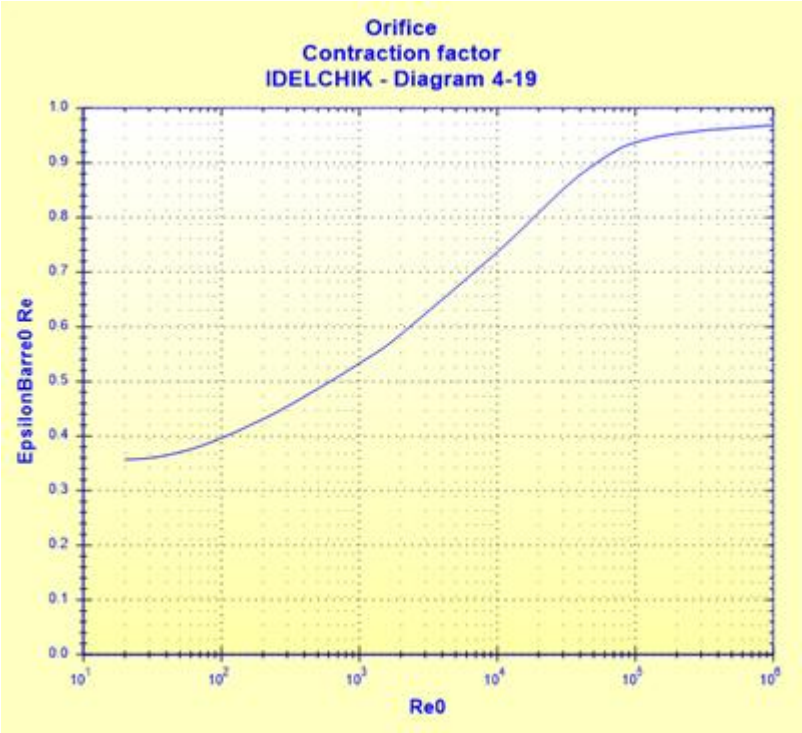
([1] diagram 4-19)



Contraction factor:

$$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re}_0)$$

([1] diagram 4-19)



Local resistance coefficient:

- $30 < Re_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $10 < Re_0 \leq 30$

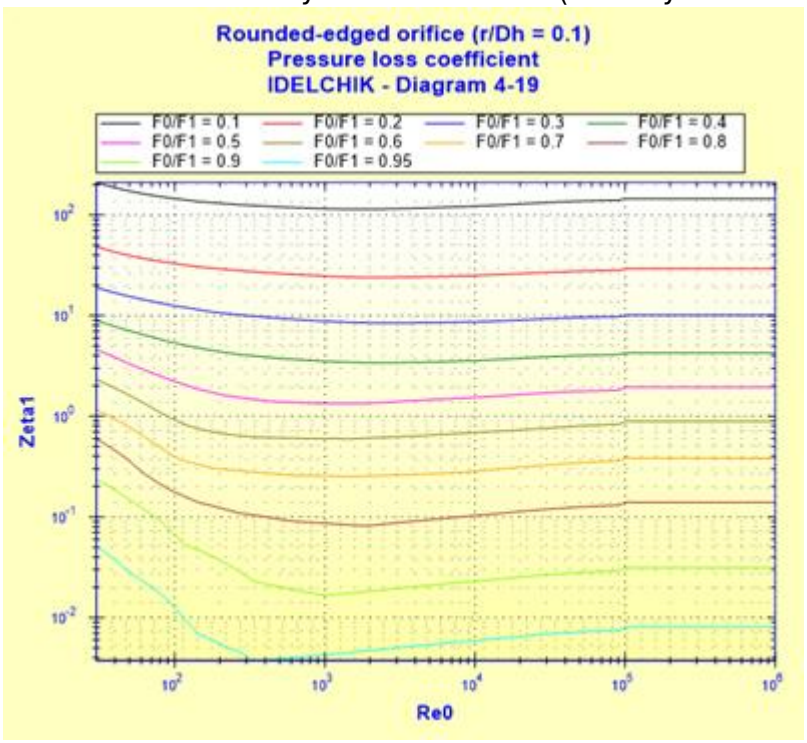
$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-19)



([1] diagram 4-19 with r/Dh = 0.1)

Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \zeta_1$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

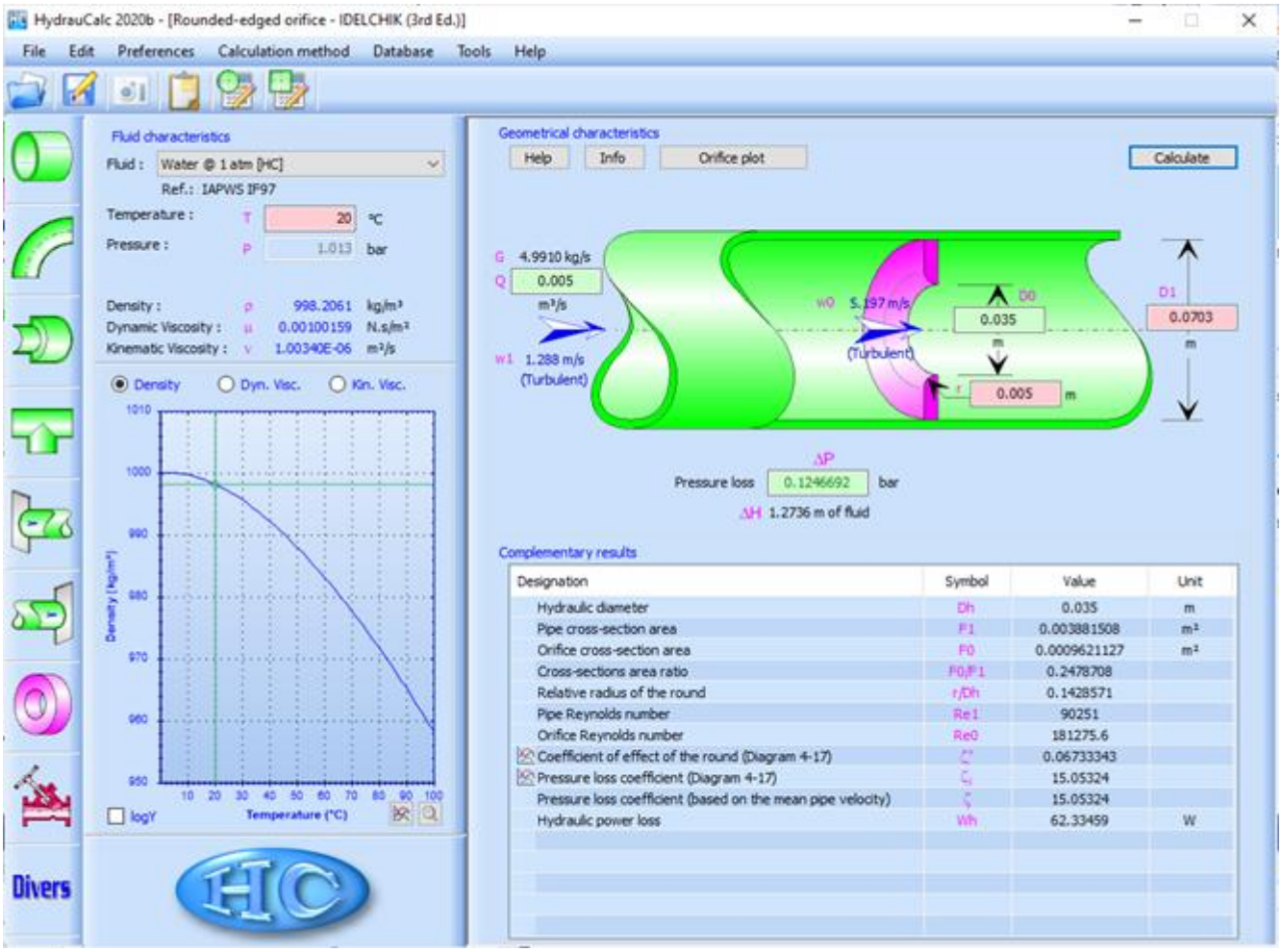
D_h	Hydraulic diameter (m)
D_1	Pipe internal diameter (m)

D_0	Orifice diameter (m)
F_1	Pipe cross-sectional area (m^2)
F_0	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_1	Mean velocity in pipe (m/s)
w_0	Mean velocity in orifice (m/s)
r	Radius of the round (m)
Re_1	Reynolds number in pipe ()
Re_0	Reynolds number in orifice ()
ζ'	Coefficient of effect of the round ()
ζ_{1quad}	Quadratic local resistance coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ_1	Local resistance coefficient ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- round radius less than the radius difference ($r < (D_1/2-D_0/2)$)

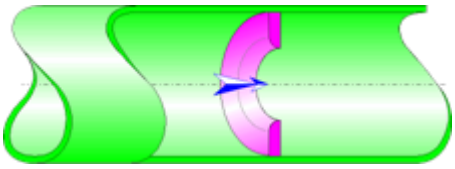
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.7.3.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a round-edged orifice installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of orifice to pipe diameters:

$$\beta = \frac{d_o}{d}$$

Pipe cross-sectional area (m²):

$$A = \pi \cdot \frac{d^2}{4}$$

Orifice cross-sectional area (m²):

$$A_o = \pi \cdot \frac{d_o^{\,2}}{4}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

Reynolds number in orifice:

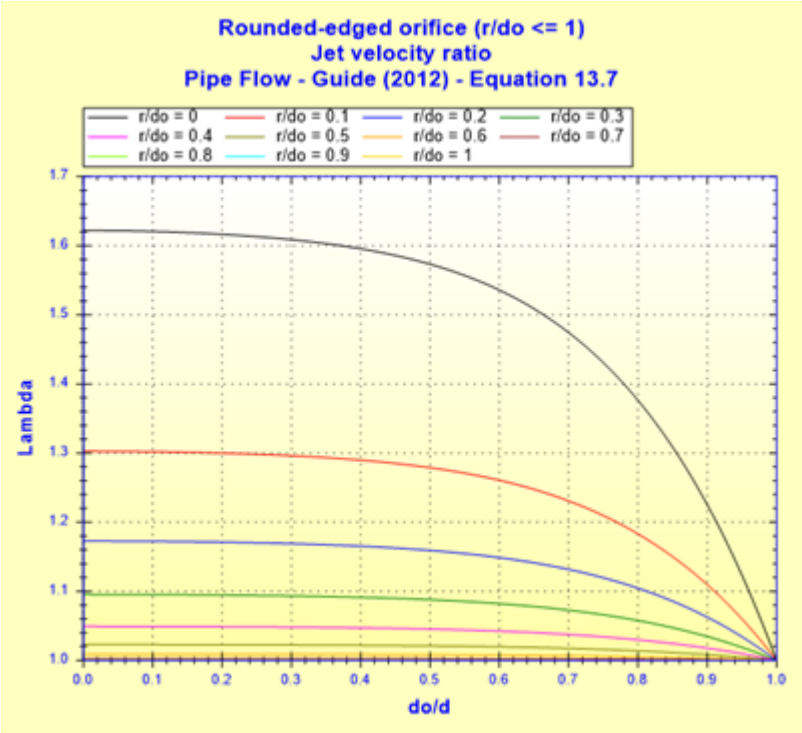
$$N_{Re_O} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

- $r/d_0 \leq 1$

$$\lambda = 1 + 0.622 \cdot \left[1 - 0.3 \cdot \sqrt{\frac{r}{d_0}} - 0.7 \cdot \frac{r}{d_0} \right]^4 \cdot \left(1 - 0.215 \cdot \beta^2 - 0.785 \cdot \beta^5 \right)$$

([1] equation 13.7)



- $r/d_0 > 1$

$$\lambda = 1$$ ([1] § 13.3.1)

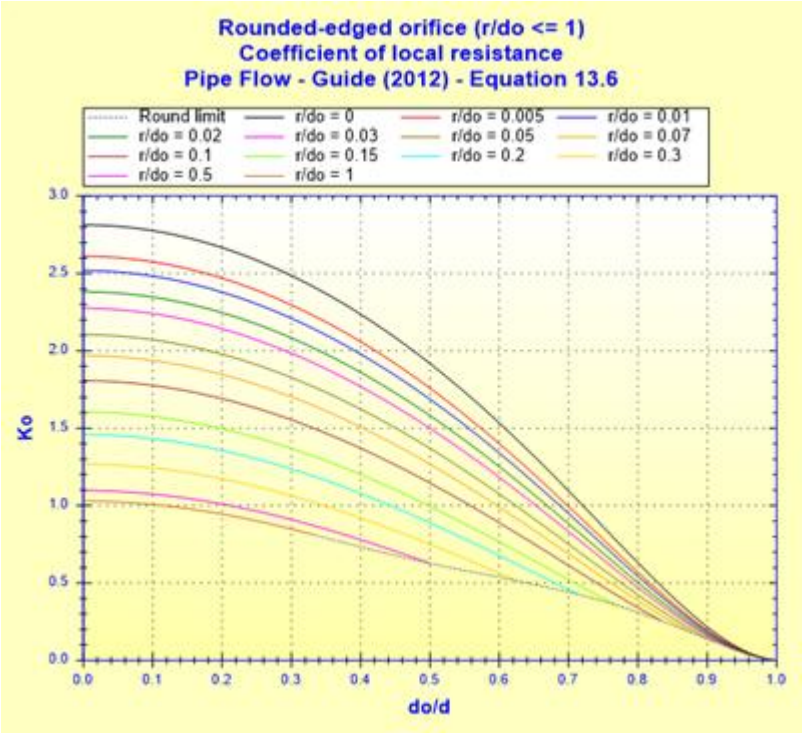
Velocity in vena contracta:

$$V_c = V_0 \cdot \lambda$$

Coefficient of local resistance:

- $r/d_0 \leq 1$

$$K_o = 0.0696 \cdot \left(1 - 0.569 \cdot \frac{r}{d_0}\right) \cdot \left(1 - \sqrt{\frac{r}{d_0}} \cdot \beta\right) \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + \left(\lambda - \beta^2\right)^2$$ ([1] equation 13.6)



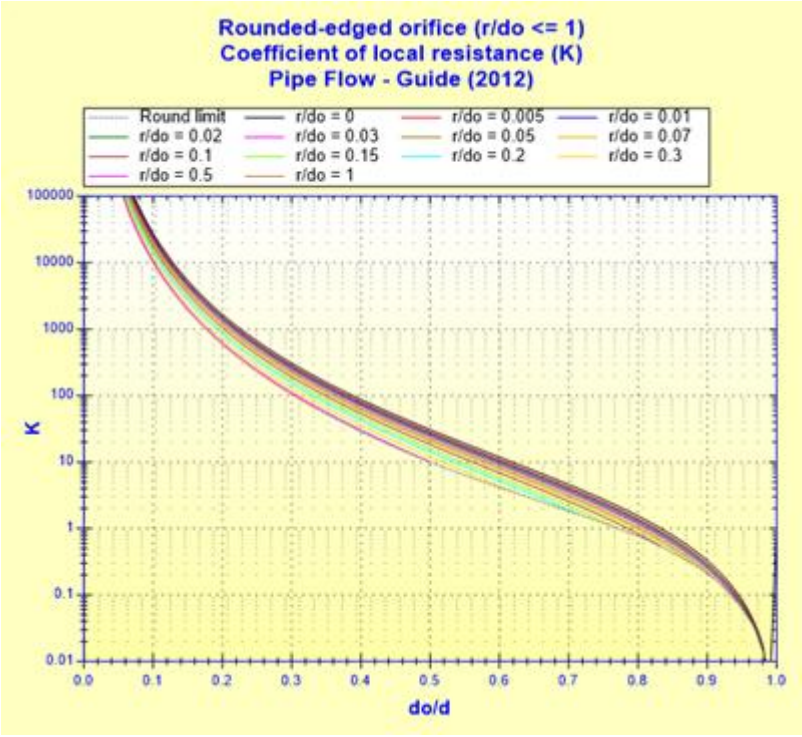
■ $r/d_0 > 1$

$$K_o = 0.03 \cdot (1-\beta) \cdot \left(1-\beta^5\right) + \left(1-\beta^2\right)^2$$ ([1] § 13.3.1)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_o} \right)^2$$

■ $r/d_0 \leq 1$



■ $r/d_0 > 1$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_0	Orifice diameter (m)
d	Internal pipe diameter (m)
β	Ratio of orifice to pipe diameters ()
A_o	Orifice cross-sectional area (m^2)
A	Pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
NRe_o	Reynolds number in orifice ()
NRe	Reynolds number in pipe ()
r	Rounding radius (m)
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
K_o	Coefficient of local resistance ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m³)

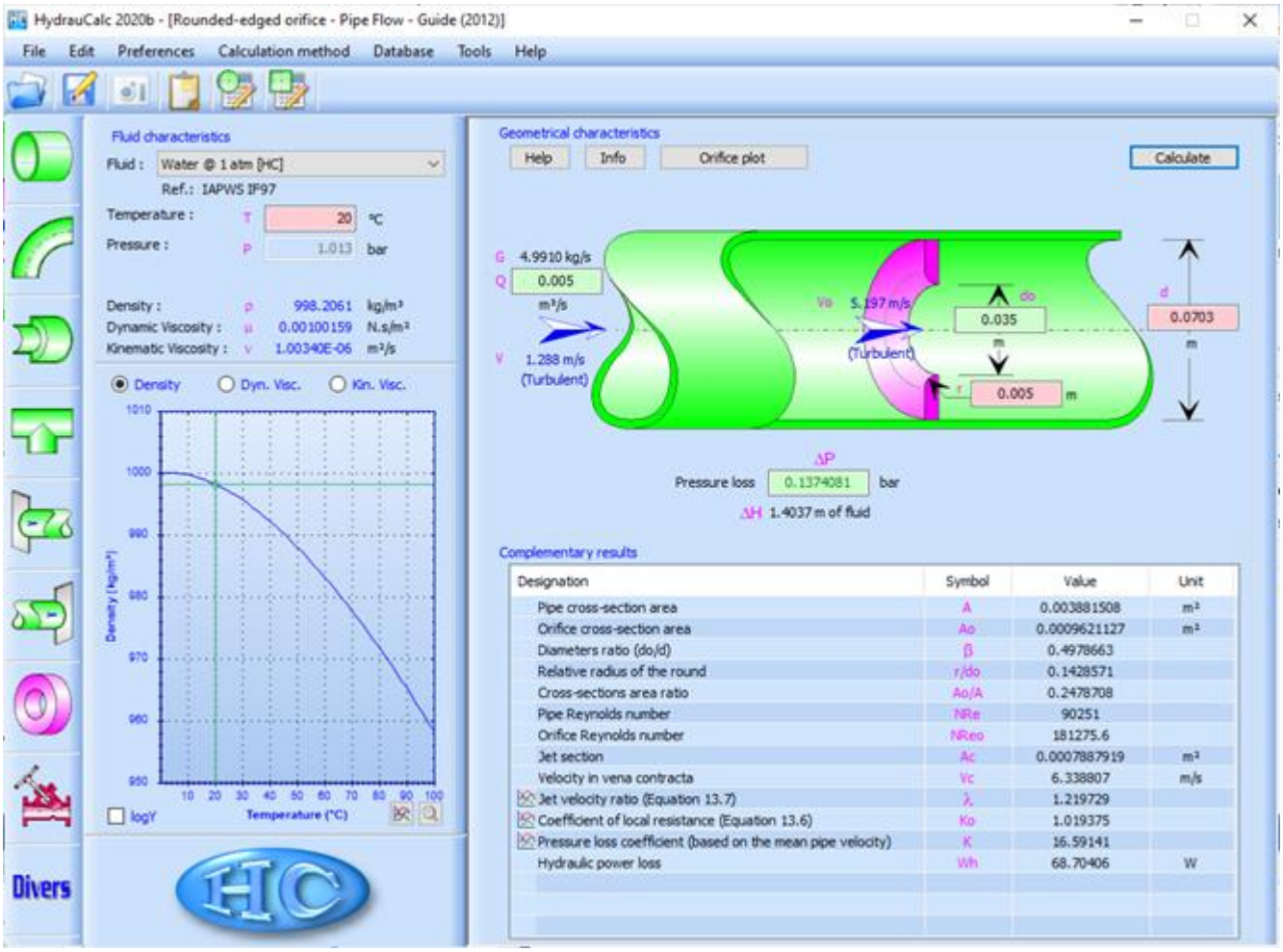
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- turbulent flow regime in orifice ($NRe_o \geq 10^4$)
- stabilized flow upstream of the orifice
- round radius less than the radius difference ($r < (d/2-d_0/2)$)

Example of application:

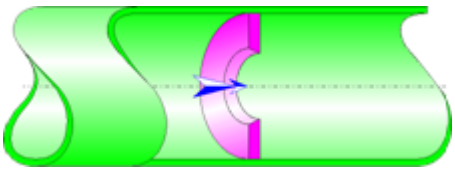


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.7.4 Bevel-edged orifice

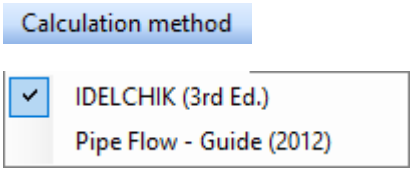
Circular Cross-Section



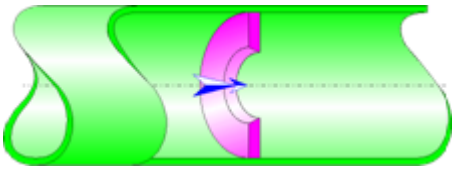
For the calculation of the pressure loss coefficient in bevelled-edged orifices, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.7.4.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a bevel-edged orifice installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Pipe cross-section area (m^2):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Orifice cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity in pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in orifice (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in orifice:

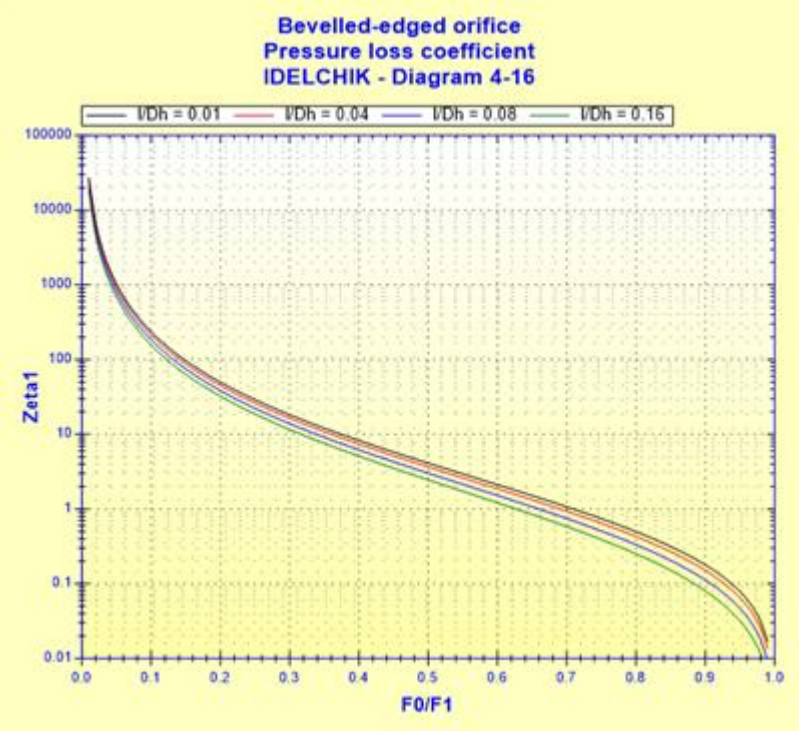
$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Local resistance coefficient:

- $\mathrm{Re}_0 \geq 10^5$

$$\zeta_1 = \left[1 - \frac{F_0}{F_1} + \sqrt{\zeta'} \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375}\right]^2 \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-16)

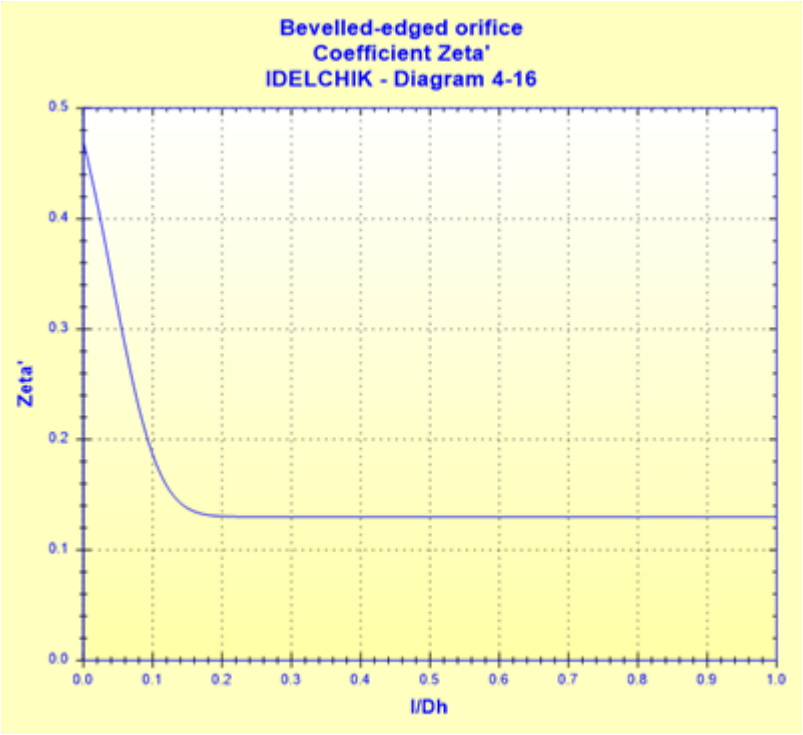


with :

Coefficient of effect of the orifice thickness:

$$\zeta' = 0.13 + 0.34 \cdot 10^{-\left(3.4\frac{l}{D_h} + 88.4\left(\frac{l}{D_h}\right)^{2.3}\right)}$$

([1] diagram 4-16)



■ $Re_0 \leq 10^5$

Quadratic local resistance coefficient:

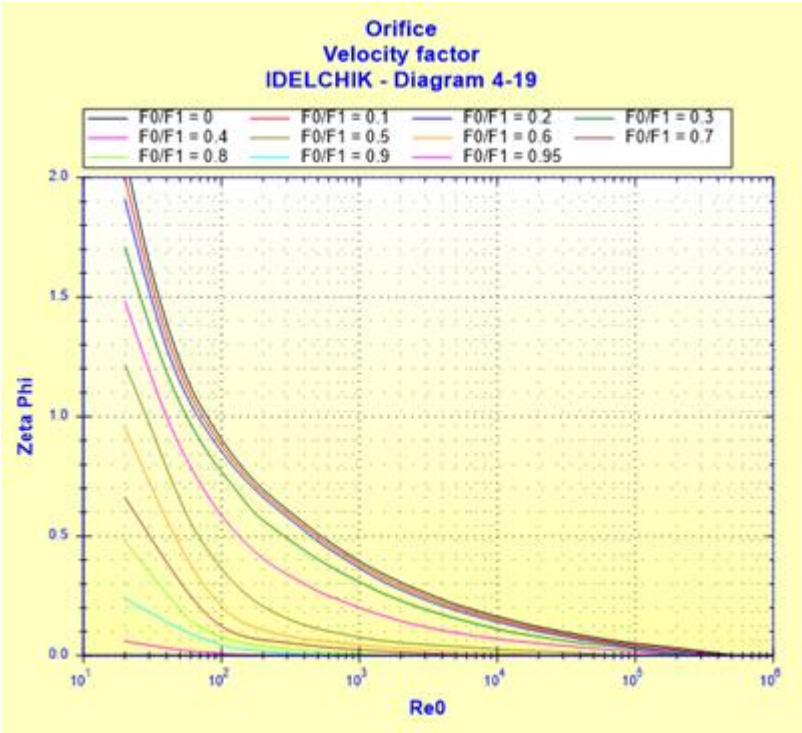
$$\zeta_{1quad} = \left[1 - \frac{F_0}{F_1} + \sqrt{\zeta'} \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375}\right]^2 \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-16)

Velocity factor:

$$\zeta_\varphi = f\left(\mathrm{Re}_0, \frac{F_0}{F_1}\right)$$

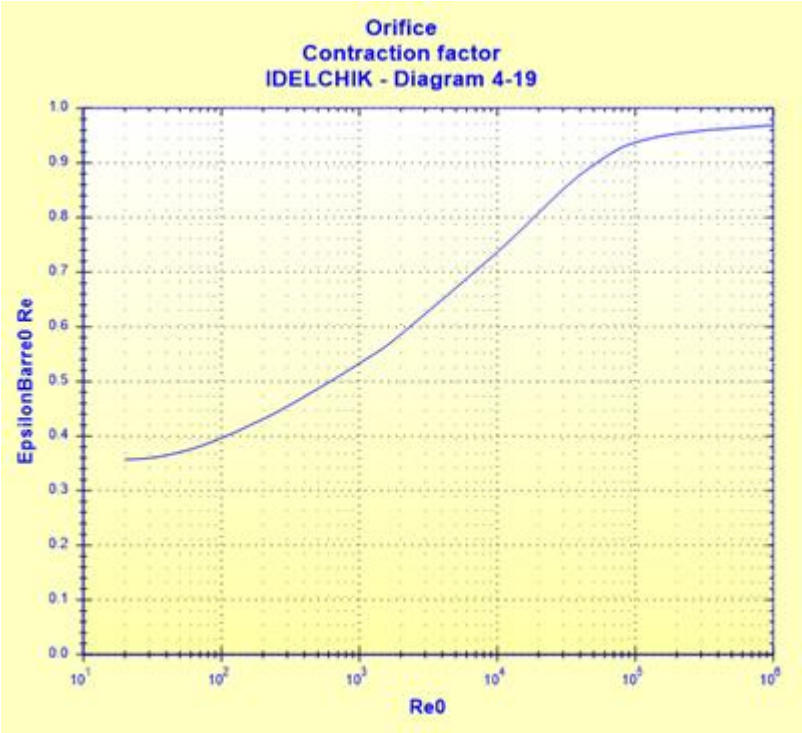
([1] diagram 4-19)



Contraction factor:

$$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re}_0)$$

([1] diagram 4-19)



Local resistance coefficient:

- $30 < Re_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $10 < Re_0 \leq 30$

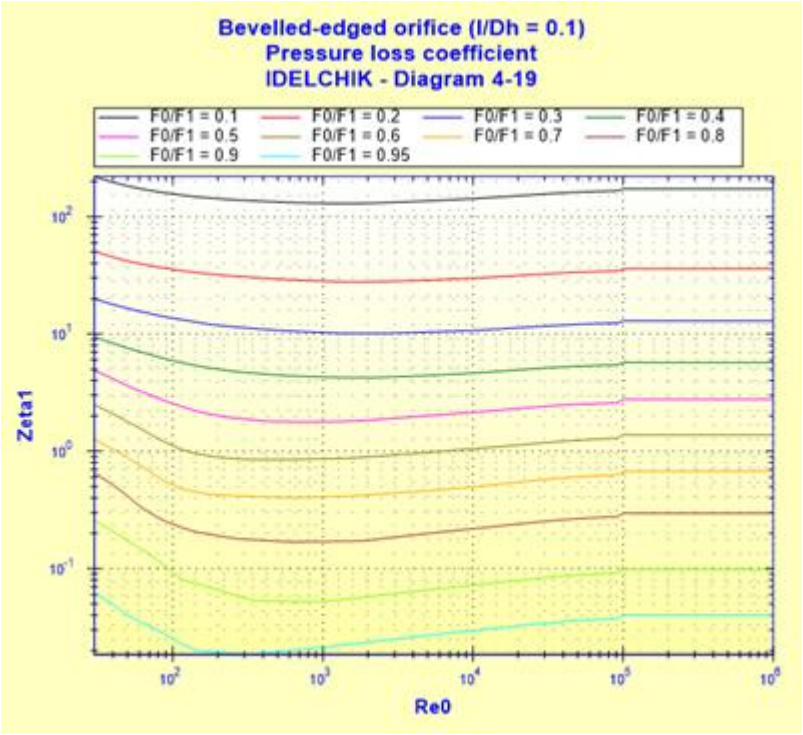
$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-19)



([1] diagram 4-19 with l/Dh = 0.1)

Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \zeta_1$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h Hydraulic diameter (m)

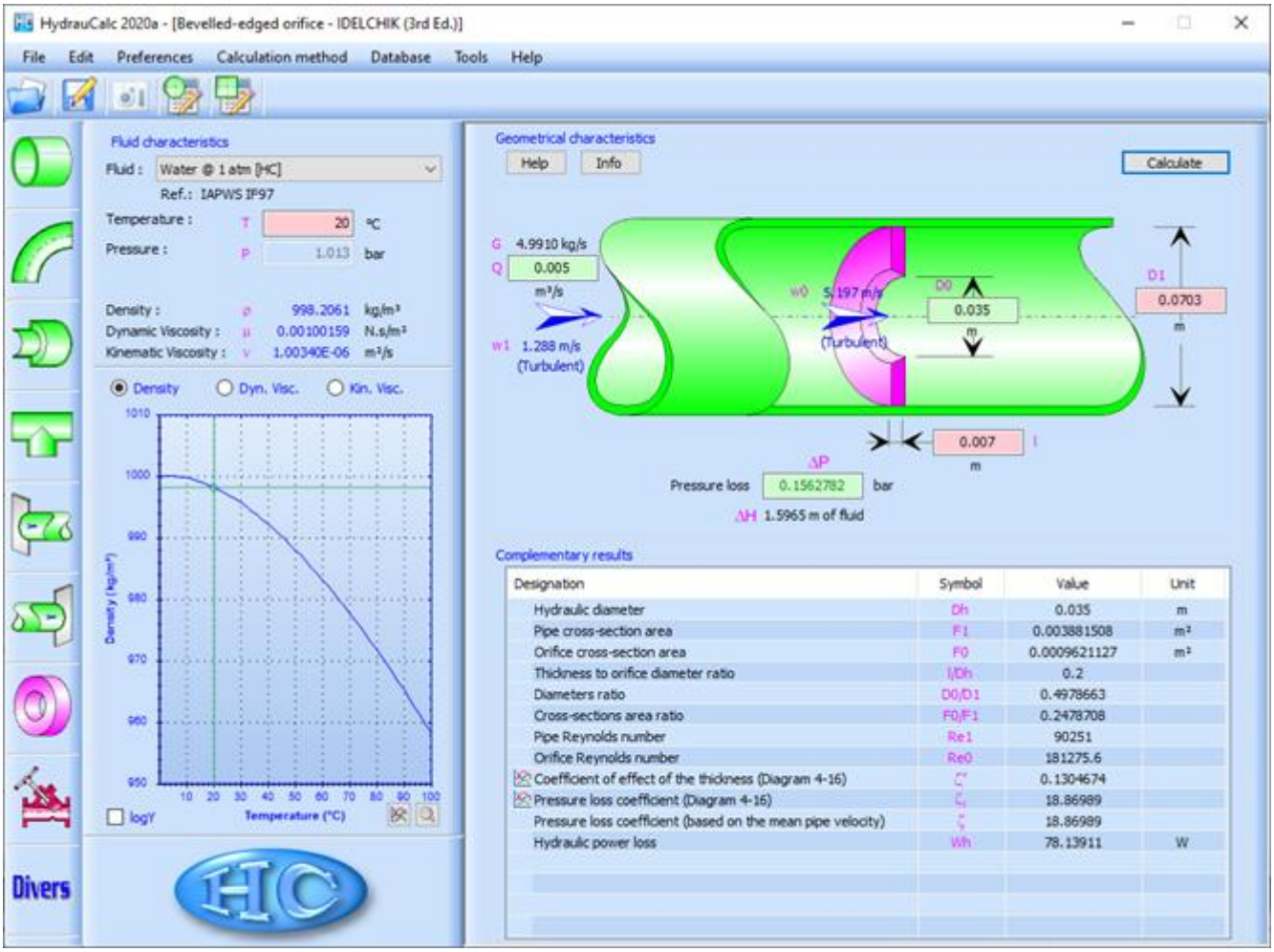
D_1 Pipe internal diameter (m)

D_0	Orifice diameter (m)
F_1	Pipe cross-sectional area (m^2)
F_0	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_1	Mean velocity in pipe (m/s)
w_0	Mean velocity in orifice (m/s)
l	Orifice thickness (m)
Re_1	Reynolds number in pipe ()
Re_0	Reynolds number in orifice ()
ζ'	Coefficient of effect of the orifice thickness ()
ζ_{1quad}	Quadratic local resistance coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ_1	Local resistance coefficient ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- angle at the top of the truncated cone between 40 ° and 60 °

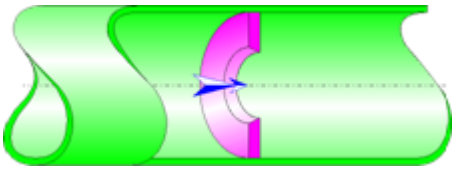
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.7.4.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a bevel-edged orifice installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of orifice to pipe diameters:

$$\beta = \frac{d_o}{d}$$

Pipe cross-sectional area (m²):

$$A = \pi \cdot \frac{d^2}{4}$$

Orifice cross-sectional area (m²):

$$A_o = \pi \cdot \frac{d_o^{\,2}}{4}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

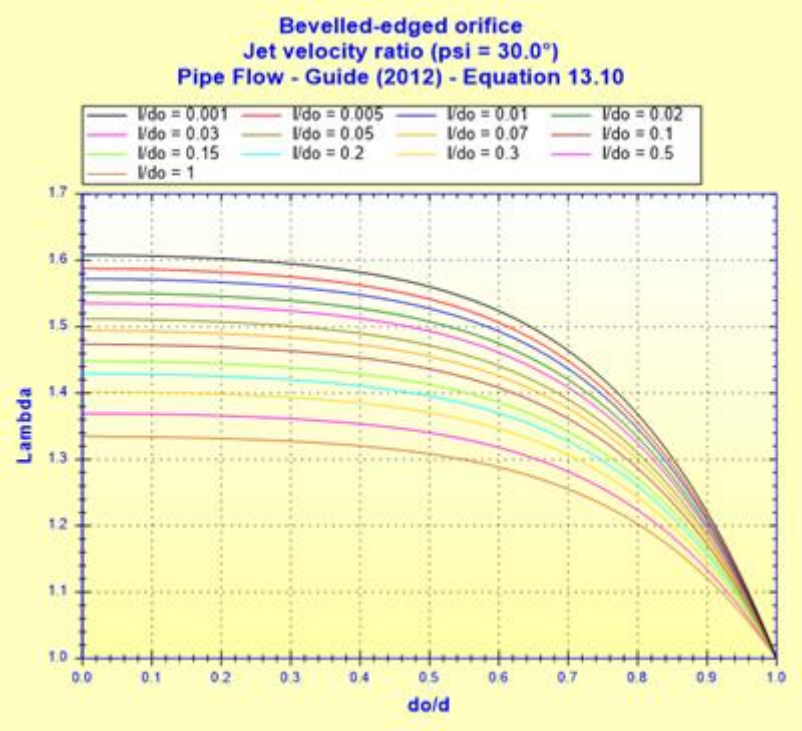
Reynolds number in orifice:

$$N_{Re_O} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left[1 - C_b \cdot \left(\frac{l}{d_0} \right)^{\frac{1-\sqrt[4]{\beta^2}}{2}} \right] \cdot \left(1 - 0.215 \cdot \beta^2 - 0.785 \cdot \beta^5 \right)$$

([1] equation 13.10)

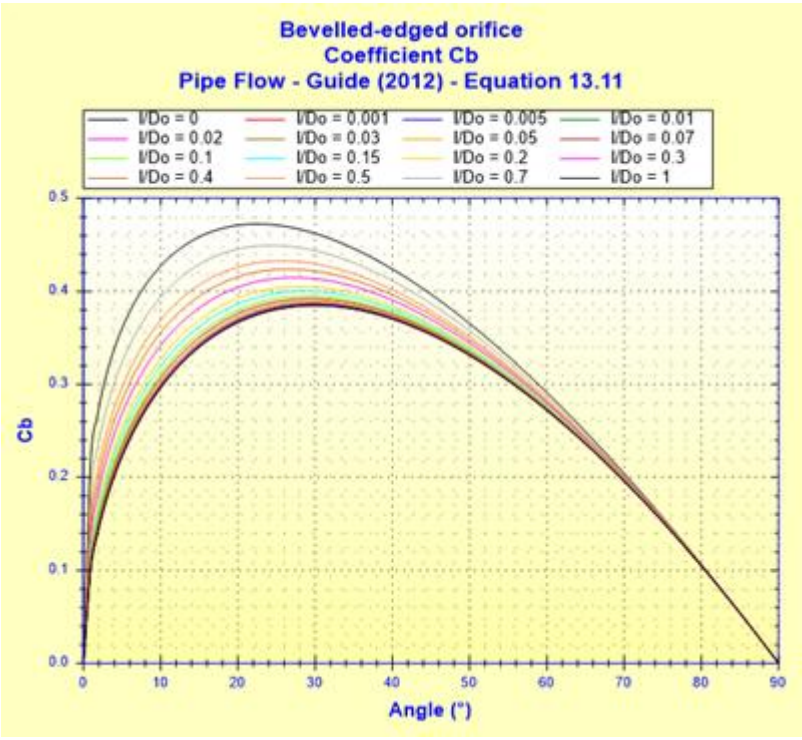


with:

Coefficient of effect of the bevel angle:

$$C_b = \left(1 - \frac{\Psi}{90}\right) \cdot \left(\frac{\Psi}{90}\right)^{\frac{1}{2 + l/d_o}}$$

([1] equation 13.11)



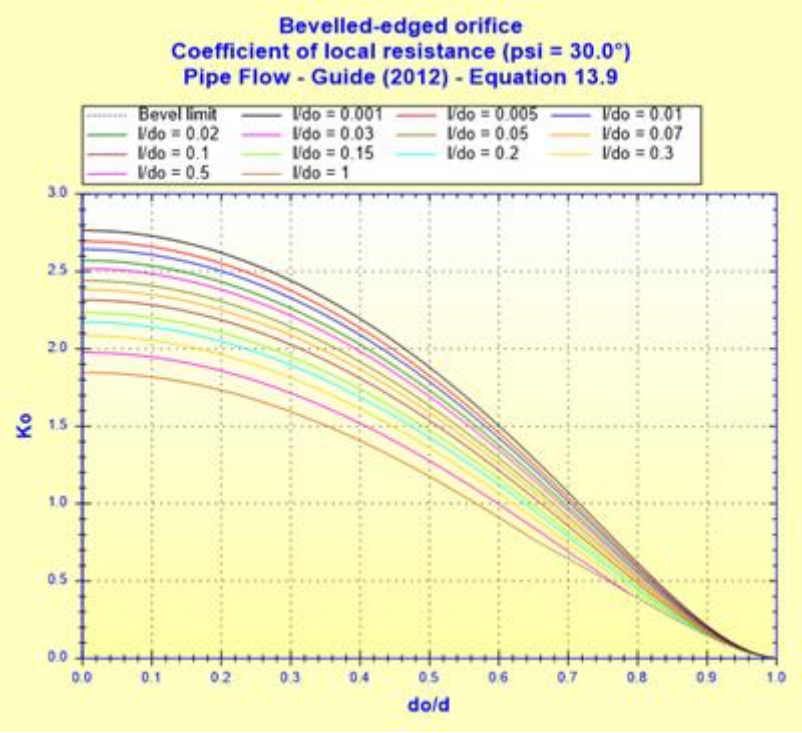
Velocity in vena contracta:

$$V_c = V_0 \cdot \lambda$$

Coefficient of local resistance ($NRe_o \geq 10^4$):

$$K_o = 0.0696 \cdot \left(1 - C_b \cdot \frac{l}{d_0}\right) \cdot \left(1 - 0.42 \cdot \sqrt{\frac{l}{d_0}} \cdot \beta^2\right) \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + \left(\lambda - \beta^2\right)^2$$

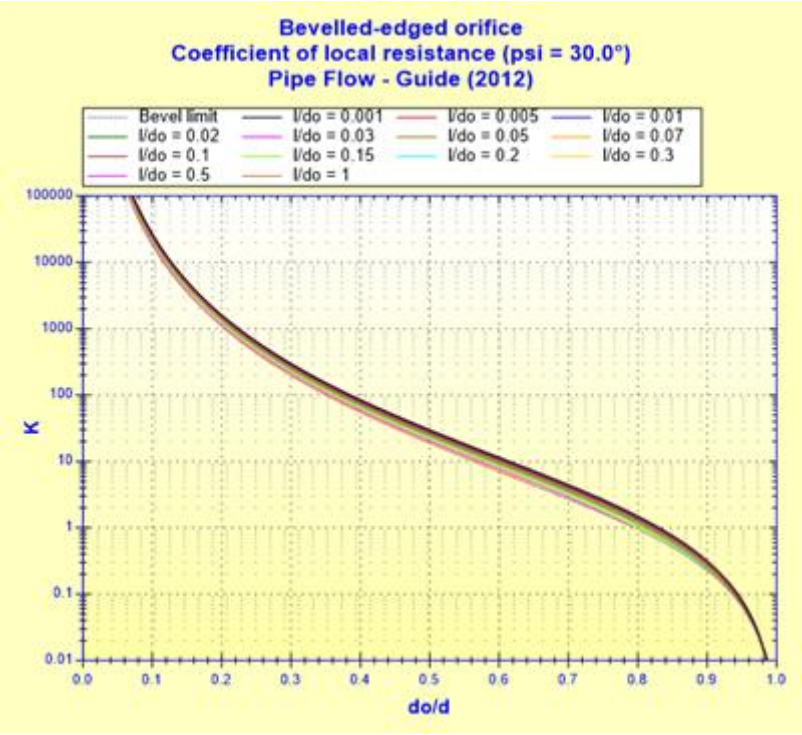
([1] equation 13.9)



(with ψ = 30°)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_0}\right)^2$$



(with ψ = 30°)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

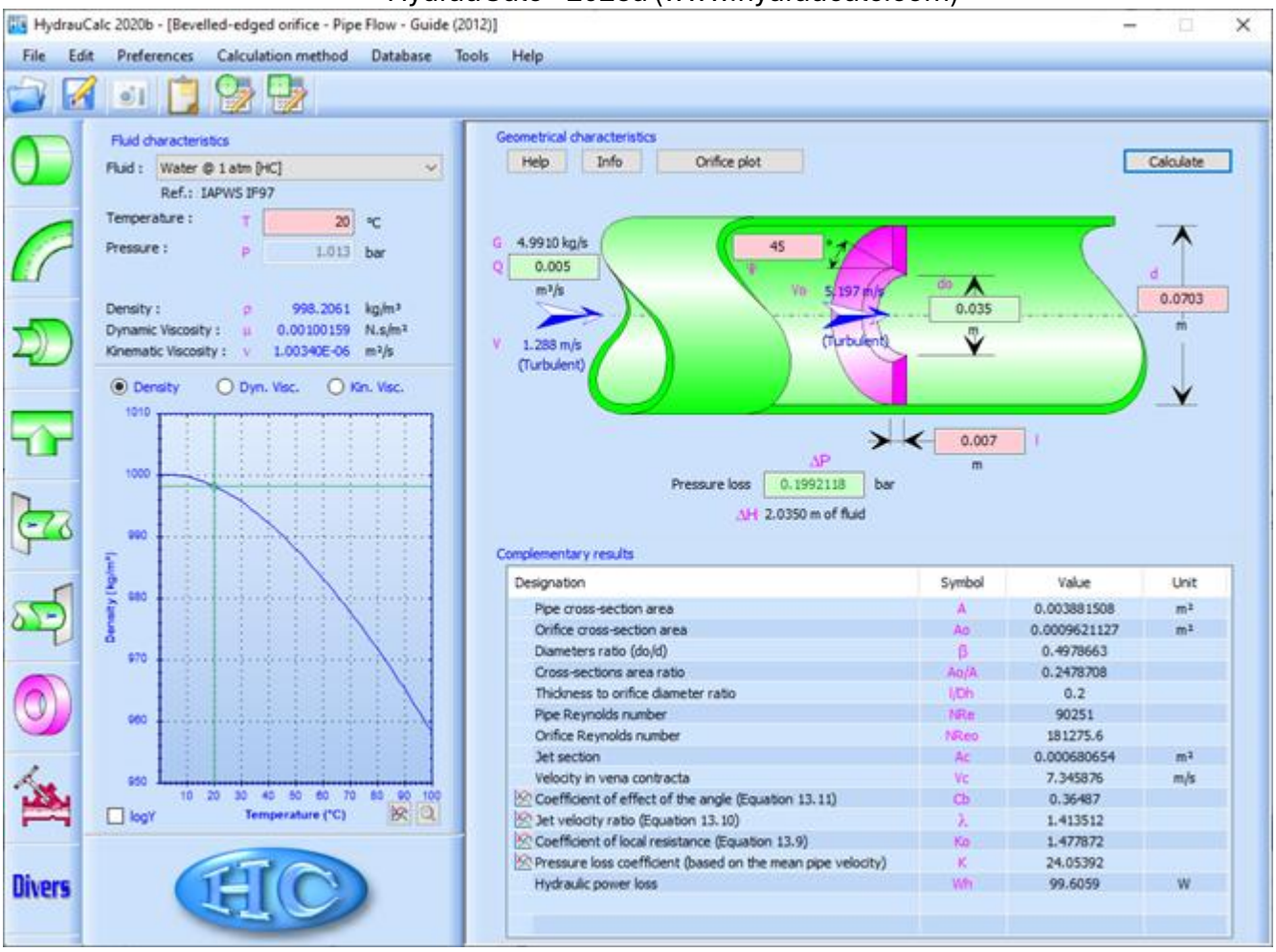
d_0	Orifice diameter (m)
d	Internal pipe diameter (m)
β	Ratio of orifice to pipe diameters ()
A_o	Orifice cross-sectional area (m^2)
A	Pipe cross-sectional area (m^2)

Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
NRe_o	Reynolds number in orifice ()
NRe	Reynolds number in pipe ()
l	Thickness orifice (m)
ψ	Bevel angle (°)
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
C_b	Coefficient of effect of the bevel angle ()
K_o	Coefficient of local resistance ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in orifice ($NRe_o \geq 10^4$)
- stabilized flow upstream of the orifice
- bevel angle less than or equal to: $\psi \leq tg^{-1}((d - d_o) / (2\ l))$

Example of application:

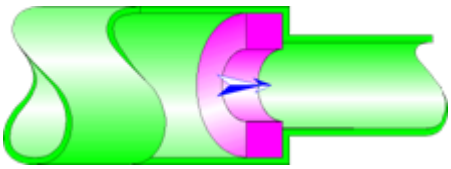


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.7.5 Thick-edged orifice (with pipe contraction)

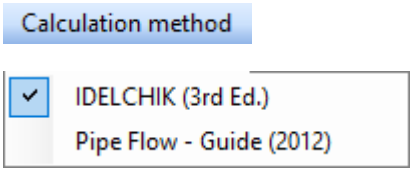
Circular Cross-Section



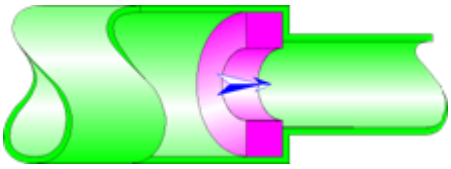
For the calculation of the pressure loss coefficient in thick-edged orifices with pipe contraction downstream of the orifice, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.7.5.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a thick-edged orifice with pipe contraction downstream of the orifice. Moreover, the head loss due to friction of the fluid on the inner walls of the orifice is also taken into account in this component and is calculated with Darcy's formula.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Major pipe cross-section area (m^2):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Minor pipe cross-section area (m^2):

$$F_2 = \pi \cdot \frac{D_2^2}{4}$$

Orifice cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^{\,2}}{4}$$

Mean velocity in major pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in minor pipe (m/s):

$$w_2 = \frac{Q}{F_2}$$

Mean velocity in orifice (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in major pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in minor pipe:

$$\mathrm{Re}_2 = \frac{w_2 \cdot D_2}{\nu}$$

Reynolds number in orifice:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Relative roughness in orifice walls:

$$\bar{\Delta} = \frac{\Delta}{D_0}$$

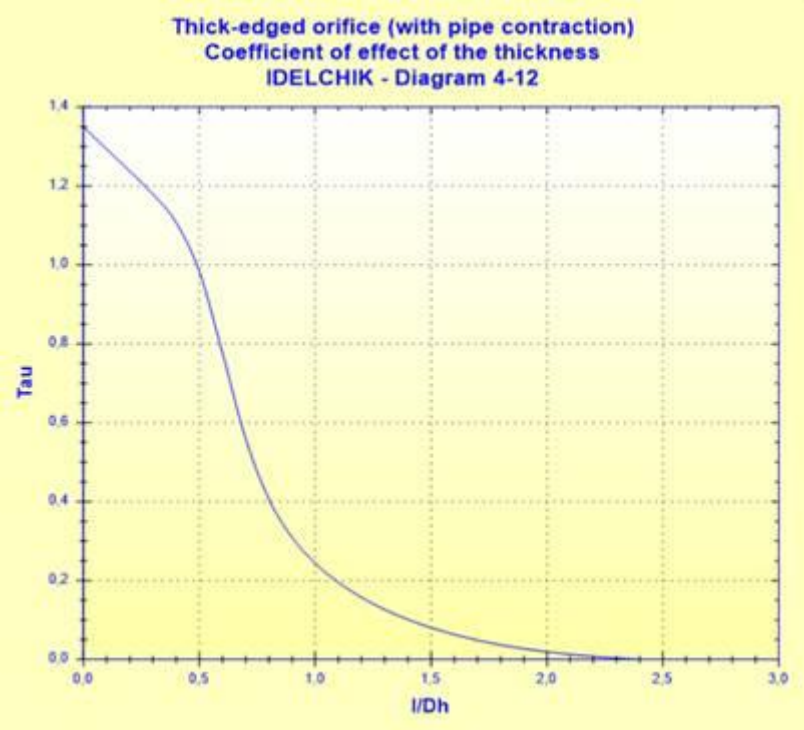
Coefficient of effect of the orifice thickness:

$$\tau = \left(2.4 - \frac{l}{D_h}\right) \cdot 10^{-\varphi\left(\frac{l}{D_h}\right)}$$

([1] diagram 4-12)

with:

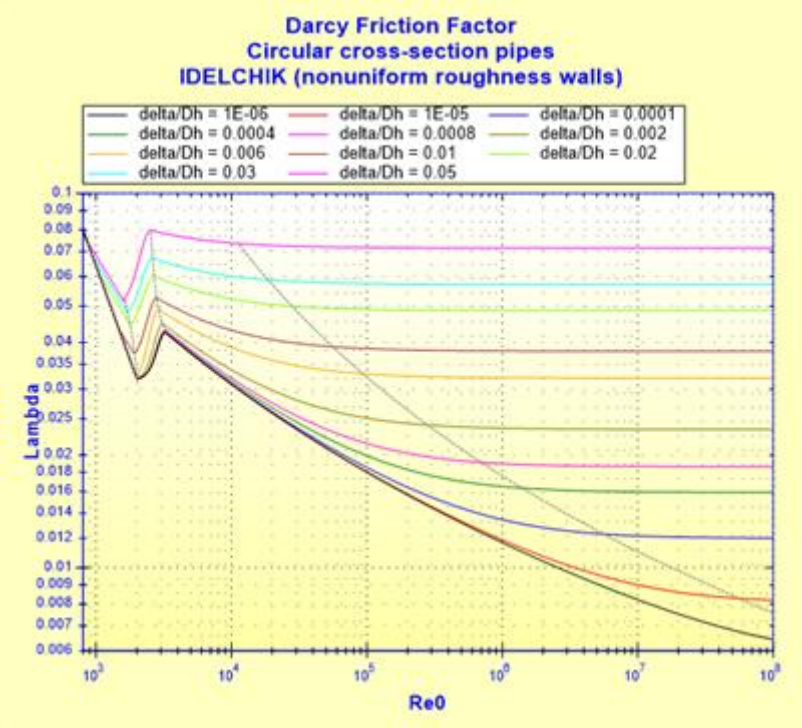
$$\varphi\left(\frac{l}{D_h}\right) = 0.25 + \frac{0.535 \cdot \left(\frac{l}{D_h}\right)^8}{0.05 + \left(\frac{l}{D_h}\right)^7}$$



Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}_0, \frac{\Delta}{D_h}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)

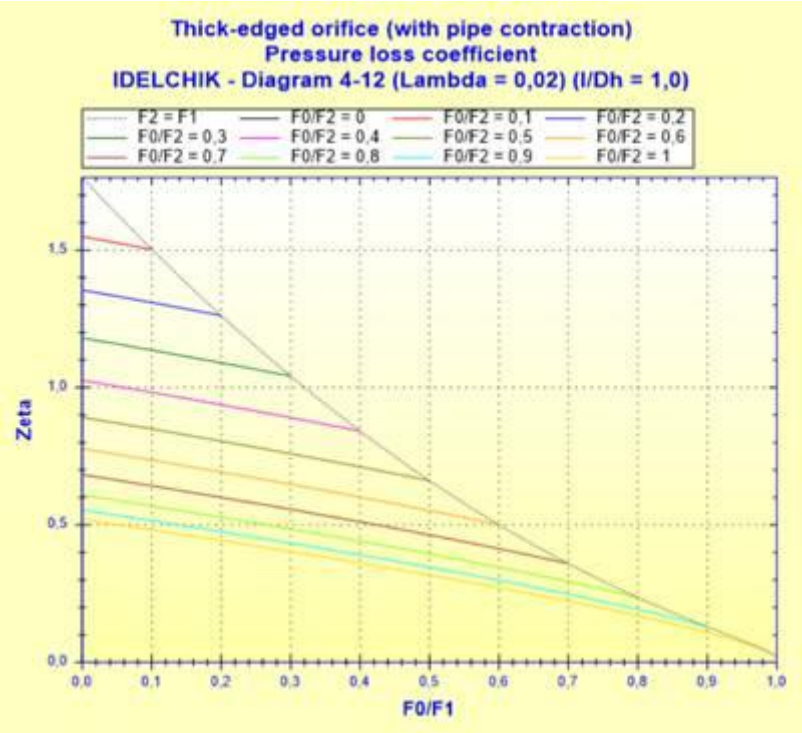


■ $Re_0 \geq 10^5$

Local resistance coefficient:

$$\zeta = \left[0.5 \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \left(1 - \frac{F_0}{F_2}\right)^2 + \tau \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375} \cdot \left(1 - \frac{F_0}{F_2}\right) + \lambda \cdot \frac{l}{D_h} \right]$$

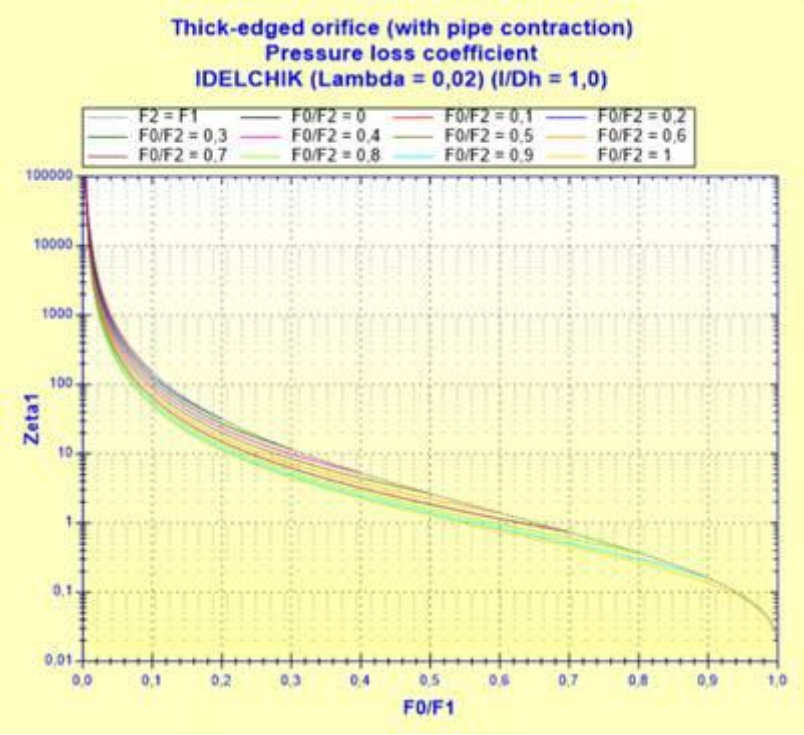
([1] diagram 4-12)



(with λ = 0.02 et l/D_h = 1)

Pressure loss coefficient (based on the major pipe velocity):

$$\zeta_1 = \zeta \cdot \left(\frac{F_1}{F_0}\right)^2$$



(with λ = 0.02 et l/D_h = 1)

■ $Re_0 < 10^5$

Quadratic local resistance coefficient:

$$\zeta_{quad} = \left[0.5 \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \left(1 - \frac{F_0}{F_2}\right)^2 + \tau \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375} \cdot \left(1 - \frac{F_0}{F_2}\right) + \lambda \cdot \frac{l}{D_h}\right]$$

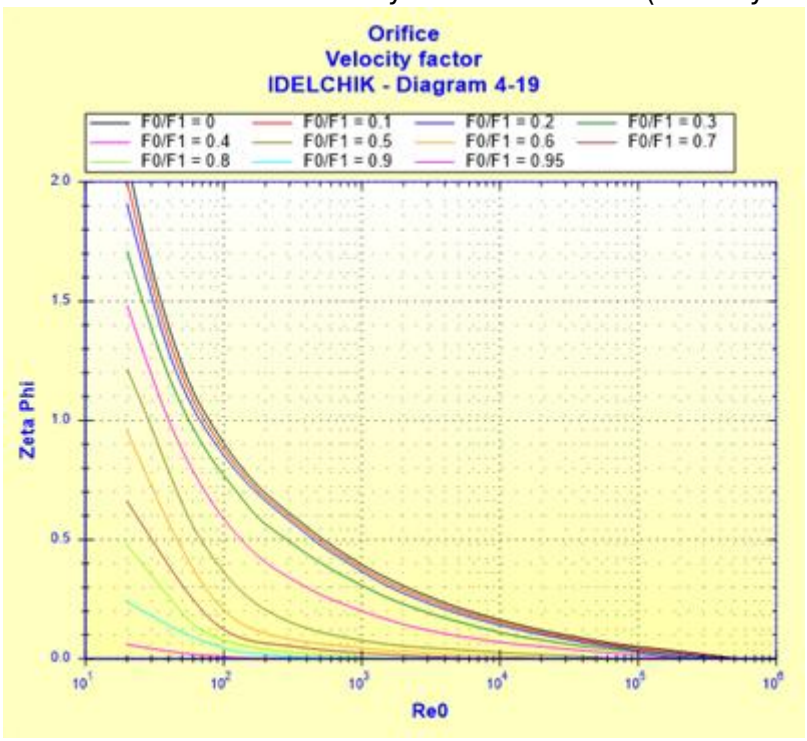
([1] diagram 4-12)

$$\zeta_{1quad} = \zeta_{quad} \cdot \left(\frac{F_1}{F_0}\right)^2$$

Velocity factor:

$$\zeta_\varphi = f\left(Re_0, \frac{F_0}{F_1}\right)$$

([1] diagram 4-19)



Contraction factor:

$\overline{\varepsilon}_{0\,Re} = f(Re_0)$ ([1] diagram 4-19)

Pressure loss coefficient (based on the major pipe velocity):

- $30 < Re_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $10 < Re_0 \leq 30$

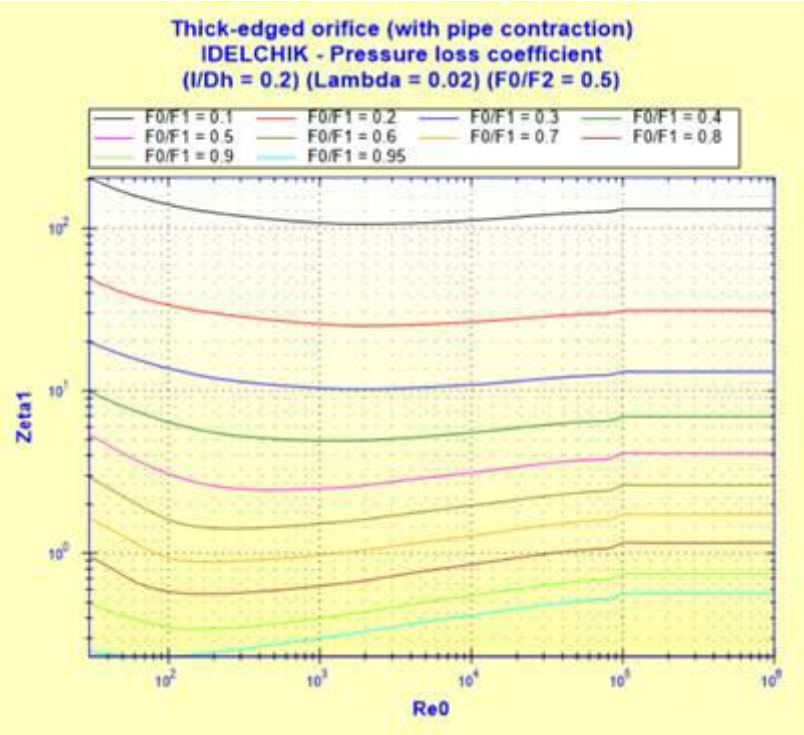
$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-19)



(with $l/D_h = 0.2$, $\lambda = 0.02$ and $F_0/F_2 = 0.5$)

Total pressure loss (Pa):

$$\Delta P = \zeta_1 \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta_1 \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_1	Major pipe internal diameter (m)
D_2	Minor pipe internal diameter (m)
D_0	Orifice diameter (m)
F_1	Major pipe cross-sectional area (m^2)
F_2	Minor pipe cross-sectional area (m^2)
F_0	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_1	Mean velocity in major pipe (m/s)
w_2	Mean velocity in minor pipe (m/s)
w_0	Mean velocity in orifice (m/s)
Re_1	Reynolds number in major pipe ()
Re_2	Reynolds number in minor pipe ()
Re_0	Reynolds number in orifice ()
Δ	Absolute roughness of orifice walls (m)
$\bar{\Delta}$	Relative roughness of orifice walls ()
l	Orifice thickness (m)
τ	Coefficient of effect of the orifice thickness ()
λ	Darcy friction coefficient in orifice ()
ζ	Local resistance coefficient (based on the orifice velocity) ()
ζ_{quad}	Quadratic local resistance coefficient (based on the orifice velocity) ()
ζ_{1quad}	Quadratic local resistance coefficient (based on the major pipe velocity) ()

ζ_{φ} Velocity factor ()

$\bar{\varepsilon}_{0Re}$ Contraction factor ()

ζ_1 Pressure loss coefficient (based on the major pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

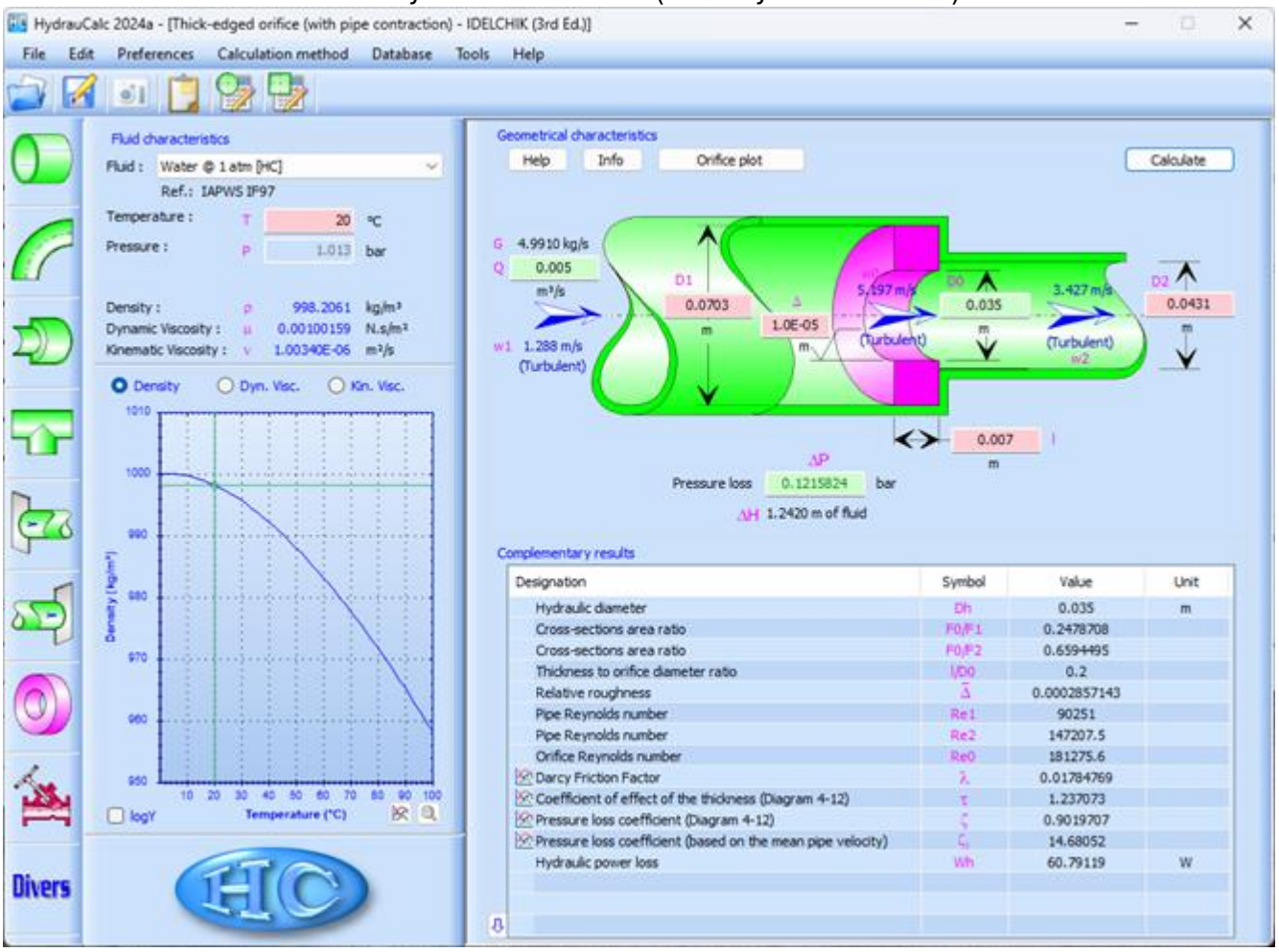
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- thickness to orifice diameter ratio (l/D_0) greater than 0.015

Example of application:



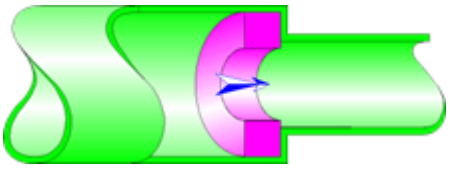
References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

[2] Идельчик.И.Е.Справочник по гидравлическим сопротивлениям.1992 (original document in Russian language)

Note: The formulation used for the calculation of the coefficient $\varphi\left(\frac{l}{D_h}\right)$ is that of the original reference document [2] which differs from that of the translated document [1]

2.7.5.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a thick-edged orifice with pipe contraction downstream of the orifice. Moreover, when the thickness of the orifice is greater than 1.4 times the diameter of the orifice, the head loss due to friction in the orifice is also taken into account because it becomes significant.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of orifice to major pipe diameters:

$$\beta = \frac{d_o}{d_1}$$

Major pipe cross-sectional area (m²):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Minor pipe cross-sectional area (m²):

$$A_2 = \pi \cdot \frac{d_2^2}{4}$$

Orifice cross-sectional area (m^2):

$$A_o = \pi \cdot \frac{d_o^2}{4}$$

Major pipe velocity (m/s):

$$V_1 = \frac{Q}{A_1}$$

Minor pipe velocity (m/s):

$$V_2 = \frac{Q}{A_2}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in major pipe:

$$N_{Re1} = \frac{V_1 \cdot d_1}{\nu}$$

Reynolds number in minor pipe:

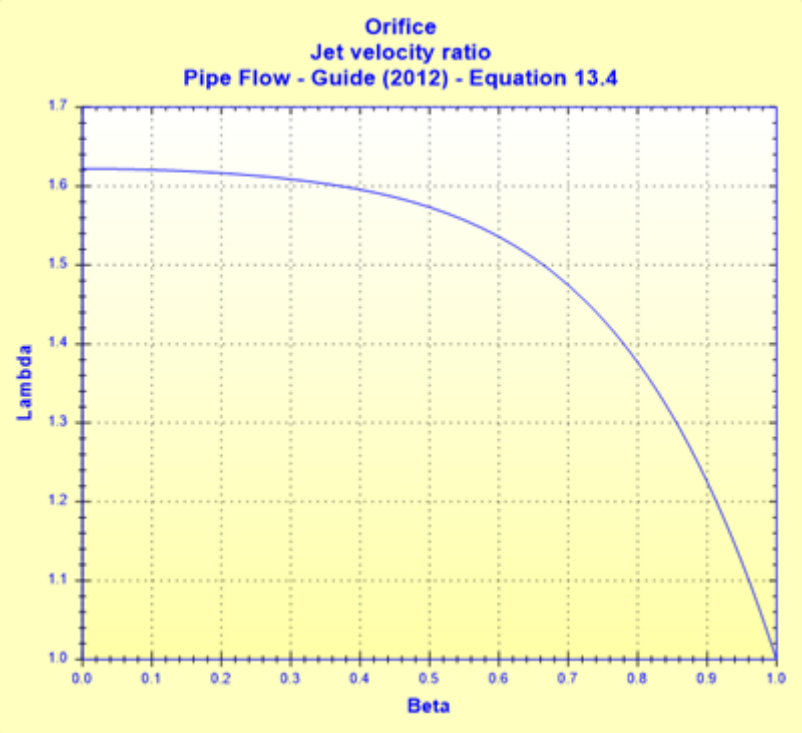
$$N_{Re2} = \frac{V_2 \cdot d_2}{\nu}$$

Reynolds number in orifice:

$$N_{Re0} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left(1 - 0.215\beta^2 - 0.785\beta^5\right)$$ ([1] equation 13.4)



Velocity in vena contracta:

$$V_C = V_0 \cdot \lambda$$

Coefficient of local resistance ($NRe_o \geq 10^4$):

- Thickness to orifice diameter ratio (t/d_o) ≤ 1.4:

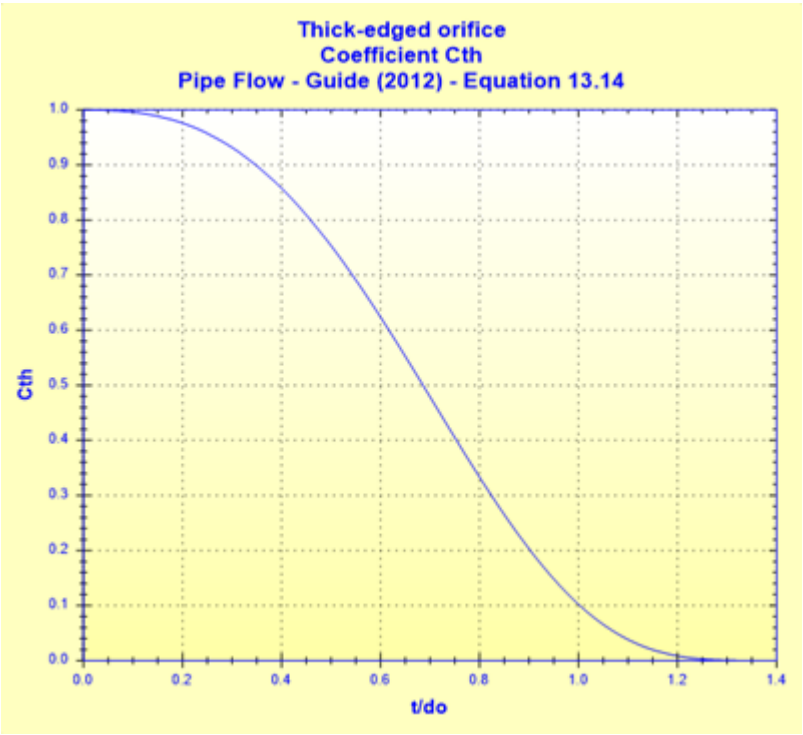
$$K_o = 0.0696 \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + C_{th} \cdot \left(\lambda - \left(\frac{d_0}{d_2}\right)^2\right)^2 + \left(1 - C_{th}\right) \cdot \left[\left(\lambda - 1\right)^2 + \left(1 - \left(\frac{d_0}{d_2}\right)^2\right)^2\right]$$ ([1] equation 13.16)

(with $t/d_0 = 1$)

with:

$$C_{th} = \left[1 - 0.50 \cdot \left(\frac{t}{1.4 d_o}\right)^{2.5} - 0.50 \cdot \left(\frac{t}{1.4 d_o}\right)^{3}\right]^{-4.5}$$

([1] equation 13.14)



■ Thickness to orifice diameter ratio (t/d_o) > 1.4:

$$K_o = 0.0696 \cdot \left(1-\beta^5\right) \cdot \lambda^2 + \left(\lambda - 1\right)^2 + \left[1 - \left(\frac{d_0}{d_2}\right)^2\right]^2 + f_o \cdot \left(\frac{t}{d_o} - 1.4\right)$$

([1] equation 13.17)

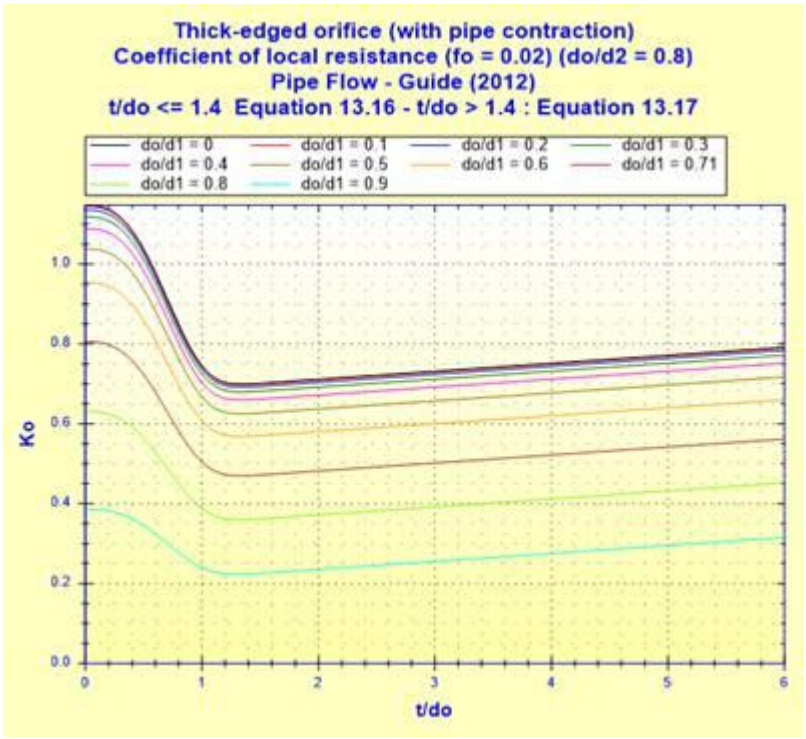
(with $f_0 = 0.02$ and $t/d_0 = 5$)

with:

$$f_o = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d_o} + \frac{2.51}{NRe_0 \cdot \sqrt{f_o}}\right)\right]^2}$$

Colebrook-White equation ([1] equation 3.6)

■ All thickness to orifice diameter ratios (t/d_o):



(with $f_0 = 0.02$ and $d_0/d_2 = 0.8$)

Total pressure loss coefficient (based on the major pipe velocity):

$$K = K_o \cdot \left(\frac{A_1}{A_o}\right)^2$$

(with $f_0 = 0.02$ and $d_0/d_2 = 0.8$)

(with $f_0 = 0.02$ and $t/d_0 = 1$)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_0	Orifice diameter (m)
d_1	Internal major pipe diameter (m)
d_2	Internal minor pipe diameter (m)
β	Ratio of orifice to major pipe diameters ()
A_0	Orifice cross-sectional area (m^2)
A_1	Major pipe cross-sectional area (m^2)
A_2	Minor pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_0	Mean velocity in orifice (m/s)
V_1	Mean velocity in major pipe (m/s)
V_2	Mean velocity in minor pipe (m/s)
NRe_0	Reynolds number in orifice ()
NRe_1	Reynolds number in major pipe ()
NRe_2	Reynolds number in minor pipe ()
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
t	Thickness orifice (m)
K_0	Coefficient of local resistance ()
Cth	Coefficient ()
ε	Absolute roughness of orifice walls (m)

f_o Friction factor ()

K Total pressure loss coefficient (based on the major pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m^3)

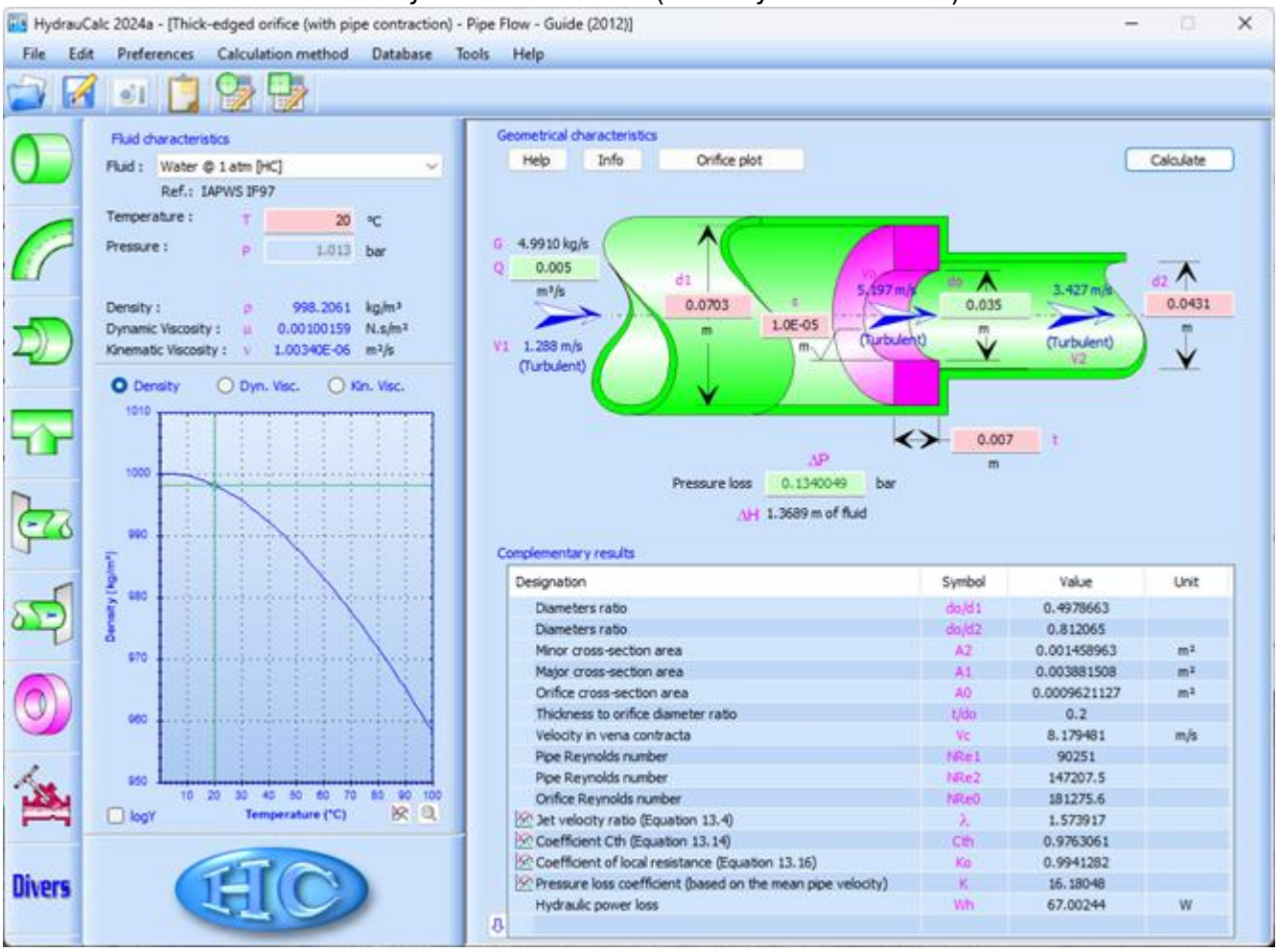
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in orifice ($NRe_o \geq 10^4$)
- stabilized flow upstream of the orifice

Example of application:

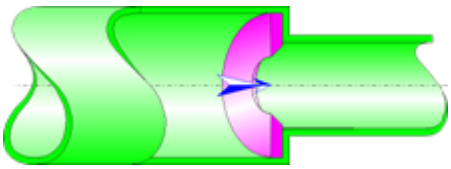


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.7.6 Sharp-edged orifice (with pipe contraction)

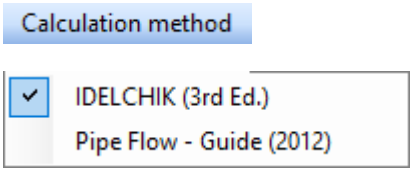
Circular Cross-Section



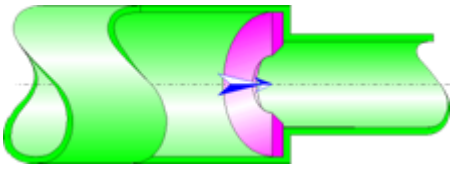
For the calculation of the pressure loss coefficient of sharp-edged orifices with pipe contraction downstream of the orifice, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.7.6.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sharp-edged orifice with pipe contraction downstream of the orifice.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Major pipe cross-section area (m^2):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Minor pipe cross-section area (m^2):

$$F_2 = \pi \cdot \frac{D_2^2}{4}$$

Orifice cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity in major pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in minor pipe (m/s):

$$w_2 = \frac{Q}{F_2}$$

Mean velocity in orifice (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in major pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in minor pipe:

$$\mathrm{Re}_2 = \frac{w_2 \cdot D_2}{\nu}$$

Reynolds number in orifice:

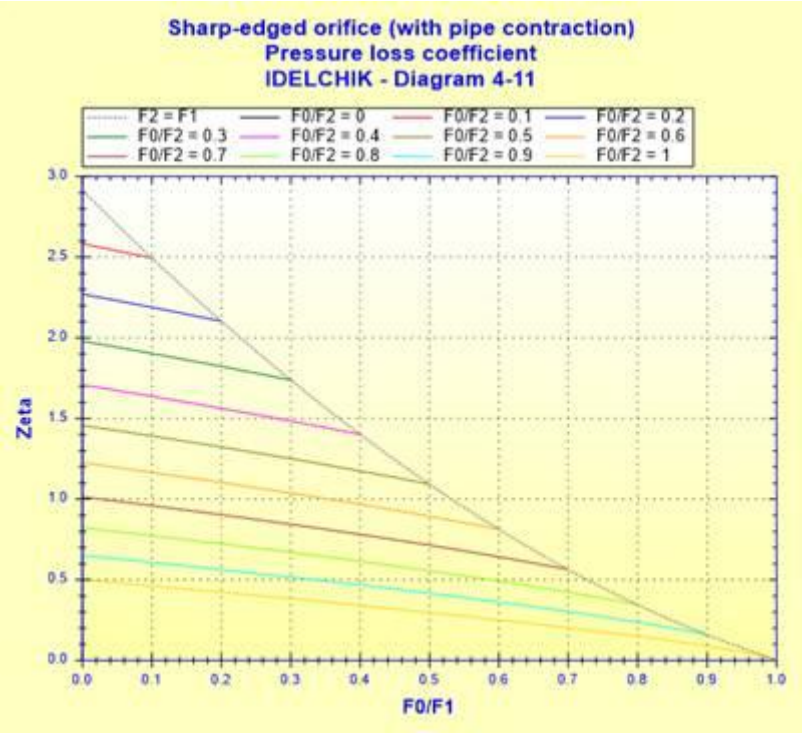
$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

■ $\mathrm{Re}_0 \geq 10^5$

Local resistance coefficient:

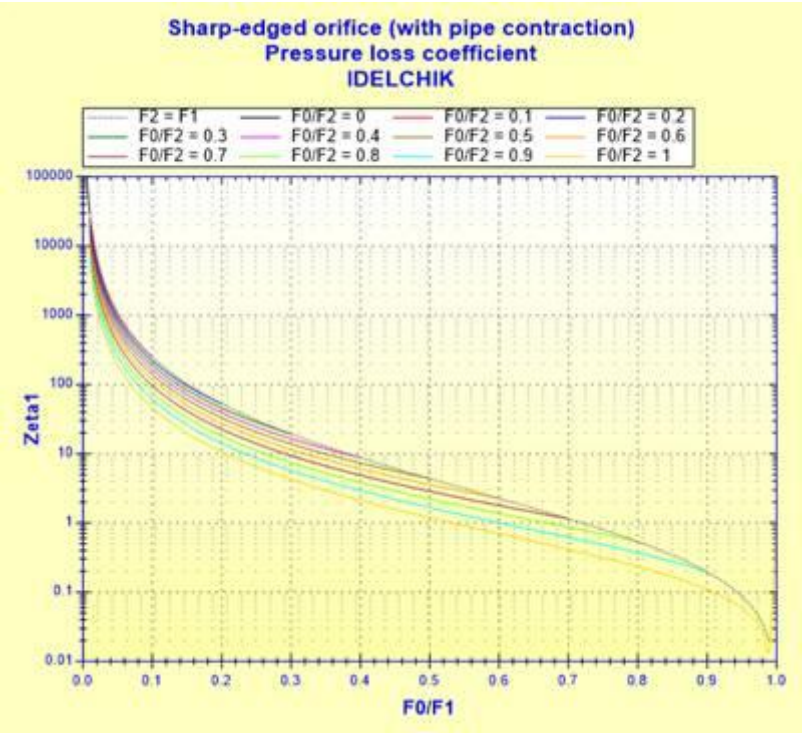
$$\zeta = \left[0.707 \cdot \left(1 - \frac{F_0}{F_1} \right)^{0.375} + \left(1 - \frac{F_0}{F_2} \right) \right]^2$$

([1] diagram 4-11)



Pressure loss coefficient (based on the major pipe velocity):

$$\zeta_1 = \zeta \cdot \left(\frac{F_1}{F_0} \right)^2$$



■ $Re_0 < 10^5$

Quadratic local resistance coefficient:

$$\zeta_{quad} = \left[0.707 \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375} + \left(1 - \frac{F_0}{F_2}\right)\right]^2$$

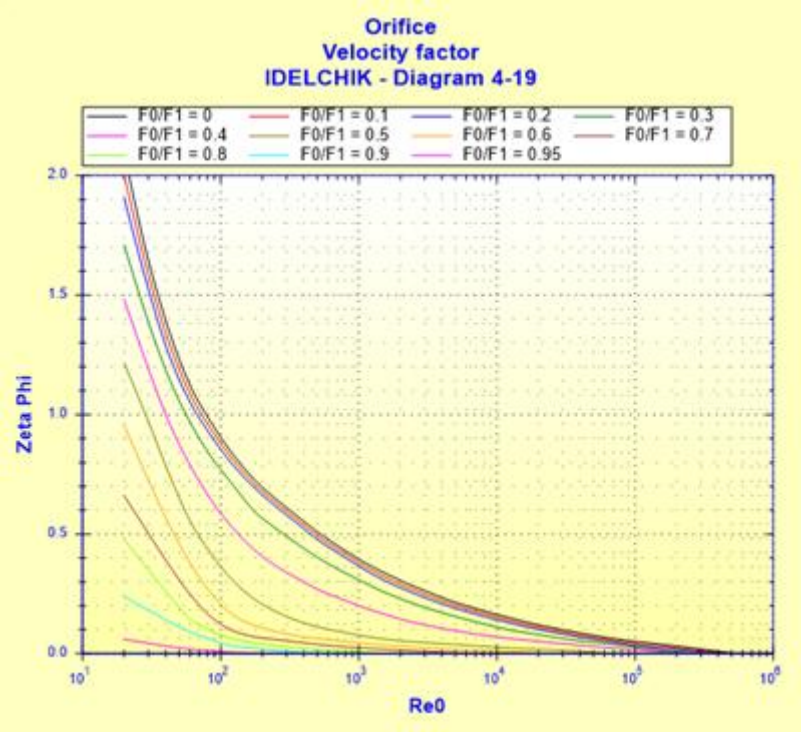
([1] diagram 4.11)

$$\zeta 1_{quad} = \zeta_{quad} \cdot \left(\frac{F_1}{F_0}\right)^2$$

Velocity factor:

$$\zeta_\varphi = f\left(Re_0, \frac{F_0}{F_1}\right)$$

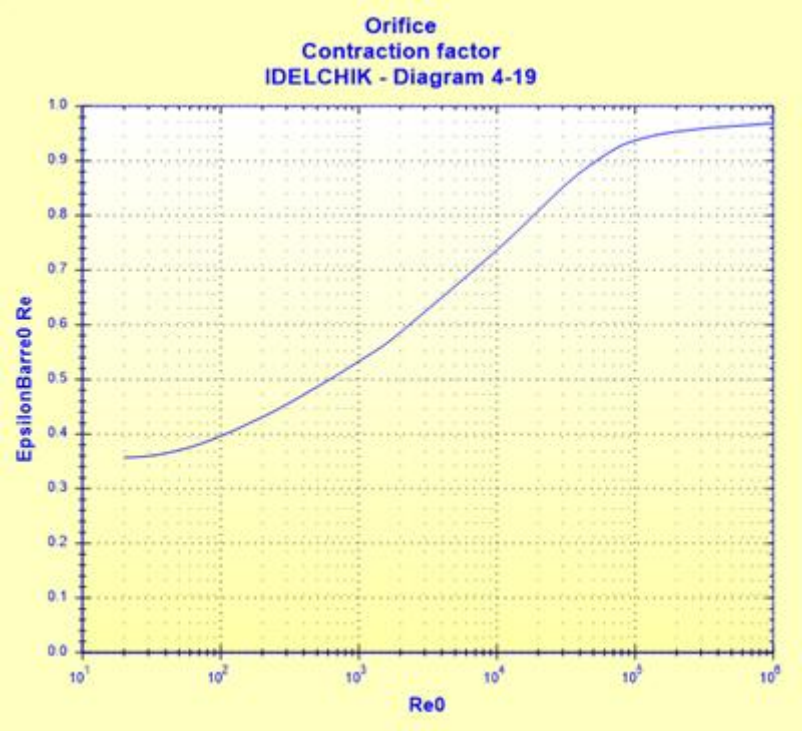
([1] diagram 4-19)



Contraction factor:

$$\bar{\varepsilon}_{0Re} = f(Re_0)$$

([1] diagram 4-19)



Pressure loss coefficient (based on the major pipe velocity):

- $30 < Re_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $10 < Re_0 \leq 30$

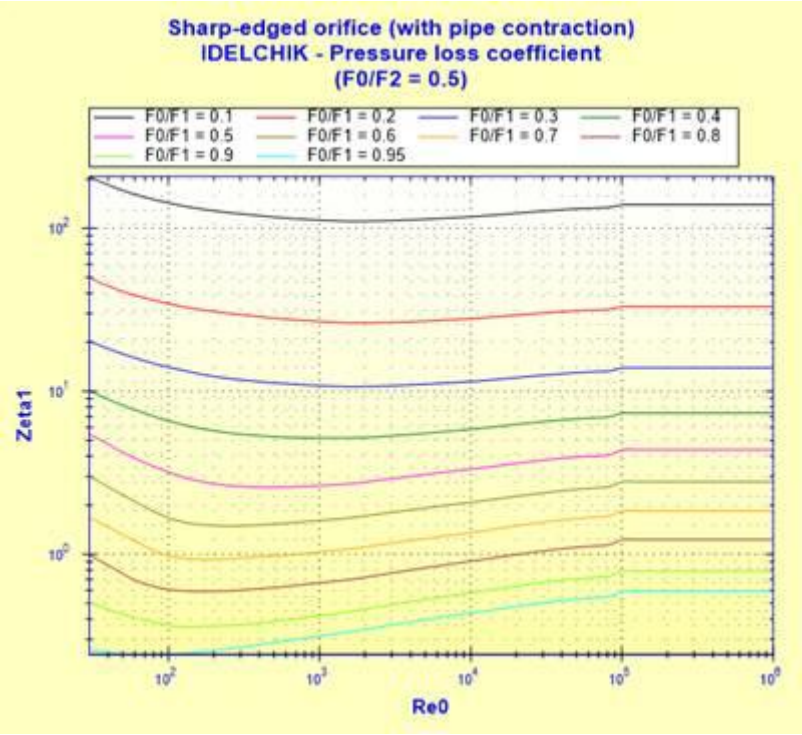
$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-19)



(with $F_0/F_2 = 0.5$)

Total pressure loss (Pa):

$$\Delta P = \zeta_1 \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta_1 \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

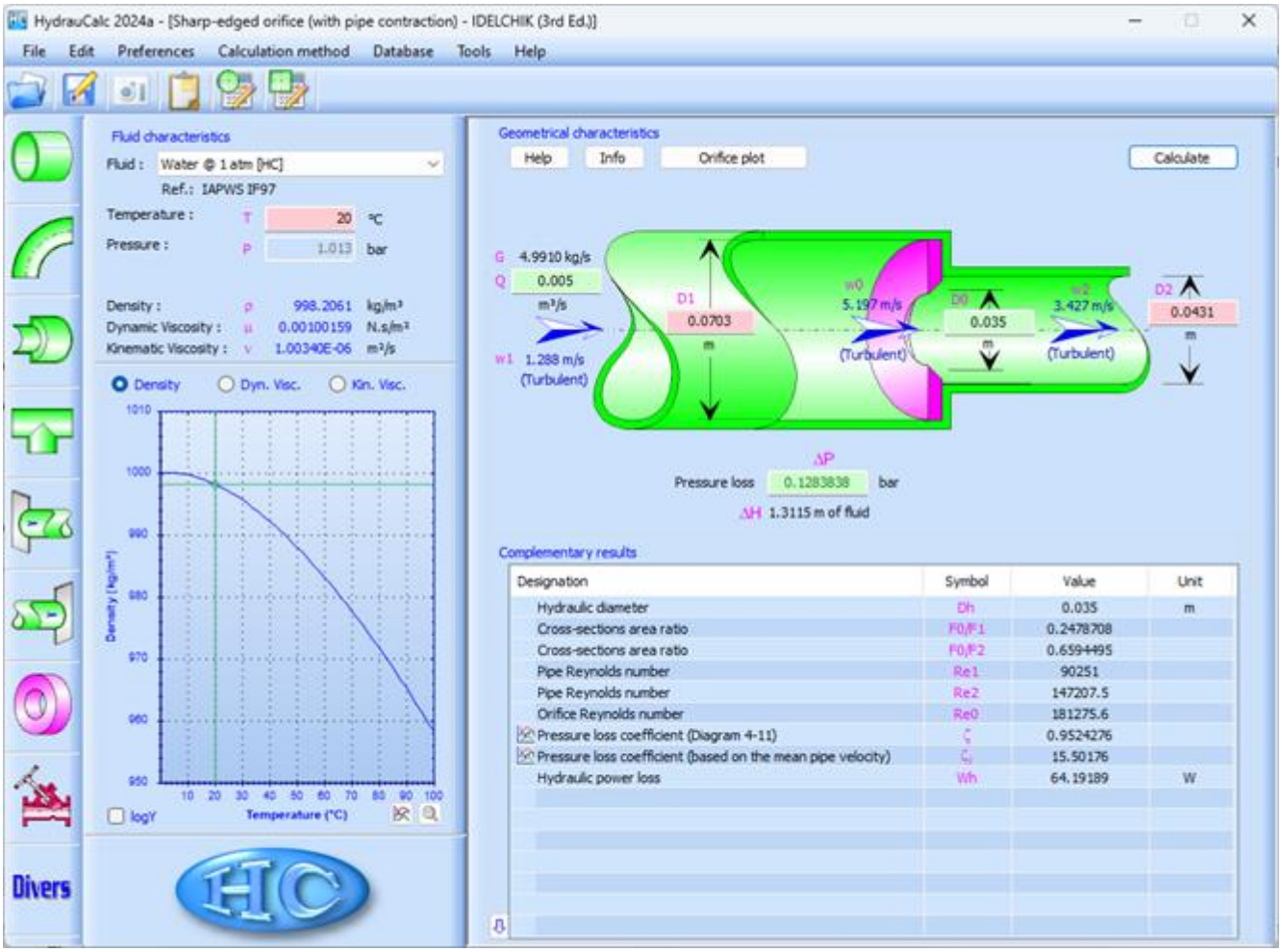
D_h	Hydraulic diameter (m)
D_1	Major pipe internal diameter (m)
D_2	Minor pipe internal diameter (m)
D_0	Orifice diameter (m)
F_1	Major pipe cross-sectional area (m^2)

F_2	Minor pipe cross-sectional area (m^2)
F_0	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_1	Mean velocity in major pipe (m/s)
w_2	Mean velocity in minor pipe (m/s)
w_0	Mean velocity in orifice (m/s)
Re_1	Reynolds number in major pipe ()
Re_2	Reynolds number in minor pipe ()
Re_0	Reynolds number in orifice ()
ζ	Local resistance coefficient (based on the orifice velocity) ()
ζ_{quad}	Quadratic local resistance coefficient (based on the orifice velocity) ()
ζ_{1quad}	Quadratic local resistance coefficient (based on the major pipe velocity) ()
ζ_{φ}	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ_1	Pressure loss coefficient (based on the major pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice

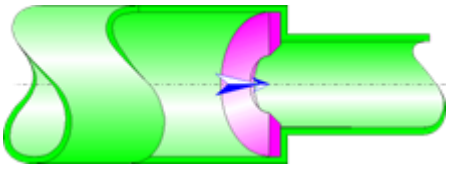
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.7.6.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sharp-edged orifice with pipe contraction downstream of the orifice.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of orifice to major pipe diameters:

$$\beta = \frac{d_o}{d_1}$$

Major pipe cross-sectional area (m²):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Minor pipe cross-sectional area (m²):

$$A_2 = \pi \cdot \frac{d_2^2}{4}$$

Orifice cross-sectional area (m²):

$$A_o = \pi \cdot \frac{d_o^2}{4}$$

Major pipe velocity (m/s):

$$V_1 = \frac{Q}{A_1}$$

Minor pipe velocity (m/s):

$$V_2 = \frac{Q}{A_2}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in major pipe:

$$N_{Re1} = \frac{V_1 \cdot d_1}{\nu}$$

Reynolds number in minor pipe:

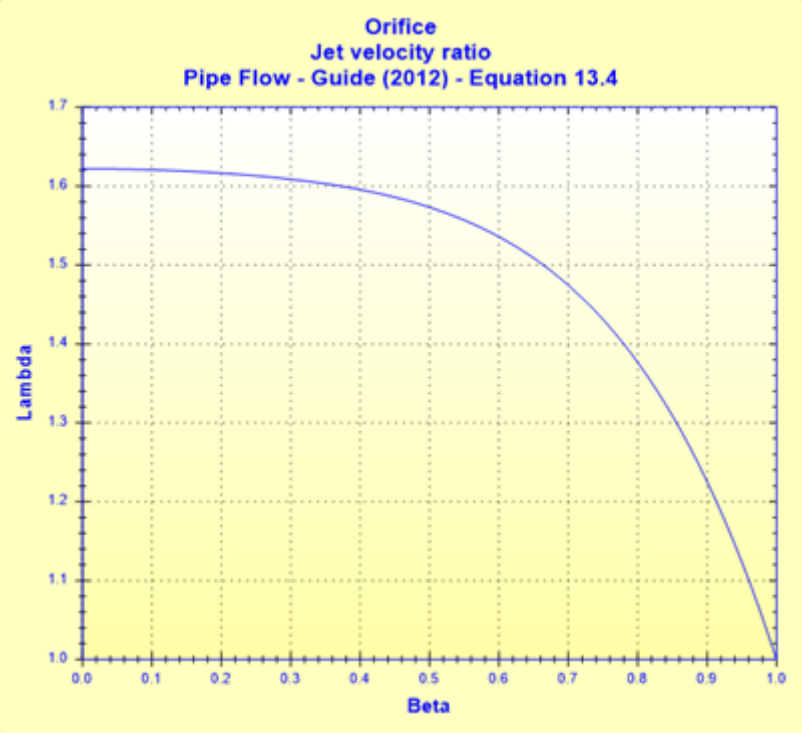
$$N_{Re2} = \frac{V_2 \cdot d_2}{\nu}$$

Reynolds number in orifice:

$$N_{Re_o} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left(1 - 0.215\beta^2 - 0.785\beta^5\right)$$ ([1] equation 13.4)



Velocity in vena contracta (m/s):

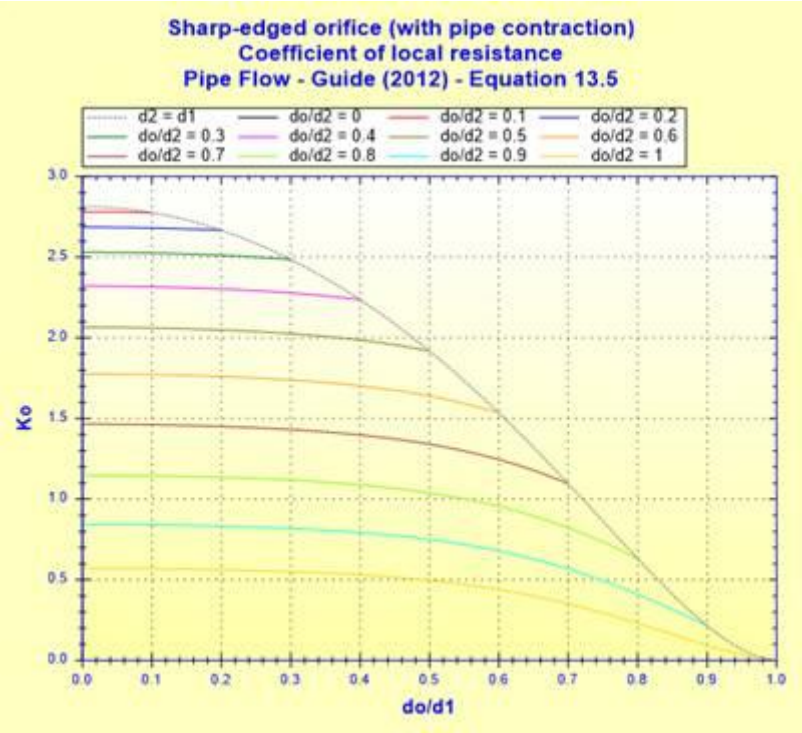
$$V_C = V_O \cdot \lambda$$

Vena contracta cross-sectional area (m^2):

$$A_C = \frac{Q}{V_C}$$

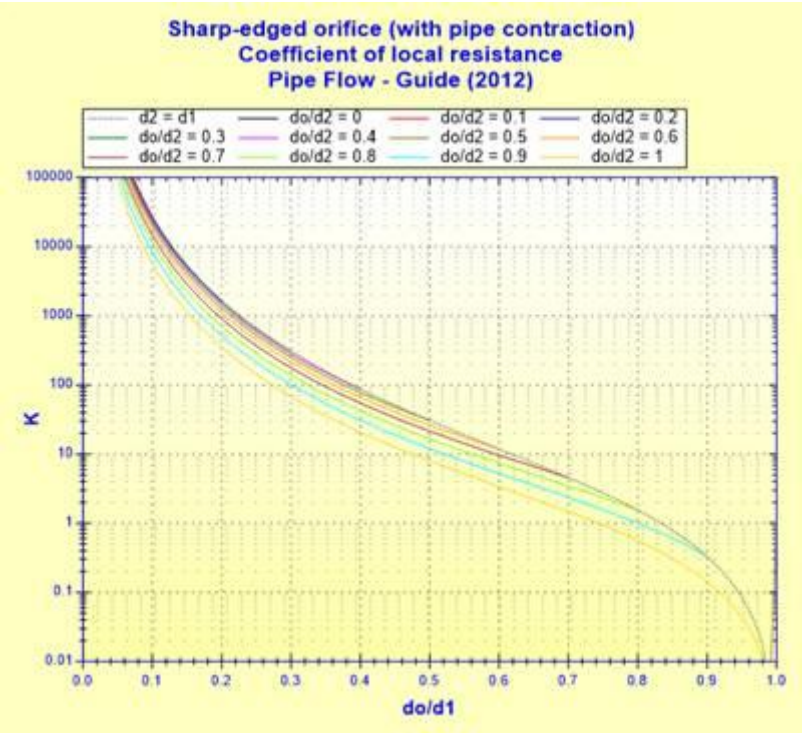
Coefficient of local resistance ($NRe_o \geq 10^4$):

$$K_o = 0.0696 \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + \left(\lambda - \left(\frac{d_0}{d_2}\right)^2\right)^2$$ ([1] equation 13.5)



Total pressure loss coefficient (based on the major pipe velocity):

$$K = K_o \cdot \left(\frac{A_1}{A_o} \right)^2$$



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_0	Orifice diameter (m)
d_1	Internal major pipe diameter (m)
d_2	Internal minor pipe diameter (m)
β	Ratio of orifice to major pipe diameters ()
A_0	Orifice cross-sectional area (m^2)
A_1	Major pipe cross-sectional area (m^2)
A_2	Minor pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_0	Mean velocity in orifice (m/s)
V_1	Mean velocity in major pipe (m/s)
V_2	Mean velocity in minor pipe (m/s)
NRe_0	Reynolds number in orifice ()
NRe_1	Reynolds number in major pipe ()
NRe_2	Reynolds number in minor pipe ()
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)

K_0 Coefficient of local resistance ()

K Total pressure loss coefficient (based on the major pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m^3)

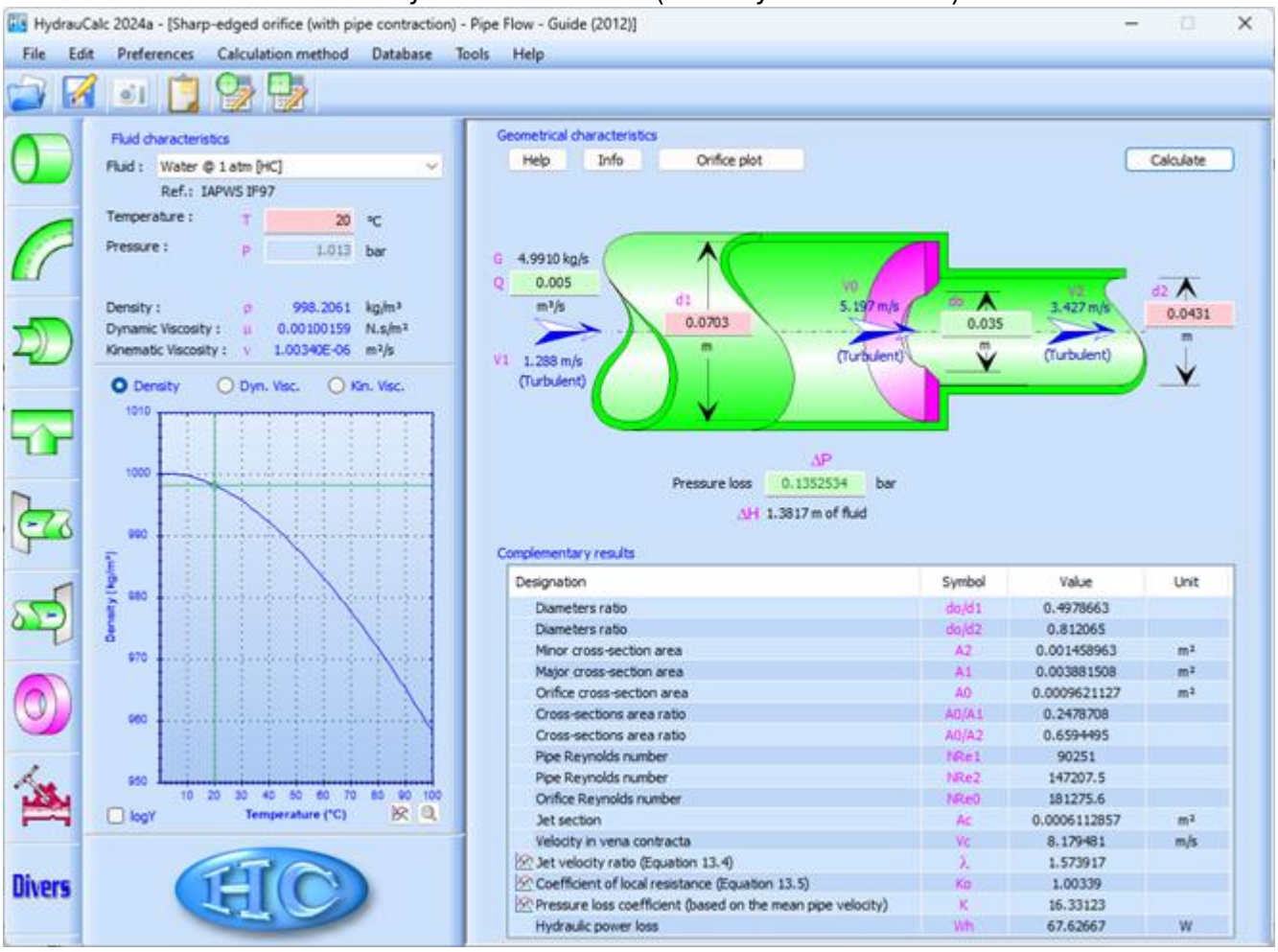
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in the orifice ($NRe_o \geq 10^4$)
- stabilized flow upstream of the orifice

Example of application:

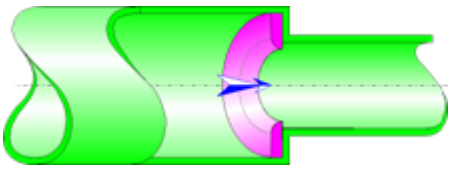


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.7.7 Round-edged orifice (with pipe contraction)

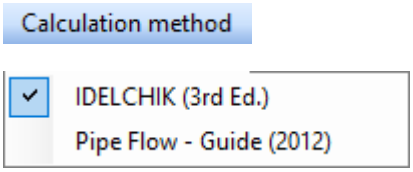
Circular Cross-Section



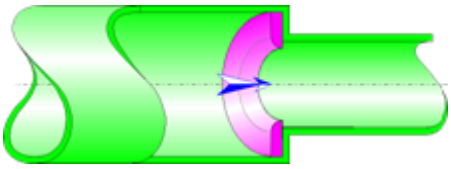
For the calculation of the pressure loss coefficient in round-edged orifices with pipe contraction downstream of the orifice, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.7.7.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a round-edged orifice with pipe contraction downstream of the orifice.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Major pipe cross-section area (m^2):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Minor pipe cross-section area (m^2):

$$F_2 = \pi \cdot \frac{D_2^2}{4}$$

Orifice cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity in major pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in minor pipe (m/s):

$$w_2 = \frac{Q}{F_2}$$

Mean velocity in orifice (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in major pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in minor pipe:

$$\mathrm{Re}_2 = \frac{w_2 \cdot D_2}{\nu}$$

Reynolds number in orifice:

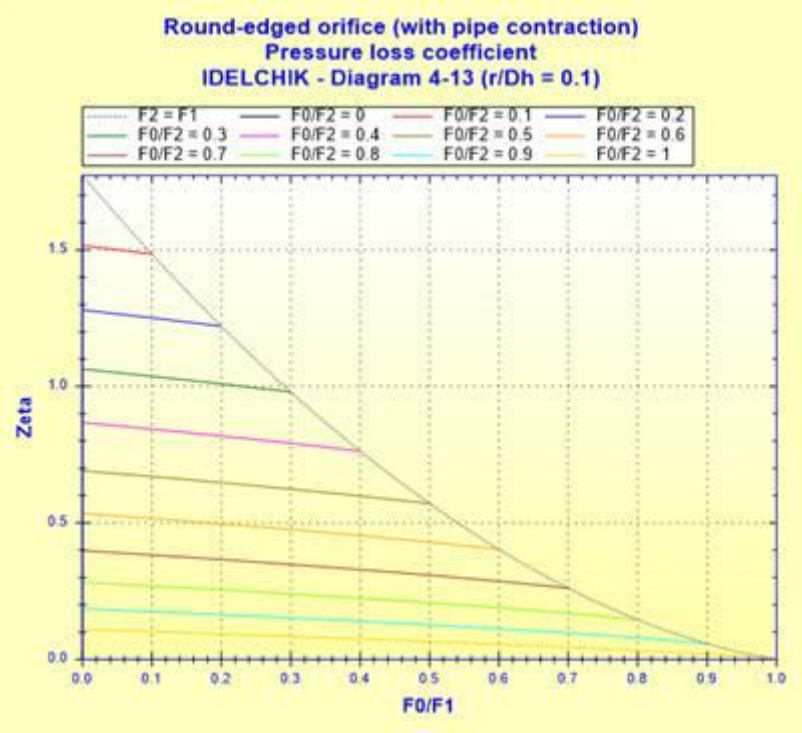
$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

■ $\mathrm{Re}_0 \geq 10^5$

Local resistance coefficient:

$$\zeta = \zeta' \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \left(1 - \frac{F_0}{F_2}\right)^2 + 2 \cdot \sqrt{\zeta'} \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375} \cdot \left(1 - \frac{F_0}{F_2}\right)$$

([2] diagram 4-13)



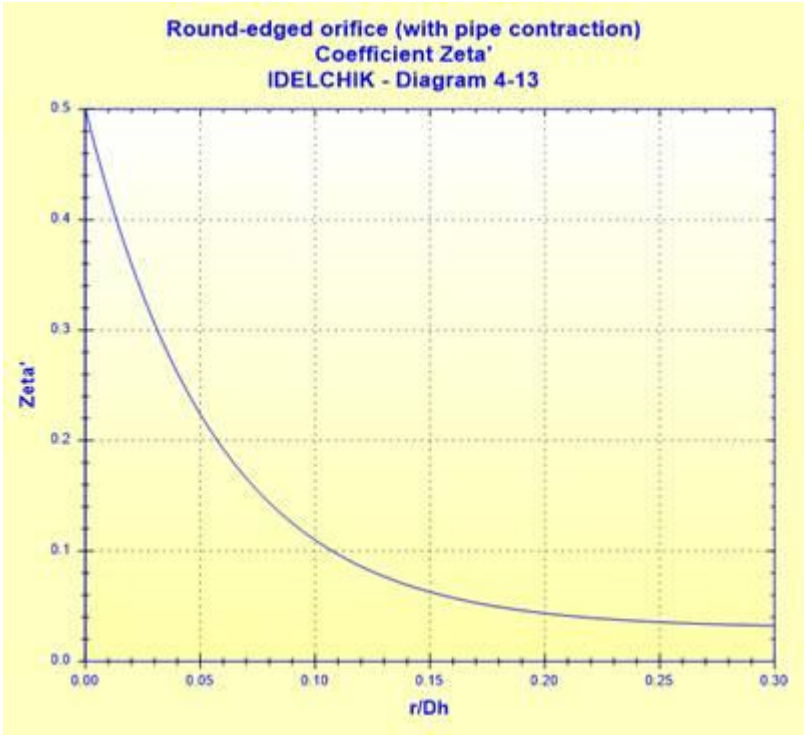
(with r/ D_h = 0.1)

with :

Coefficient of effect of the round:

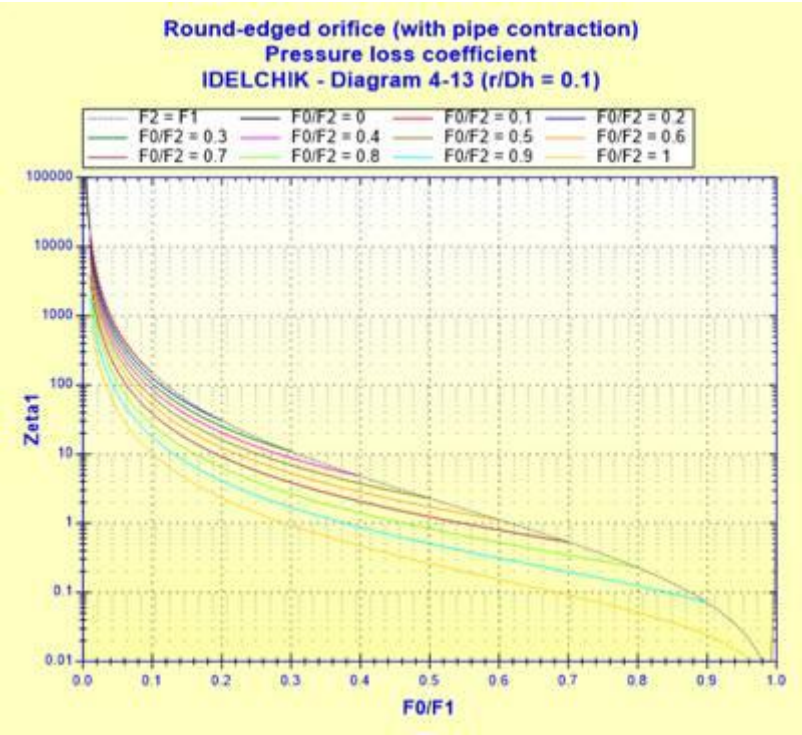
$$\zeta' = 0.03 + 0.47 \cdot 10^{-7.7 \cdot \frac{r}{D_h}}$$

([1] diagram 4-13)



Coefficient de perte de pression (basé sur la vitesse dans le grand tuyau) :

$$\zeta_1 = \zeta \cdot \left(\frac{F_1}{F_0}\right)^2$$



(with r/ D_h = 0.1)

■ $Re_0 < 10^5$

Quadratic local resistance coefficient:

$$\zeta_{quad} = \left[\zeta' \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \left(1 - \frac{F_0}{F_2}\right)^2 + 2 \cdot \sqrt{\zeta'} \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375} \cdot \left(1 - \frac{F_0}{F_2}\right)\right]$$

([2] diagram 4-13)

with :

$$\zeta' = 0.03 + 0.47 \cdot 10^{-7.7 \cdot \frac{r}{D_h}}$$

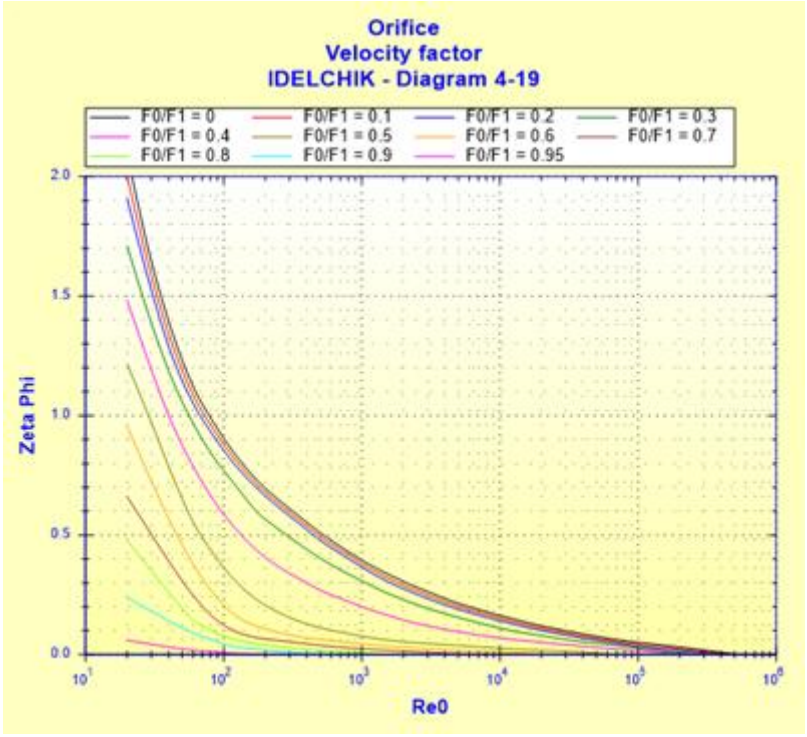
([1] diagram 4-13)

$$\zeta_{1quad} = \zeta_{quad} \cdot \left(\frac{F_1}{F_0}\right)^2$$

Velocity factor:

$$\zeta_\varphi = f\left(Re_0, \frac{F_0}{F_1}\right)$$

([1] diagram 4-19)



Contraction factor:

$\overline{\varepsilon}_{0\,\mathrm{Re}} = f(\mathrm{Re}_0)$ ([1] diagram 4-19)

Pressure loss coefficient (based on the major pipe velocity):

- $30 < \mathrm{Re}_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $10 < Re_0 \leq 30$

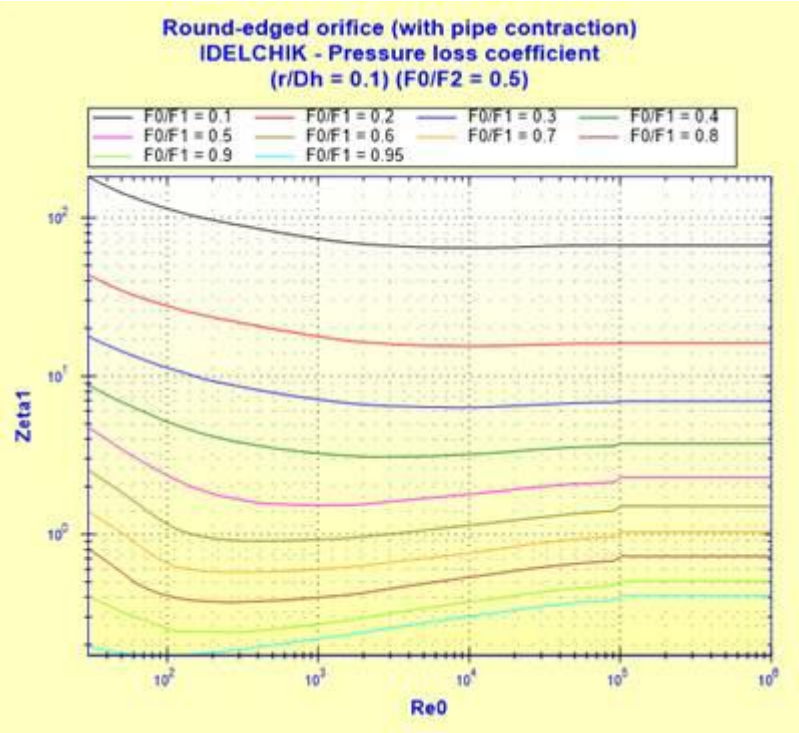
$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-19)



(with $r/D_h = 0.1$ and $F_0/F_2 = 0.5$)

Total pressure loss (Pa):

$$\Delta P = \zeta_1 \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta_1 \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_1	Major pipe internal diameter (m)
D_2	Minor pipe internal diameter (m)
D_0	Orifice diameter (m)
F_1	Major pipe cross-sectional area (m^2)
F_2	Minor pipe cross-sectional area (m^2)
F_0	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_1	Mean velocity in major pipe (m/s)
w_2	Mean velocity in minor pipe (m/s)
w_0	Mean velocity in orifice (m/s)
Re_1	Reynolds number in major pipe ()
Re_2	Reynolds number in minor pipe ()
Re_0	Reynolds number in orifice ()
r	Radius of the round (m)
ζ'	Coefficient of effect of the round ()
ζ	Local resistance coefficient (based on the orifice velocity) ()
ζ_{quad}	Quadratic local resistance coefficient (based on the orifice velocity) ()
ζ_{1quad}	Quadratic local resistance coefficient (based on the major pipe velocity) ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ_1	Pressure loss coefficient (based on the major pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

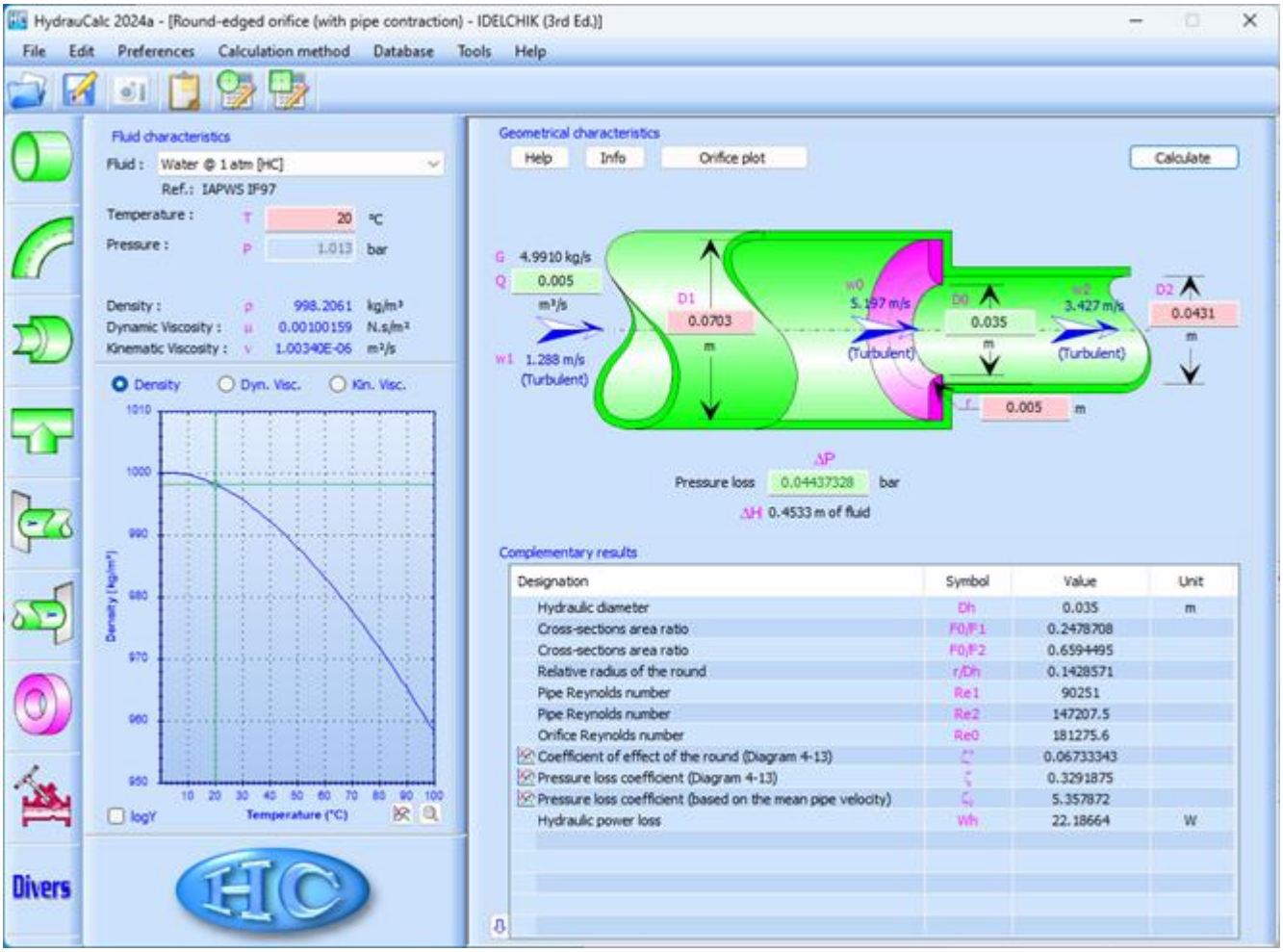
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- round radius less than the radius difference ($r < (D_1/2-D_0/2)$)

Example of application:



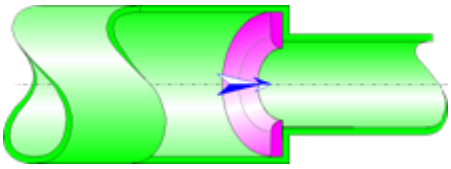
References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

[2] Идельчик.И.Е.Справочник по гидравлическим сопротивлениям.1992 (original document in Russian language)

Note: The formulation used for the calculation of the local resistance coefficients ζ and ζ_{quad} is that of the original reference document [2] which differs from that of the translated document [1]

2.7.7.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a round-edged orifice with pipe contraction downstream of the orifice.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of orifice to major pipe diameters:

$$\beta = \frac{d_o}{d_1}$$

Major pipe cross-sectional area (m²):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Minor pipe cross-sectional area (m²):

$$A_2 = \pi \cdot \frac{d_2^2}{4}$$

Orifice cross-sectional area (m²):

$$A_o = \pi \cdot \frac{d_o^2}{4}$$

Major pipe velocity (m/s):

$$V_1 = \frac{Q}{A_1}$$

Minor pipe velocity (m/s):

$$V_2 = \frac{Q}{A_2}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in major pipe:

$$N_{Re1} = \frac{V_1 \cdot d_1}{\nu}$$

Reynolds number in minor pipe:

$$N_{Re2} = \frac{V_2 \cdot d_2}{\nu}$$

Reynolds number in orifice:

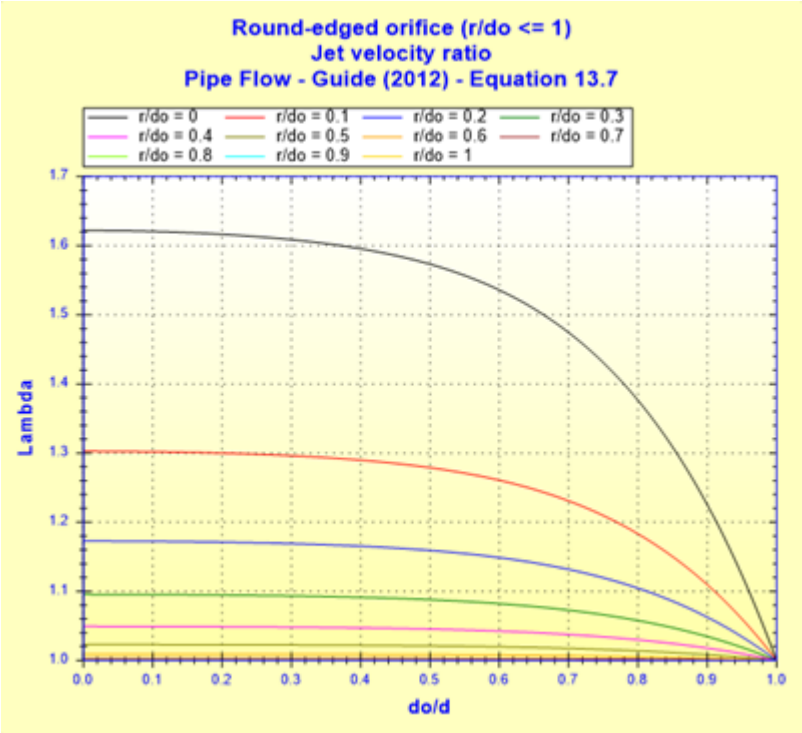
$$N_{Re_o} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

- $r/d_0 \leq 1$

$$\lambda = 1 + 0.622 \cdot \left[1 - 0.3 \cdot \sqrt{\frac{r}{d_0}} - 0.7 \cdot \frac{r}{d_0} \right]^4 \cdot \left(1 - 0.215 \cdot \beta^2 - 0.785 \cdot \beta^5 \right)$$

([1] equation 13.7)



- $r/d_0 > 1$

$$\lambda = 1$$

([1] § 13.3.1)

Velocity in vena contracta:

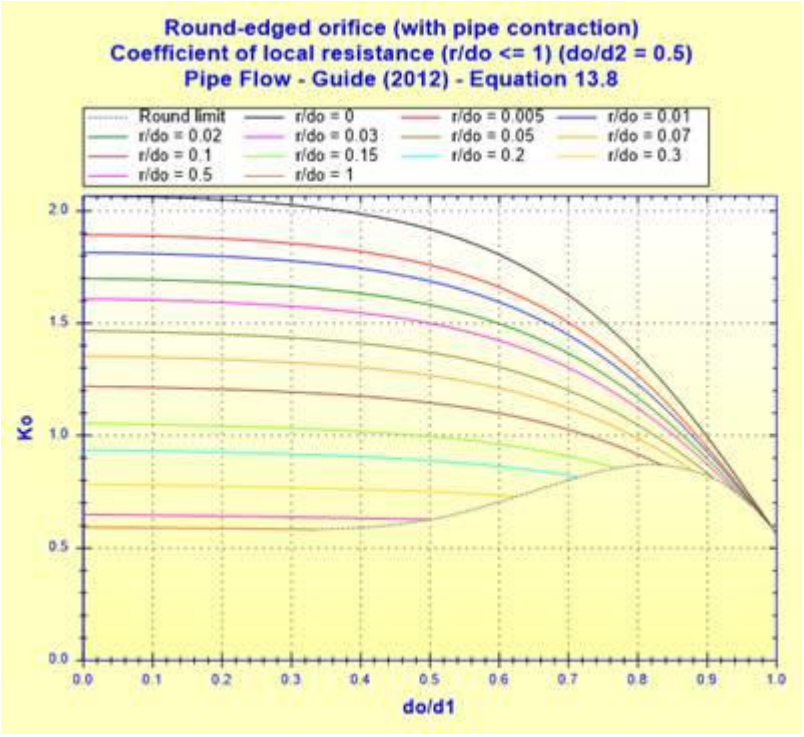
$$V_c = V_0 \cdot \lambda$$

Coefficient of local resistance:

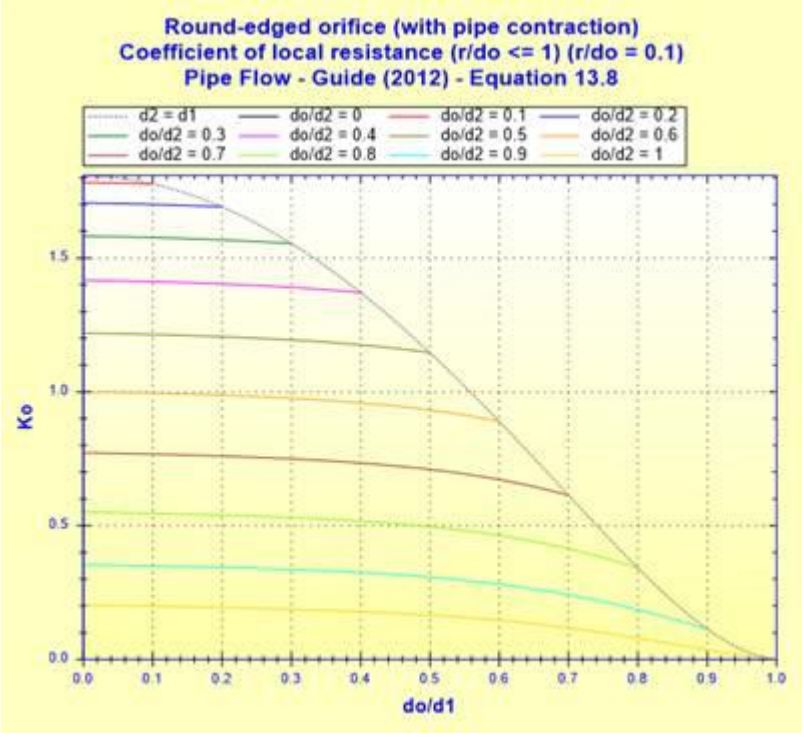
- $r/d_0 \leq 1$

$$K_o = 0.0696 \cdot \left(1 - 0.569 \cdot \frac{r}{d_0} \right) \cdot \left(1 - \sqrt{\frac{r}{d_0}} \cdot \beta \right) \cdot \left(1 - \beta^5 \right) \cdot \lambda^2 + \left[\lambda - \left(\frac{d_0}{d_2} \right)^2 \right]^2$$

([1] equation 13.8)



(with $d_0/d_2 = 0.5$)



(with $r/d_0 = 0.1$)

■ $r/d_0 > 1$

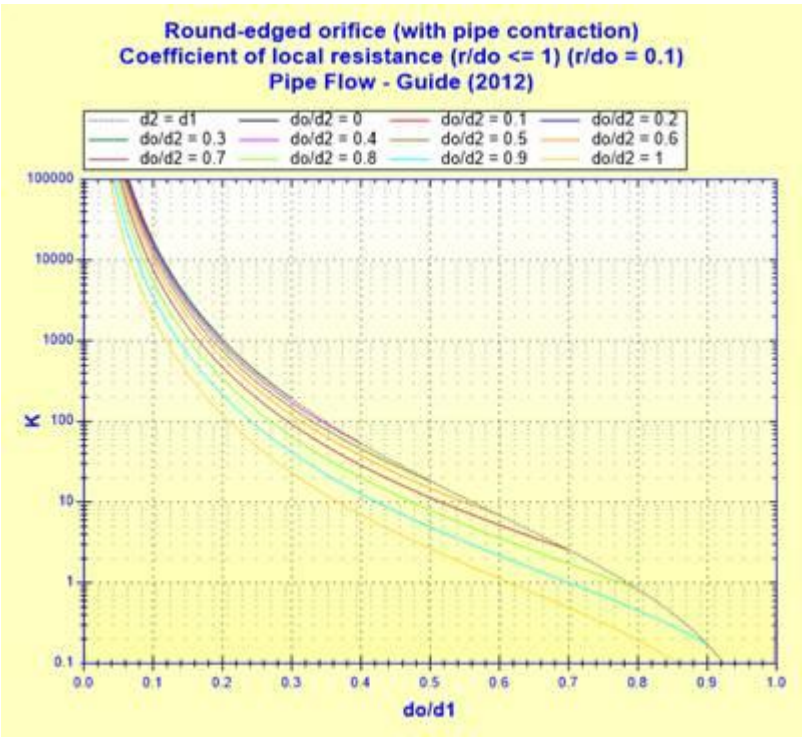
$$K_o = 0.03 \cdot (1-\beta) \cdot \left(1-\beta^5\right) + \left[1-\left(\frac{d_0}{d_2}\right)^2\right]^2$$

([1] § 13.3.2)

Total pressure loss coefficient (based on the major pipe velocity):

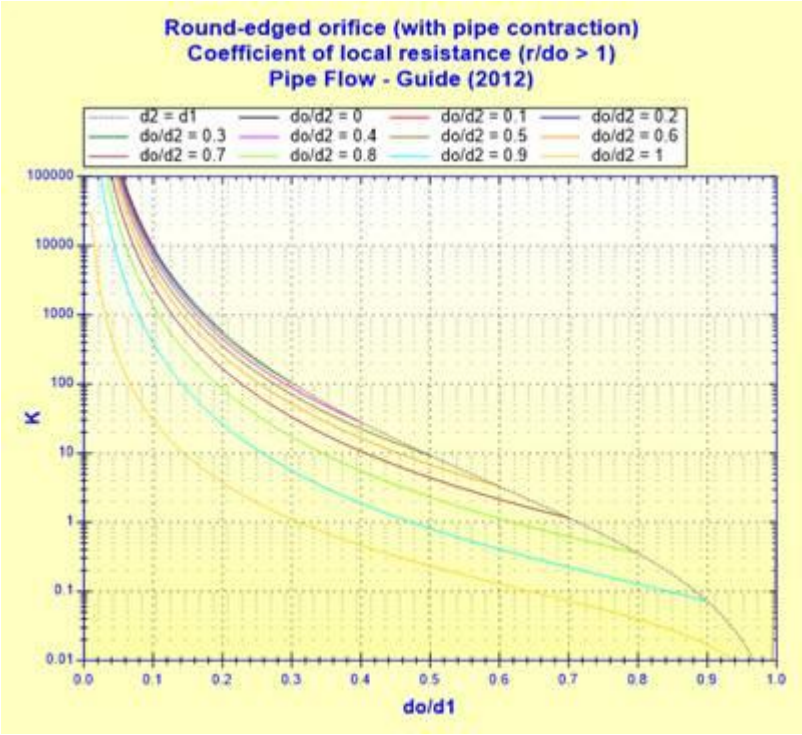
$$K = K_o \cdot \left(\frac{A_1}{A_o}\right)^2$$

- $r/d_0 \leq 1$



(with $r/d_0 = 0.1$)

■ $r/d_0 > 1$



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

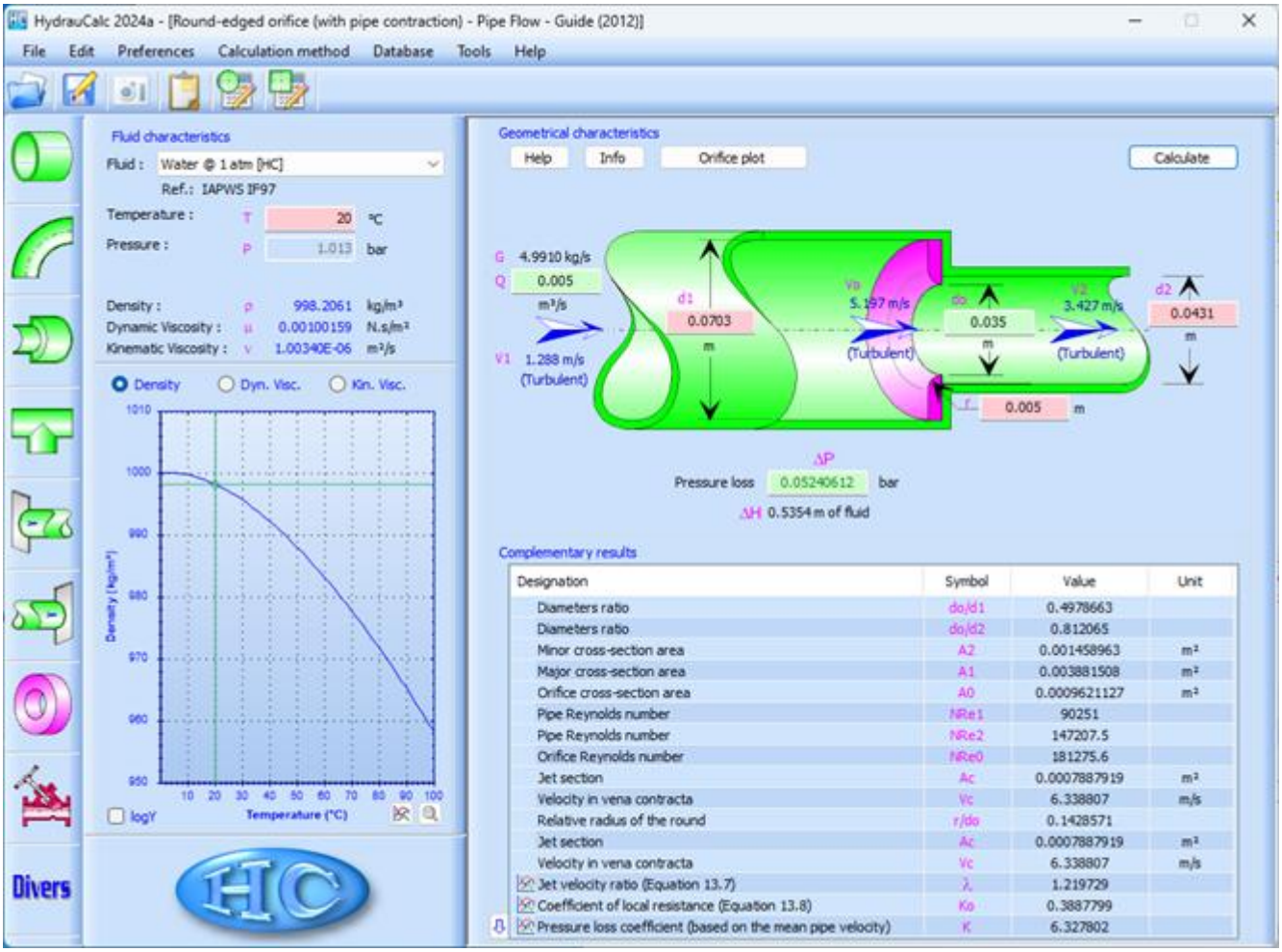
d_0	Orifice diameter (m)
d_1	Internal major pipe diameter (m)
d_2	Internal minor pipe diameter (m)
β	Ratio of orifice to major pipe diameters ()

A_o	Orifice cross-sectional area (m^2)
A_1	Major pipe cross-sectional area (m^2)
A_2	Minor pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in orifice (m/s)
V_1	Mean velocity in major pipe (m/s)
V_2	Mean velocity in minor pipe (m/s)
NRe_o	Reynolds number in orifice ()
NRe_1	Reynolds number in major pipe ()
NRe_2	Reynolds number in minor pipe ()
r	Radius of the round (m)
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
K_o	Coefficient of local resistance ()
K	Total pressure loss coefficient (based on the major pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in orifice ($NRe_o \geq 10^4$)
- stabilized flow upstream of the orifice
- round radius less than the radius difference ($r < (d_1/2-d_0/2)$)

Example of application:

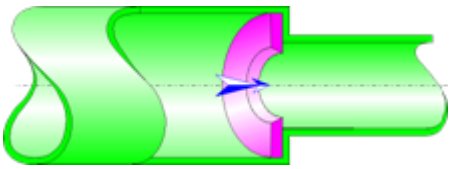


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.7.8 Bevel-edged orifice (with pipe contraction)

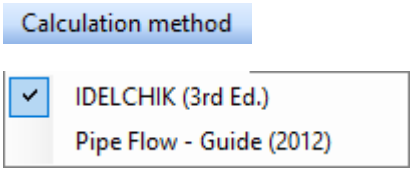
Circular Cross-Section



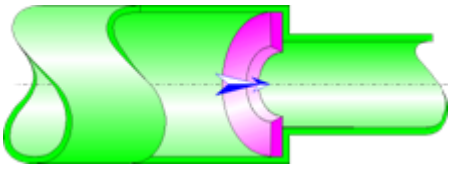
For the calculation of the pressure loss coefficient in bevel-edged orifices with pipe contraction downstream of the orifice, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.7.8.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a bevel-edged orifice with pipe contraction downstream of the orifice.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Major pipe cross-section area (m^2):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Minor pipe cross-section area (m^2):

$$F_2 = \pi \cdot \frac{D_2^2}{4}$$

Orifice cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity in major pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in minor pipe (m/s):

$$w_2 = \frac{Q}{F_2}$$

Mean velocity in orifice (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in major pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in minor pipe:

$$\mathrm{Re}_2 = \frac{w_2 \cdot D_2}{\nu}$$

Reynolds number in orifice:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

■ $\mathrm{Re}_0 \geq 10^5$

Local resistance coefficient:

$$\zeta = \zeta' \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \left(1 - \frac{F_0}{F_2}\right)^2 + 2 \cdot \sqrt{\zeta'} \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375} \cdot \left(1 - \frac{F_0}{F_2}\right)$$

([2] diagram 4-13)

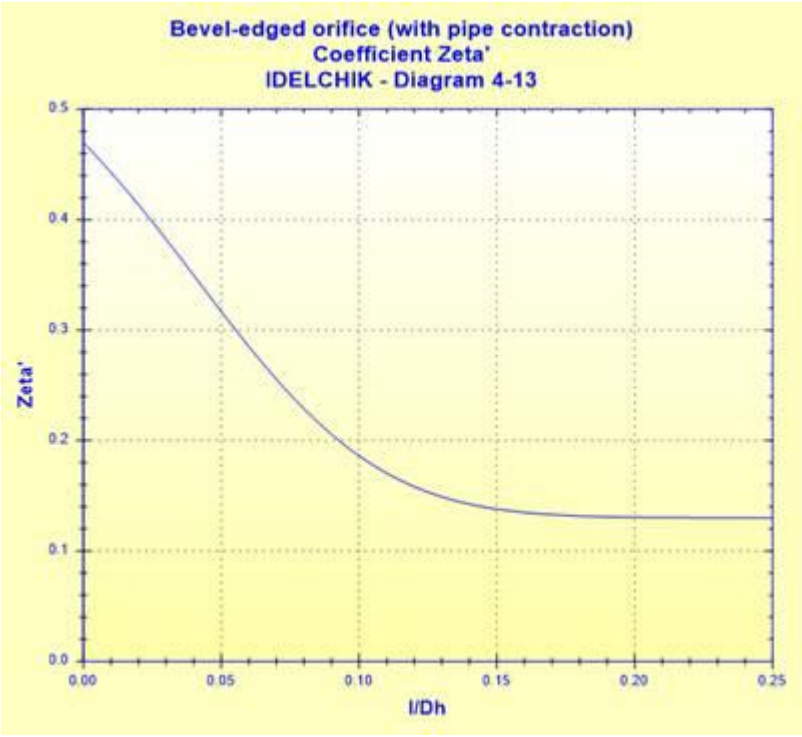
(with l/ D_h = 0.1)

with :

Coefficient of effect of the thickness:

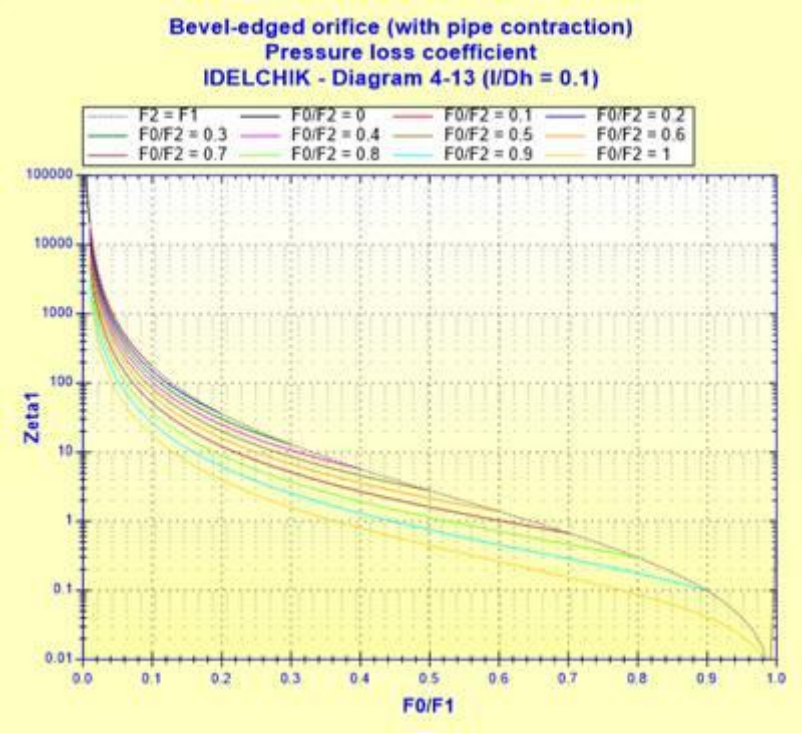
$$\zeta' = 0.13 + 0.34 \cdot 10^{-\left(3.4 \cdot \frac{l}{D_h} + 88.4 \cdot \left(\frac{l}{D_h}\right)^{2.3}\right)}$$

([2] diagram 4-13)



Pressure loss coefficient (based on the major pipe velocity):

$$\zeta_1 = \zeta \cdot \left(\frac{F_1}{F_0}\right)^2$$



(with l/ D_h = 0.1)

■ $Re_0 < 10^5$

Quadratic local resistance coefficient:

$$\zeta_{quad} = \left[\zeta' \cdot \left(1-\frac{F_0}{F_1}\right)^{0.75} + \left(1-\frac{F_0}{F_2}\right)^2 + 2\cdot\sqrt{\zeta'}\cdot\left(1-\frac{F_0}{F_1}\right)^{0.375}\cdot\left(1-\frac{F_0}{F_2}\right)\right]$$

([1] diagram 4-13)

with :

$$\zeta' = 0.13 + 0.34 \cdot 10^{-\left(3.4\cdot\frac{l}{D_h}+88.4\cdot\left(\frac{l}{D_h}\right)^{2.3}\right)}$$

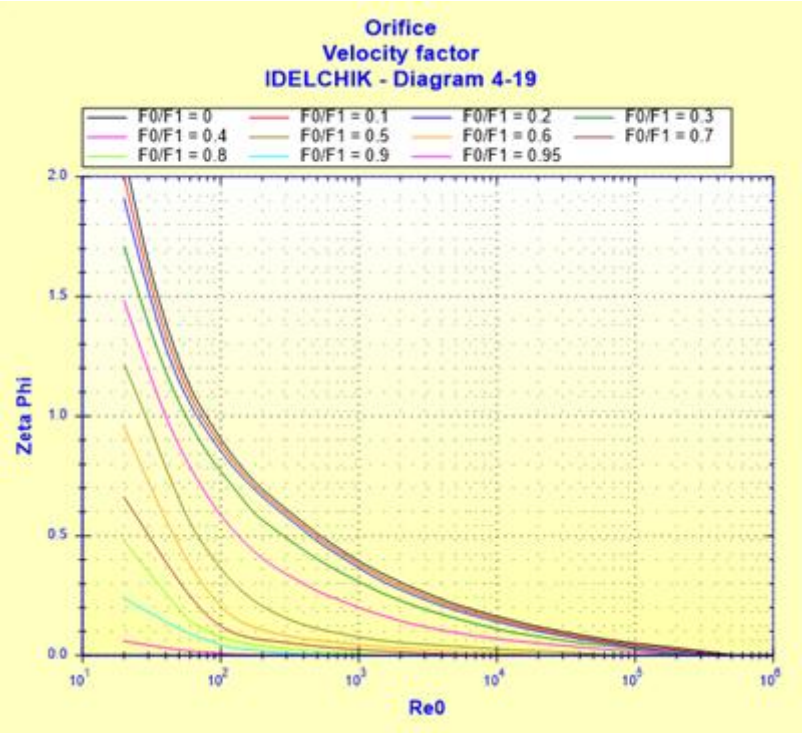
([1] diagram 4-13)

$$\zeta_{1quad} = \zeta_{quad} \cdot \left(\frac{F_1}{F_0}\right)^2$$

Velocity factor:

$$\zeta_\varphi = f\left(Re_0, \frac{F_0}{F_1}\right)$$

([1] diagram 4-19)



Contraction factor:

$\bar{\varepsilon}_{0\,\mathrm{Re}} = f(\mathrm{Re}_0)$ ([1] diagram 4-19)

Pressure loss coefficient (based on the major pipe velocity):

- $30 < \mathrm{Re}_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $10 < Re_0 \leq 30$

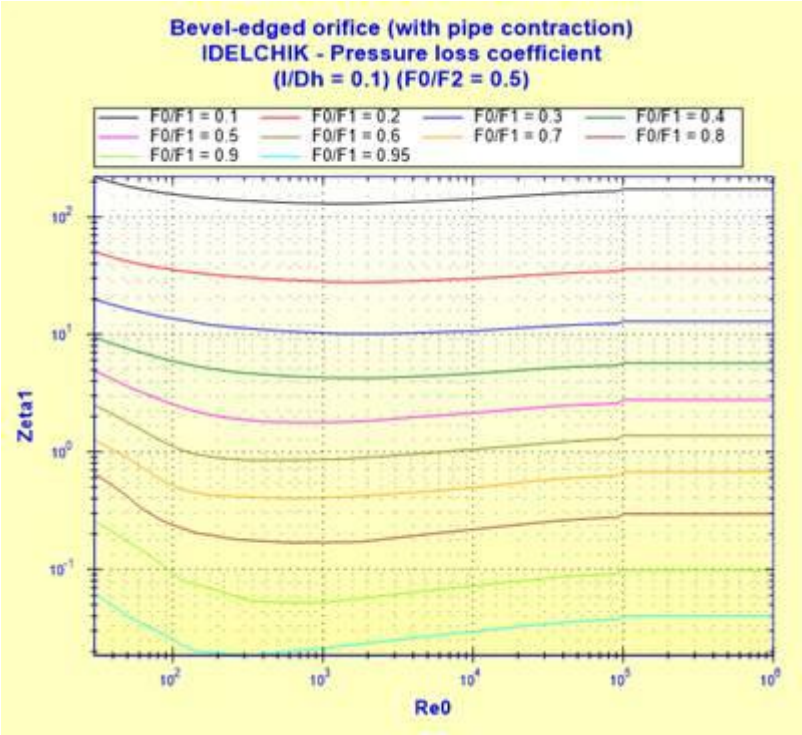
$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-19)



(with $l/D_h = 0.1$ and $F_0/F_2 = 0.5$)

Total pressure loss (Pa):

$$\Delta P = \zeta_1 \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta_1 \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_1	Major pipe internal diameter (m)
D_2	Minor pipe internal diameter (m)
D_0	Orifice diameter (m)
F_1	Major pipe cross-sectional area (m^2)
F_2	Minor pipe cross-sectional area (m^2)
F_0	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_1	Mean velocity in major pipe (m/s)
w_2	Mean velocity in minor pipe (m/s)
w_0	Mean velocity in orifice (m/s)
Re_1	Reynolds number in major pipe ()
Re_2	Reynolds number in minor pipe ()
Re_0	Reynolds number in orifice ()
l	Orifice thickness (m)
ζ'	Coefficient of effect of the thickness ()
ζ	Local resistance coefficient (based on the orifice velocity) ()
ζ_{quad}	Quadratic local resistance coefficient (based on the orifice velocity) ()
ζ_{1quad}	Quadratic local resistance coefficient (based on the major pipe velocity) ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ_1	Pressure loss coefficient (based on the major pipe velocity) ()
ΔP	Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

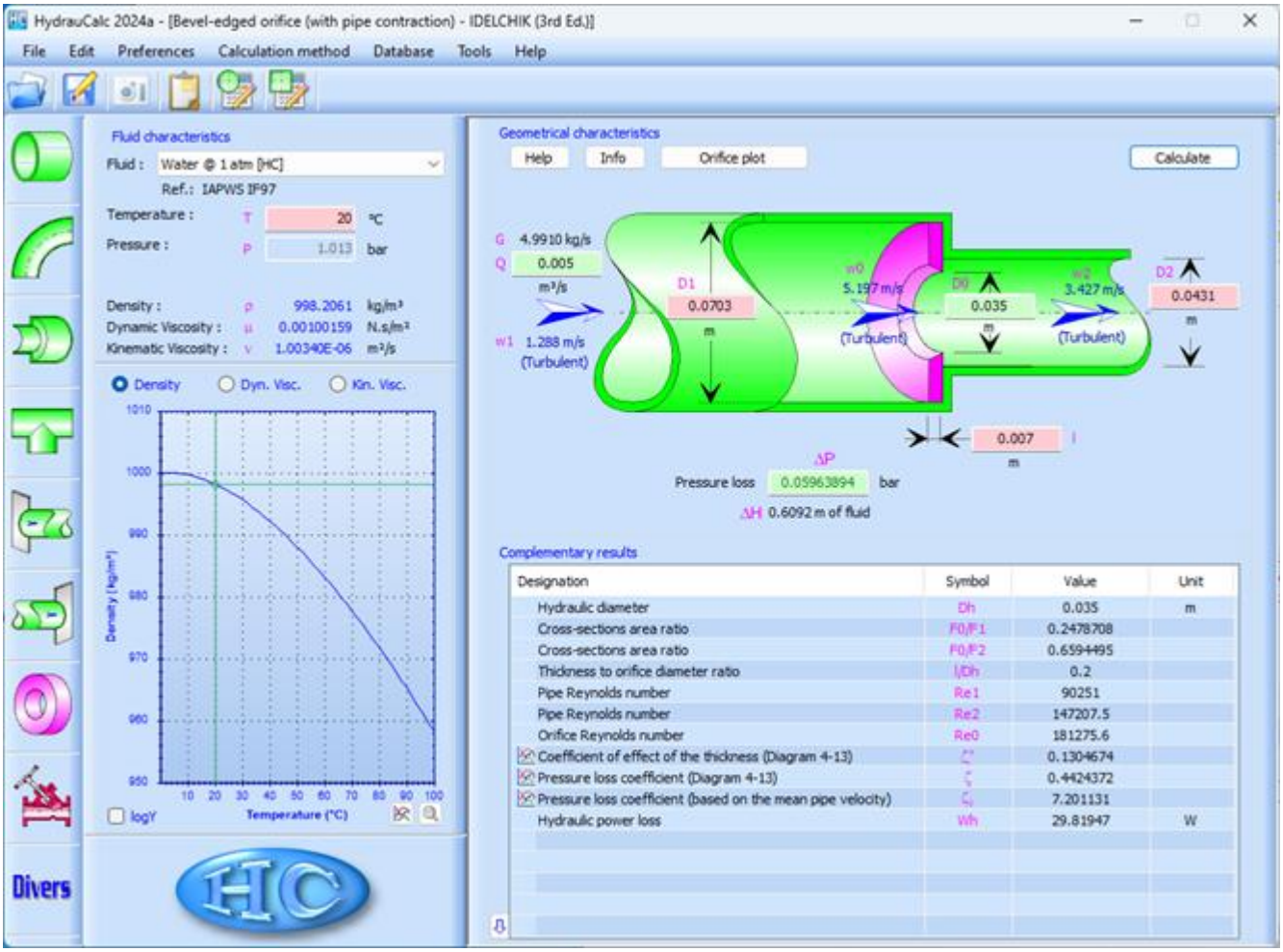
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- angle at the top of the truncated cone between 40 ° and 60 °

Example of application:



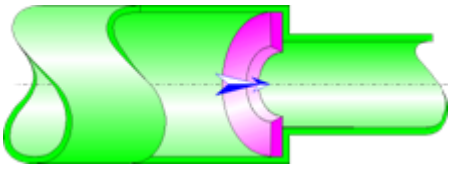
References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

[2] Идельчик.И.Е.Справочник по гидравлическим сопротивлениям.1992 (original document in Russian language)

Note: The formulation used for the calculation of the local resistance coefficients ζ and ζ_{quad} is that of the original reference document [2] which differs from that of the translated document [1]

2.7.8.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a bevel-edged orifice with pipe contraction downstream of the orifice.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of orifice to major pipe diameters:

$$\beta = \frac{d_o}{d_1}$$

Major pipe cross-sectional area (m²):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Minor pipe cross-sectional area (m²):

$$A_2 = \pi \cdot \frac{d_2^2}{4}$$

Orifice cross-sectional area (m²):

$$A_o = \pi \cdot \frac{d_o^2}{4}$$

Major pipe velocity (m/s):

$$V_1 = \frac{Q}{A_1}$$

Minor pipe velocity (m/s):

$$V_2 = \frac{Q}{A_2}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in major pipe:

$$N_{Re1} = \frac{V_1 \cdot d_1}{\nu}$$

Reynolds number in minor pipe:

$$N_{Re2} = \frac{V_2 \cdot d_2}{\nu}$$

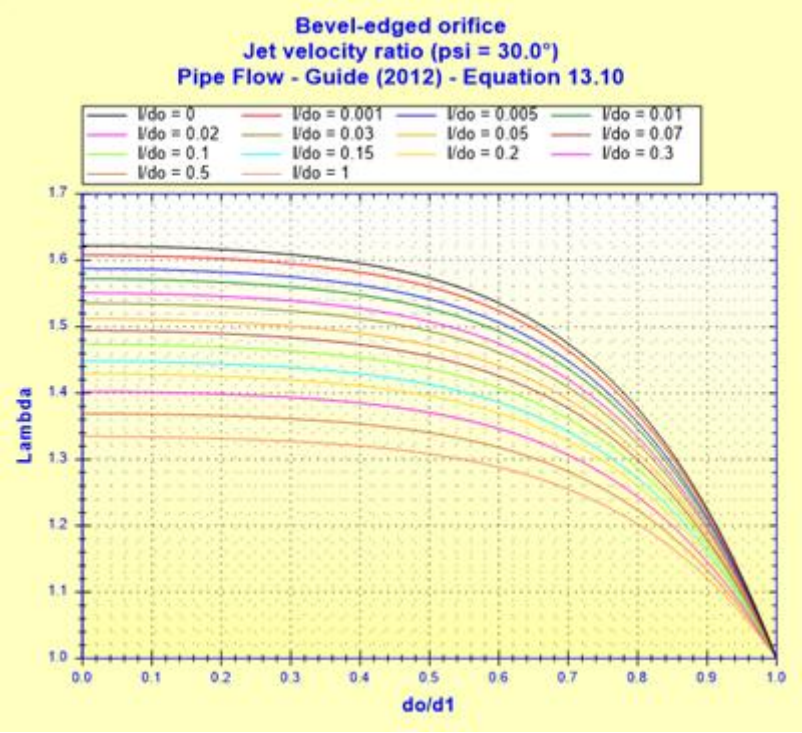
Reynolds number in orifice:

$$N_{Re_o} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left[1 - C_b \cdot \left(\frac{l}{d_0} \right)^{\frac{1-\sqrt{l/d_0}}{2}} \right] \cdot \left(1 - 0.215 \cdot \beta^2 - 0.785 \cdot \beta^5 \right)$$

([1] equation 13.10)



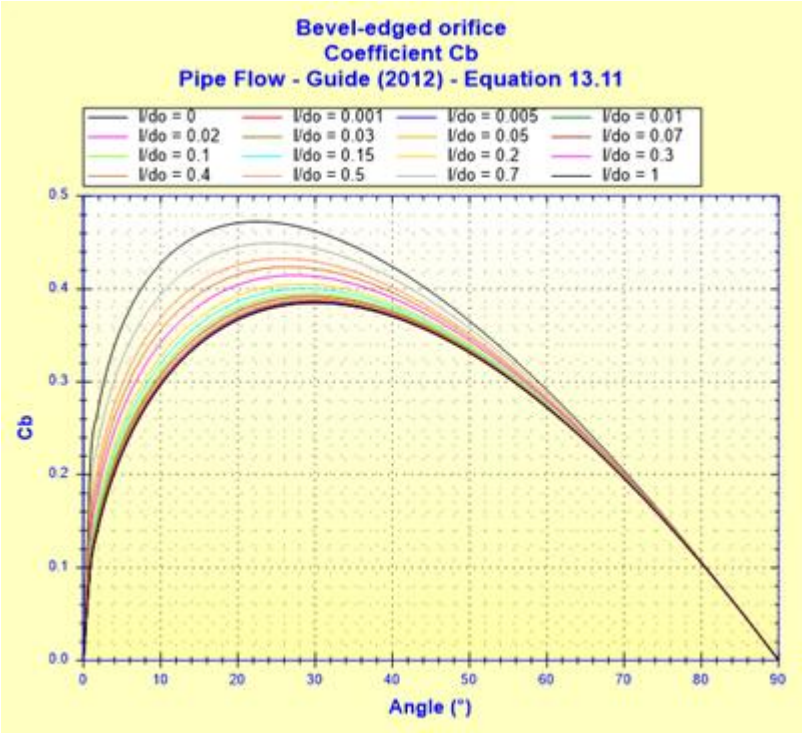
(with ψ = 30°)

with:

Coefficient of effect of the bevel angle:

$$C_b = \left(1 - \frac{\Psi}{90} \right) \cdot \left(\frac{\Psi}{90} \right)^{\frac{1}{2+l/d_0}}$$

([1] equation 13.11)



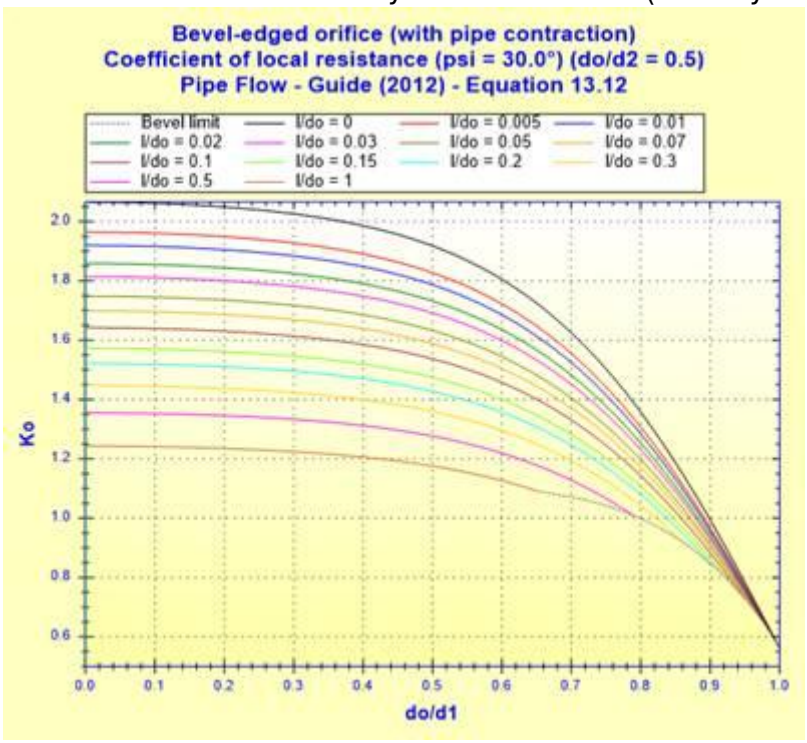
Velocity in vena contracta:

$$V_c = V_0 \cdot \lambda$$

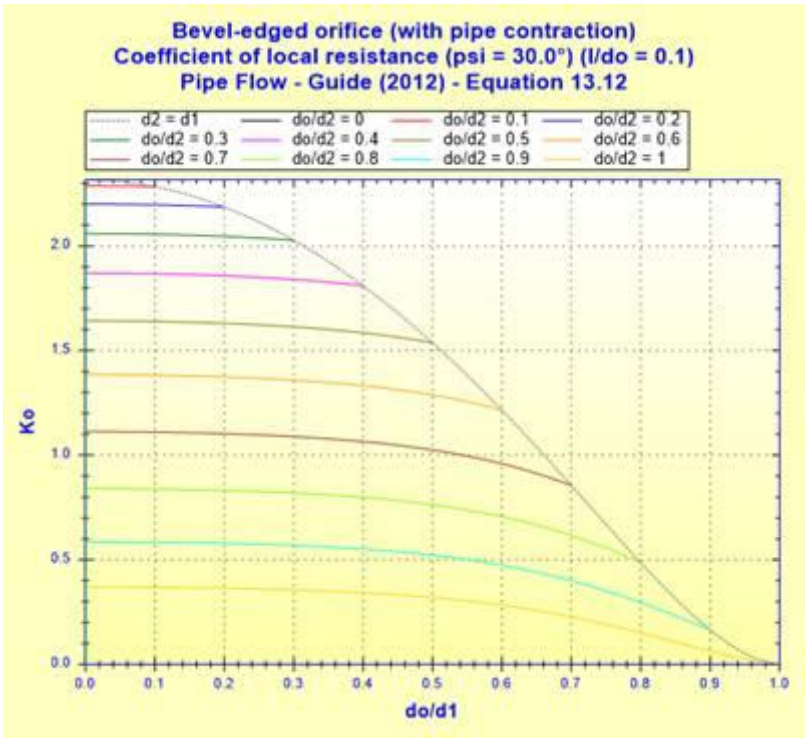
Coefficient of local resistance ($NRe_o \geq 10^4$):

$$K_o = 0.0696 \cdot \left(1 - C_b \cdot \frac{l}{d_0}\right) \cdot \left(1 - 0.42 \cdot \sqrt{\frac{l}{d_0}} \cdot \beta^2\right) \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + \left(\lambda - \left(\frac{d_0}{d_2}\right)^2\right)^2$$

([1] equation 13.12)



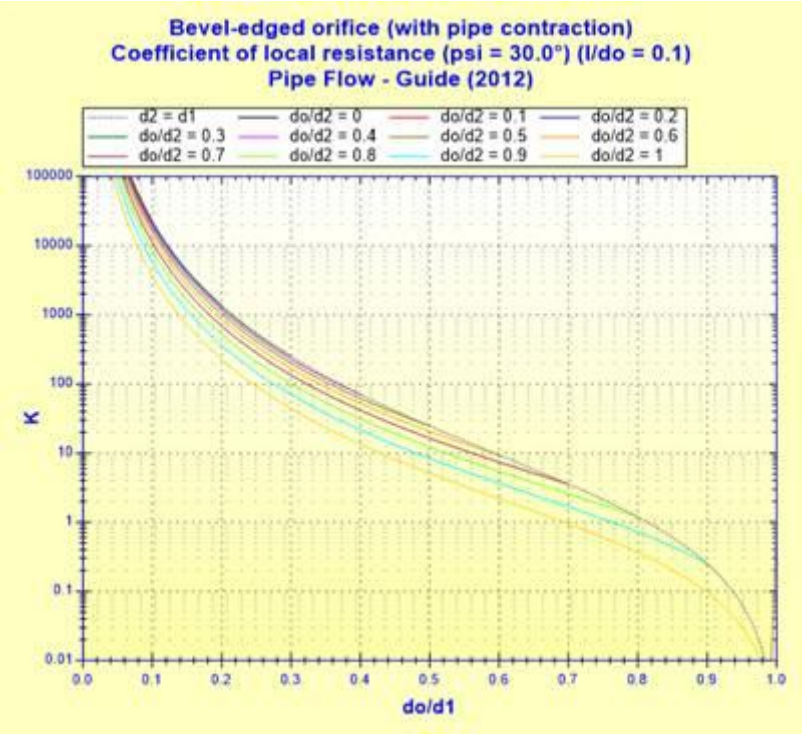
(with ψ = 30° and d_0/d_2 = 0.5)



(with ψ = 30° and l/d_0 = 0.1)

Total pressure loss coefficient (based on the major pipe velocity):

$$K = K_o \cdot \left(\frac{A_1}{A_o} \right)^2$$



(with ψ = 30° and l/d_o = 0.1)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_0	Orifice diameter (m)
d_1	Internal major pipe diameter (m)
d_2	Internal minor pipe diameter (m)
β	Ratio of orifice to major pipe diameters ()
A_0	Orifice cross-sectional area (m^2)

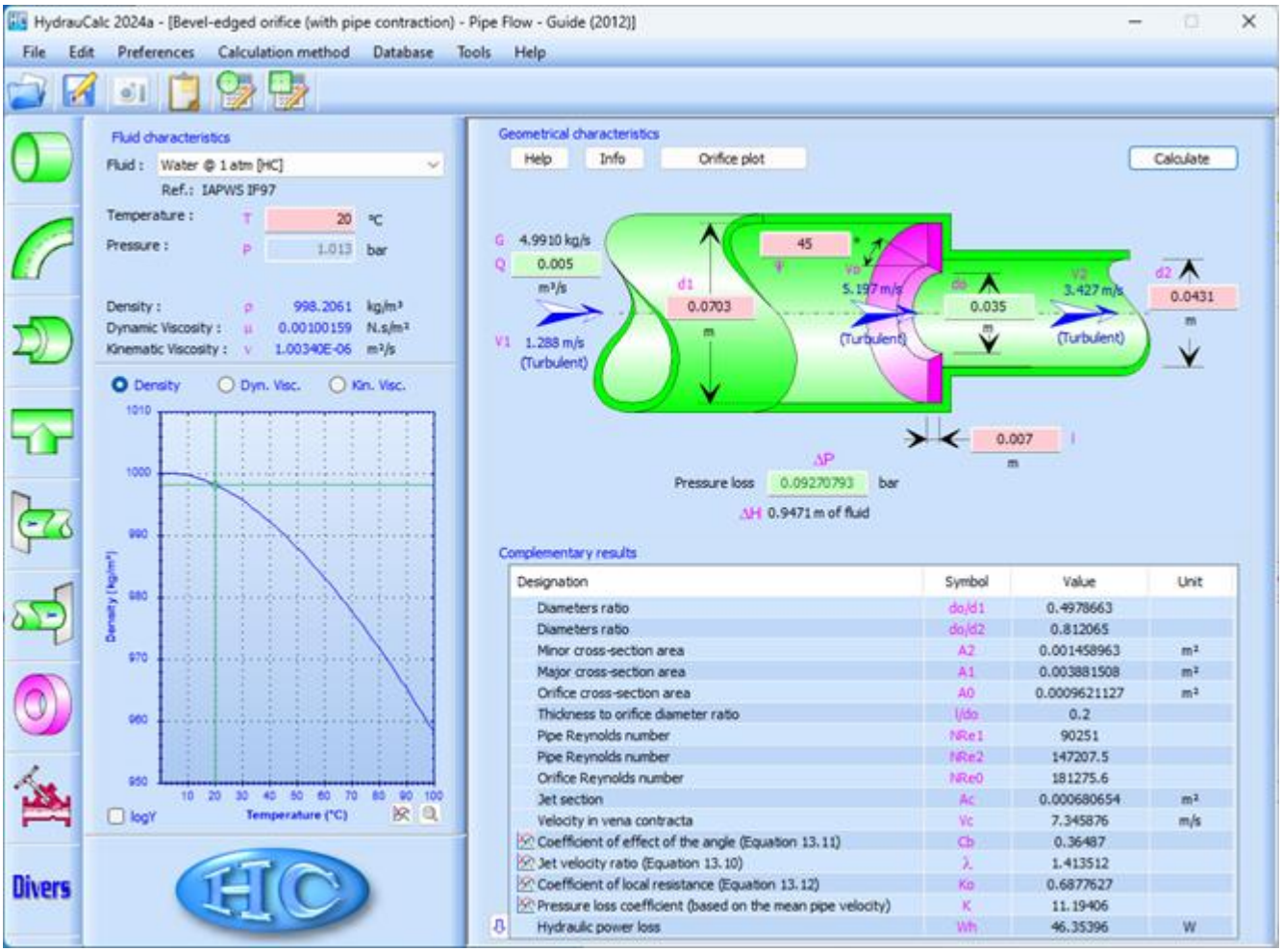
A_1	Major pipe cross-sectional area (m^2)
A_2	Minor pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_0	Mean velocity in orifice (m/s)
V_1	Mean velocity in major pipe (m/s)
V_2	Mean velocity in minor pipe (m/s)
NRe_0	Reynolds number in orifice ()
NRe_1	Reynolds number in major pipe ()
NRe_2	Reynolds number in minor pipe ()
l	Orifice thickness (m)
ψ	Bevel angle (°)
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
C_b	Coefficient of effect of the bevel angle ()
K_0	Coefficient of local resistance ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in orifice ($NRe_o \geq 10^4$)

- stabilized flow upstream of the orifice
- bevel angle less than or equal to: $\psi \leq tg^{-1}((d_1 - d_o) / (2\ l))$

Example of application:

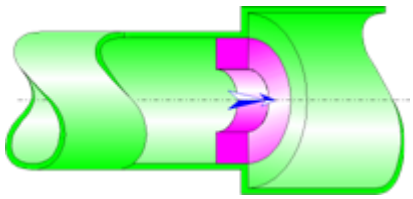


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.7.9 Thick-edged orifice (with pipe expansion)

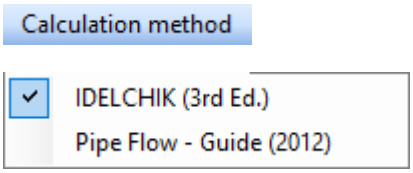
Circular Cross-Section



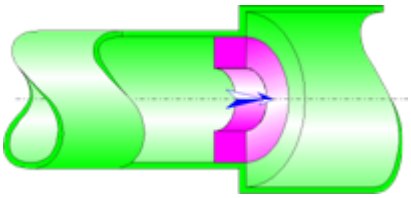
For the calculation of the pressure loss coefficient in thick-edged orifices with pipe expansion downstream of the orifice, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.7.9.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a thick-edged orifice with pipe expansion downstream of the orifice. Moreover, the head loss due to friction of the fluid on the inner walls of the orifice is also taken into account in this component and is calculated with Darcy's formula.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Minor pipe cross-section area (m^2):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Major pipe cross-section area (m^2):

$$F_2 = \pi \cdot \frac{D_2^2}{4}$$

Orifice cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^2}{4}$$

Mean velocity in minor pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in major pipe (m/s):

$$w_2 = \frac{Q}{F_2}$$

Mean velocity in orifice (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in minor pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in major pipe:

$$\mathrm{Re}_2 = \frac{w_2 \cdot D_2}{\nu}$$

Reynolds number in orifice:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Relative roughness in orifice walls:

$$\bar{\Delta} = \frac{\Delta}{D_0}$$

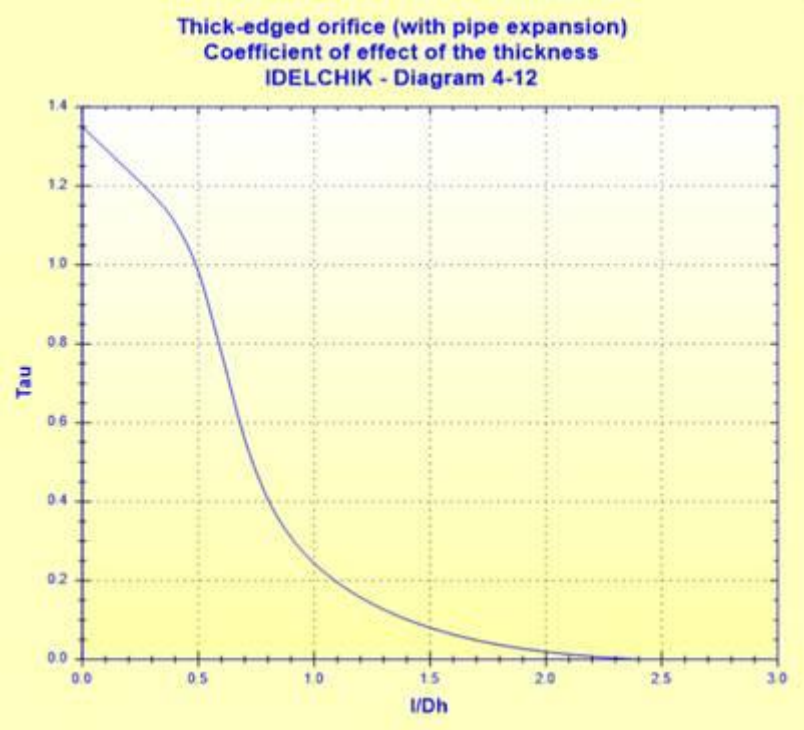
Coefficient of effect of the orifice thickness:

$$\tau = \left(2.4 - \frac{l}{D_h}\right) \cdot 10^{-\varphi\left(\frac{l}{D_h}\right)}$$

([1] diagram 4-12)

with:

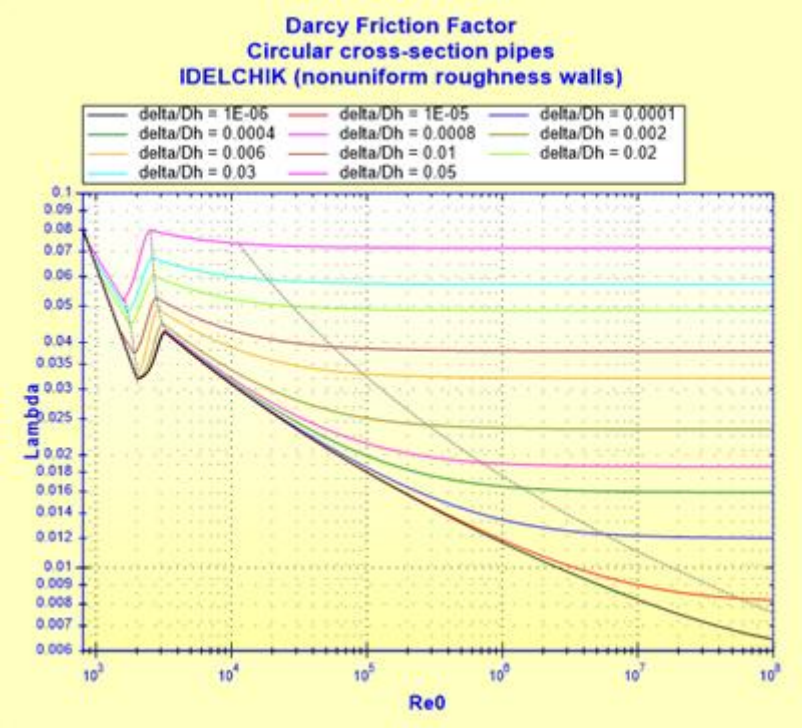
$$\varphi\left(\frac{l}{D_h}\right) = 0.25 + \frac{0.535 \cdot \left(\frac{l}{D_h}\right)^8}{0.05 + \left(\frac{l}{D_h}\right)^7}$$



Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}_0, \frac{\Delta}{D_h}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)

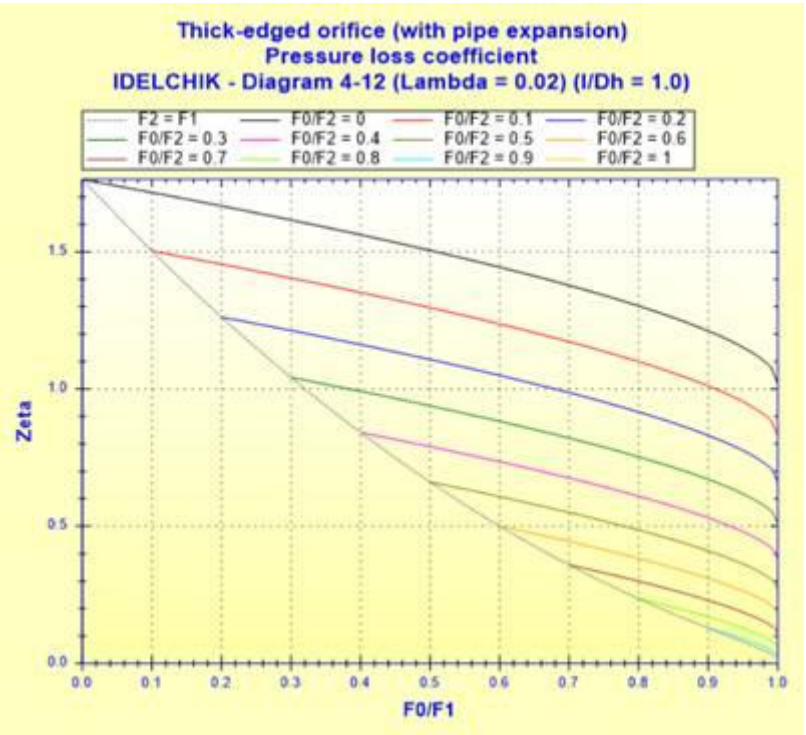


■ $Re_0 \geq 10^5$

Local resistance coefficient:

$$\zeta = \left[0.5 \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \left(1 - \frac{F_0}{F_2}\right)^2 + \tau \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375} \cdot \left(1 - \frac{F_0}{F_2}\right) + \lambda \cdot \frac{l}{D_h} \right]$$

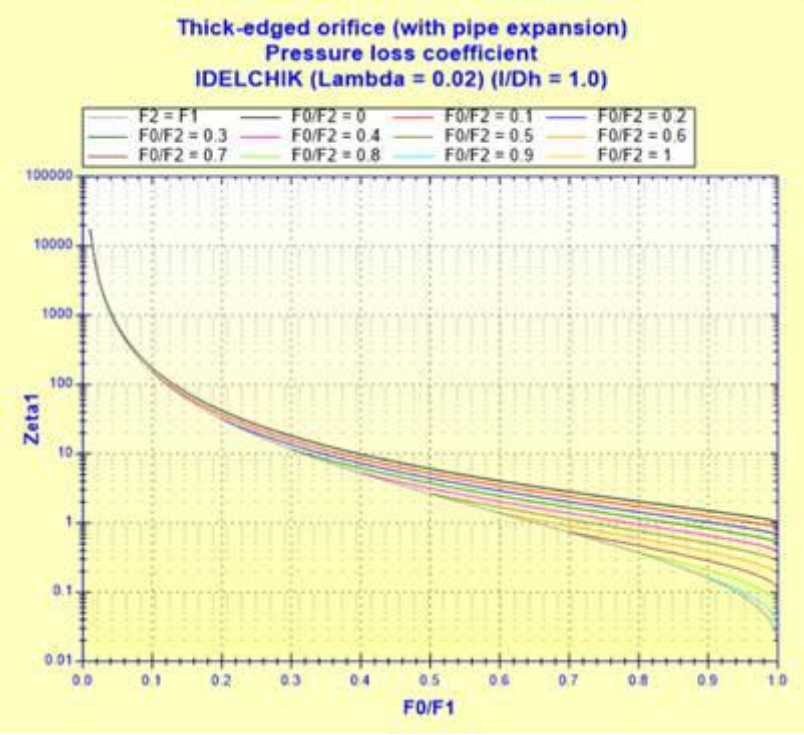
([1] diagram 4-12)



(with λ = 0.02 et l/D_h = 1)

Pressure loss coefficient (based on the minor pipe velocity):

$$\zeta_1 = \zeta \cdot \left(\frac{F_1}{F_0}\right)^2$$



(with λ = 0.02 et l/D_h = 1)

■ $Re_0 < 10^5$

Quadratic local resistance coefficient:

$$\zeta_{quad} = \left[0.5 \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \left(1 - \frac{F_0}{F_2}\right)^2 + \tau \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375} \cdot \left(1 - \frac{F_0}{F_2}\right) + \lambda \cdot \frac{l}{D_h}\right]$$

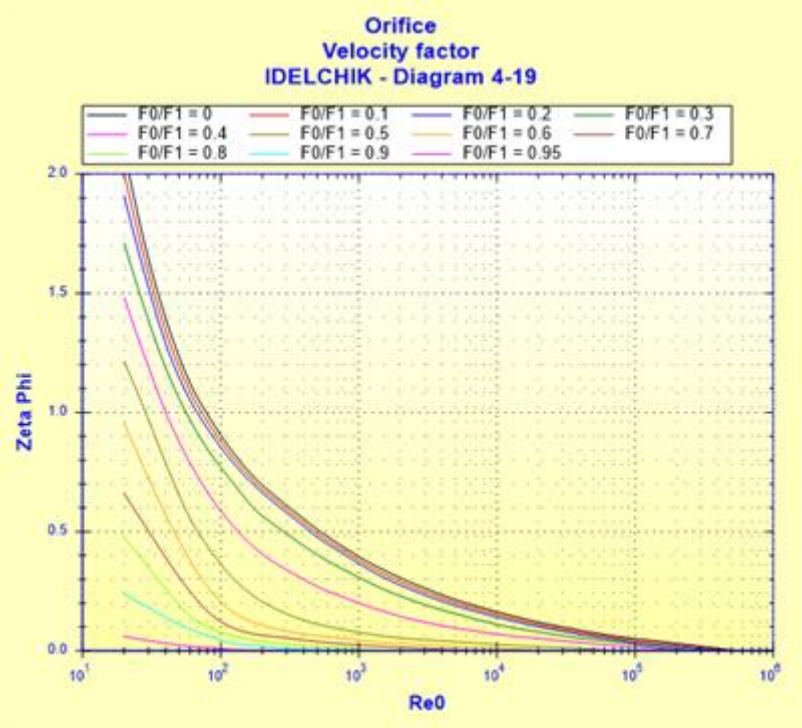
([1] diagram 4-12)

$$\zeta_{1quad} = \zeta_{quad} \cdot \left(\frac{F_1}{F_0}\right)^2$$

Velocity factor:

$$\zeta_\varphi = f\left(Re_0, \frac{F_0}{F_1}\right)$$

([1] diagram 4-19)



Contraction factor:

$\overline{\varepsilon}_{0\,Re} = f(Re_0)$ ([1] diagram 4-19)

Pressure loss coefficient (based on the minor pipe velocity):

- $30 < Re_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $10 < Re_0 \leq 30$

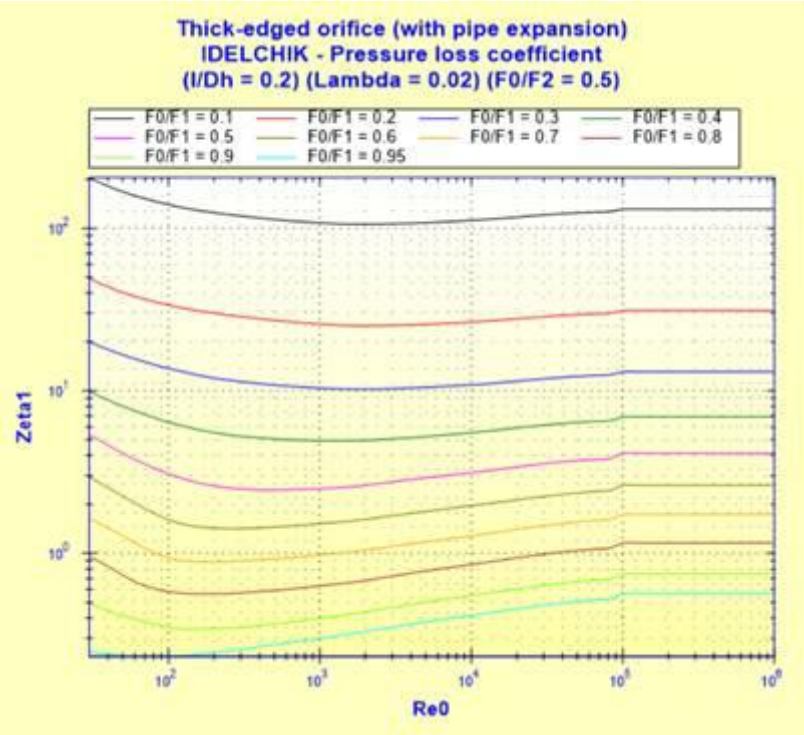
$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-19)



(with $l/D_h = 0.2$, $\lambda = 0.02$ and $F_0/F_2 = 0.5$)

Total pressure loss (Pa):

$$\Delta P = \zeta_1 \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta_1 \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_1	Minor pipe internal diameter (m)
D_2	Major pipe internal diameter (m)
D_0	Orifice diameter (m)
F_1	Minor pipe cross-sectional area (m^2)
F_2	Major pipe cross-sectional area (m^2)
F_0	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_1	Mean velocity in minor pipe (m/s)
w_2	Mean velocity in major pipe (m/s)
w_0	Mean velocity in orifice (m/s)
Re_1	Reynolds number in minor pipe ()
Re_2	Reynolds number in major pipe ()
Re_0	Reynolds number in orifice ()
Δ	Absolute roughness of orifice walls (m)
$\bar{\Delta}$	Relative roughness of orifice walls ()
l	Orifice thickness (m)
τ	Coefficient of effect of the orifice thickness ()
λ	Darcy friction coefficient in orifice ()
ζ	Local resistance coefficient (based on the orifice velocity) ()
ζ_{quad}	Quadratic local resistance coefficient (based on the orifice velocity) ()
ζ_{1quad}	Quadratic local resistance coefficient (based on the minor pipe velocity) ()

ζ_φ Velocity factor ()

$\bar{\varepsilon}_{0Re}$ Contraction factor ()

ζ_1 Pressure loss coefficient (based on the minor pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

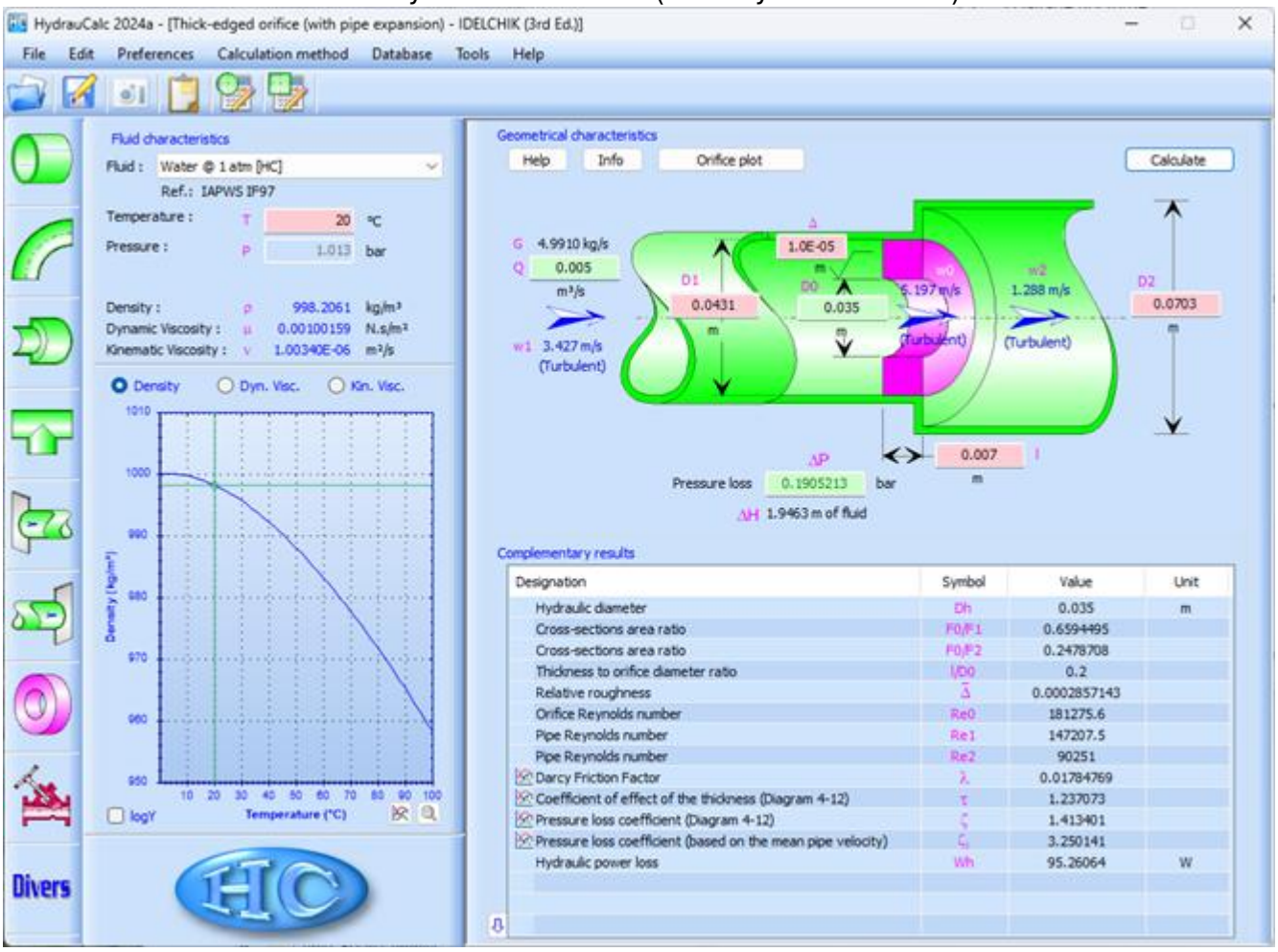
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- thickness to orifice diameter ratio (l/D_0) greater than 0.015

Example of application:



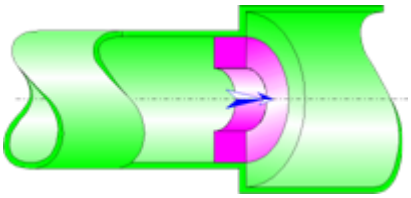
References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

[2] Идельчик.И.Е.Справочник по гидравлическим сопротивлениям.1992 (original document in Russian language)

Note: The formulation used for the calculation of the coefficient $\varphi\left(\frac{l}{D_h}\right)$ is that of the original reference document [2] which differs from that of the translated document [1]

2.7.9.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a thick-edged orifice with pipe expansion downstream of the orifice. Moreover, when the thickness of the orifice is greater than 1.4 times the diameter of the orifice, the head loss due to friction in the orifice is also taken into account because it becomes significant.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of orifice to minor pipe diameters:

$$\beta = \frac{d_o}{d_1}$$

Minor pipe cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Major pipe cross-sectional area (m^2):

$$A_2 = \pi \cdot \frac{d_2^2}{4}$$

Orifice cross-sectional area (m^2):

$$A_o = \pi \cdot \frac{d_o^2}{4}$$

Minor pipe velocity (m/s):

$$V_1 = \frac{Q}{A_1}$$

Major pipe velocity (m/s):

$$V_2 = \frac{Q}{A_2}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in minor pipe:

$$N_{Re1} = \frac{V_1 \cdot d_1}{\nu}$$

Reynolds number in major pipe:

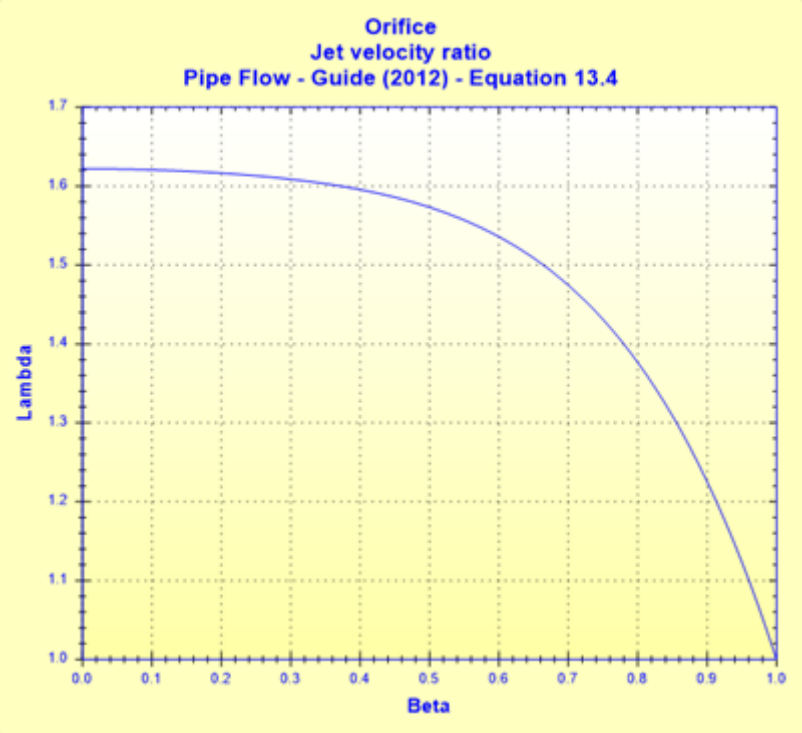
$$N_{Re2} = \frac{V_2 \cdot d_2}{\nu}$$

Reynolds number in orifice:

$$N_{Re0} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left(1 - 0.215\beta^2 - 0.785\beta^5\right)$$ ([1] equation 13.4)



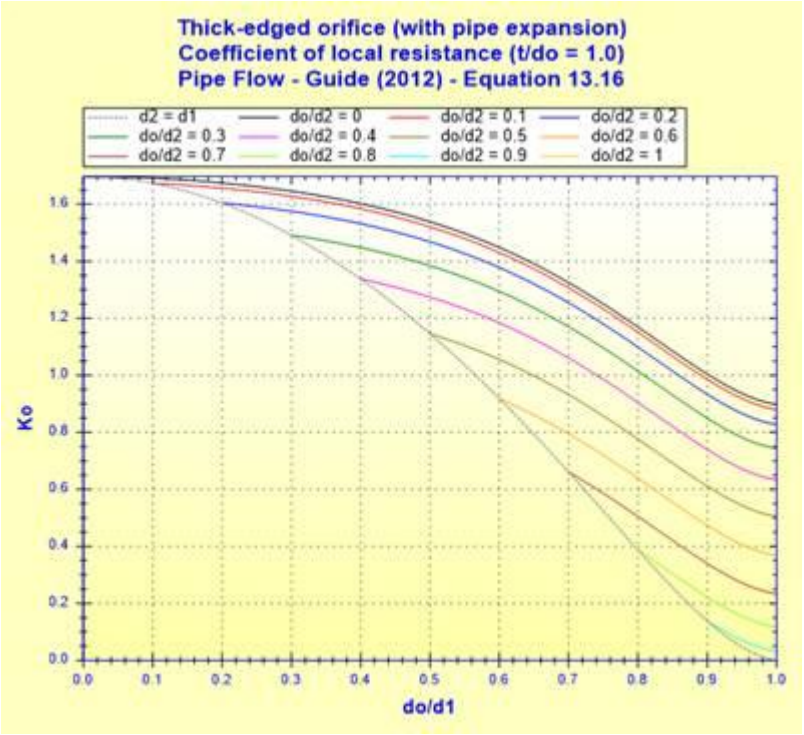
Velocity in vena contracta:

$$V_C = V_0 \cdot \lambda$$

Coefficient of local resistance ($NRe_o \geq 10^4$):

- Thickness to orifice diameter ratio (t/d_o) ≤ 1.4:

$$K_o = 0.0696 \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + C_{th} \cdot \left(\lambda - \left(\frac{d_0}{d_2}\right)^2\right)^2 + \left(1 - C_{th}\right) \cdot \left[\left(\lambda - 1\right)^2 + \left(1 - \left(\frac{d_0}{d_2}\right)^2\right)^2\right]$$ ([1] equation 13.16)

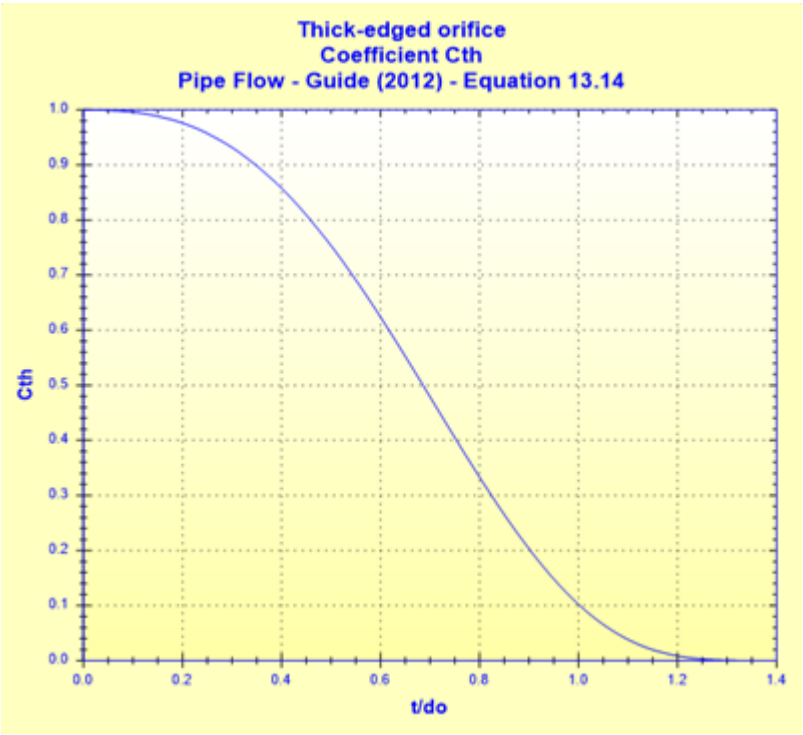


(with $t/d_0 = 1$)

with:

$$C_{th} = \left[1 - 0.50 \cdot \left(\frac{t}{1.4 d_o}\right)^{2.5} - 0.50 \cdot \left(\frac{t}{1.4 d_o}\right)^{3}\right]^{-4.5}$$

([1] equation 13.14)



- Thickness to orifice diameter ratio (t/d_o) > 1.4:

$$K_o = 0.0696 \cdot \left(1-\beta^5\right) \cdot \lambda^2 + \left(\lambda - 1\right)^2 + \left[1 - \left(\frac{d_0}{d_2}\right)^2\right]^2 + f_o \cdot \left(\frac{t}{d_o} - 1.4\right)$$

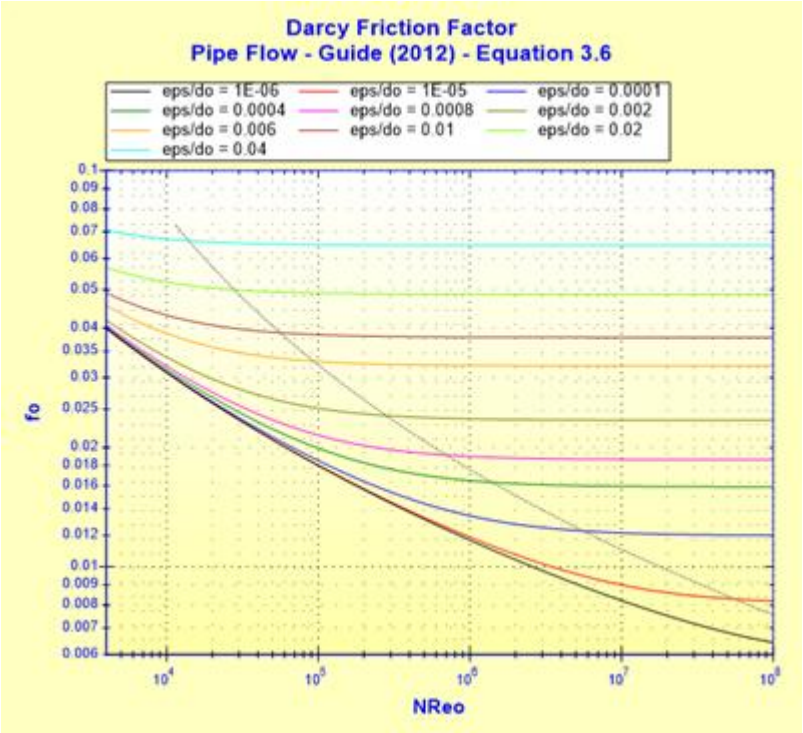
([1] § 13.5.2)

(with $f_0 = 0.02$ and $t/d_0 = 5$)

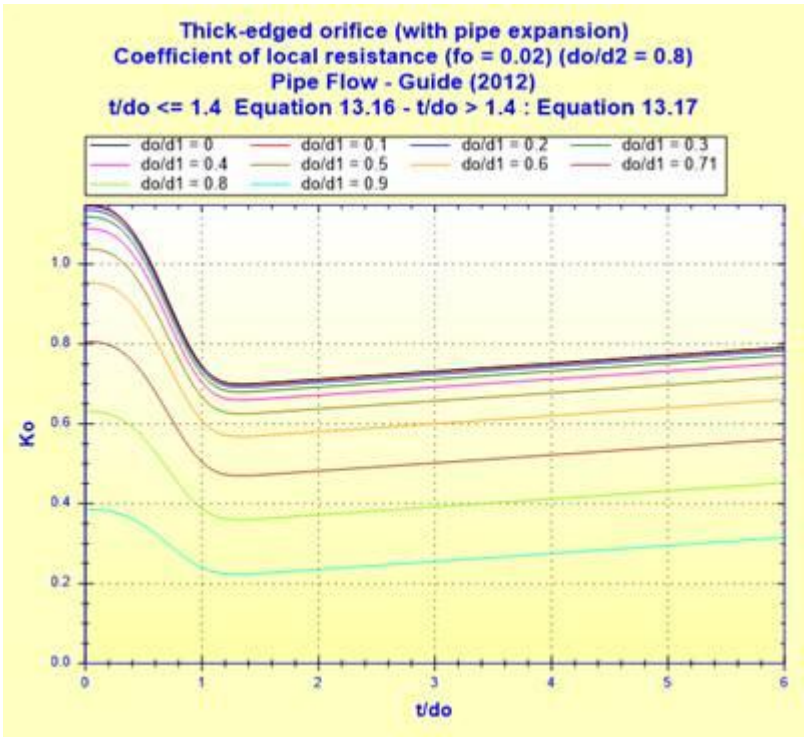
with:

$$f_o = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d_o} + \frac{2.51}{NRe_0 \cdot \sqrt{f_o}}\right)\right]^2}$$

Colebrook-White equation ([1] equation 3.6)



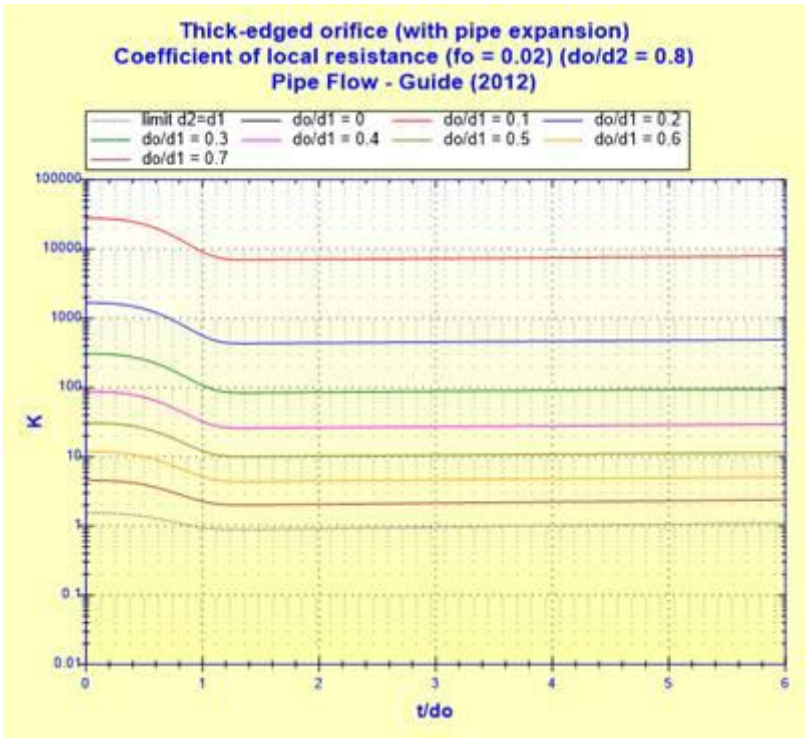
■ All thickness to orifice diameter ratios (t/d_o):



(with $f_0 = 0.02$ and $d_0/d_2 = 0.8$)

Total pressure loss coefficient (based on the minor pipe velocity):

$$K = K_o \cdot \left(\frac{A_1}{A_o}\right)^2$$



(with $f_0 = 0.02$ and $d_0/d_2 = 0.8$)

(with $f_0 = 0.02$ and $t/d_0 = 1$)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_0	Orifice diameter (m)
d_1	Internal minor pipe diameter (m)
d_2	Internal major pipe diameter (m)
β	Ratio of orifice to minor pipe diameters ()
A_0	Orifice cross-sectional area (m^2)
A_1	Minor pipe cross-sectional area (m^2)
A_2	Major pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_0	Mean velocity in orifice (m/s)
V_1	Mean velocity in minor pipe (m/s)
V_2	Mean velocity in major pipe (m/s)
NRe_0	Reynolds number in orifice ()
NRe_1	Reynolds number in minor pipe ()
NRe_2	Reynolds number in major pipe ()
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
t	Thickness orifice (m)
K_0	Coefficient of local resistance ()
Cth	Coefficient ()
ε	Absolute roughness of orifice walls (m)

f_o Friction factor ()

K Total pressure loss coefficient (based on the minor pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m^3)

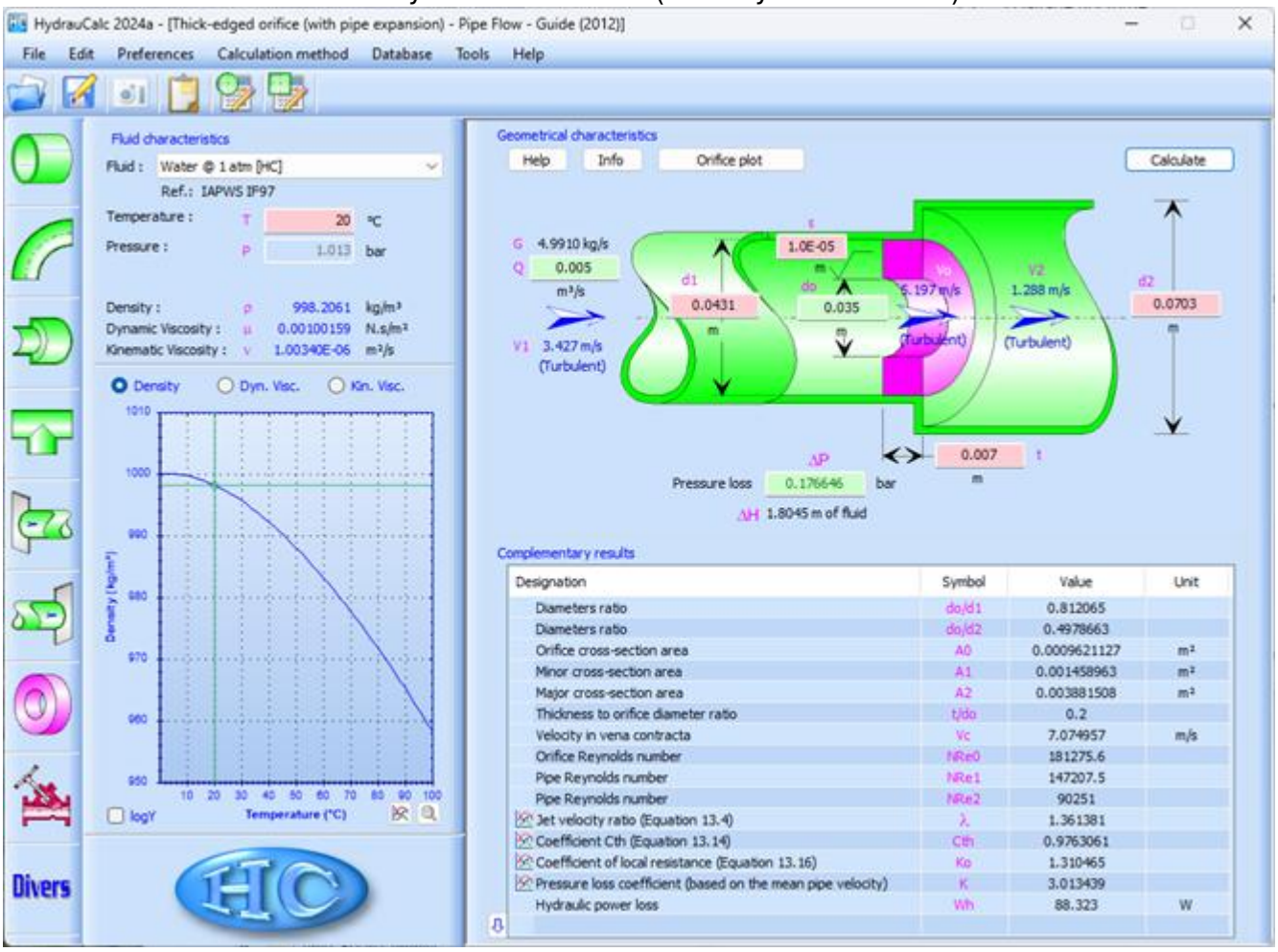
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in orifice ($NRe_o \geq 10^4$)
- stabilized flow upstream of the orifice

Example of application:

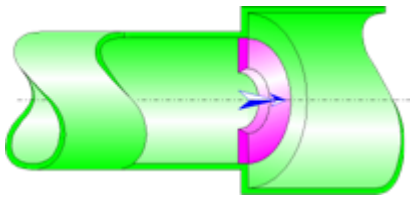


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.7.10 Sharp-edged orifice (with pipe expansion)

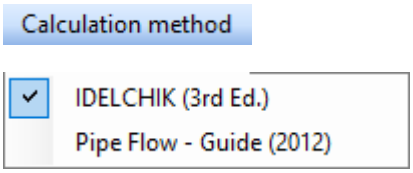
Circular Cross-Section



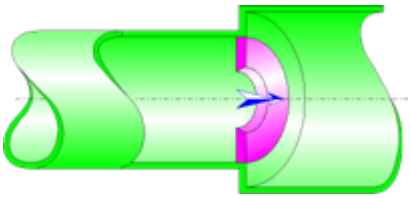
For the calculation of the pressure loss coefficient of sharp-edged orifices with pipe expansion downstream of the orifice, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.7.10.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sharp-edged orifice with pipe expansion downstream of the orifice.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Minor pipe cross-section area (m^2):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Major pipe cross-section area (m^2):

$$F_2 = \pi \cdot \frac{D_2^2}{4}$$

Orifice cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^{\,2}}{4}$$

Mean velocity in minor pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in major pipe (m/s):

$$w_2 = \frac{Q}{F_2}$$

Mean velocity in orifice (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in minor pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in major pipe:

$$\mathrm{Re}_2 = \frac{w_2 \cdot D_2}{\nu}$$

Reynolds number in orifice:

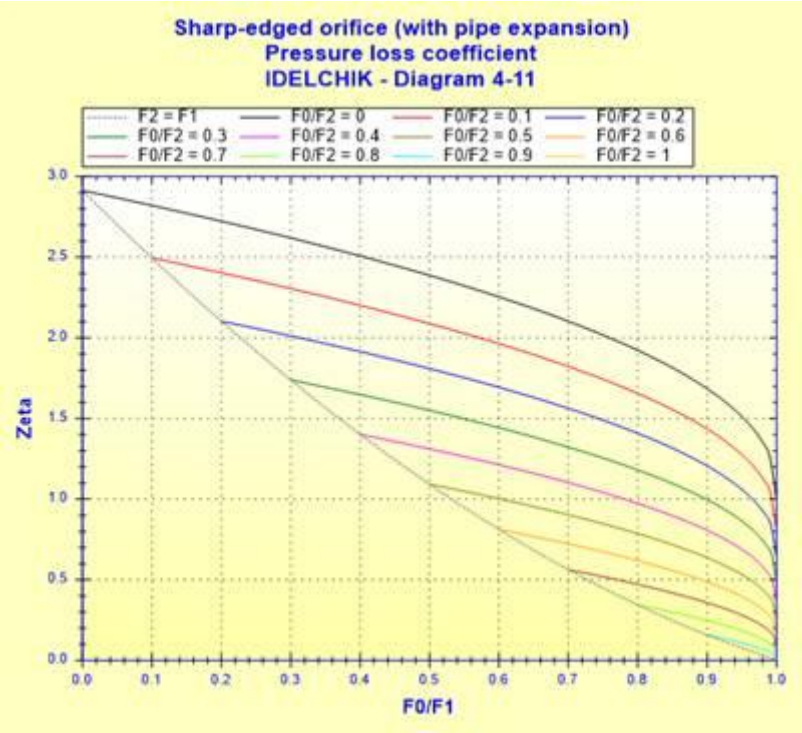
$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

■ $\mathrm{Re}_0 \geq 10^5$

Local resistance coefficient:

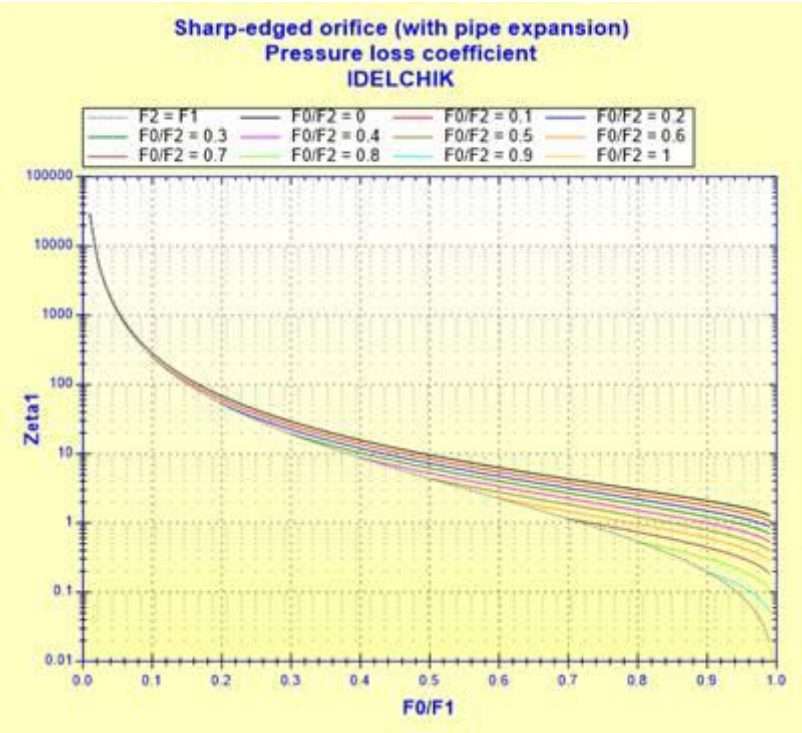
$$\zeta = \left[0.707 \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375} + \left(1 - \frac{F_0}{F_2}\right)\right]^2$$

([1] diagram 4-11)



Pressure loss coefficient (based on the minor pipe velocity):

$$\zeta_1 = \zeta \cdot \left(\frac{F_1}{F_0}\right)^2$$



■ $Re_0 < 10^5$

Quadratic local resistance coefficient:

$$\zeta_{quad} = \left[0.707 \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375} + \left(1 - \frac{F_0}{F_2}\right)\right]^2$$

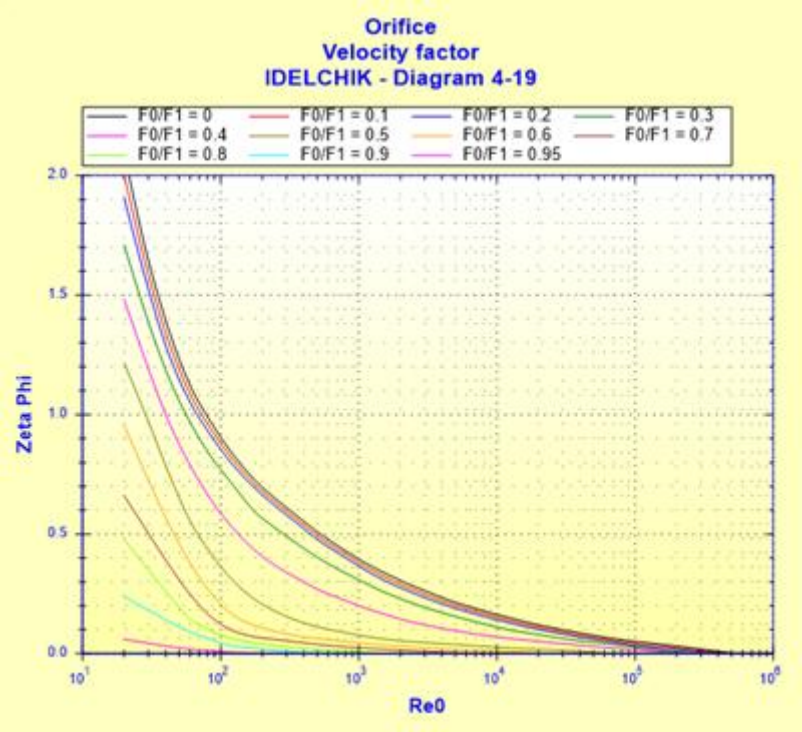
([1] diagram 4.11)

$$\zeta 1_{quad} = \zeta_{quad} \cdot \left(\frac{F_1}{F_0}\right)^2$$

Velocity factor:

$$\zeta_\varphi = f\left(Re_0, \frac{F_0}{F_1}\right)$$

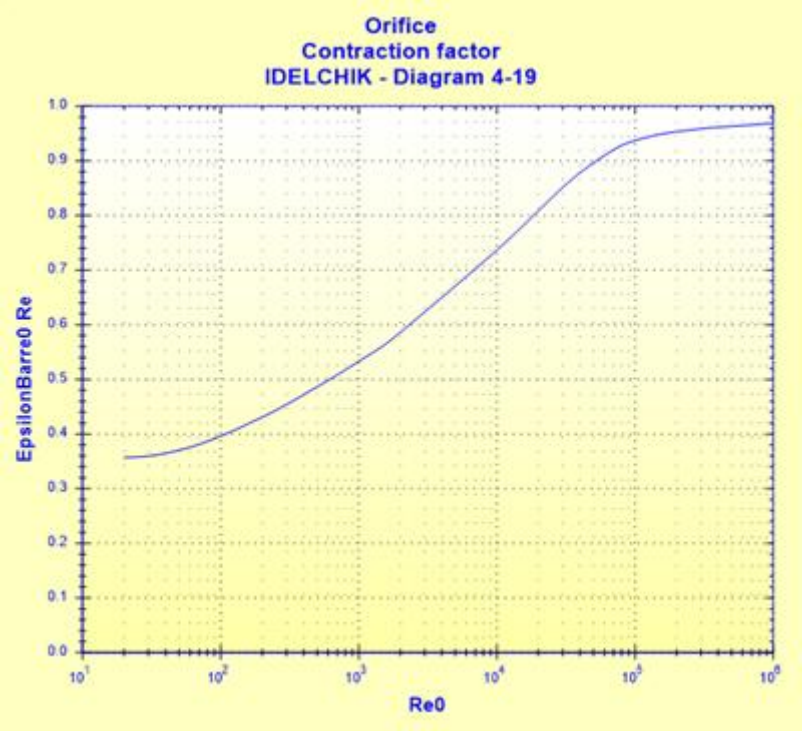
([1] diagram 4-19)



Contraction factor:

$$\bar{\varepsilon}_{0Re} = f(Re_0)$$

([1] diagram 4-19)



Pressure loss coefficient (based on the minor pipe velocity):

- $30 < Re_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $10 < Re_0 \leq 30$

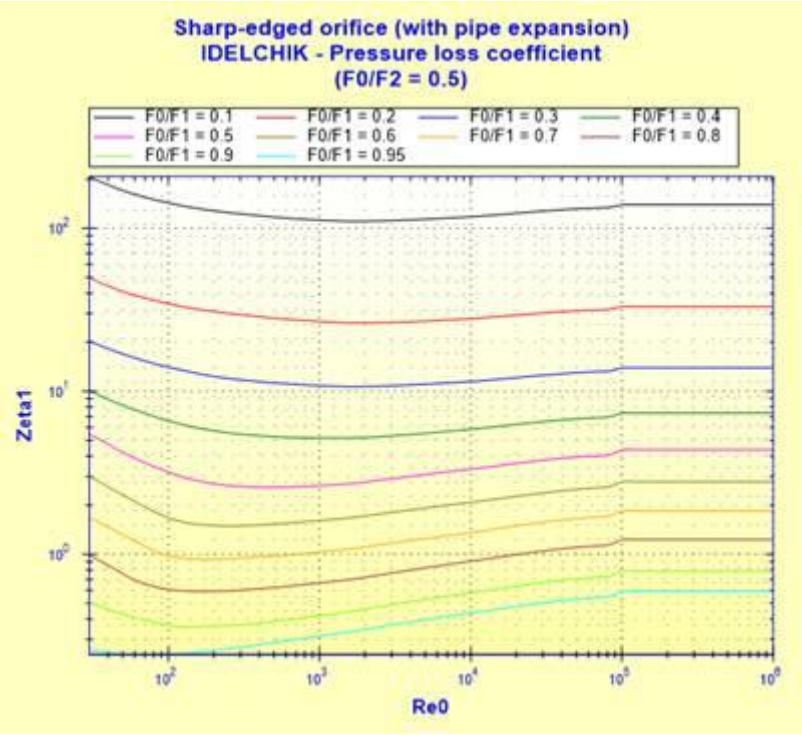
$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-19)



(with $F_0/F_2 = 0.5$)

Total pressure loss (Pa):

$$\Delta P = \zeta_1 \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta_1 \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

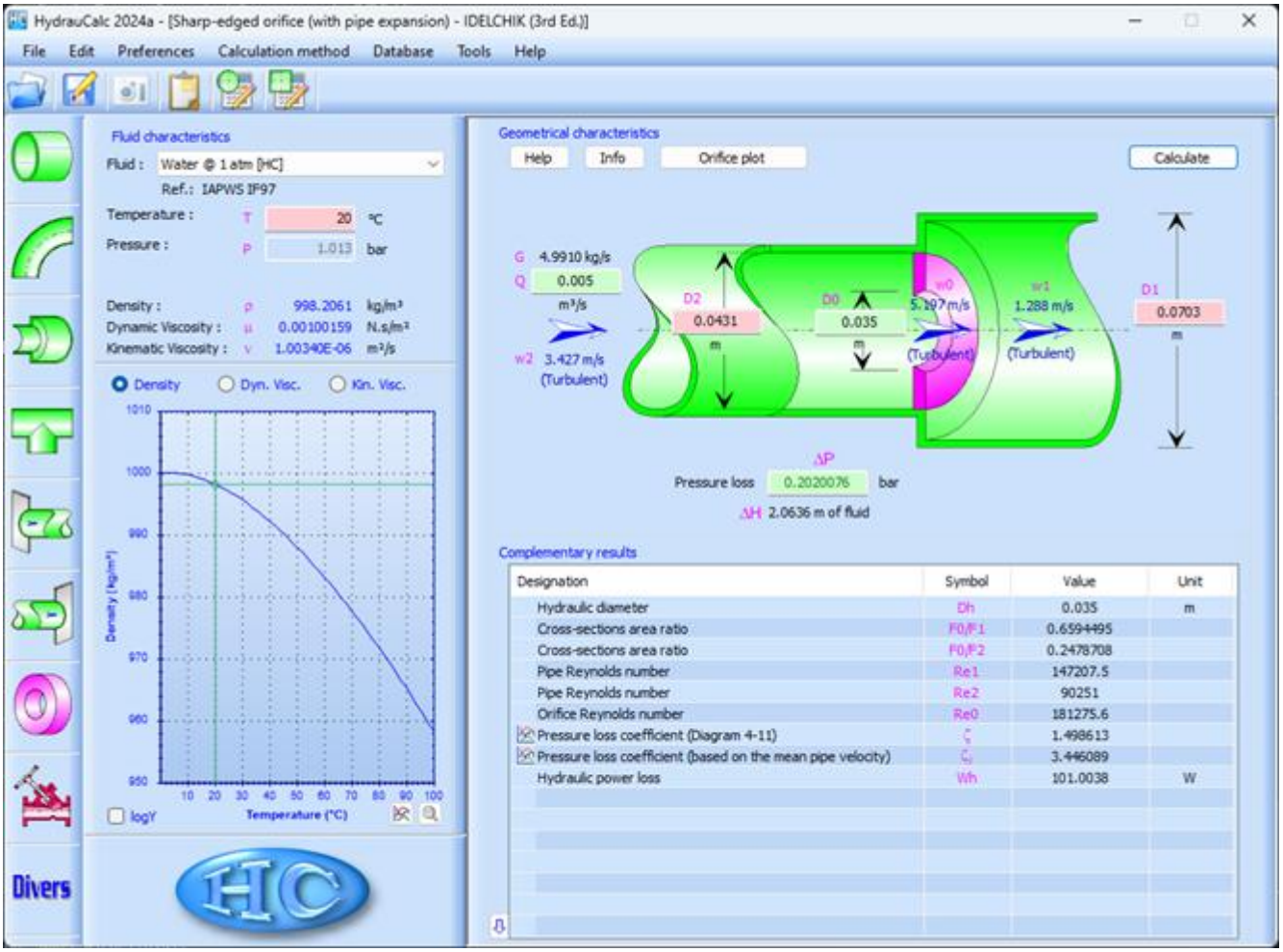
D_h	Hydraulic diameter (m)
D_1	Minor pipe internal diameter (m)
D_2	Major pipe internal diameter (m)
D_0	Orifice diameter (m)
F_1	Minor pipe cross-sectional area (m^2)

F_2	Major pipe cross-sectional area (m^2)
F_0	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_1	Mean velocity in minor pipe (m/s)
w_2	Mean velocity in major pipe (m/s)
w_0	Mean velocity in orifice (m/s)
Re_1	Reynolds number in minor pipe ()
Re_2	Reynolds number in major pipe ()
Re_0	Reynolds number in orifice ()
ζ	Local resistance coefficient (based on the orifice velocity) ()
ζ_{quad}	Quadratic local resistance coefficient (based on the orifice velocity) ()
ζ_{1quad}	Quadratic local resistance coefficient (based on the minor pipe velocity) ()
ζ_{φ}	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ_1	Pressure loss coefficient (based on the minor pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice

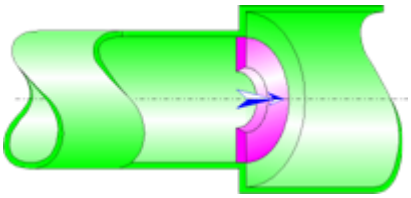
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.7.10.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sharp-edged orifice with pipe expansion downstream of the orifice.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of orifice to minor pipe diameters:

$$\beta = \frac{d_o}{d_1}$$

Minor pipe cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Major pipe cross-sectional area (m^2):

$$A_2 = \pi \cdot \frac{d_2^2}{4}$$

Orifice cross-sectional area (m^2):

$$A_o = \pi \cdot \frac{d_o^2}{4}$$

Minor pipe velocity (m/s):

$$V_1 = \frac{Q}{A_1}$$

Major pipe velocity (m/s):

$$V_2 = \frac{Q}{A_2}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in minor pipe:

$$N_{Re1} = \frac{V_1 \cdot d_1}{\nu}$$

Reynolds number in major pipe:

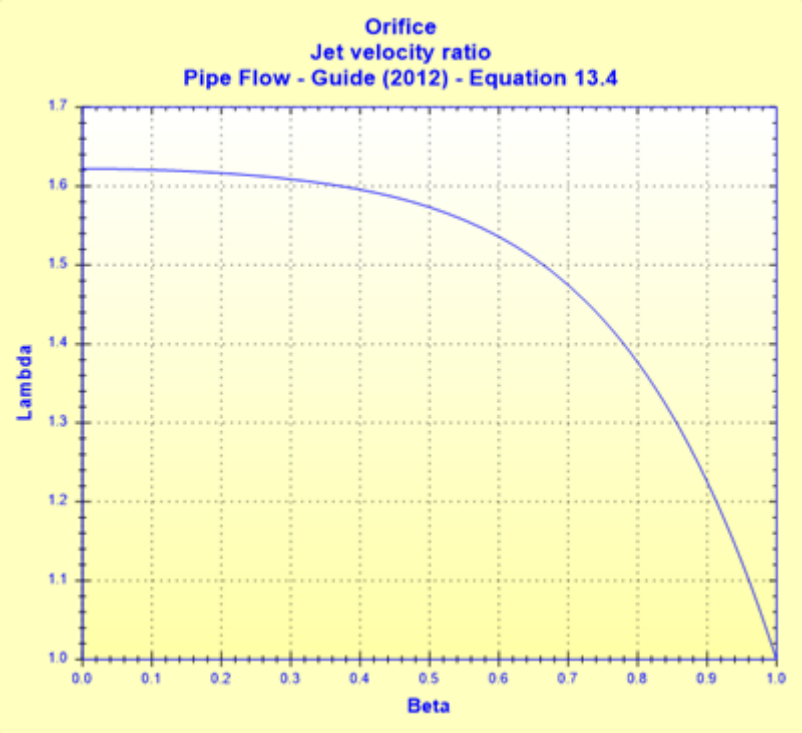
$$N_{Re2} = \frac{V_2 \cdot d_2}{\nu}$$

Reynolds number in orifice:

$$N_{Re_o} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left(1 - 0.215\beta^2 - 0.785\beta^5\right)$$ ([1] equation 13.4)



Velocity in vena contracta (m/s):

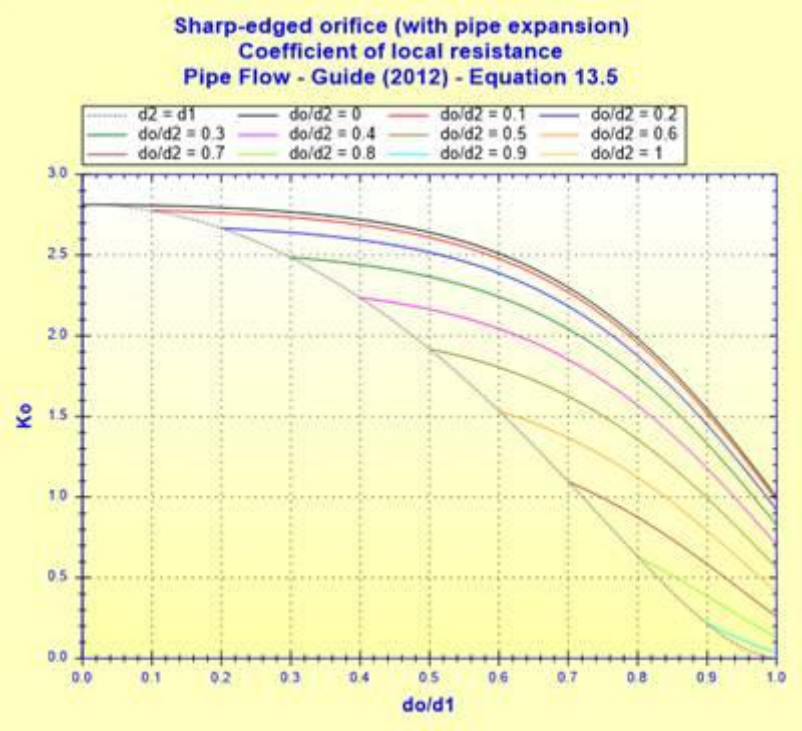
$$V_C = V_O \cdot \lambda$$

Vena contracta cross-sectional area (m^2):

$$A_C = \frac{Q}{V_C}$$

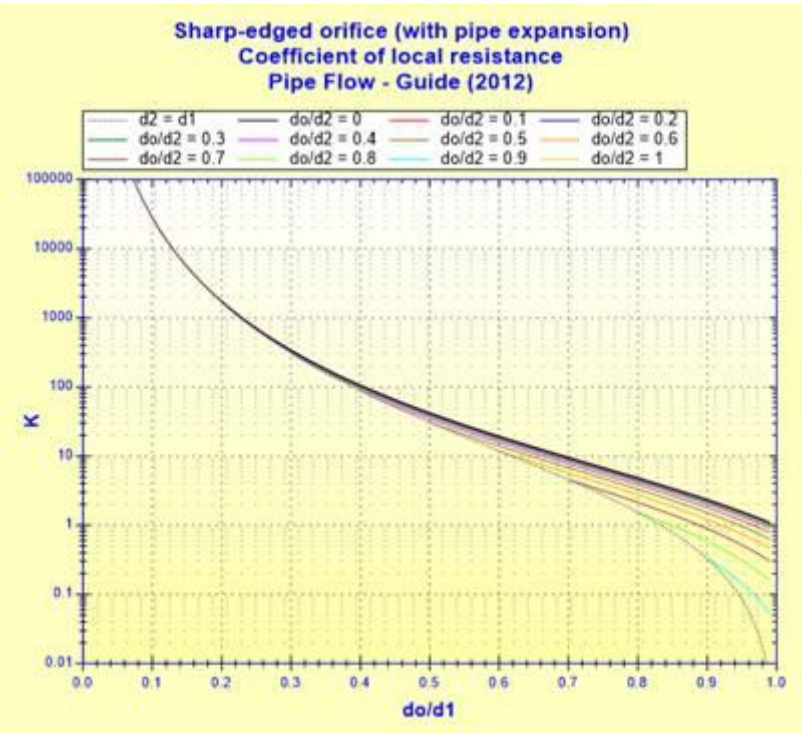
Coefficient of local resistance ($NRe_o \geq 10^4$):

$$K_o = 0.0696 \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + \left(\lambda - \left(\frac{d_0}{d_2}\right)^2\right)^2$$ ([1] equation 13.5)



Total pressure loss coefficient (based on the minor pipe velocity):

$$K = K_o \cdot \left(\frac{A_1}{A_o} \right)^2$$



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_0	Orifice diameter (m)
d_1	Internal minor pipe diameter (m)
d_2	Internal major pipe diameter (m)
β	Ratio of orifice to minor pipe diameters ()
A_0	Orifice cross-sectional area (m^2)
A_1	Minor pipe cross-sectional area (m^2)
A_2	Major pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_0	Mean velocity in orifice (m/s)
V_1	Mean velocity in minor pipe (m/s)
V_2	Mean velocity in major pipe (m/s)
NRe_0	Reynolds number in orifice ()
NRe_1	Reynolds number in minor pipe ()
NRe_2	Reynolds number in major pipe ()
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)

K_0 Coefficient of local resistance ()

K Total pressure loss coefficient (based on the minor pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m^3)

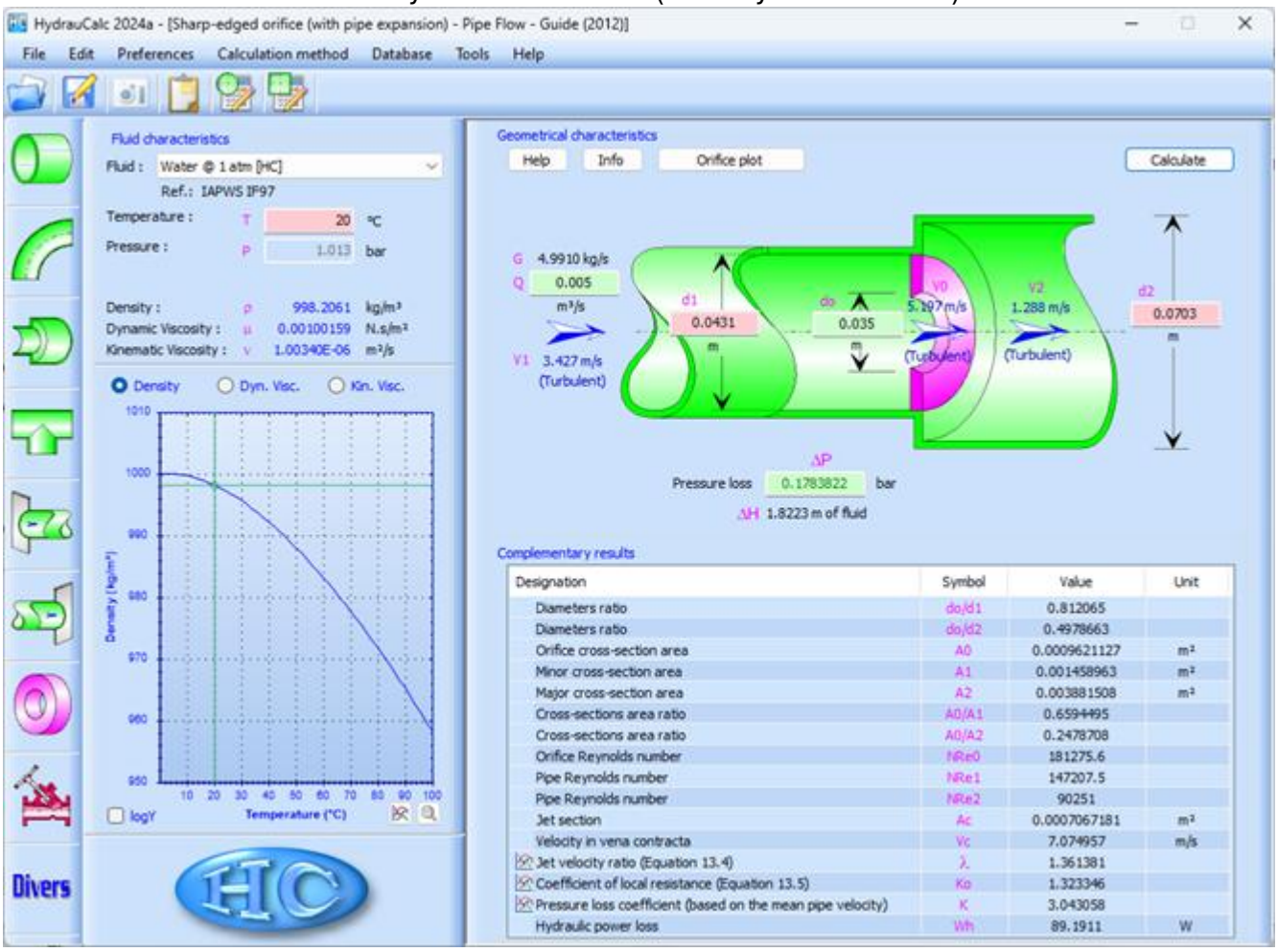
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in the orifice ($NRe_o \geq 10^4$)
- stabilized flow upstream of the orifice

Example of application:

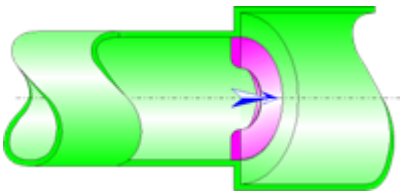


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.7.11 Round-edged orifice (with pipe expansion)

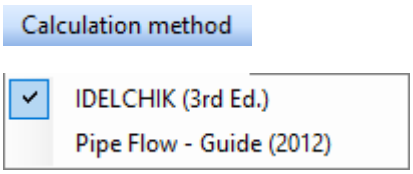
Circular Cross-Section



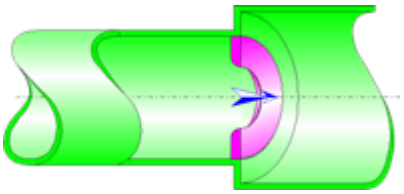
For the calculation of the pressure loss coefficient in round-edged orifices with pipe expansion downstream of the orifice, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.7.11.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a round-edged orifice with pipe expansion downstream of the orifice.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Minor pipe cross-section area (m²):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Major - pipe cross-section area (m²):

$$F_2 = \pi \cdot \frac{D_2^2}{4}$$

Orifice cross-section area (m²):

$$F_0 = \pi \cdot \frac{D_0^{\,2}}{4}$$

Mean velocity in minor pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in major pipe (m/s):

$$w_2 = \frac{Q}{F_2}$$

Mean velocity in orifice (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in minor pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in major pipe:

$$\mathrm{Re}_2 = \frac{w_2 \cdot D_2}{\nu}$$

Reynolds number in orifice:

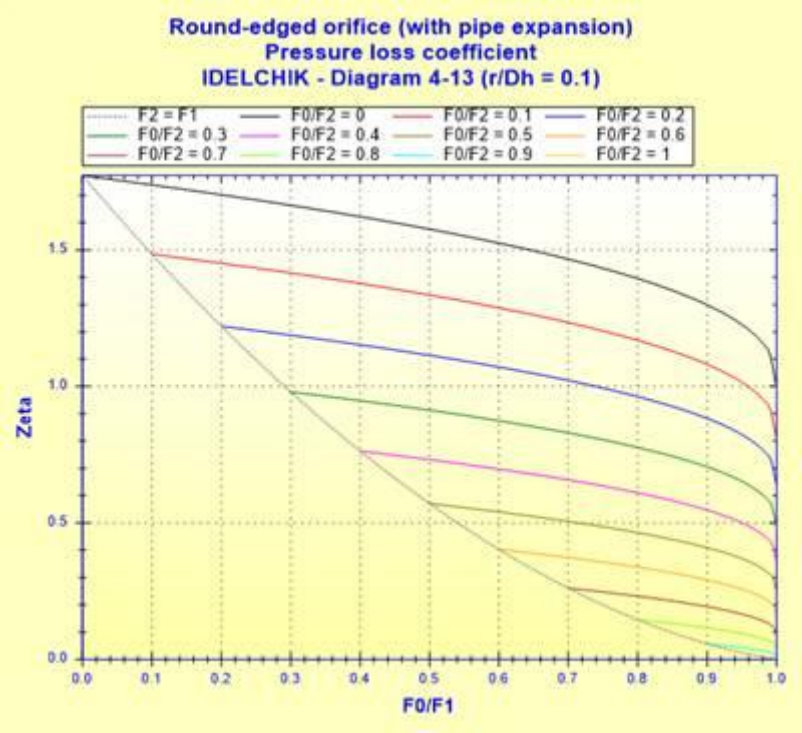
$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

■ $\mathrm{Re}_0 \geq 10^5$

Local resistance coefficient:

$$\zeta = \zeta' \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \left(1 - \frac{F_0}{F_2}\right)^2 + 2 \cdot \sqrt{\zeta'} \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375} \cdot \left(1 - \frac{F_0}{F_2}\right)$$

([2] diagram 4-13)



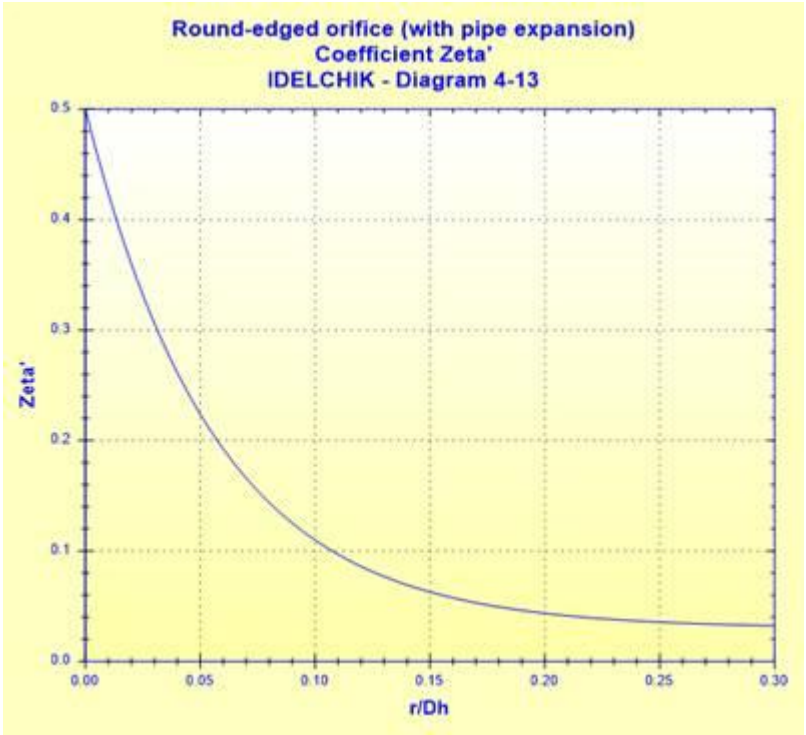
(with r/ D_h = 0.1)

with :

Coefficient of effect of the round:

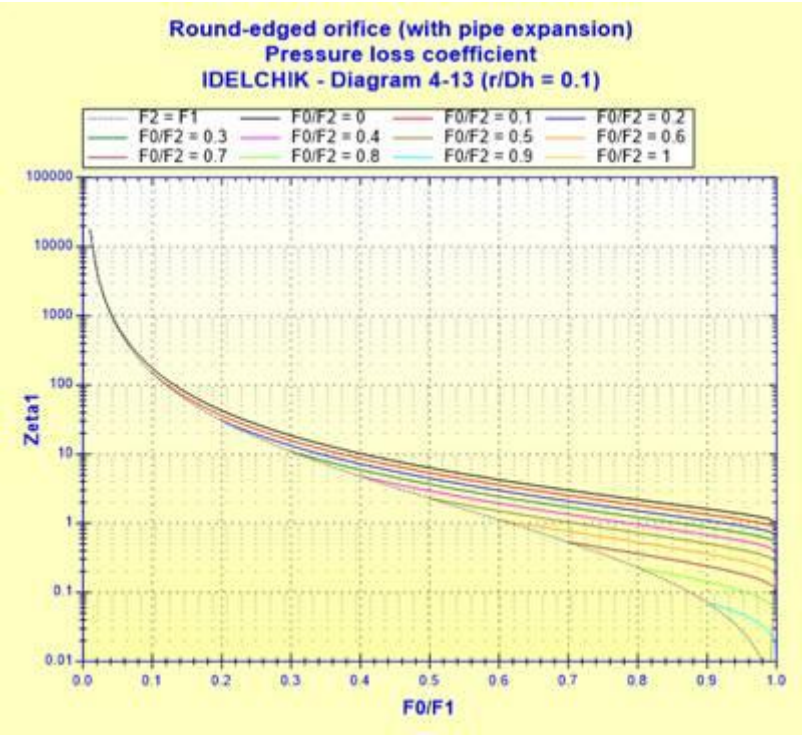
$$\zeta' = 0.03 + 0.47 \cdot 10^{-7.7 \cdot \frac{r}{D_h}}$$

([1] diagram 4-13)



Coefficient de perte de pression (basé sur la vitesse dans le grand - tuyau) :

$$\zeta_1 = \zeta \cdot \left(\frac{F_1}{F_0}\right)^2$$



(with r/ D_h = 0.1)

■ $Re_0 < 10^5$

Quadratic local resistance coefficient:

$$\zeta_{quad} = \zeta' \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \left(1 - \frac{F_0}{F_2}\right)^2 + 2 \cdot \sqrt{\zeta'} \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375} \cdot \left(1 - \frac{F_0}{F_2}\right)$$

([2] diagram 4-13)

with :

$$\zeta' = 0.03 + 0.47 \cdot 10^{-7.7 \cdot \frac{r}{D_h}}$$

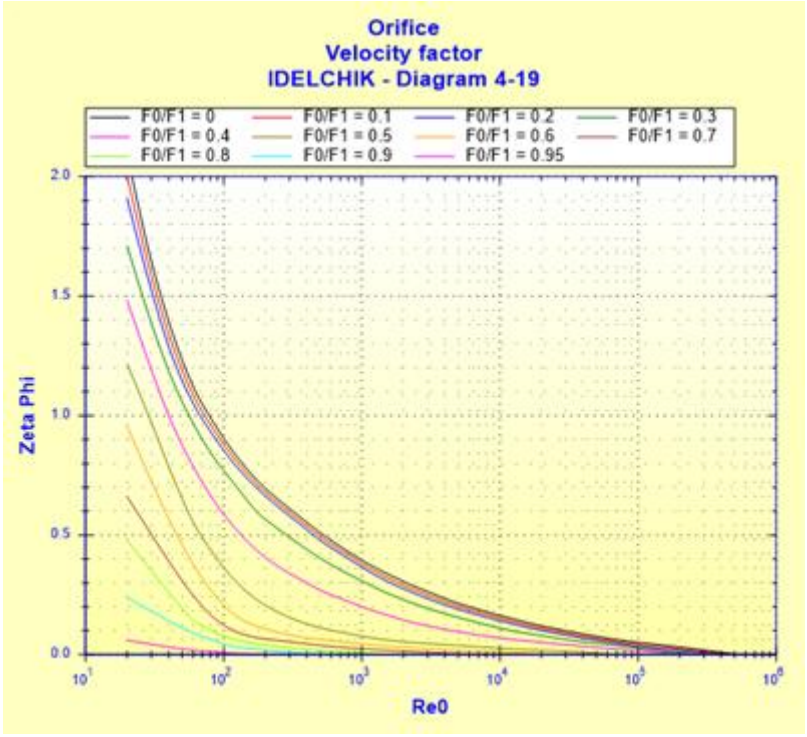
([1] diagram 4-13)

$$\zeta_{1quad} = \zeta_{quad} \cdot \left(\frac{F_1}{F_0}\right)^2$$

Velocity factor:

$$\zeta_\varphi = f\left(Re_0, \frac{F_0}{F_1}\right)$$

([1] diagram 4-19)



Contraction factor:

$\overline{\varepsilon}_{0\,\mathrm{Re}} = f(\mathrm{Re}_0)$ ([1] diagram 4-19)

Pressure loss coefficient (based on the minor pipe velocity):

- $30 < \mathrm{Re}_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $10 < Re_0 \leq 30$

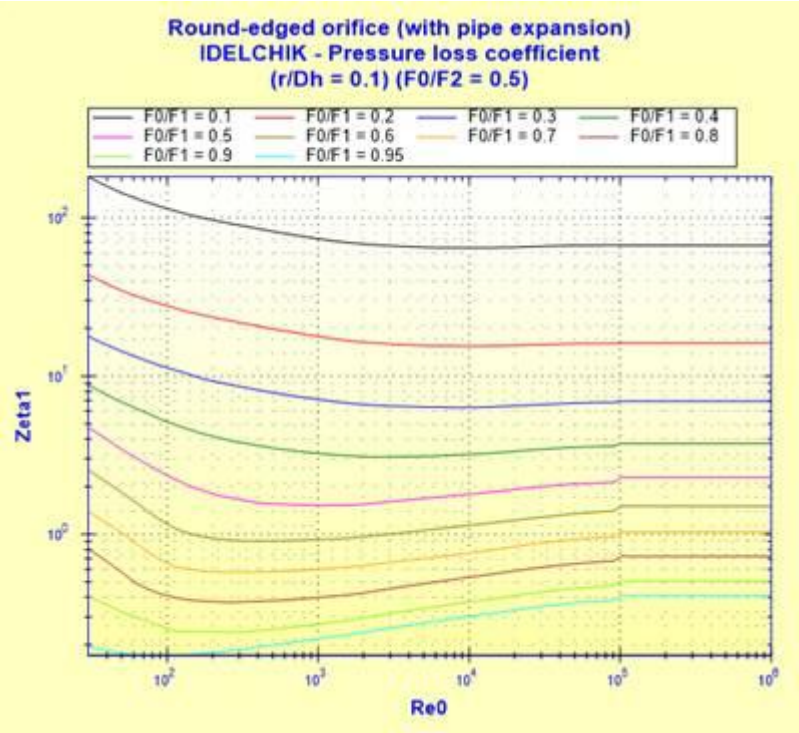
$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-19)



(with r/ D_h = 0.1 and F_0/F_2 = 0.5)

Total pressure loss (Pa):

$$\Delta P = \zeta_1 \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta_1 \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_1	Minor pipe internal diameter (m)
D_2	Major - pipe internal diameter (m)
D_0	Orifice diameter (m)
F_1	Minor pipe cross-sectional area (m^2)
F_2	Major - pipe cross-sectional area (m^2)
F_0	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_1	Mean velocity in minor pipe (m/s)
w_2	Mean velocity in major pipe (m/s)
w_0	Mean velocity in orifice (m/s)
Re_1	Reynolds number in minor pipe ()
Re_2	Reynolds number in major pipe ()
Re_0	Reynolds number in orifice ()
r	Radius of the round (m)
ζ'	Coefficient of effect of the round ()
ζ	Local resistance coefficient (based on the orifice velocity) ()
ζ_{quad}	Quadratic local resistance coefficient (based on the orifice velocity) ()
ζ_{1quad}	Quadratic local resistance coefficient (based on the minor pipe velocity) ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ_1	Pressure loss coefficient (based on the minor pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

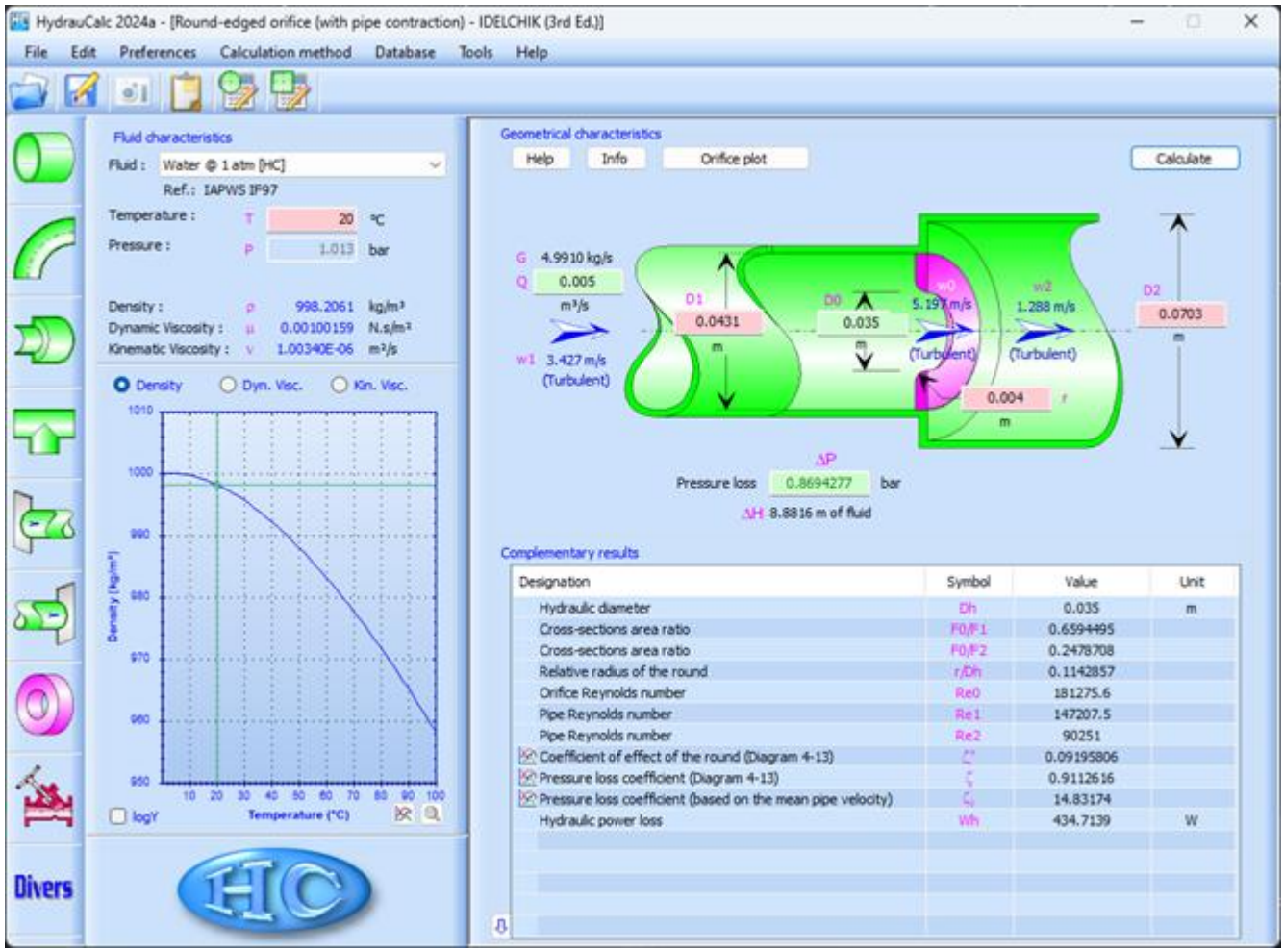
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- round radius less than the radius difference ($r < (D_1/2-D_0/2)$)

Example of application:



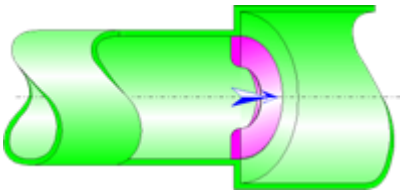
References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

[2] Идельчик.И.Е.Справочник по гидравлическим сопротивлениям.1992 (original document in Russian language)

Note: The formulation used for the calculation of the local resistance coefficients ζ and ζ_{quad} is that of the original reference document [2] which differs from that of the translated document [1]

2.7.11.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a round-edged orifice with pipe expansion downstream of the orifice.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of orifice to minor pipe diameters:

$$\beta = \frac{d_o}{d_1}$$

Minor pipe cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Major pipe cross-sectional area (m^2):

$$A_2 = \pi \cdot \frac{d_2^2}{4}$$

Orifice cross-sectional area (m^2):

$$A_o = \pi \cdot \frac{d_o^2}{4}$$

Minor pipe velocity (m/s):

$$V_1 = \frac{Q}{A_1}$$

Major pipe velocity (m/s):

$$V_2 = \frac{Q}{A_2}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in minor pipe:

$$N_{Re1} = \frac{V_1 \cdot d_1}{\nu}$$

Reynolds number in major pipe:

$$N_{Re2} = \frac{V_2 \cdot d_2}{\nu}$$

Reynolds number in orifice:

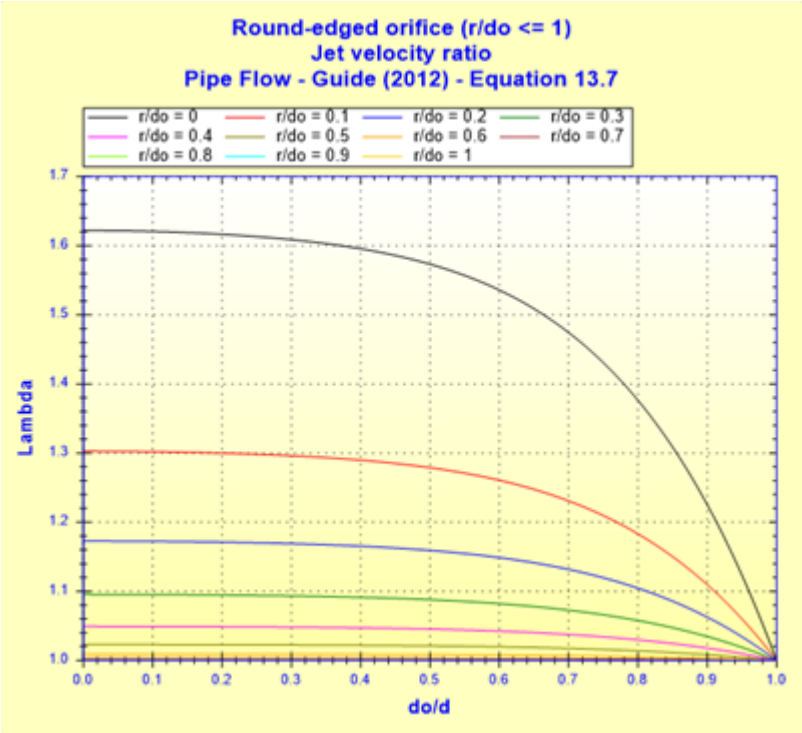
$$N_{Re_o} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

- $r/d_0 \leq 1$

$$\lambda = 1 + 0.622 \cdot \left[1 - 0.3 \cdot \sqrt{\frac{r}{d_0}} - 0.7 \cdot \frac{r}{d_0} \right]^4 \cdot \left(1 - 0.215 \cdot \beta^2 - 0.785 \cdot \beta^5 \right)$$

([1] equation 13.7)



- $r/d_0 > 1$

$$\lambda = 1$$

([1] § 13.3.1)

Velocity in vena contracta:

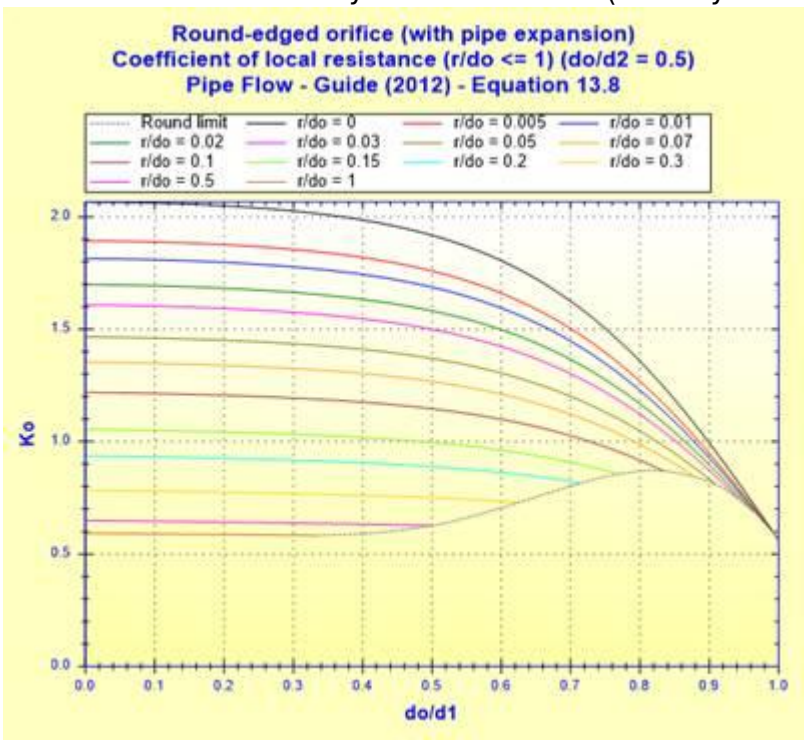
$$V_c = V_0 \cdot \lambda$$

Coefficient of local resistance:

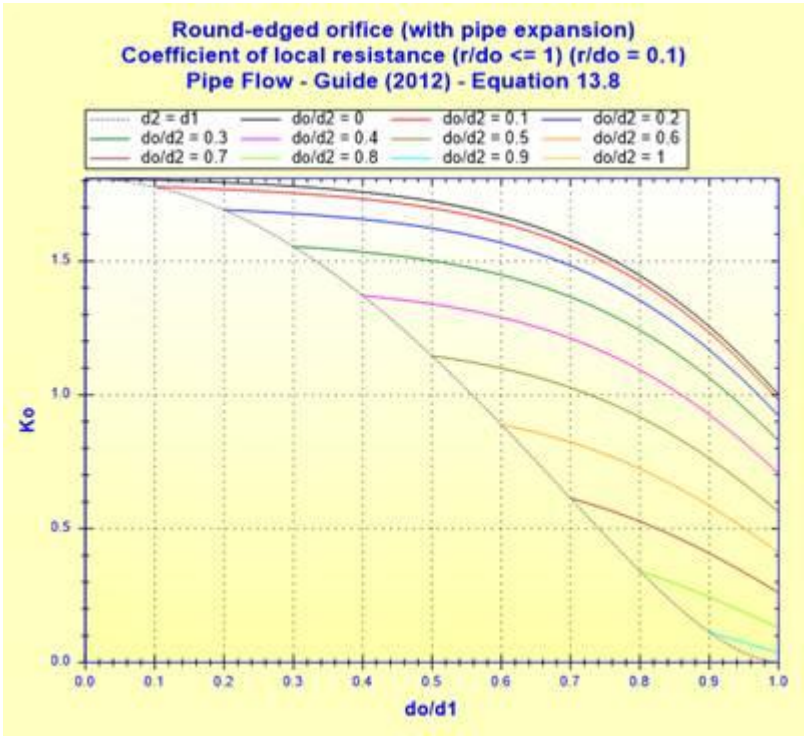
- $r/d_0 \leq 1$

$$K_o = 0.0696 \cdot \left(1 - 0.569 \cdot \frac{r}{d_0} \right) \cdot \left(1 - \sqrt{\frac{r}{d_0}} \cdot \beta \right) \cdot \left(1 - \beta^5 \right) \cdot \lambda^2 + \left[\lambda - \left(\frac{d_0}{d_2} \right)^2 \right]^2$$

([1] equation 13.8)



(with $d_0/d_2 = 0.5$)

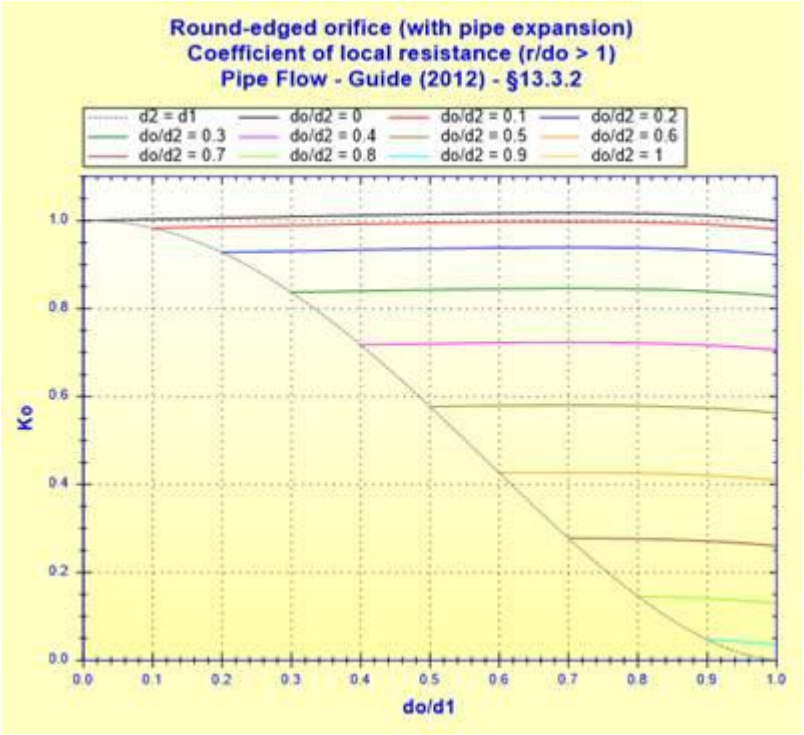


(with $r/d_0 = 0.1$)

■ $r/d_0 > 1$

$$K_o = 0.03 \cdot (1-\beta) \cdot \left(1-\beta^5\right) + \left[1-\left(\frac{d_0}{d_2}\right)^2\right]^2$$

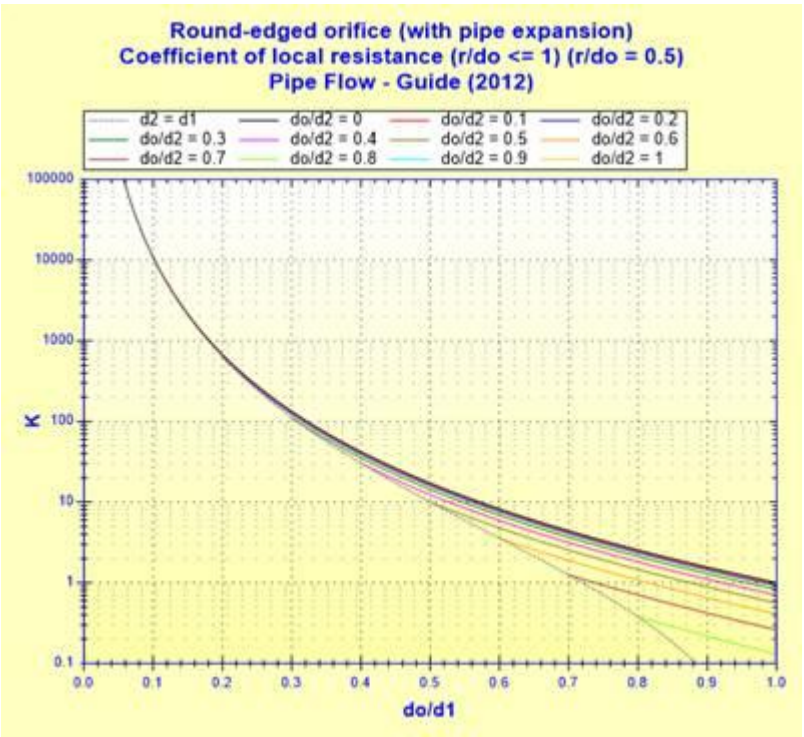
([1] § 13.3.2)



Total pressure loss coefficient (based on the minor pipe velocity):

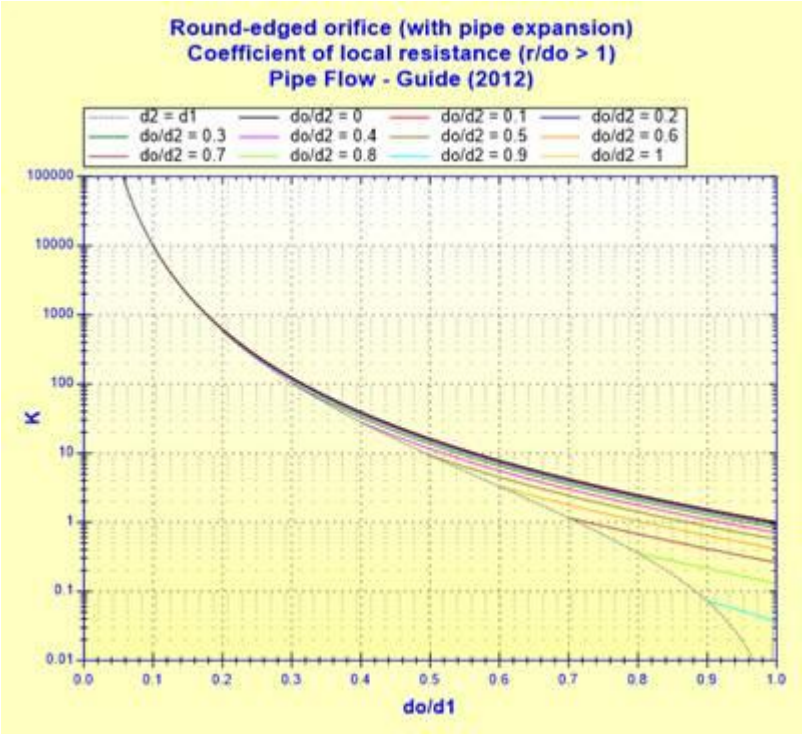
$$K = K_o \cdot \left(\frac{A_1}{A_o} \right)^2$$

- $r/d_0 \leq 1$



(with $r/d_0 = 0.1$)

■ $r/d_0 > 1$



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

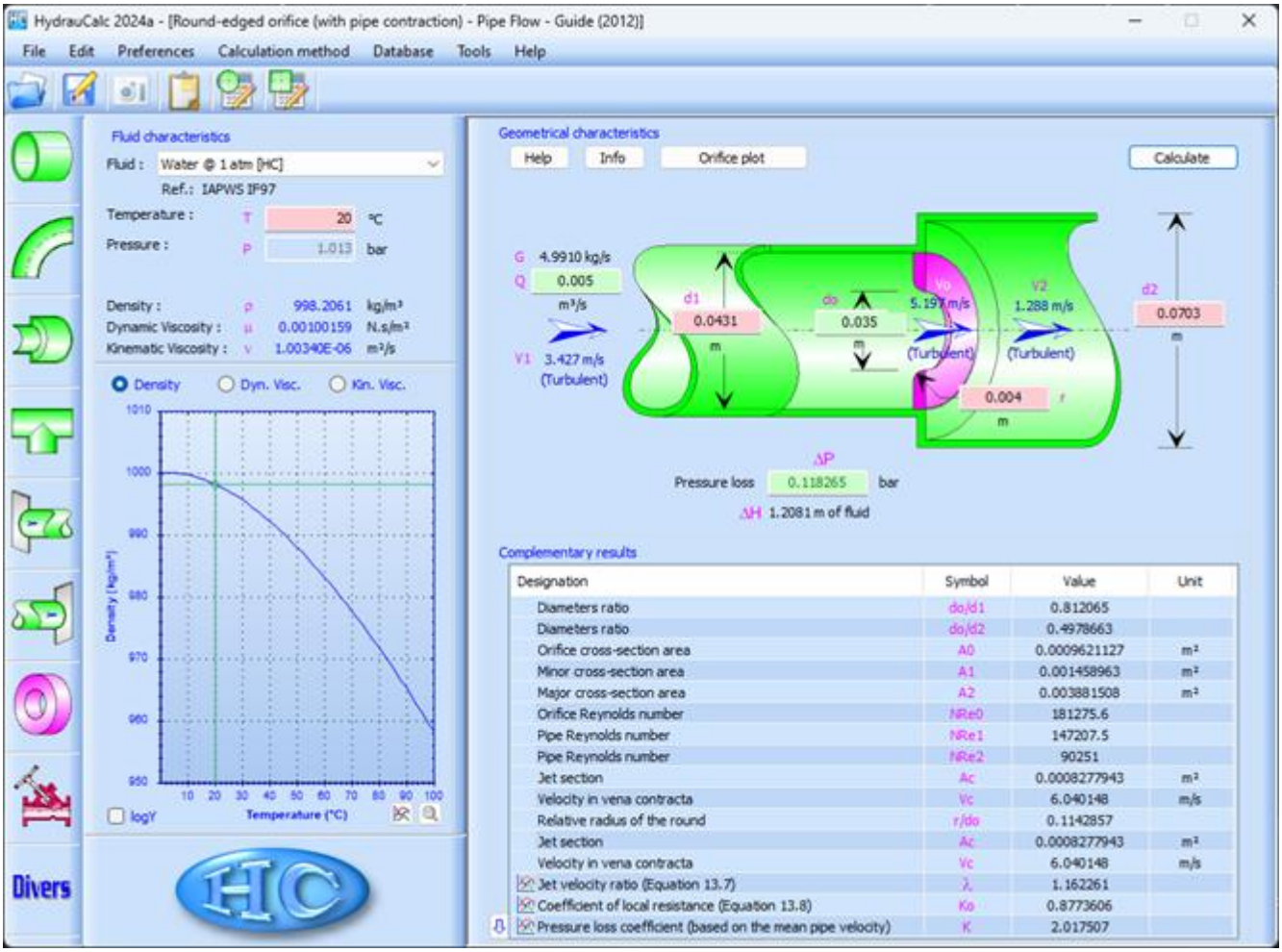
d_0	Orifice diameter (m)
d_1	Internal minor pipe diameter (m)
d_2	Internal major pipe diameter (m)
β	Ratio of orifice to minor pipe diameters ()

A_o	Orifice cross-sectional area (m^2)
A_1	Minor pipe cross-sectional area (m^2)
A_2	Major pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in orifice (m/s)
V_1	Mean velocity in minor pipe (m/s)
V_2	Mean velocity in major pipe (m/s)
NRe_o	Reynolds number in orifice ()
NRe_1	Reynolds number in minor pipe ()
NRe_2	Reynolds number in major pipe ()
r	Radius of the round (m)
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
K_o	Coefficient of local resistance ()
K	Total pressure loss coefficient (based on the minor pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in orifice ($NRe_o \geq 10^4$)
- stabilized flow upstream of the orifice
- round radius less than the radius difference ($r < (d_1/2-d_0/2)$)

Example of application:

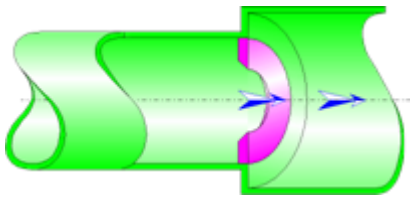


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.7.12 Bevel-edged orifice (with pipe expansion)

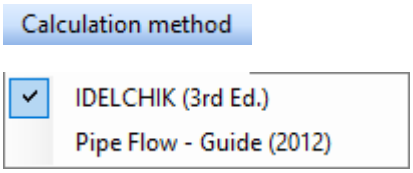
Circular Cross-Section



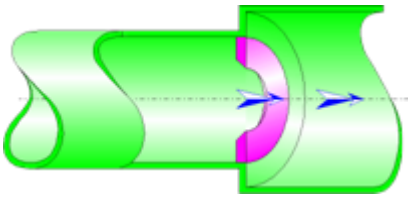
For the calculation of the pressure loss coefficient in bevel-edged orifices with pipe expansion downstream of the orifice, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.7.12.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a bevel-edged orifice with pipe expansion downstream of the orifice.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Minor pipe cross-section area (m^2):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Major pipe cross-section area (m^2):

$$F_2 = \pi \cdot \frac{D_2^2}{4}$$

Orifice cross-section area (m^2):

$$F_0 = \pi \cdot \frac{D_0^{\,2}}{4}$$

Mean velocity in minor pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in major pipe (m/s):

$$w_2 = \frac{Q}{F_2}$$

Mean velocity in orifice (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in minor pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in major pipe:

$$\mathrm{Re}_2 = \frac{w_2 \cdot D_2}{\nu}$$

Reynolds number in orifice:

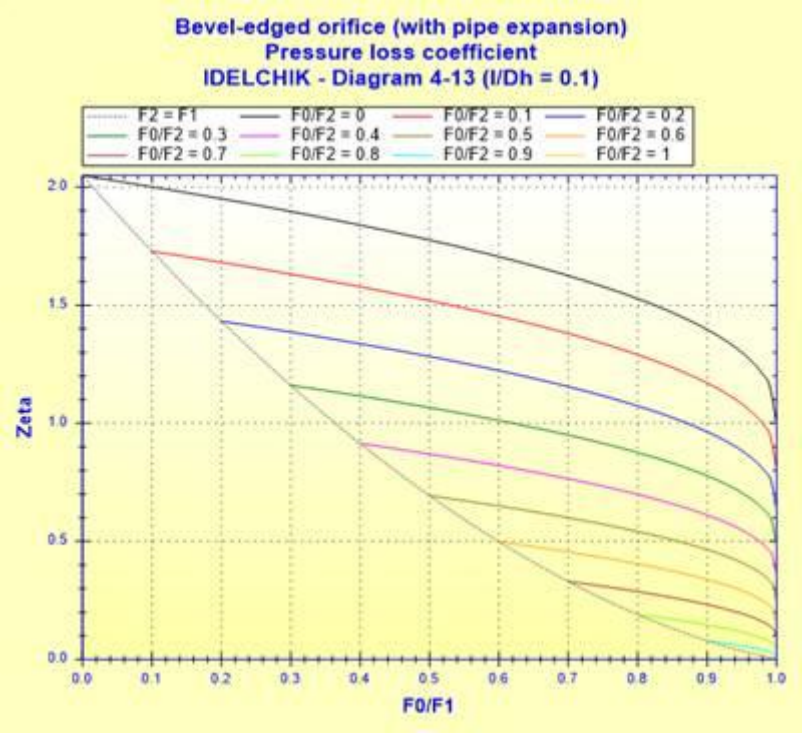
$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

■ $\mathrm{Re}_0 \geq 10^5$

Local resistance coefficient:

$$\zeta = \zeta' \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \left(1 - \frac{F_0}{F_2}\right)^2 + 2 \cdot \sqrt{\zeta'} \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375} \cdot \left(1 - \frac{F_0}{F_2}\right)$$

([2] diagram 4-13)



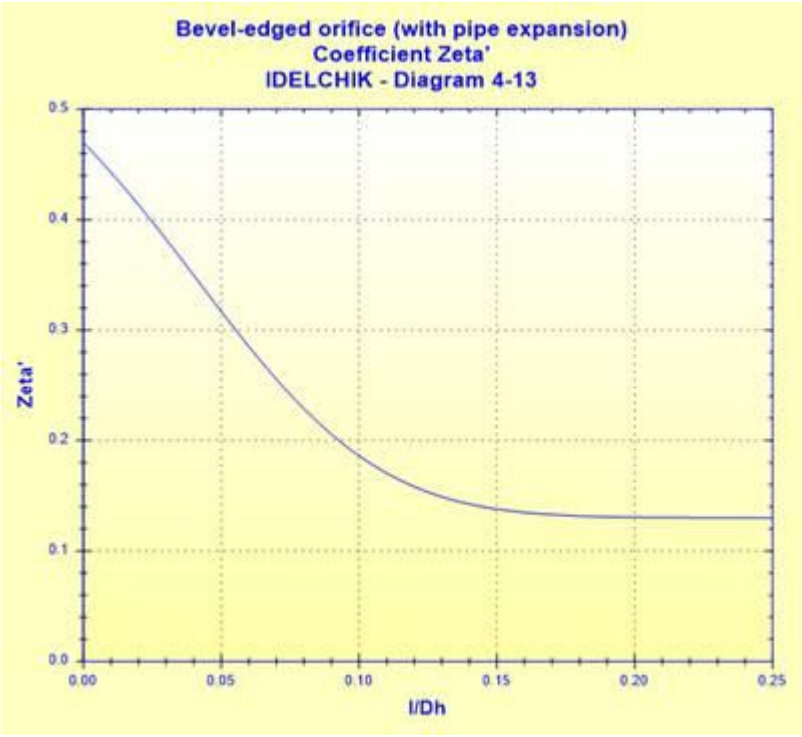
(with l/ D_h = 0.1)

with :

Coefficient of effect of the thickness:

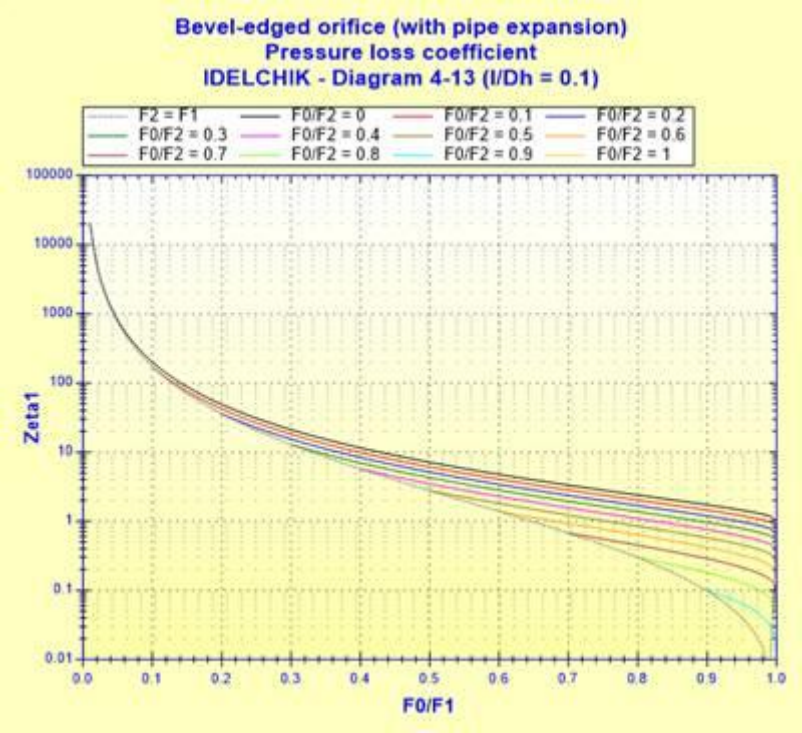
$$\zeta' = 0.13 + 0.34 \cdot 10^{-\left(3.4 \cdot \frac{l}{D_h} + 88.4 \cdot \left(\frac{l}{D_h}\right)^{2.3}\right)}$$

([2] diagram 4-13)



Pressure loss coefficient (based on the minor pipe velocity):

$$\zeta_1 = \zeta \cdot \left(\frac{F_1}{F_0}\right)^2$$



(with l/ D_h = 0.1)

■ $Re_0 < 10^5$

Quadratic local resistance coefficient:

$$\zeta_{quad} = \zeta' \cdot \left(1-\frac{F_0}{F_1}\right)^{0.75} + \left(1-\frac{F_0}{F_2}\right)^2 + 2 \cdot \sqrt{\zeta'} \cdot \left(1-\frac{F_0}{F_1}\right)^{0.375} \cdot \left(1-\frac{F_0}{F_2}\right)$$

([2] diagram 4-13)

with :

$$\zeta' = 0.13 + 0.34 \cdot 10^{-\left(3.4\frac{l}{D_h}+88.4\left(\frac{l}{D_h}\right)^{2.3}\right)}$$

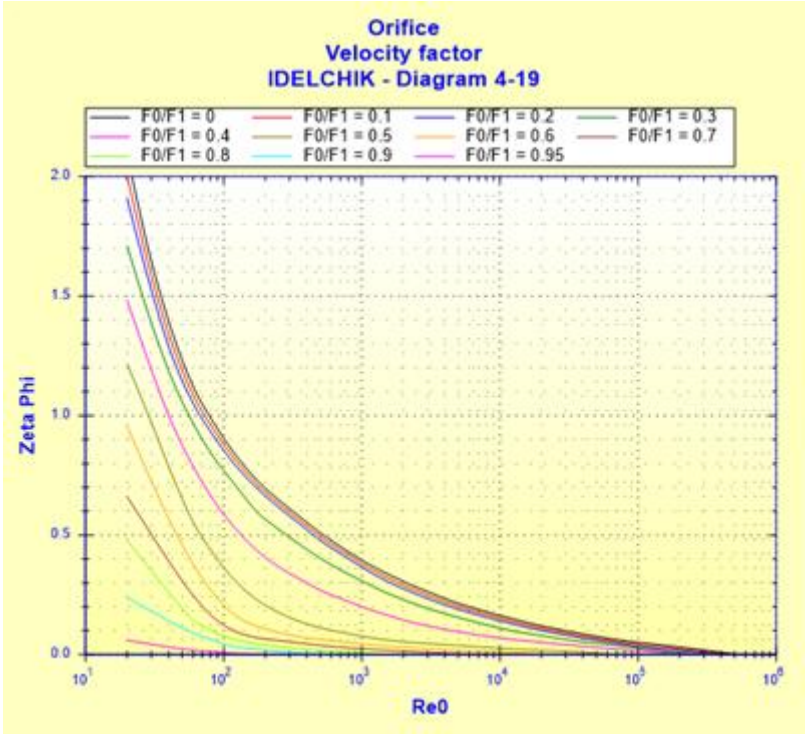
([1] diagram 4-13)

$$\zeta_{1quad} = \zeta_{quad} \cdot \left(\frac{F_1}{F_0}\right)^2$$

Velocity factor:

$$\zeta_\varphi = f\left(Re_0, \frac{F_0}{F_1}\right)$$

([1] diagram 4-19)



Contraction factor:

$\overline{\varepsilon}_{0\,Re} = f(Re_0)$ ([1] diagram 4-19)

Pressure loss coefficient (based on the minor pipe velocity):

- $30 < Re_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0\mathrm{Re}} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $10 < Re_0 \leq 30$

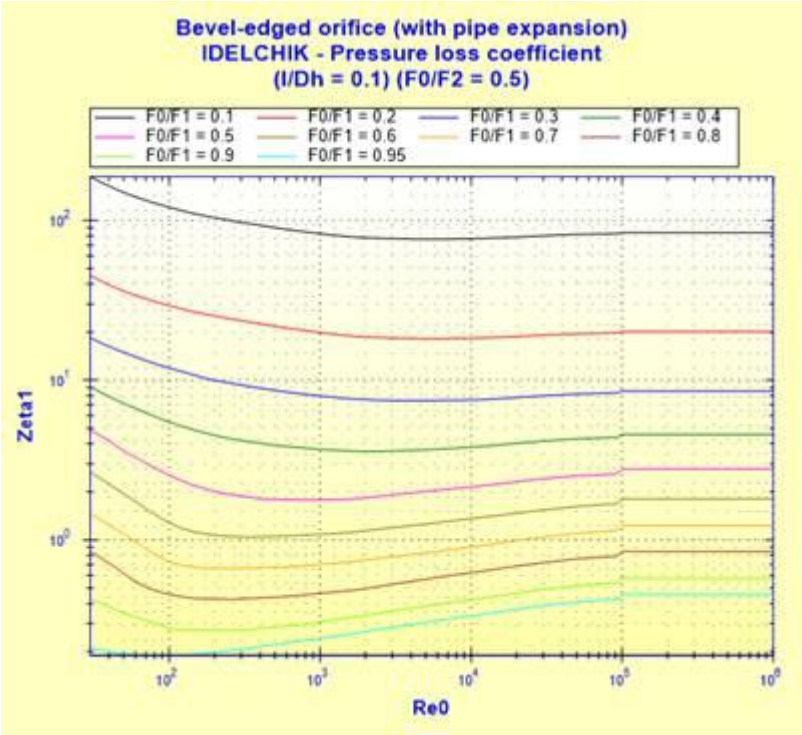
$$\zeta_1 = \frac{33}{\mathrm{Re}_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0\mathrm{Re}} \cdot \zeta_{1quad}$$

([1] diagram 4-19)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{\mathrm{Re}_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 4-19)



(with $l/D_h = 0.1$ and $F_0/F_2 = 0.5$)

Total pressure loss (Pa):

$$\Delta P = \zeta_1 \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta_1 \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_1	Minor pipe internal diameter (m)
D_2	Major pipe internal diameter (m)
D_0	Orifice diameter (m)
F_1	Minor pipe cross-sectional area (m^2)
F_2	Major pipe cross-sectional area (m^2)
F_0	Orifice cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w_1	Mean velocity in minor pipe (m/s)
w_2	Mean velocity in major pipe (m/s)
w_0	Mean velocity in orifice (m/s)
Re_1	Reynolds number in minor pipe ()
Re_2	Reynolds number in major pipe ()
Re_0	Reynolds number in orifice ()
l	Orifice thickness (m)
ζ'	Coefficient of effect of the thickness ()
ζ	Local resistance coefficient (based on the orifice velocity) ()
ζ_{quad}	Quadratic local resistance coefficient (based on the orifice velocity) ()
ζ_{1quad}	Quadratic local resistance coefficient (based on the minor pipe velocity) ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ_1	Pressure loss coefficient (based on the minor pipe velocity) ()
ΔP	Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

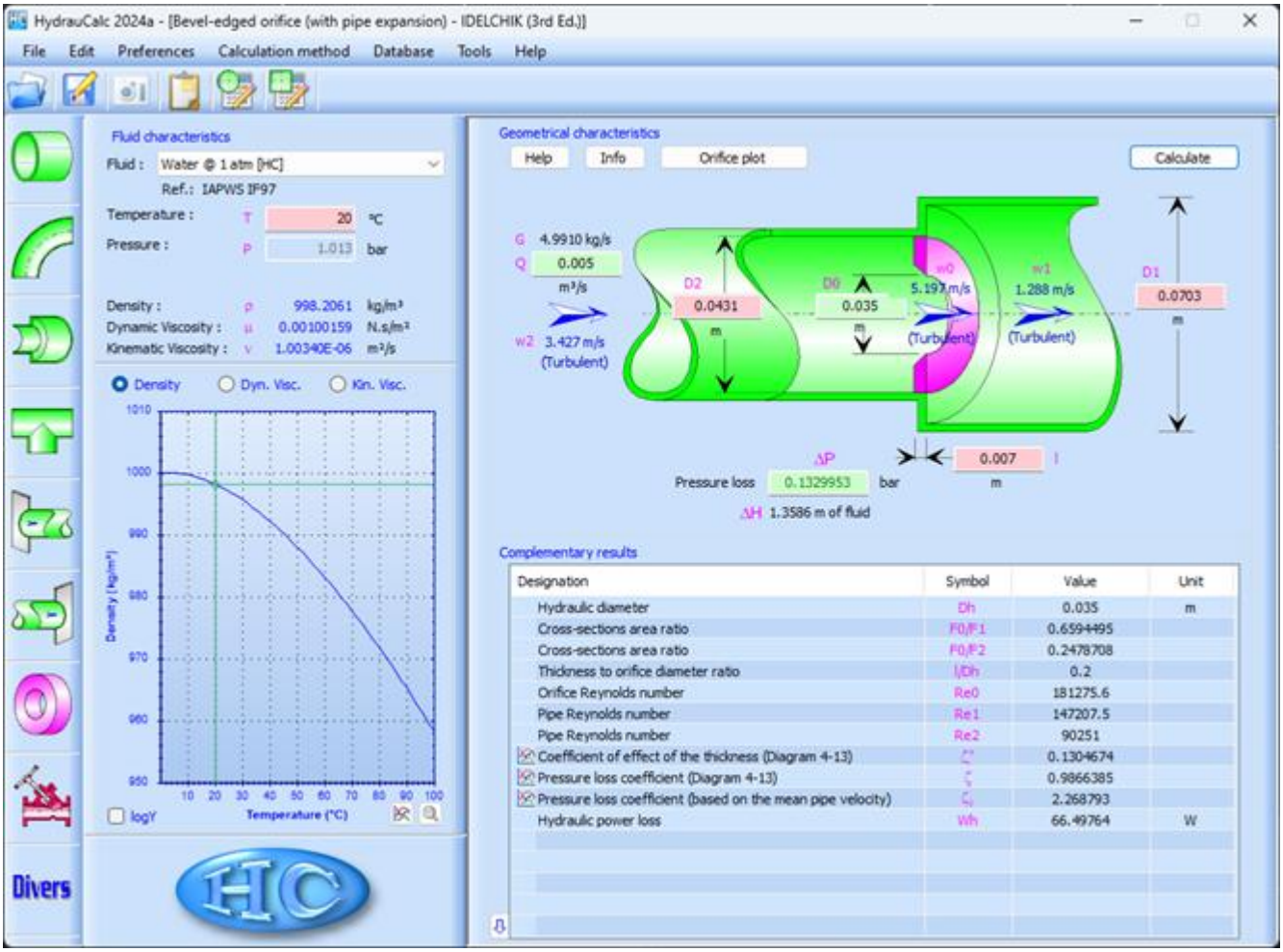
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice
- angle at the top of the truncated cone between 40 ° and 60 °

Example of application:



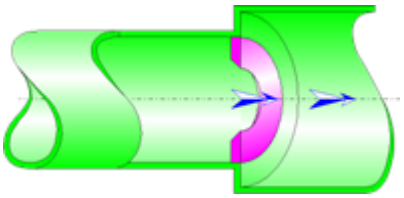
References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

[2] Идельчик.И.Е.Справочник по гидравлическим сопротивлениям.1992 (original document in Russian language)

Note: The formulation used for the calculation of the local resistance coefficients ζ and ζ_{quad} is that of the original reference document [2] which differs from that of the translated document [1]

2.7.12.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a bevel-edged orifice with pipe expansion downstream of the orifice.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of orifice to minor pipe diameters:

$$\beta = \frac{d_o}{d_1}$$

Minor pipe cross-sectional area (m²):

$$A_1 = \pi \cdot \frac{d_1^2}{4}$$

Major pipe cross-sectional area (m²):

$$A_2 = \pi \cdot \frac{d_2^2}{4}$$

Orifice cross-sectional area (m²):

$$A_o = \pi \cdot \frac{d_o^2}{4}$$

Minor pipe velocity (m/s):

$$V_1 = \frac{Q}{A_1}$$

Major pipe velocity (m/s):

$$V_2 = \frac{Q}{A_2}$$

Orifice velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in minor pipe:

$$N_{Re1} = \frac{V_1 \cdot d_1}{\nu}$$

Reynolds number in major pipe:

$$N_{Re2} = \frac{V_2 \cdot d_2}{\nu}$$

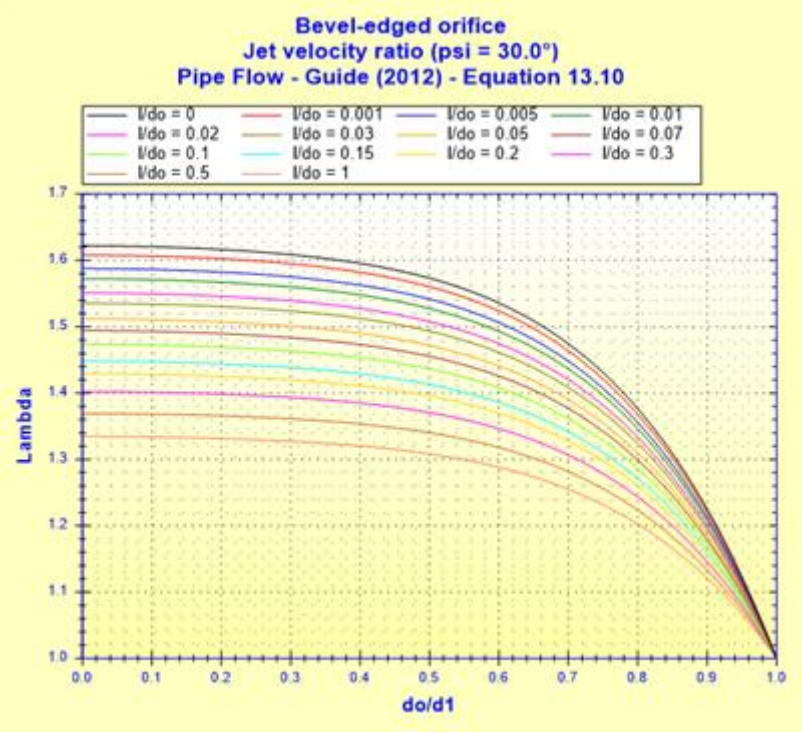
Reynolds number in orifice:

$$N_{Re_o} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left[1 - C_b \cdot \left(\frac{l}{d_0} \right)^{\frac{1-\sqrt{l/d_0}}{2}} \right] \cdot \left(1 - 0.215 \cdot \beta^2 - 0.785 \cdot \beta^5 \right)$$

([1] equation 13.10)



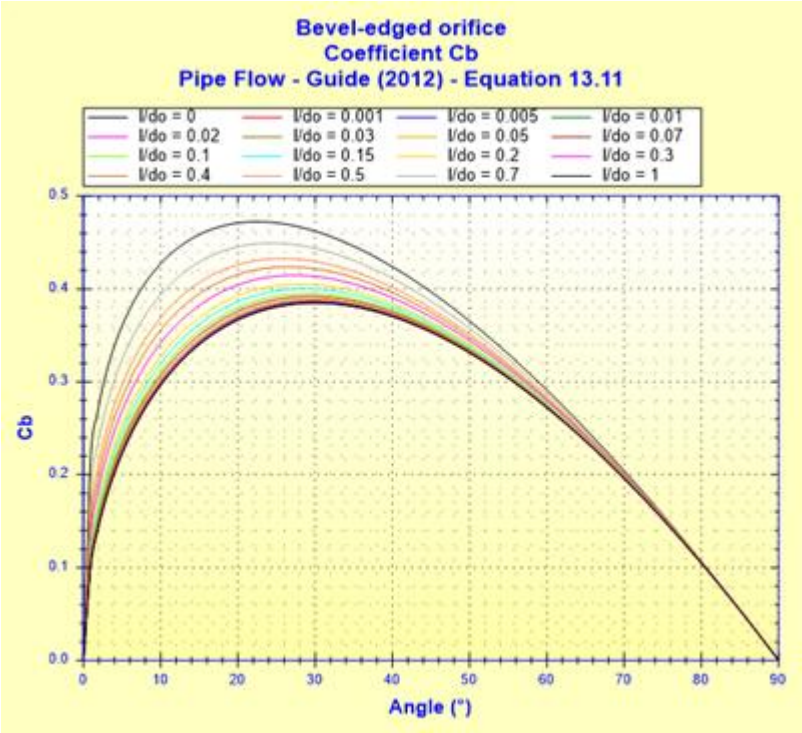
(with ψ = 30°)

with:

Coefficient of effect of the bevel angle:

$$C_b = \left(1 - \frac{\Psi}{90} \right) \cdot \left(\frac{\Psi}{90} \right)^{\frac{1}{2+l/d_0}}$$

([1] equation 13.11)



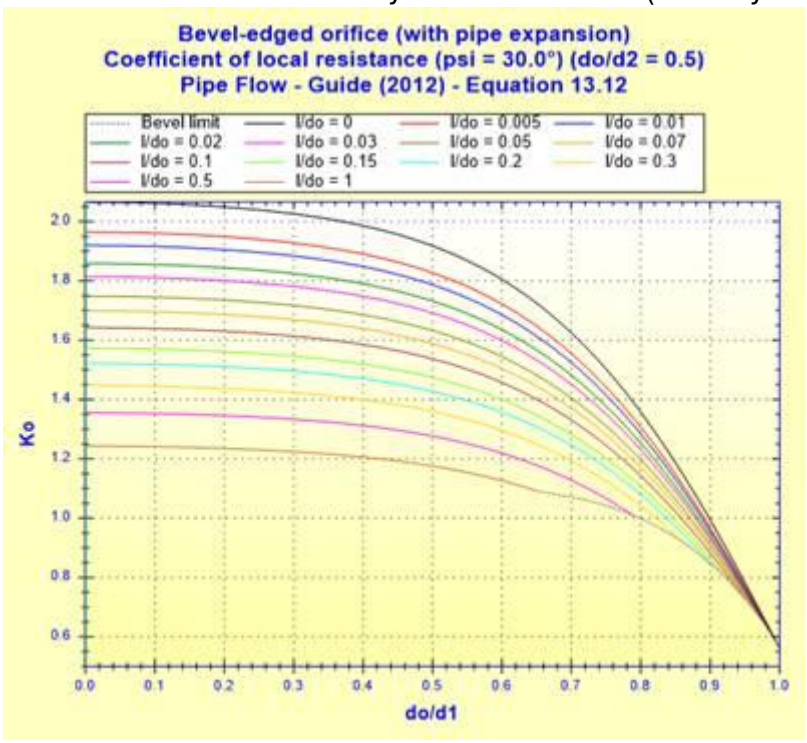
Velocity in vena contracta:

$$V_c = V_0 \cdot \lambda$$

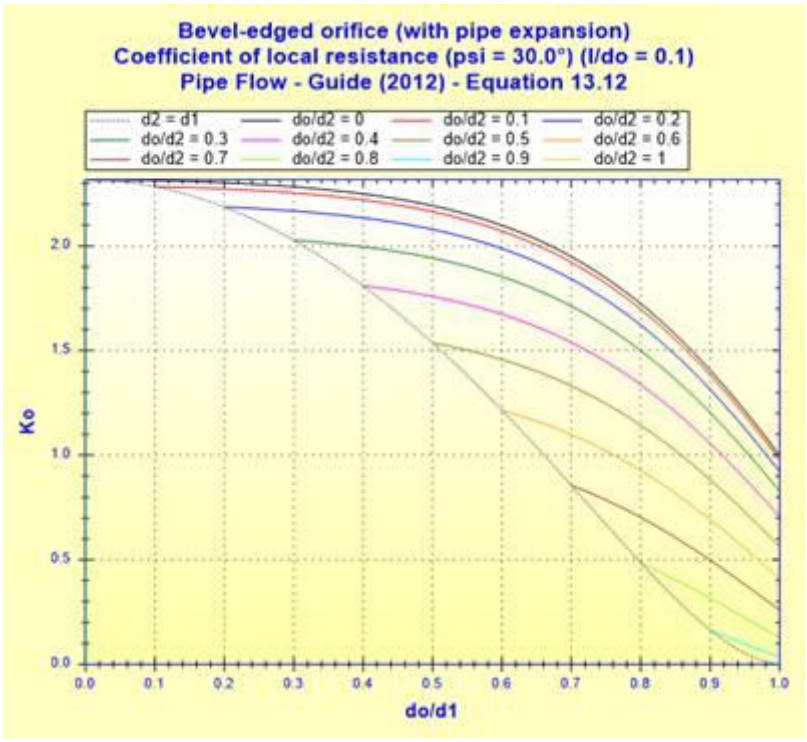
Coefficient of local resistance ($NRe_o \geq 10^4$):

$$K_o = 0.0696 \cdot \left(1 - C_b \cdot \frac{l}{d_0}\right) \cdot \left(1 - 0.42 \cdot \sqrt{\frac{l}{d_0}} \cdot \beta^2\right) \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + \left(\lambda - \left(\frac{d_0}{d_2}\right)^2\right)^2$$

([1] equation 13.12)



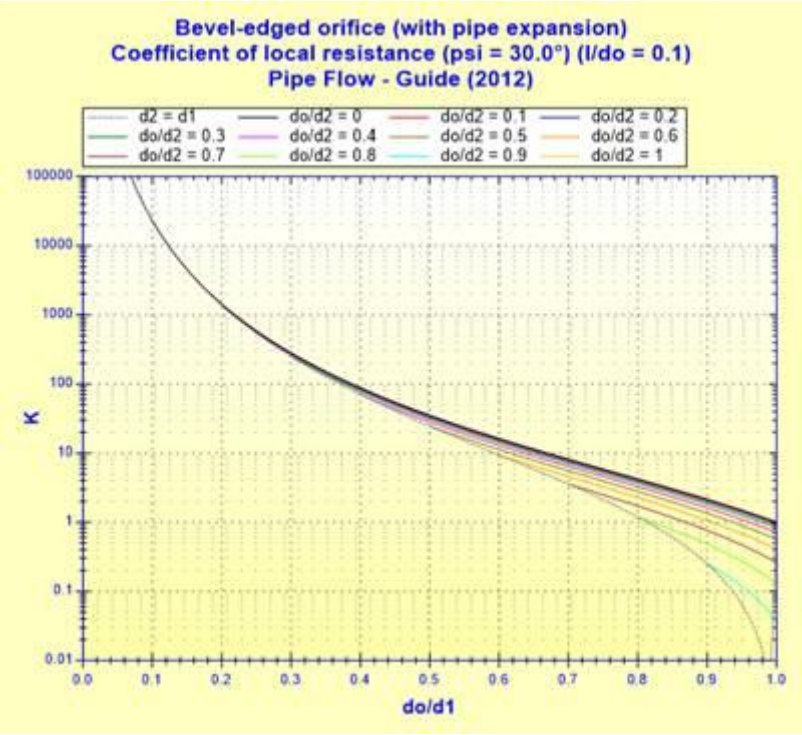
(with ψ = 30° and d_0/d_2 = 0.5)



(with ψ = 30° and l/d_0 = 0.1)

Total pressure loss coefficient (based on the minor pipe velocity):

$$K = K_o \cdot \left(\frac{A_1}{A_o} \right)^2$$



(with ψ = 30° and l/d_o = 0.1)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d_0	Orifice diameter (m)
d_1	Internal minor pipe diameter (m)
d_2	Internal major pipe diameter (m)
β	Ratio of orifice to minor pipe diameters ()
A_0	Orifice cross-sectional area (m^2)

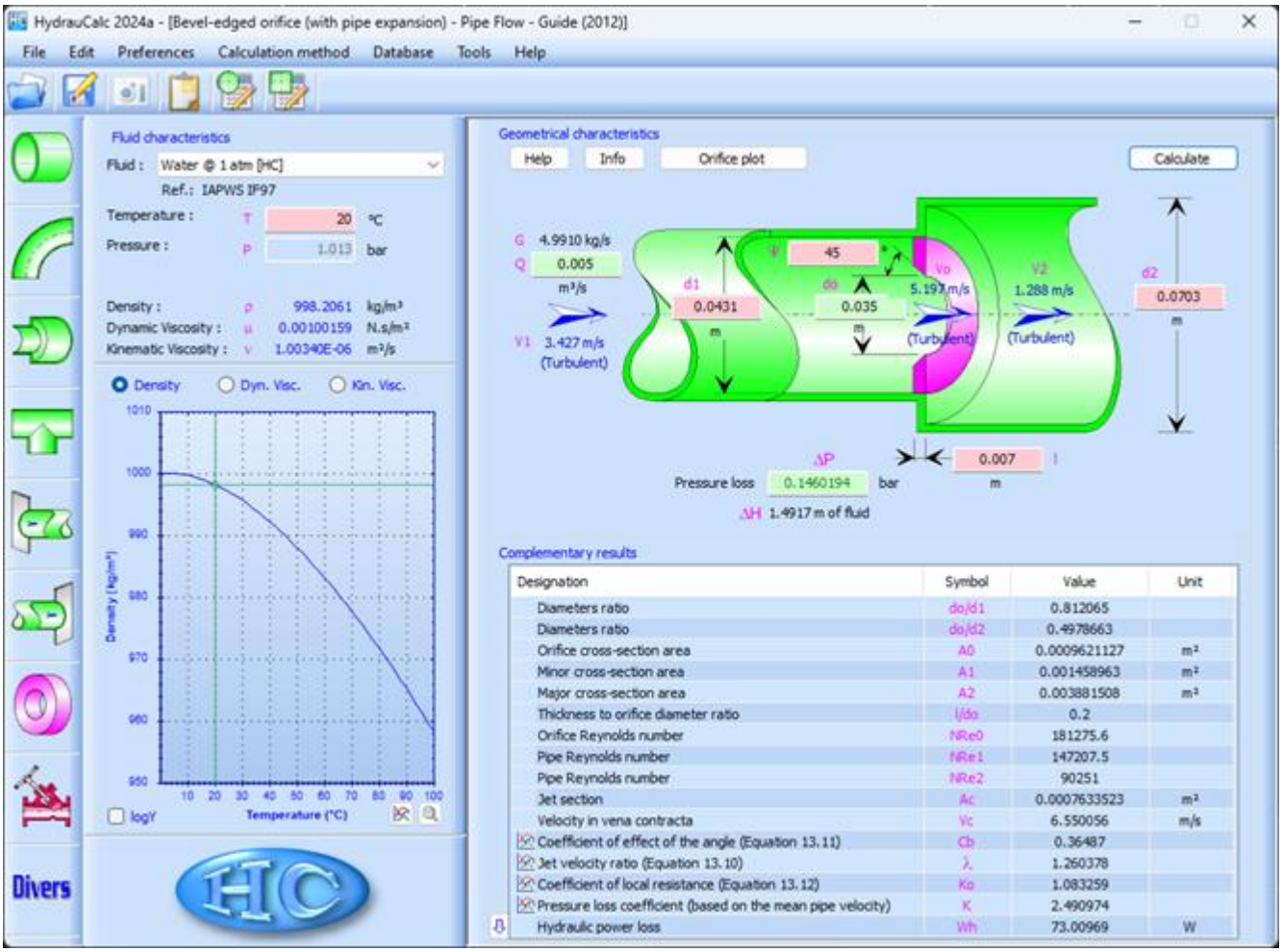
A_1	Minor pipe cross-sectional area (m^2)
A_2	Major pipe cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_0	Mean velocity in orifice (m/s)
V_1	Mean velocity in minor pipe (m/s)
V_2	Mean velocity in major pipe (m/s)
NRe_0	Reynolds number in orifice ()
NRe_1	Reynolds number in minor pipe ()
NRe_2	Reynolds number in major pipe ()
l	Orifice thickness (m)
ψ	Bevel angle (°)
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
C_b	Coefficient of effect of the bevel angle ()
K_0	Coefficient of local resistance ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in orifice ($NRe_o \geq 10^4$)

- stabilized flow upstream of the orifice
- bevel angle less than or equal to: $\psi \leq tg^{-1}((d_1 - d_o) / (2\ l))$

Example of application:



References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.8 Grids

This subsection regroups the set of grids that can be modeled and calculated. The types of grid available are:

- Thick-edged grid

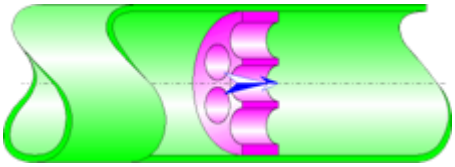
- Sharp-edged grid

- Round-edged grid

- Bevel-edged grid

2.8.1 Thick-edged grid

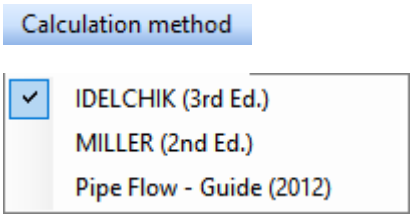
Circular Cross-Section



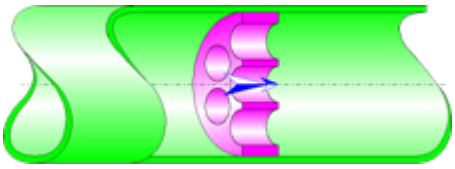
For the calculation of the pressure loss coefficient of thick-edged grid, the user can choose from one of the methods described in the following three reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.8.1.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a thick-edged grid (perforated plate) installed in a straight pipe. Moreover, the head loss due to friction of the fluid on the inner walls of the holes is also taken into account in this component and is calculated with Darcy's formula.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Pipe cross-section area (m²):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Cross-section area of one hole (m²):

$$f_0 = \pi \cdot \frac{D_0^2}{4}$$

Clear cross-sectional area of the grid (m²):

$$F_0 = f_0 \cdot N$$

Mean velocity in pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in holes (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in holes:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Relative roughness in holes walls:

$$\overline{\Delta} = \frac{\Delta}{D_0}$$

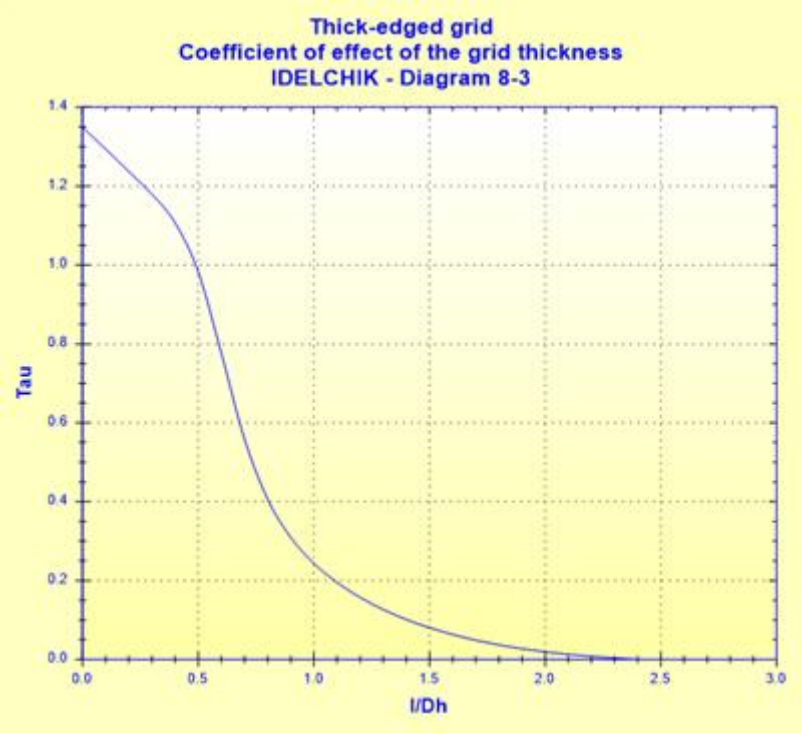
Coefficient of effect of the grid thickness:

$$\tau = \left(2.4 - \frac{l}{D_h}\right) \cdot 10^{-\varphi\left(\frac{l}{D_h}\right)}$$

([1] diagram 8-3)

with:

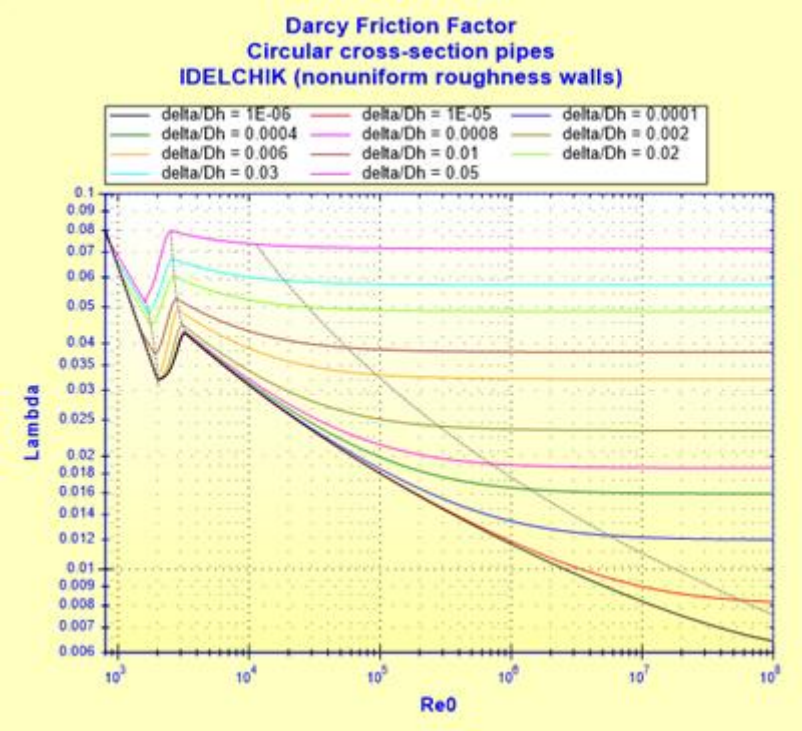
$$\varphi\left(\frac{l}{D_h}\right) = 0.25 + \frac{0.535 \cdot \left(\frac{l}{D_h}\right)^8}{0.05 + \left(\frac{l}{D_h}\right)^7}$$



Darcy friction factor:

$$\lambda = f\left(\mathrm{Re}_0, \frac{\Delta}{D_h}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)

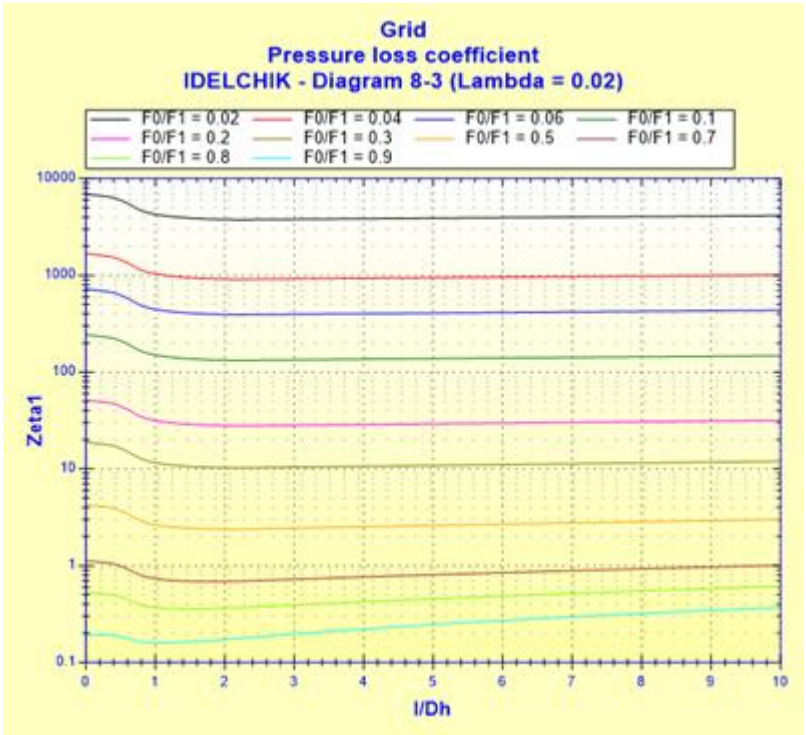


Coefficient of local resistance:

- $Re_0 \geq 10^5$

$$\zeta_1 = \frac{0.5 \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \tau \cdot \left(1 - \frac{F_0}{F_1}\right)^{1.375} + \left(1 - \frac{F_0}{F_1}\right)^2 + \lambda \cdot \frac{l}{D_h}}{\left(\frac{F_0}{F_1}\right)^2}$$

([1] diagram 8-3)



([1] diagram 8-3 with $\lambda = 0.02$)

■ $Re_0 < 10^5$

Quadratic coefficient of local resistance:

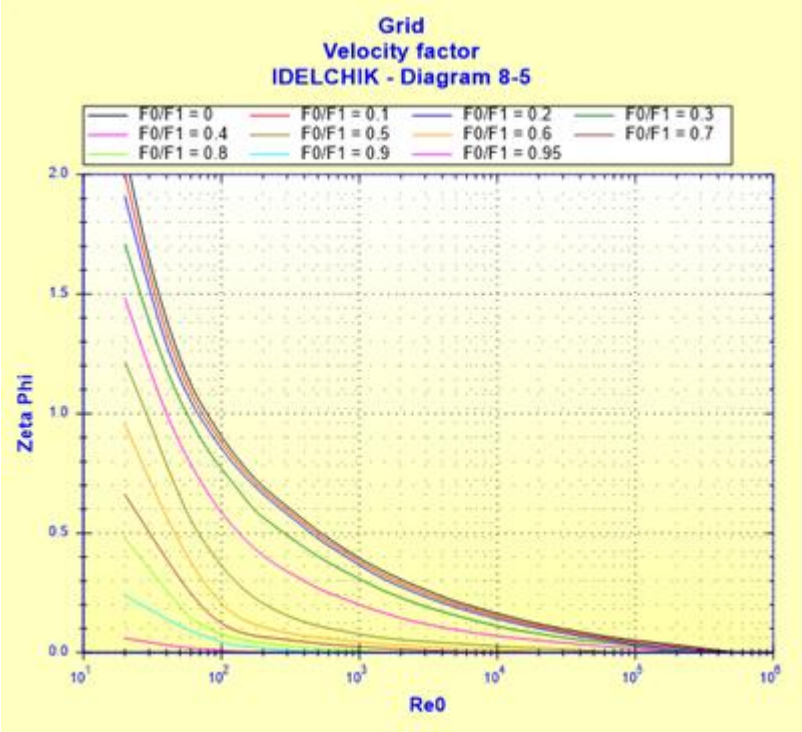
$$\zeta_{1quad} = \frac{0.5 \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \tau \cdot \left(1 - \frac{F_0}{F_1}\right)^{1.375} + \left(1 - \frac{F_0}{F_1}\right)^2 + \lambda \cdot \frac{l}{D_h}}{\left(\frac{F_0}{F_1}\right)^2}$$

([1] diagram 8-3)

Velocity factor:

$$\zeta_\varphi = f\left(Re_0, \frac{F_0}{F_1}\right)$$

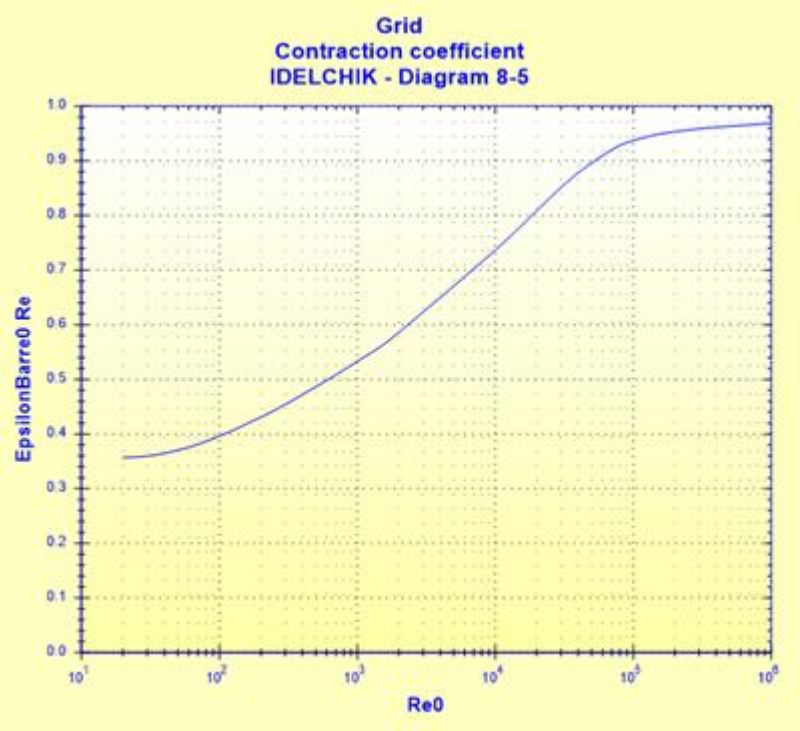
([1] diagram 8-5)



Contraction factor:

$$\bar{\varepsilon}_{0Re} = f(Re_0)$$

([1] diagram 8-5)



Coefficient of local resistance:

- $30 < Re_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 8-5)

- $10 < Re_0 \leq 30$

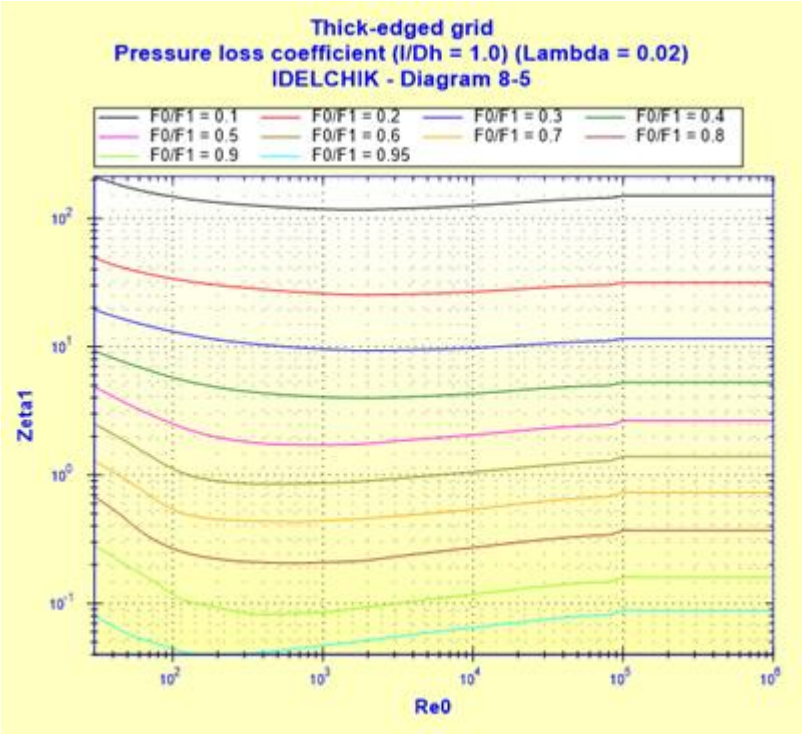
$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 8-5)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 8-5)



([1] diagram 8-5 with l/Dh = 1 and λ = 0.02)

Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \zeta_1$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_1	Pipe internal diameter (m)

F_1 Pipe cross-sectional area (m^2)

N Holes number ()

D_0 Holes diameter (m)

F_0 Clear cross-sectional area of the grid (m^2)

f_0 Cross-section area of one hole (m^2)

Q Volume flow rate (m^3/s)

w_1 Mean velocity in pipe (m/s)

w_0 Mean velocity in holes (m/s)

G Mass flow rate (kg/s)

Re_1 Reynolds number in pipe ()

Re_0 Reynolds number in holes ()

Δ Absolute roughness of holes walls (m)

$\bar{\Delta}$ Relative roughness of holes walls ()

l Grid thickness (m)

τ Coefficient of effect of the grid thickness ()

λ Darcy friction factor in holes ()

ζ_{1quad} Quadratic pressure loss coefficient determined as Re = 10^5 ()

ζ_φ Velocity factor ()

$\bar{\varepsilon}_{0Re}$ Contraction factor ()

ζ_1 Coefficient of local resistance ()

ζ Pressure loss coefficient (based on the mean pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m^3)

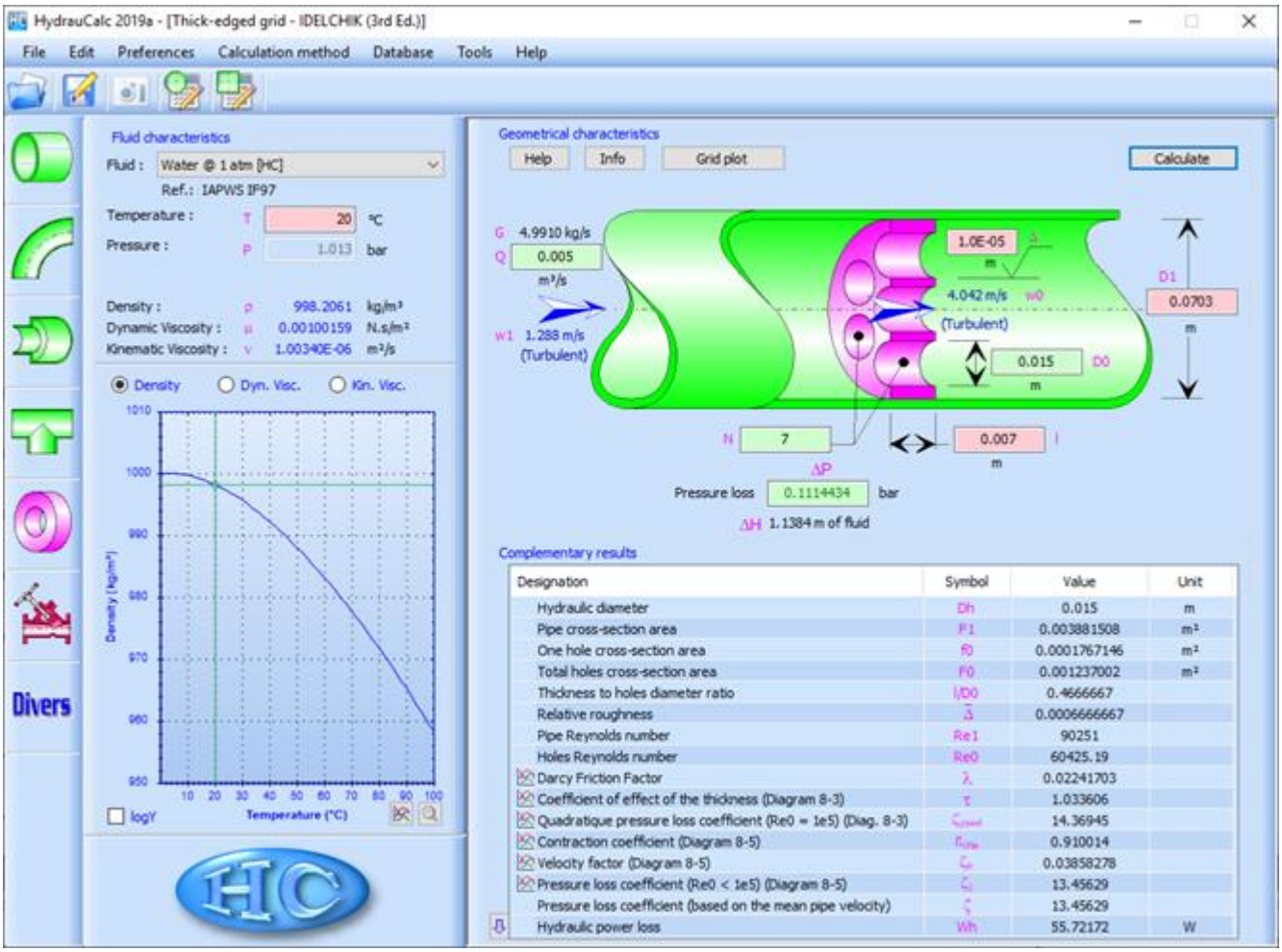
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the grid
- thickness to hole diameter ratio (l/D_0) greater than 0.015

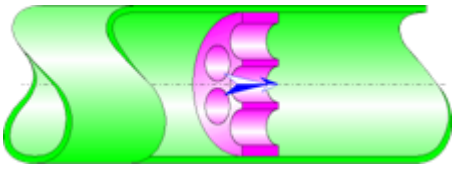
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.8.1.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a thick-edged grid (perforated plate) installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Pipe cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{D^2}{4}$$

Cross-section area of one hole (m^2):

$$a_2 = \pi \cdot \frac{d^2}{4}$$

Clear cross-sectional area of the grid (m^2):

$$A_2 = a_2 \cdot N$$

Equivalent section orifice diameter (m):

$$d' = \sqrt{\frac{4 \cdot A_2}{\pi}}$$ ([1] figure 5.72)

Equivalent section orifice thickness (m):

$$t' = t \cdot \frac{d'}{d}$$ ([1] figure 5.72)

Mean velocity in pipe (m/s):

$$U = \frac{Q}{A_1}$$

Mean velocity in holes (m/s):

$$u = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

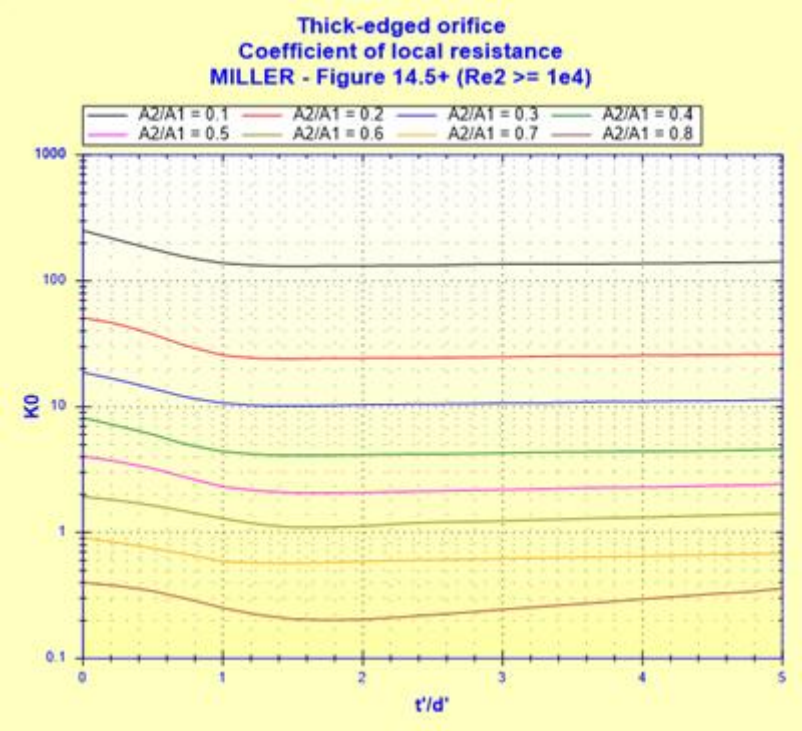
$$\mathrm{Re}_1 = \frac{U \cdot D}{\nu}$$

Reynolds number in holes:

$$\mathrm{Re}_2 = \frac{u \cdot d}{\nu}$$

Local resistance coefficient:

$$K_0 = f\left(\frac{t'}{d'}, \frac{A_2}{A_1}\right)$$ ([1] figure 14.5+)



Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_0$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

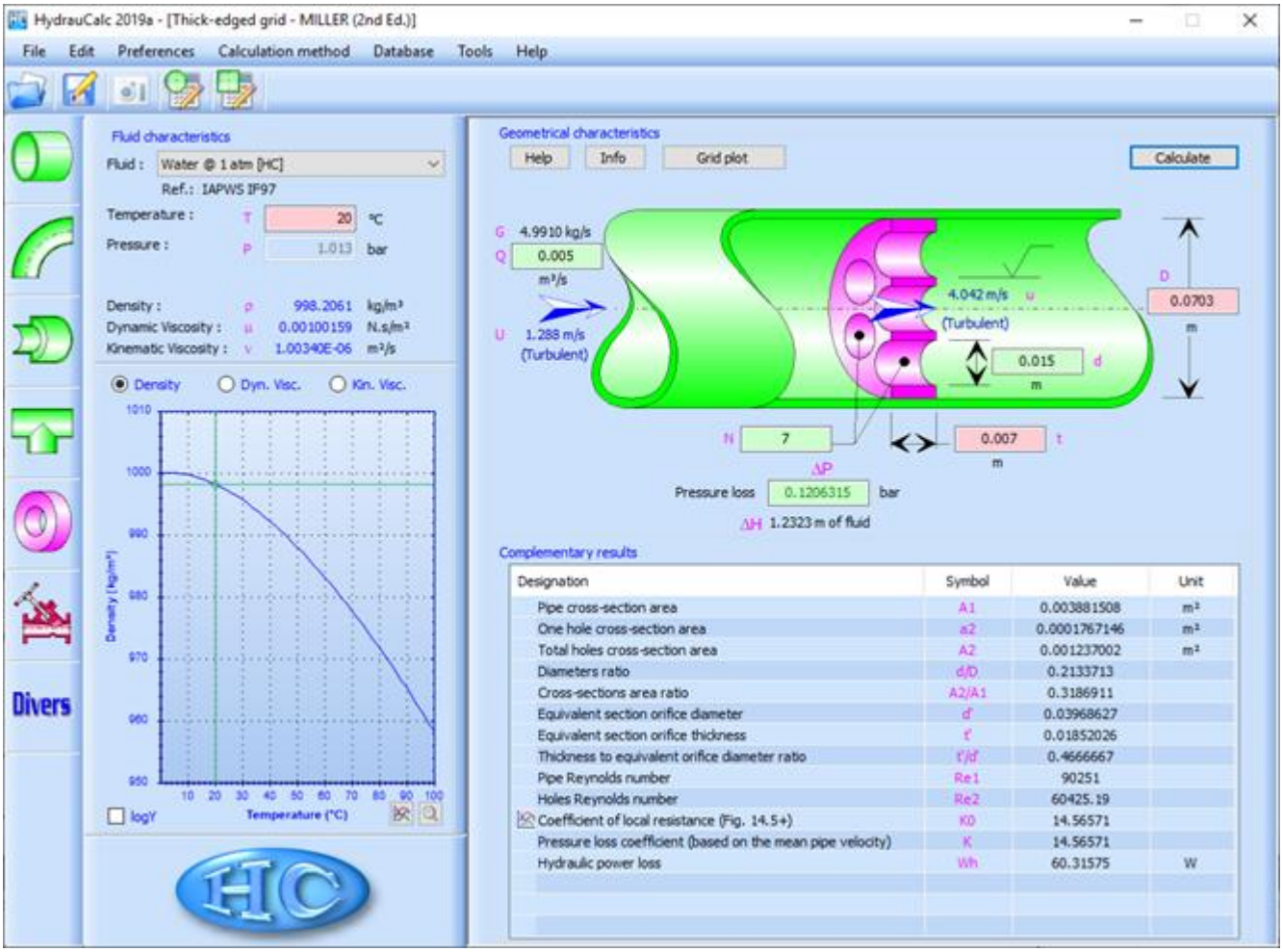
D	Pipe internal diameter (m)
A_1	Pipe cross-sectional area (m^2)

d	Hole diameter (m)
a_2	Cross-section area of one hole (m^2)
N	Holes number ()
A_2	Clear cross-sectional area of the grid (m^2)
d'	Equivalent section orifice diameter (m)
t	Grid thickness (m)
t'	Equivalent section orifice thickness (m)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity in pipe (m/s)
u	Mean velocity in holes (m/s)
Re_1	Reynolds number in pipe ()
Re_2	Reynolds number in holes ()
K_0	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in holes ($Re_2 \geq 10^4$)
- stabilized flow upstream of the grid

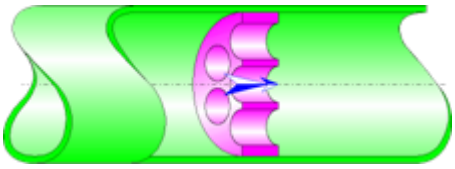
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.8.1.3 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a thick-edged grid (perforated plate) installed in a straight pipe. Moreover, when the thickness of the grid is greater than 1.4 times the diameter of the equivalent section orifice of the holes, the head loss due to friction in the holes is also taken into account because it becomes significant.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Pipe cross-sectional area (m²):

$$A = \pi \cdot \frac{d^2}{4}$$

Cross-sectional area of one hole (m²):

$$a_o = \pi \cdot \frac{d_o^2}{4}$$

Clear cross-sectional area of the grid (m²):

$$A_0 = a_0 \cdot N$$

Porosity:

$$\phi = \frac{A_0}{A}$$

Equivalent section orifice diameter (m):

$$d_e = \sqrt{\frac{4 \cdot A_0}{\pi}}$$

Ratio between the diameters of the equivalent section orifice and the pipe:

$$\beta = \frac{d_e}{d}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Holes velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

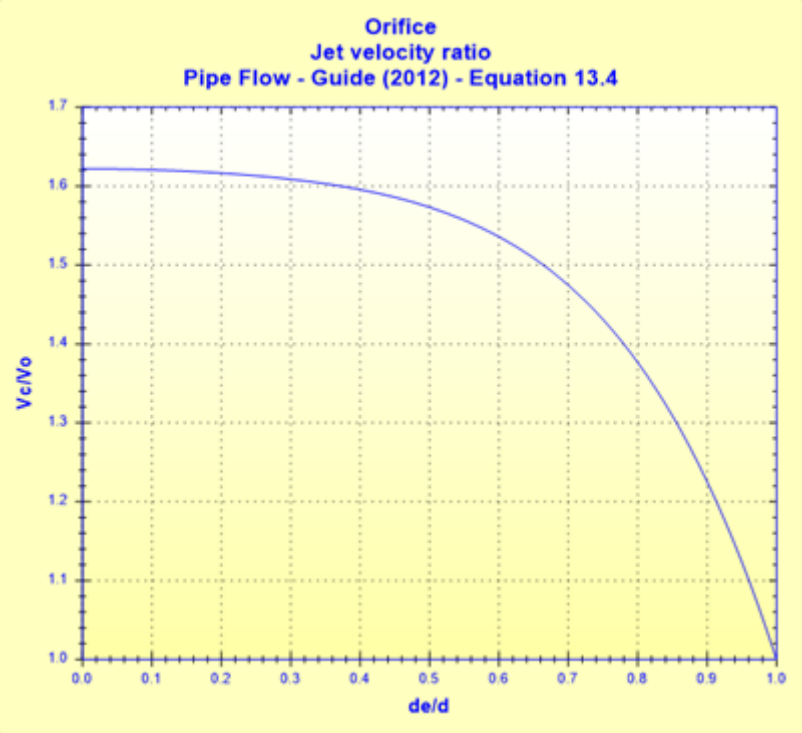
$$N_{Re} = \frac{V \cdot d}{\nu}$$

Reynolds number in holes:

$$N_{Re_O} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left(1 - 0.215\beta^2 - 0.785\beta^5\right)$$ ([1] equation 13.4)



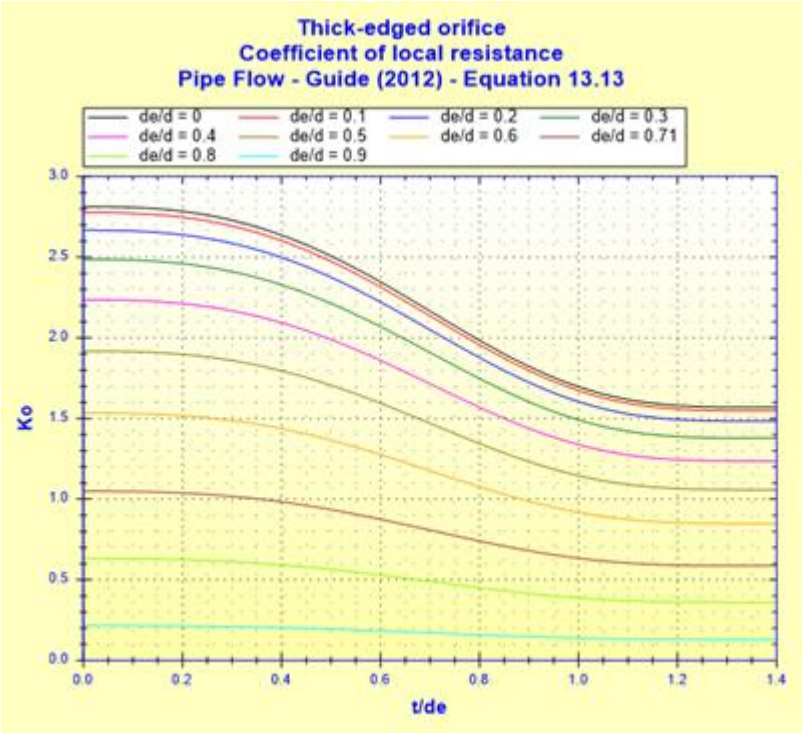
Velocity in vena contracta:

$$V_c = V_0 \cdot \lambda$$

Coefficient of local resistance:

- Thickness to equivalent diameter ratio (t/d_e) ≤ 1.4:

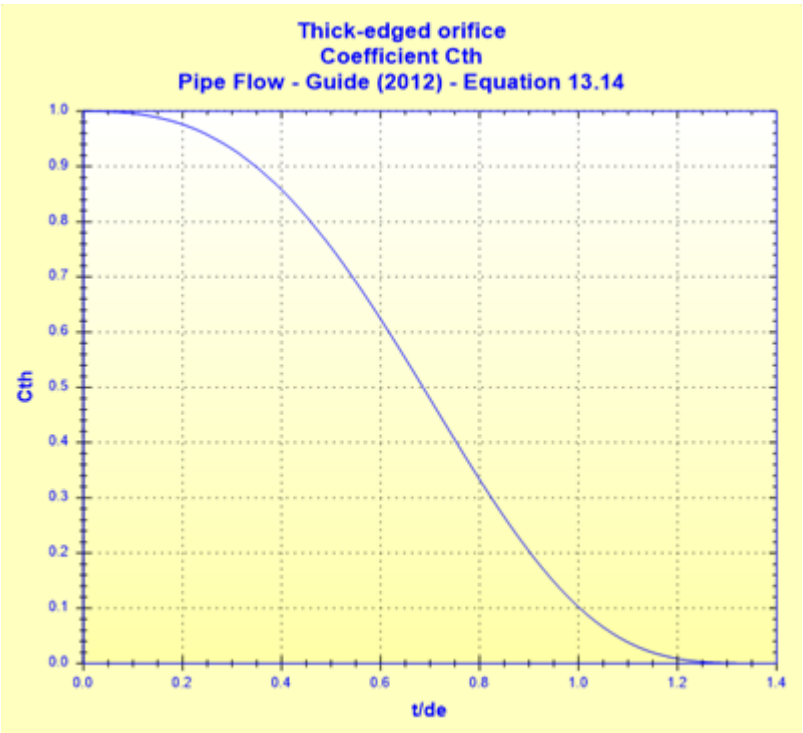
$$K_o = 0.0696 \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + C_{th} \cdot \left(\lambda - \beta^2\right)^2 + \left(1 - C_{th}\right) \cdot \left[(\lambda - 1)^2 + \left(1 - \beta^2\right)^2\right]$$ ([1] equation 13.13)



with:

$$C_{th} = \left[1 - 0.50 \cdot \left(\frac{t}{1.4 d_e}\right)^{2.5} - 0.50 \cdot \left(\frac{t}{1.4 d_e}\right)^{3}\right]^{4.5}$$

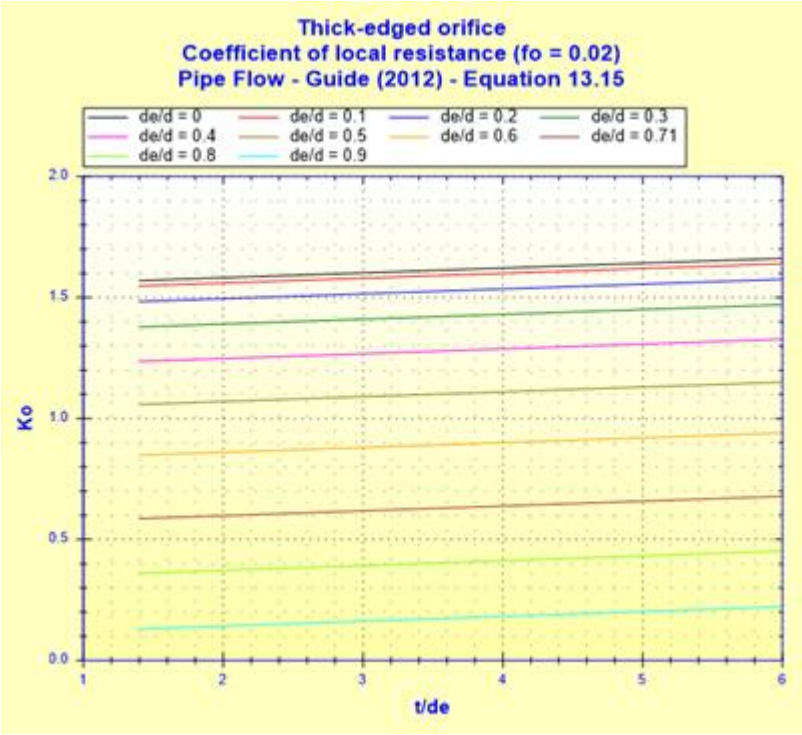
([1] equation 13.14)



■ Thickness to equivalent diameter ratio (t/d_e) > 1.4:

$$K_o = 0.0696 \cdot \left(1-\beta^5\right) \cdot \lambda^2 + \left(\lambda - 1\right)^2 + \left(1-\beta^2\right)^2 + f_o \cdot \left(\frac{t}{d_e} - 1.4\right)$$

([1] equation 13.15)

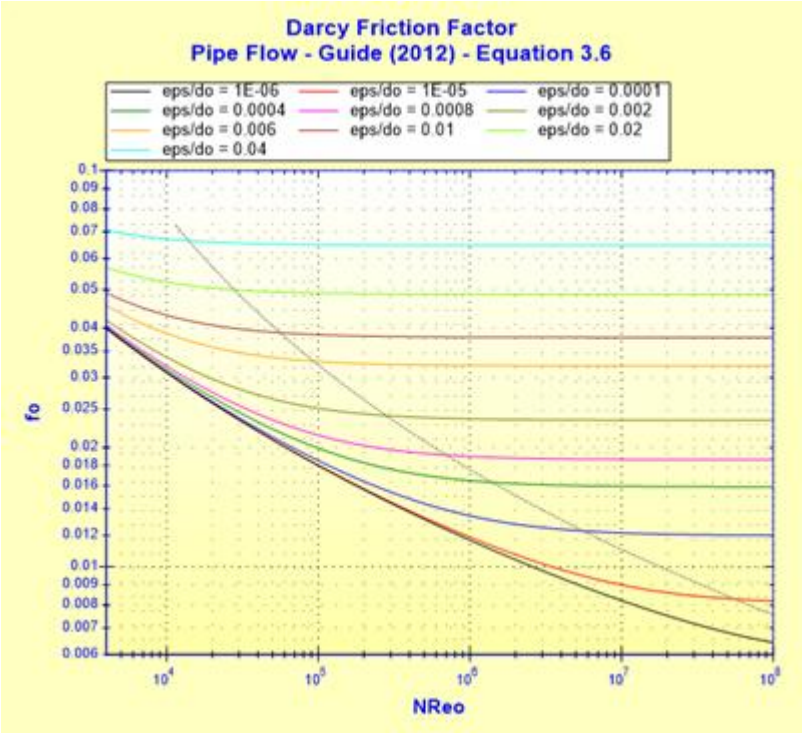


([1] equation 13.15 with fo = 0.02)

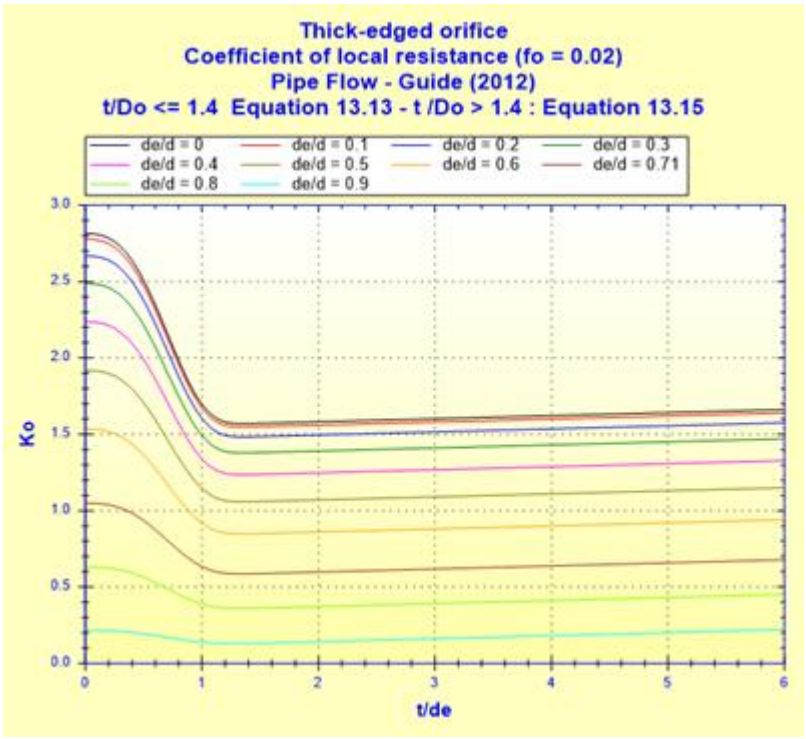
with:

$$f_o = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d_o} + \frac{2.51}{N\mathrm{Re}_0 \cdot \sqrt{f_o}}\right)\right]^2}$$

Colebrook-White equation ([1] equation 3.6)



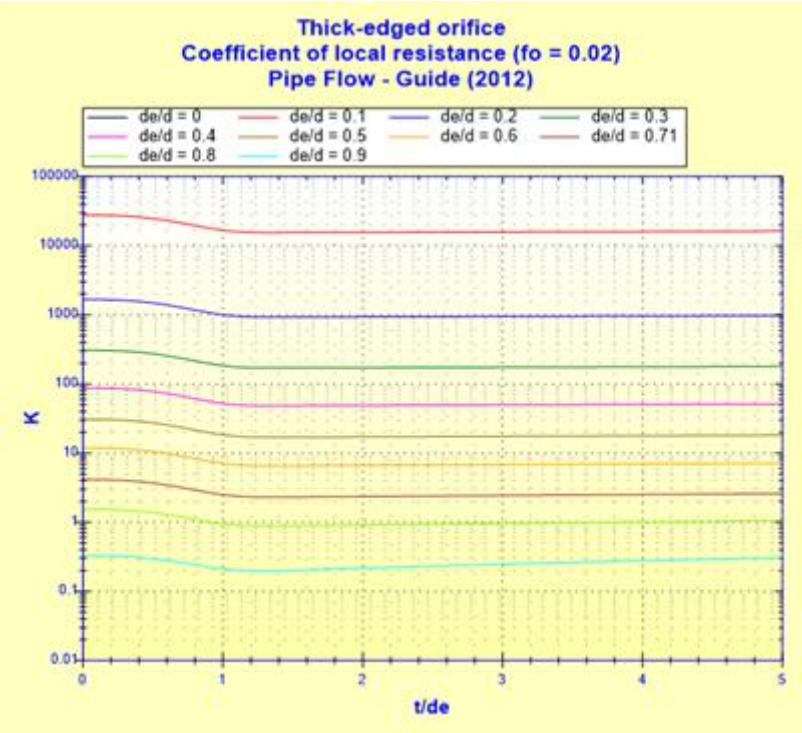
- All thickness to equivalent diameter ratios (t/d_e):



([1] equations 13.13 and 13.15 with fo = 0.02)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_o} \right)^2$$



(with fo = 0.02)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

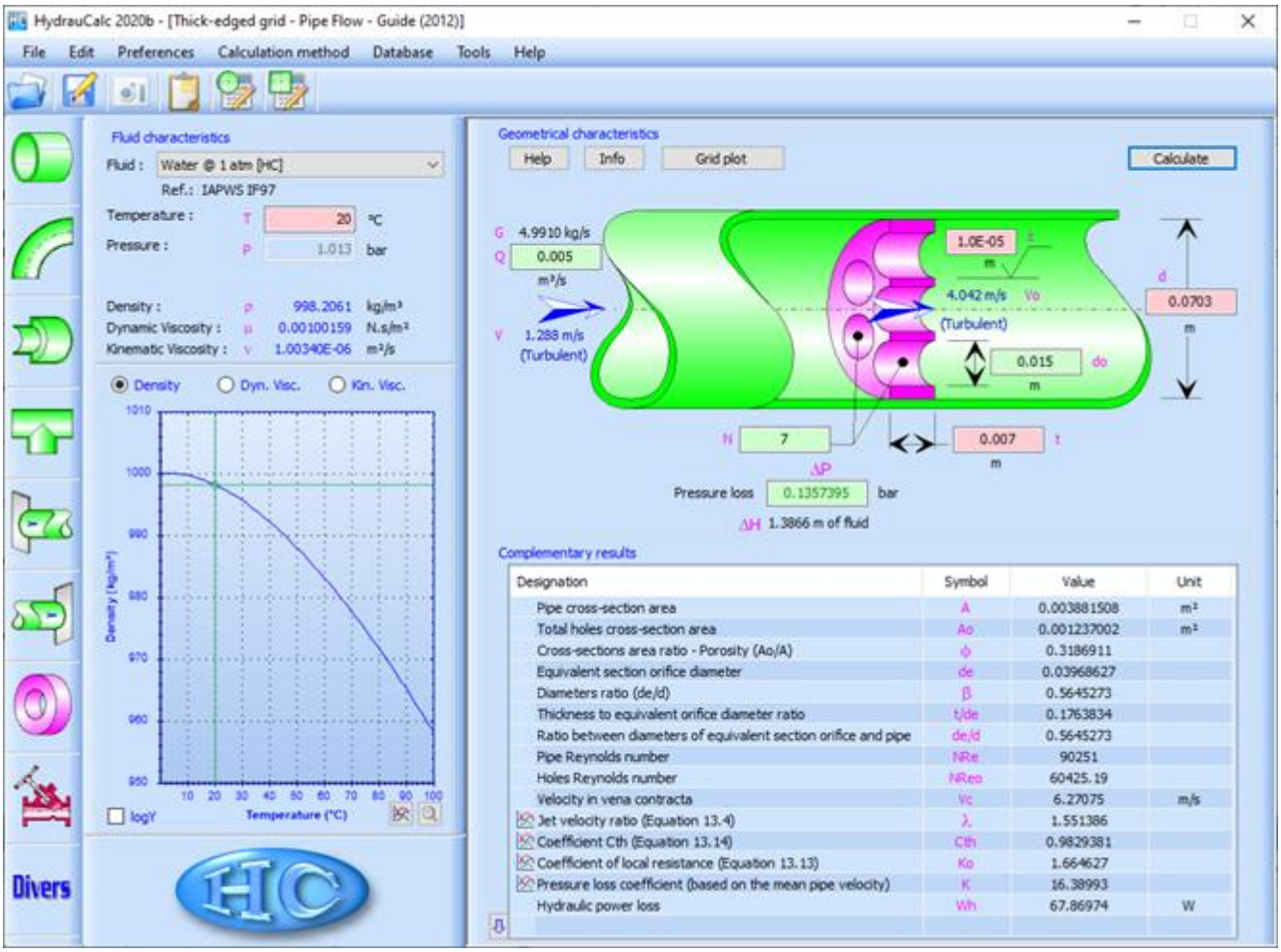
d	Internal pipe diameter (m)
A	Pipe cross-sectional area (m^2)
d_0	Holes diameter (m)

a_o	Cross-sectional area of one hole (m^2)
N	Holes number ()
A_0	Clear cross-sectional area of the grid (m^2)
ϕ	Porosity ()
d_e	Equivalent section orifice diameter (m)
β	Ratio between the diameters of the equivalent section orifice and the pipe ()
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in holes (m/s)
V	Mean velocity in pipe (m/s)
NRe_o	Reynolds number in holes ()
NRe	Reynolds number in pipe ()
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
t	Thickness grid (m)
K_o	Coefficient of local resistance ()
Cth	Coefficient ()
f_o	Darcy Friction factor ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in holes ($NRe_o \geq 10^4$)
- stabilized flow upstream of the grid

Example of application:

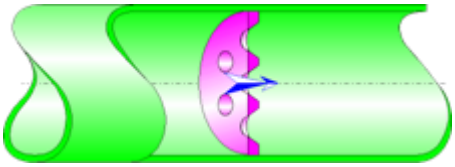


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.8.2 Sharp-edged grid

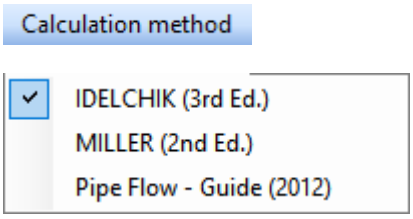
Circular Cross-Section



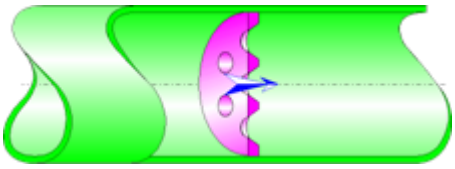
For the calculation of the pressure loss coefficient of sharp-edged grid, the user can choose from one of the methods described in the following three reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.8.2.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sharp-edged grid (perforated plate) installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Pipe cross-section area (m²):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Cross-section area of one hole (m²):

$$f_0 = \pi \cdot \frac{D_0^2}{4}$$

Clear cross-sectional area of the grid (m²):

$$F_0 = f_0 \cdot N$$

Mean velocity in pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in holes (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in holes:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Coefficient of local resistance:

- $\mathrm{Re}_0 \geq 10^5$

$$\zeta_1 = \left[0.707 \cdot \left(1 - \frac{F_0}{F_1} \right)^{0.375} + \left(1 - \frac{F_0}{F_1} \right) \right]^2 \cdot \left(\frac{F_1}{F_0} \right)^2$$

([1] diagram 8-1)

■ $Re_0 < 10^5$

Quadratic coefficient of local resistance:

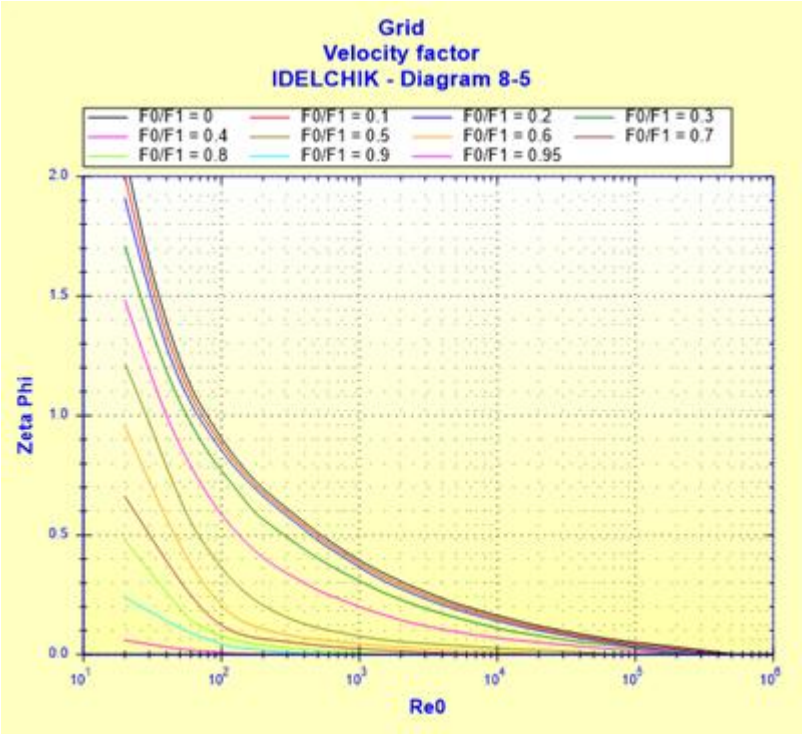
$$\zeta_{1quad} = \left[0.707 \cdot \left(1 - \frac{F_0}{F_1} \right)^{0.375} + \left(1 - \frac{F_0}{F_1} \right) \right]^2 \cdot \left(\frac{F_1}{F_0} \right)^2$$

([1] diagram 8-1)

Velocity factor:

$$\zeta_\varphi = f\left(Re_0, \frac{F_0}{F_1} \right)$$

([1] diagram 8-5)



Contraction factor:

$\bar{\varepsilon}_{0\,\mathrm{Re}} = f(\mathrm{Re}_0)$ ([1] diagram 8-5)

Coefficient of local resistance:

- $30 < \mathrm{Re}_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 8-5)

- $10 < Re_0 \leq 30$

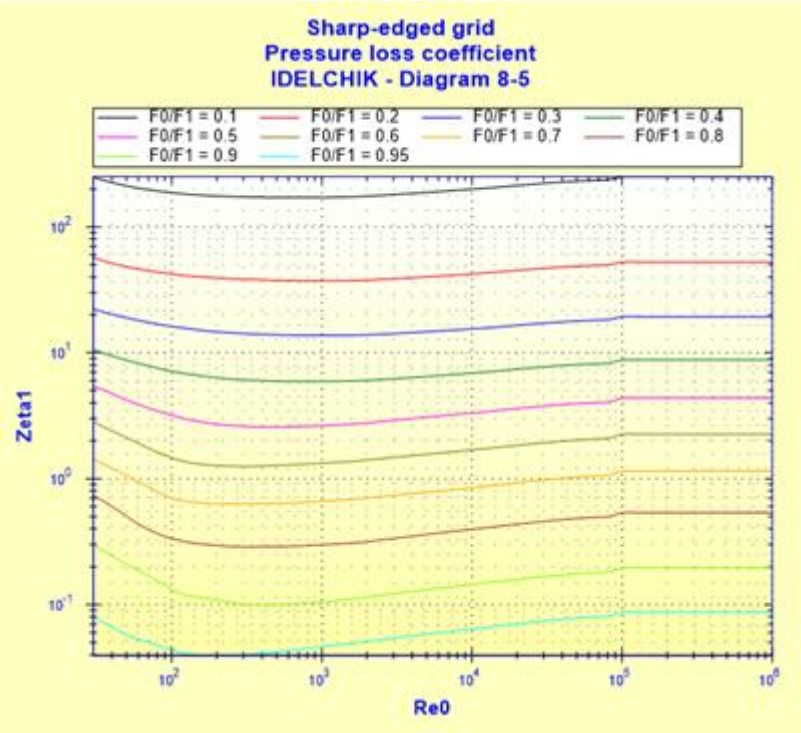
$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 8-5)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 8-5)



Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \zeta_1$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{w_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_1	Pipe internal diameter (m)
F_1	Pipe cross-sectional area (m^2)
N	Holes number ()
D_0	Holes diameter (m)
F_0	Clear cross-sectional area of the grid (m^2)
f_0	Cross-section area of one hole (m^2)
Q	Volume flow rate (m^3/s)
w_1	Mean velocity in pipe (m/s)
w_0	Mean velocity in holes (m/s)
G	Mass flow rate (kg/s)
Re_1	Reynolds number in pipe ()
Re_0	Reynolds number in holes ()
l	Grid thickness (m)
ζ_{1quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ_1	Coefficient of local resistance ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

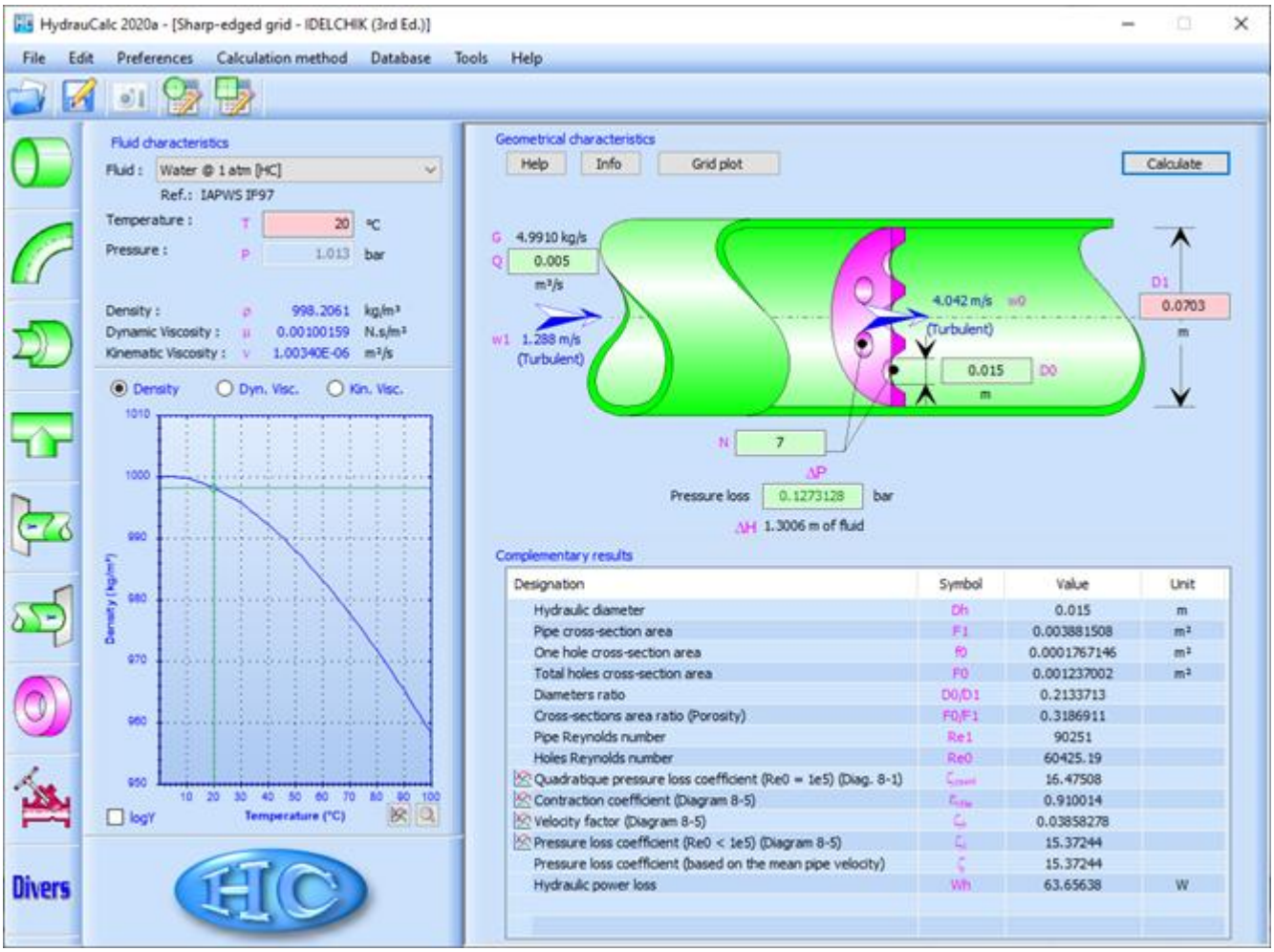
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the grid
- thickness to orifice diameter ratio (l/D_0) lower than or equal to 0.015

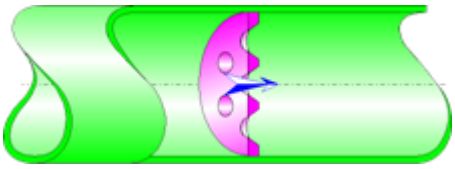
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.8.2.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sharp-edged grid (perforated plate) installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Pipe cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{D^2}{4}$$

Cross-section area of one hole (m^2):

$$a_2 = \pi \cdot \frac{d^2}{4}$$

Clear cross-sectional area of the grid (m^2):

$$A_2 = a_2 \cdot N$$

Equivalent section orifice diameter (m):

$$d_e = \sqrt{\frac{4 \cdot A_2}{\pi}}$$

Mean velocity in pipe (m/s):

$$U = \frac{Q}{A_1}$$

Mean velocity in holes (m/s):

$$u = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_1 = \frac{U \cdot D}{\nu}$$

Reynolds number in holes:

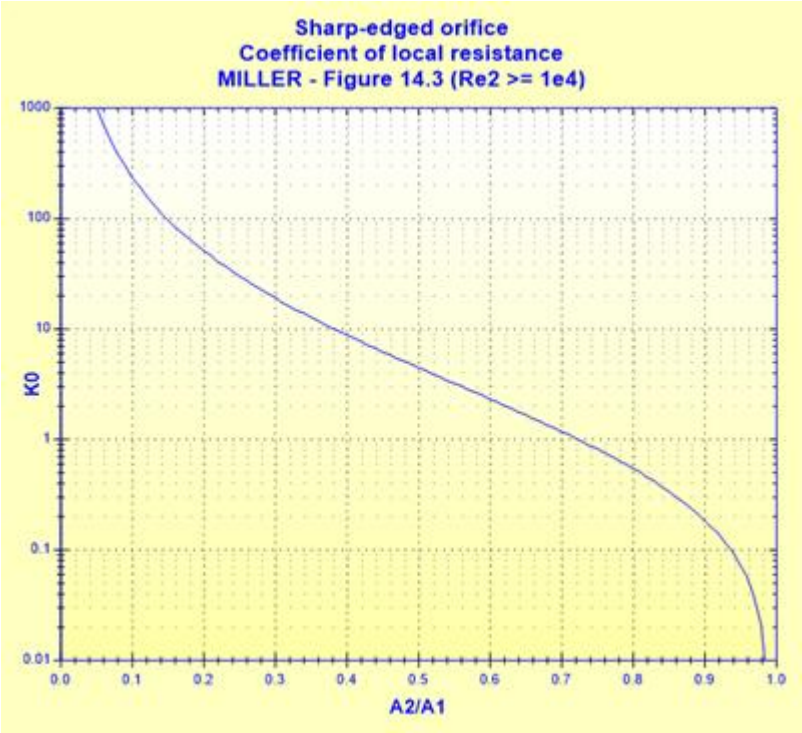
$$\mathrm{Re}_2 = \frac{u \cdot d}{\nu}$$

Local resistance Coefficient:

- $\mathrm{Re}_2 \geq 10^4$

$$K_0 = f\left(\frac{A_2}{A_1}\right)$$

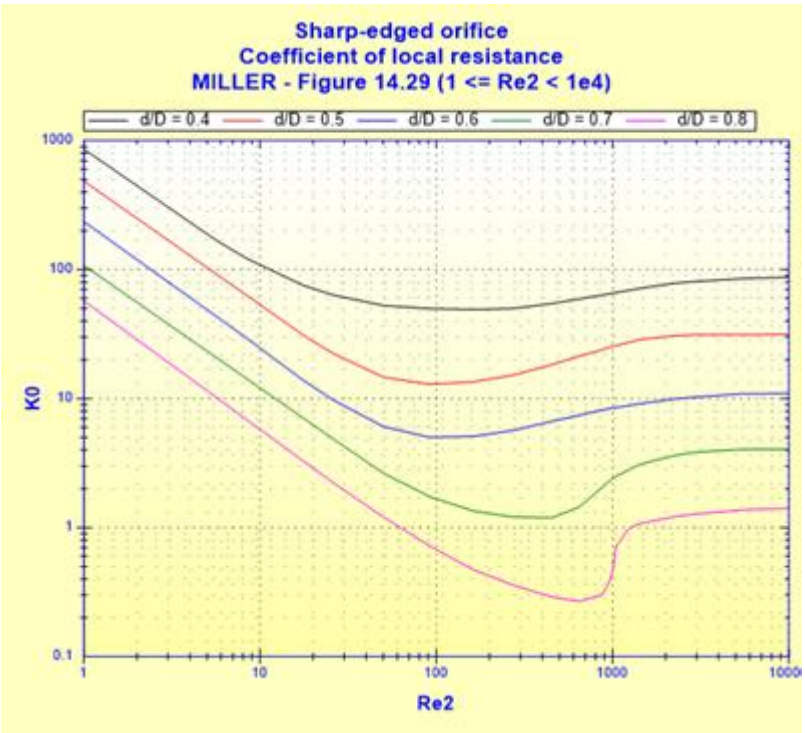
([1] figure 14.3)



■ $Re_2 < 10^4$

$$K_0 = f\left(\mathrm{Re}_2, \frac{d_e}{D}\right)$$

([1] figure 14.29)



Total pressure loss coefficient (based on mean velocity in pipe):

$$K = K_0$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Pipe internal diameter (m)
A_1	Pipe cross-sectional area (m^2)
d	Hole diameter (m)
a_2	Cross-section area of one hole (m^2)
N	Holes number ()
A_2	Clear cross-sectional area of the grid (m^2)
d_e	Equivalent section orifice diameter (m)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity in pipe (m/s)
u	Mean velocity in holes (m/s)
Re_1	Reynolds number in pipe ()
Re_2	Reynolds number in holes ()
K_0	Local resistance coefficient ()
K	Total pressure loss coefficient (based on mean velocity in pipe) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

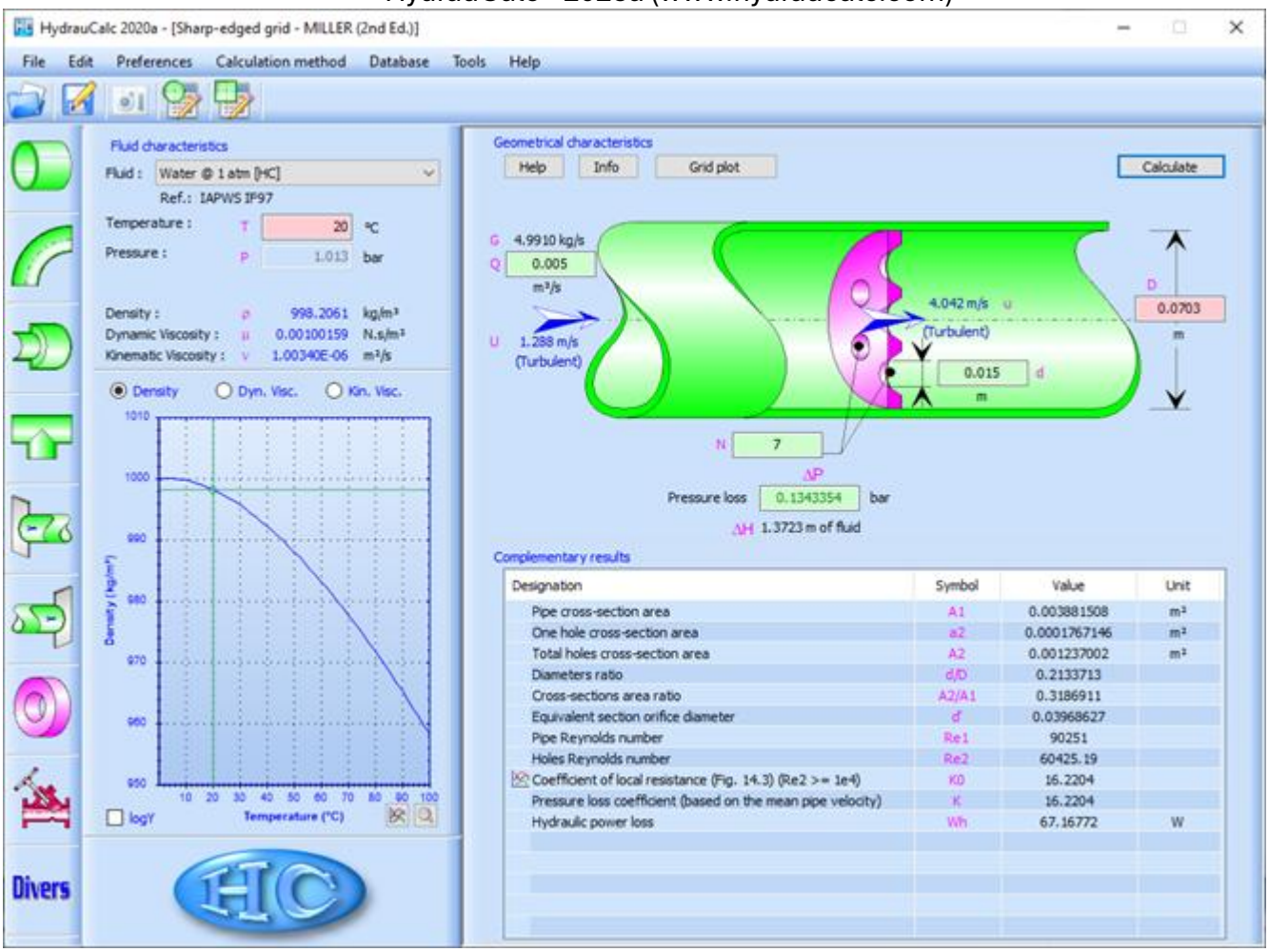
Validity range:

- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice

note: 1) for diameters ratios "d_e/D" lower than 0.4 or greater than 0.8 and when the Reynolds number in the orifice "Re_2" is lower than 10^4, the local resistance coefficient "K_0" is extrapolated

---

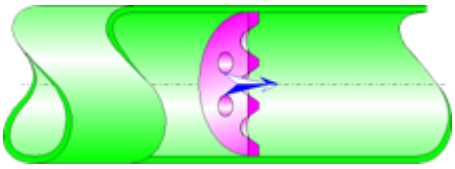
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.8.2.3 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a sharp-edged grid (perforated plate) installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Cross-sectional area of one hole (m^2):

$$a_o = \pi \cdot \frac{d_o^2}{4}$$

Clear cross-sectional area of the grid (m^2):

$$A_0 = a_0 \cdot N$$

Porosity:

$$\phi = \frac{A_0}{A}$$

Equivalent section orifice diameter (m):

$$d_e = \sqrt{\frac{4 \cdot A_0}{\pi}}$$

Ratio between the diameters of the equivalent section orifice and the pipe:

$$\beta = \frac{d_e}{d}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Holes velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

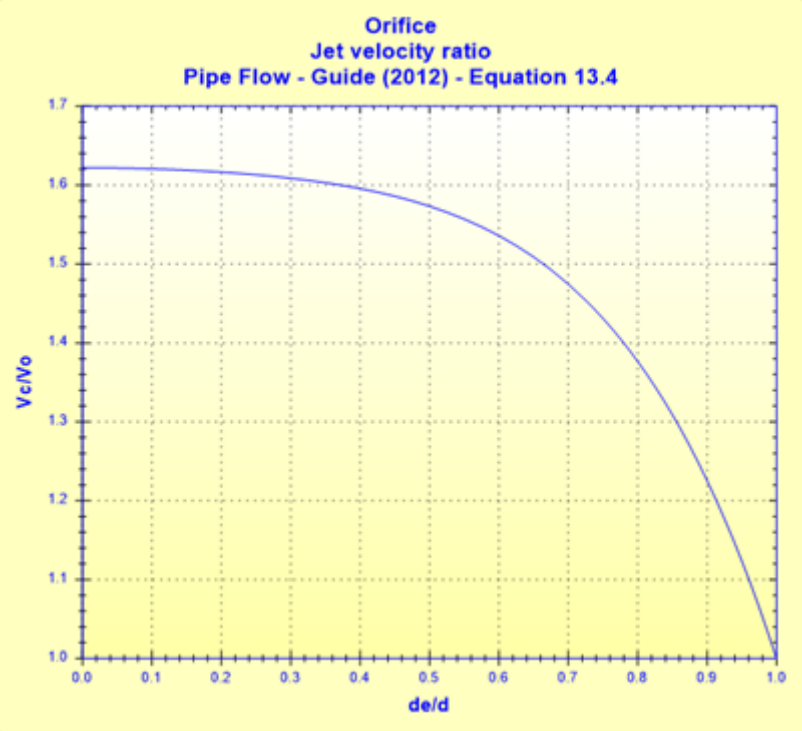
$$N_{Re} = \frac{V \cdot d}{\nu}$$

Reynolds number in holes:

$$N_{Re_O} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left(1 - 0.215\beta^2 - 0.785\beta^5\right)$$ ([1] equation 13.4)



Velocity in vena contracta:

$$V_C = V_0 \cdot \lambda$$

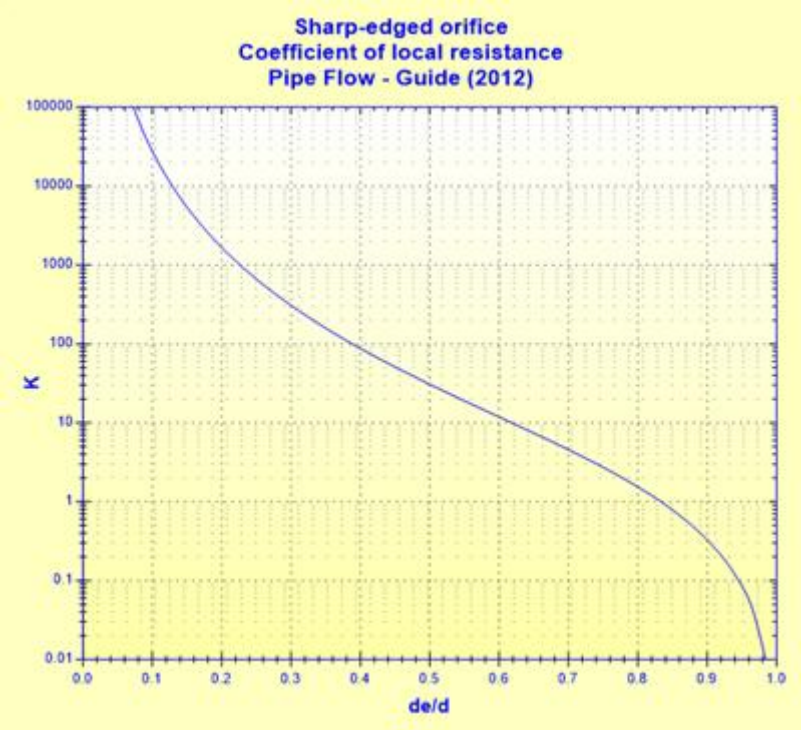
Coefficient of local resistance ($NRe_o \geq 10^4$):

$$K_0 = 0.0696 \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + \left(\lambda - \beta^2\right)^2$$

([1] equation 13.3)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_o} \right)^2$$



Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

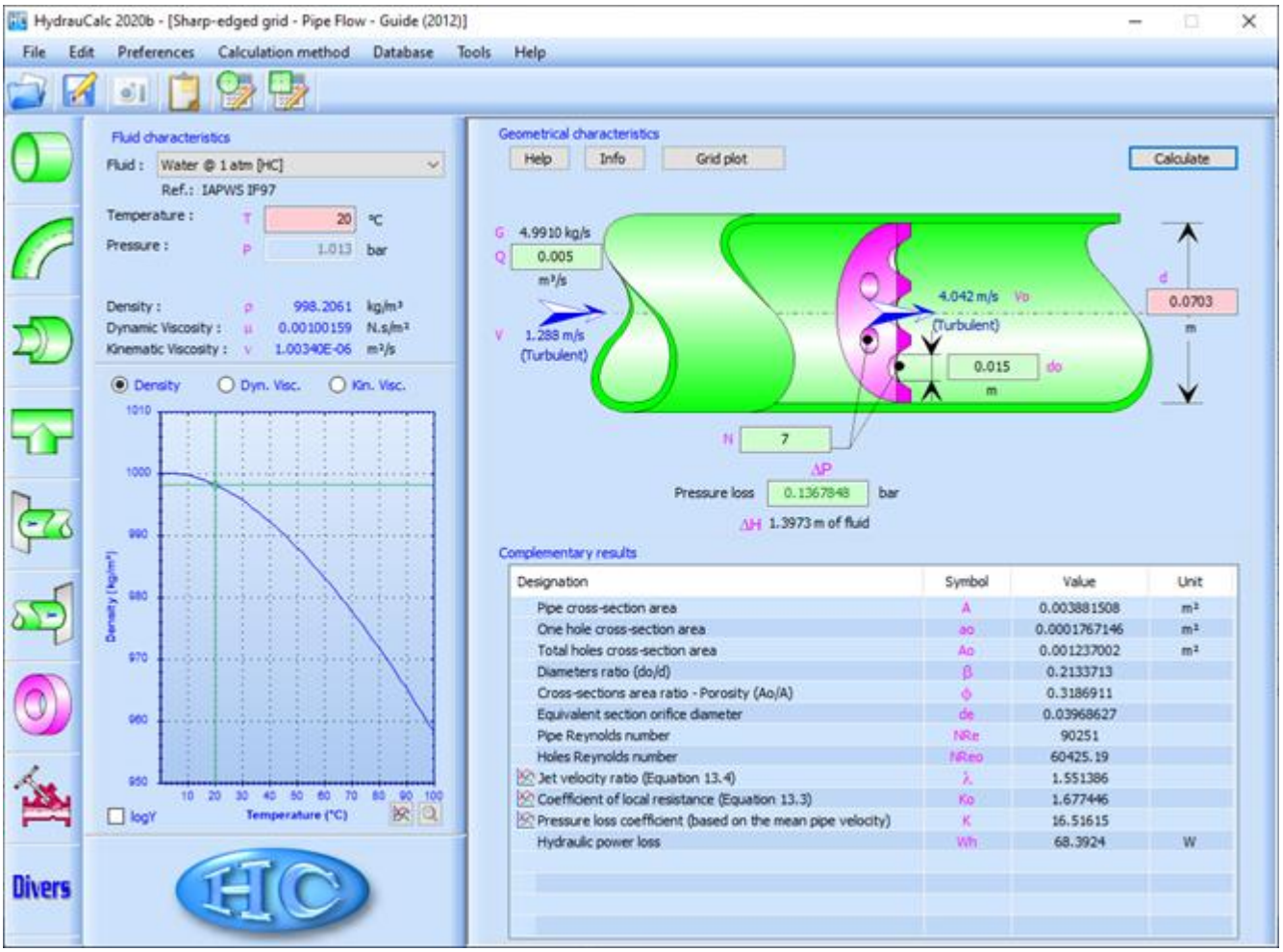
d Internal pipe diameter (m)

A	Pipe cross-sectional area (m^2)
d_0	Holes diameter (m)
a_o	Cross-sectional area of one hole (m^2)
N	Holes number ()
A_0	Clear cross-sectional area of the grid (m^2)
ϕ	Porosity ()
d_e	Equivalent section orifice diameter (m)
β	Ratio between the diameters of the equivalent section orifice and the pipe ()
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in holes (m/s)
V	Mean velocity in pipe (m/s)
NRe_o	Reynolds number in holes ()
NRe	Reynolds number in pipe ()
λ	Jet velocity ratio ()
V_c	Mean velocity in vena contracta (m/s)
K_o	Coefficient of local resistance ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in holes ($NRe_o \geq 10^4$)
- stabilized flow upstream of the grid

Example of application:

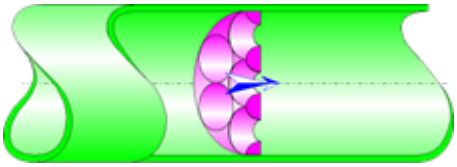


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.8.3 Round-edged grid

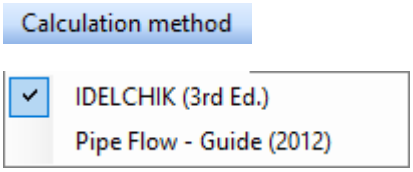
Circular Cross-Section



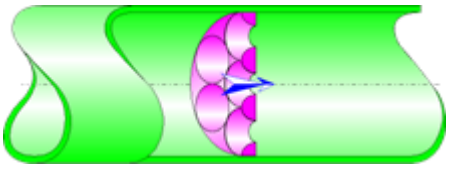
For the calculation of the pressure loss coefficient of round-edged grid, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.8.3.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a round-edged grid (perforated plate) installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Pipe cross-section area (m²):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Cross-section area of one hole (m²):

$$f_0 = \pi \cdot \frac{D_0^2}{4}$$

Clear cross-sectional area of the grid (m²):

$$F_0 = f_0 \cdot N$$

Mean velocity in pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in holes (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in holes:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Local resistance coefficient:

- $\mathrm{Re}_0 \geq 10^5$

$$\zeta_1 = \left[\sqrt{\zeta'} \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \left(1 - \frac{F_0}{F_1}\right) \right]^2 \cdot \left(\frac{F_1}{F_0}\right)^2$$

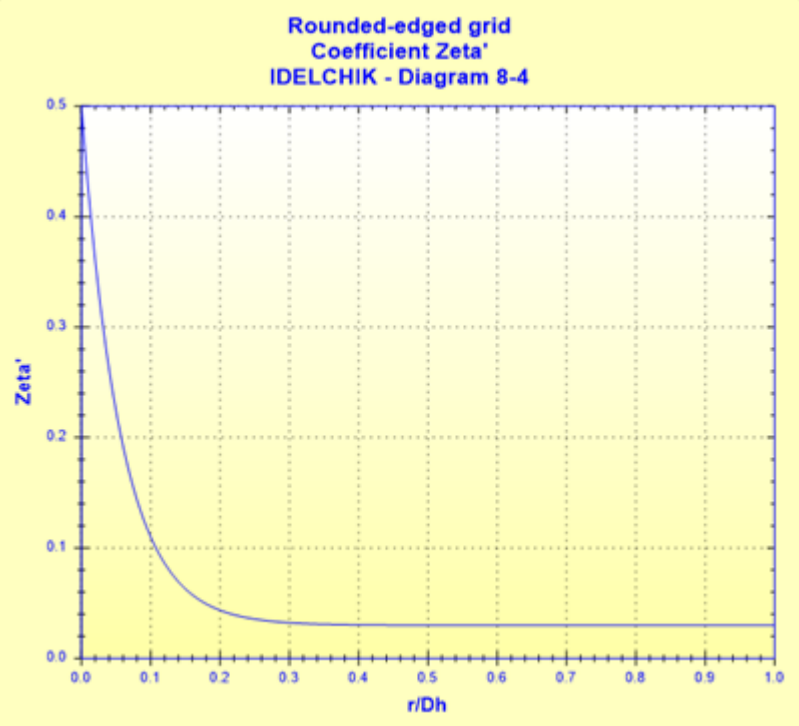
([1] diagram 8-4)

with :

Coefficient of effect of the round:

$$\zeta' = 0.03 + 0.47 \cdot 10^{-7.7 \cdot \frac{r}{D_h}}$$

([1] diagram 8-4)



■ $Re_0 \leq 10^5$

Quadratic local resistance coefficient:

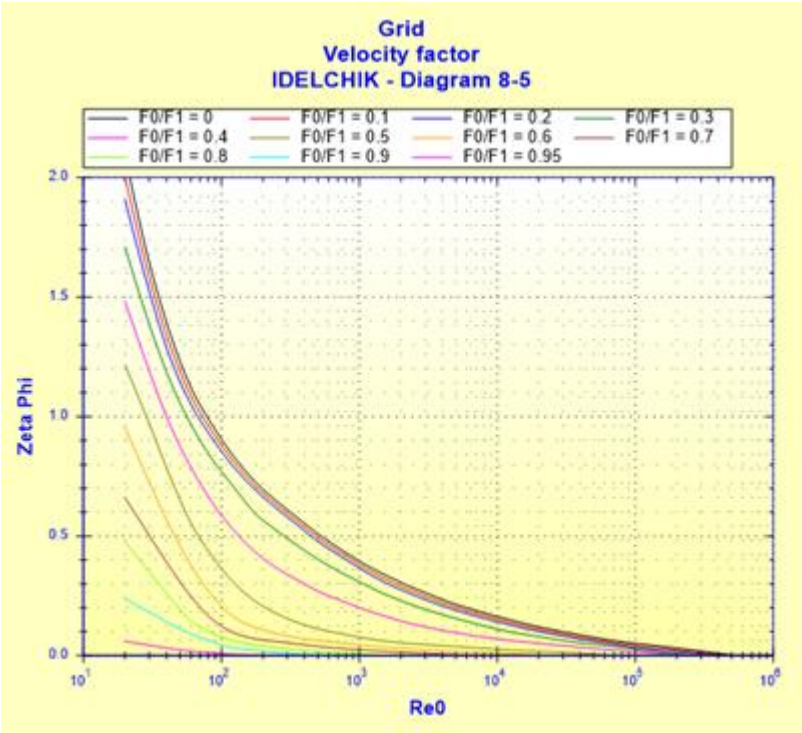
$$\zeta_{1quad} = \left[\sqrt{\zeta'} \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \left(1 - \frac{F_0}{F_1}\right) \right]^2 \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 8-4)

Velocity factor:

$$\zeta_\varphi = f\left(\mathrm{Re}_0, \frac{F_0}{F_1}\right)$$

([1] diagram 8-5)



Contraction factor:

$$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re}_0)$$

([1] diagram 8-5)

Coefficient of local resistance:

- $30 < Re_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 8-5)

- $10 < Re_0 \leq 30$

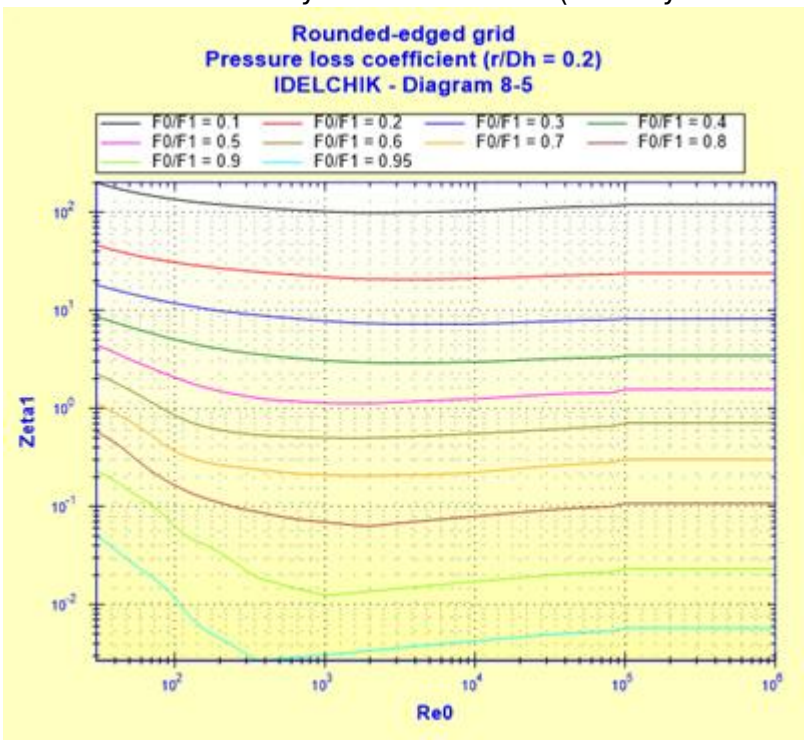
$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 8-5)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 8-5)



([1] diagram 8-5 with r/Dh = 0.2)

Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \zeta_1$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_1	Pipe internal diameter (m)

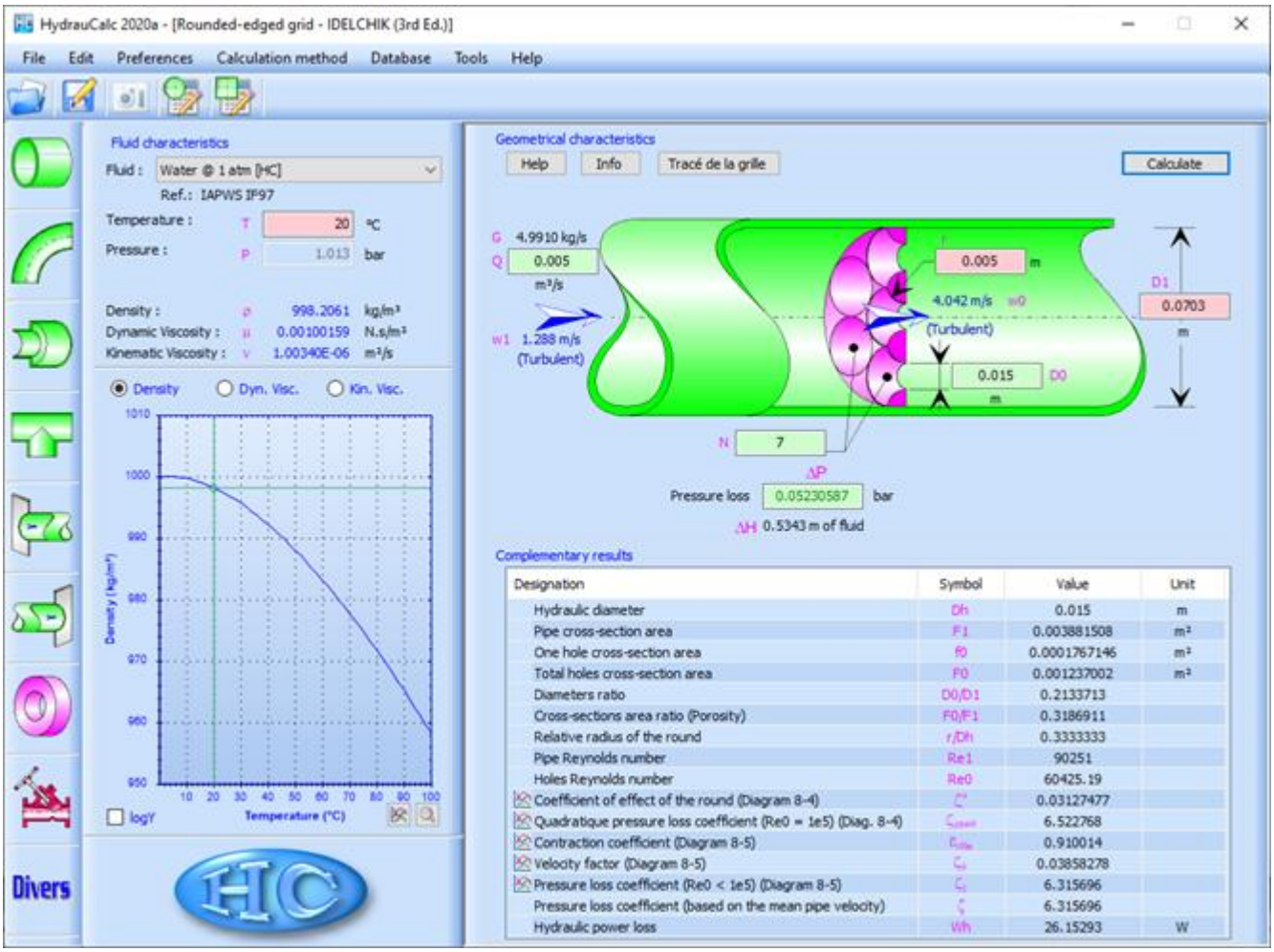
F_1	Pipe cross-sectional area (m^2)
N	Holes number ()
D_0	Holes diameter (m)
F_0	Clear cross-sectional area of the grid (m^2)
f_0	Cross-section area of one hole (m^2)
Q	Volume flow rate (m^3/s)
w_1	Mean velocity in pipe (m/s)
w_0	Mean velocity in holes (m/s)
G	Mass flow rate (kg/s)
r	Radius of the round (m)
Re_1	Reynolds number in pipe ()
Re_0	Reynolds number in holes ()
ζ_{1quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ_1	Coefficient of local resistance ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent

- stabilized flow upstream of the grid

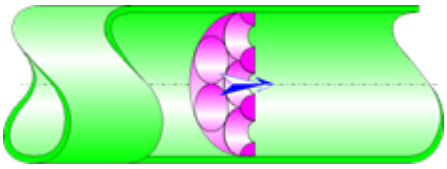
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.8.3.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a round-edged grid (perforated plate) installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Cross-sectional area of one hole (m^2):

$$a_o = \pi \cdot \frac{d_o^2}{4}$$

Clear cross-sectional area of the grid (m^2):

$$A_0 = a_0 \cdot N$$

Porosity:

$$\phi = \frac{A_0}{A}$$

Equivalent section orifice diameter (m):

$$d_e = \sqrt{\frac{4 \cdot A_0}{\pi}}$$

Ratio between the diameters of the equivalent section orifice and the pipe:

$$\beta = \frac{d_e}{d}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Holes velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

Reynolds number in holes:

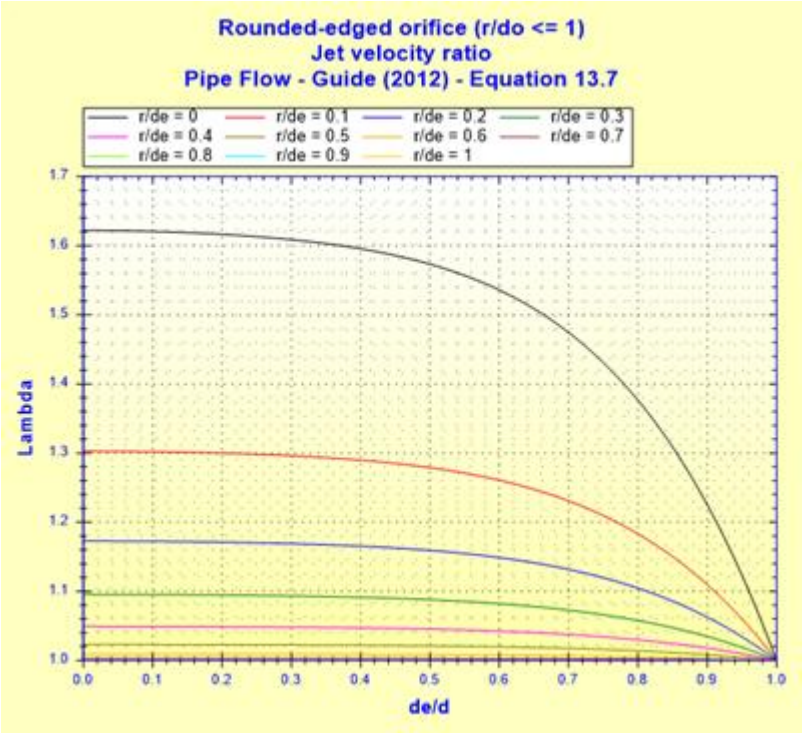
$$N_{Re_O} = \frac{V_o \cdot d_o}{\nu}$$

Jet velocity ratio:

- $r/d_e \leq 1$

$$\lambda = 1 + 0.622 \cdot \left[1 - 0.3 \cdot \sqrt{\frac{r}{d_e}} - 0.7 \cdot \frac{r}{d_e} \right]^4 \cdot \left(1 - 0.215 \cdot \beta^2 - 0.785 \cdot \beta^5 \right)$$

([1] equation 13.7)



- $r/d_e > 1$

$$\lambda = 1$$

([1] § 13.3.1)

Velocity in vena contracta:

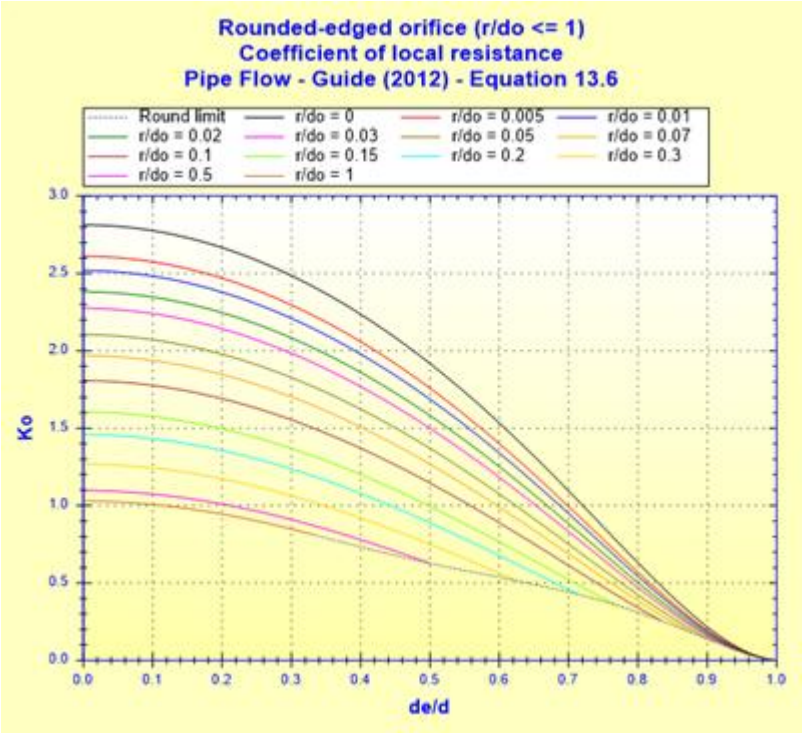
$$V_C = V_0 \cdot \lambda$$

Coefficient of local resistance:

- $r/d_e \leq 1$

$$K_o = 0.0696 \cdot \left(1 - 0.569 \cdot \frac{r}{d_e} \right) \cdot \left(1 - \sqrt{\frac{r}{d_e}} \cdot \beta \right) \cdot \left(1 - \beta^5 \right) \cdot \lambda^2 + \left(\lambda - \beta^2 \right)^2$$

([1] equation 13.6)



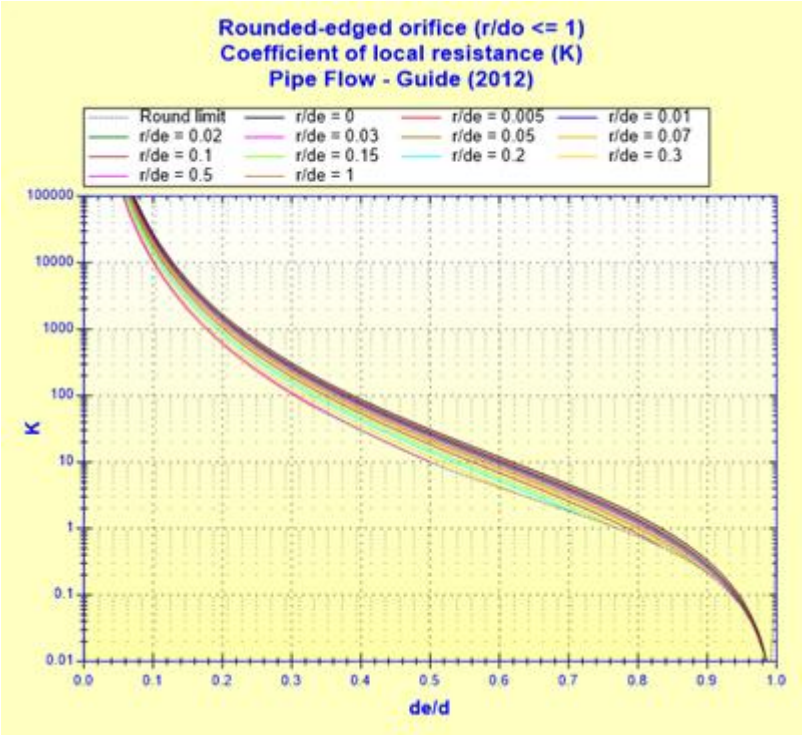
■ $r/d_e > 1$

$$K_o = 0.03 \cdot (1-\beta) \cdot \left(1-\beta^5\right) + \left(1-\beta^2\right)^2$$ ([1] § 13.3.1)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_o} \right)^2$$

■ $r/d_e \leq 1$



■ $r/d_e > 1$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

d	Internal pipe diameter (m)
A	Pipe cross-sectional area (m^2)
d_0	Holes diameter (m)
a_o	Cross-sectional area of one hole (m^2)
N	Holes number ()
A_0	Clear cross-sectional area of the grid (m^2)
ϕ	Porosity ()
d_e	Equivalent section orifice diameter (m)
β	Ratio between the diameters of the equivalent section orifice and the pipe ()
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in holes (m/s)
V	Mean velocity in pipe (m/s)
NRe_o	Reynolds number in holes ()
NRe	Reynolds number in pipe ()
λ	Jet velocity ratio ()
r	Rounding radius (m)

V_c Mean velocity in vena contracta (m/s)

K_o Coefficient of local resistance ()

K Total pressure loss coefficient (based on the mean pipe velocity) ()

ΔP Total pressure loss (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ_m Fluid density (kg/m^3)

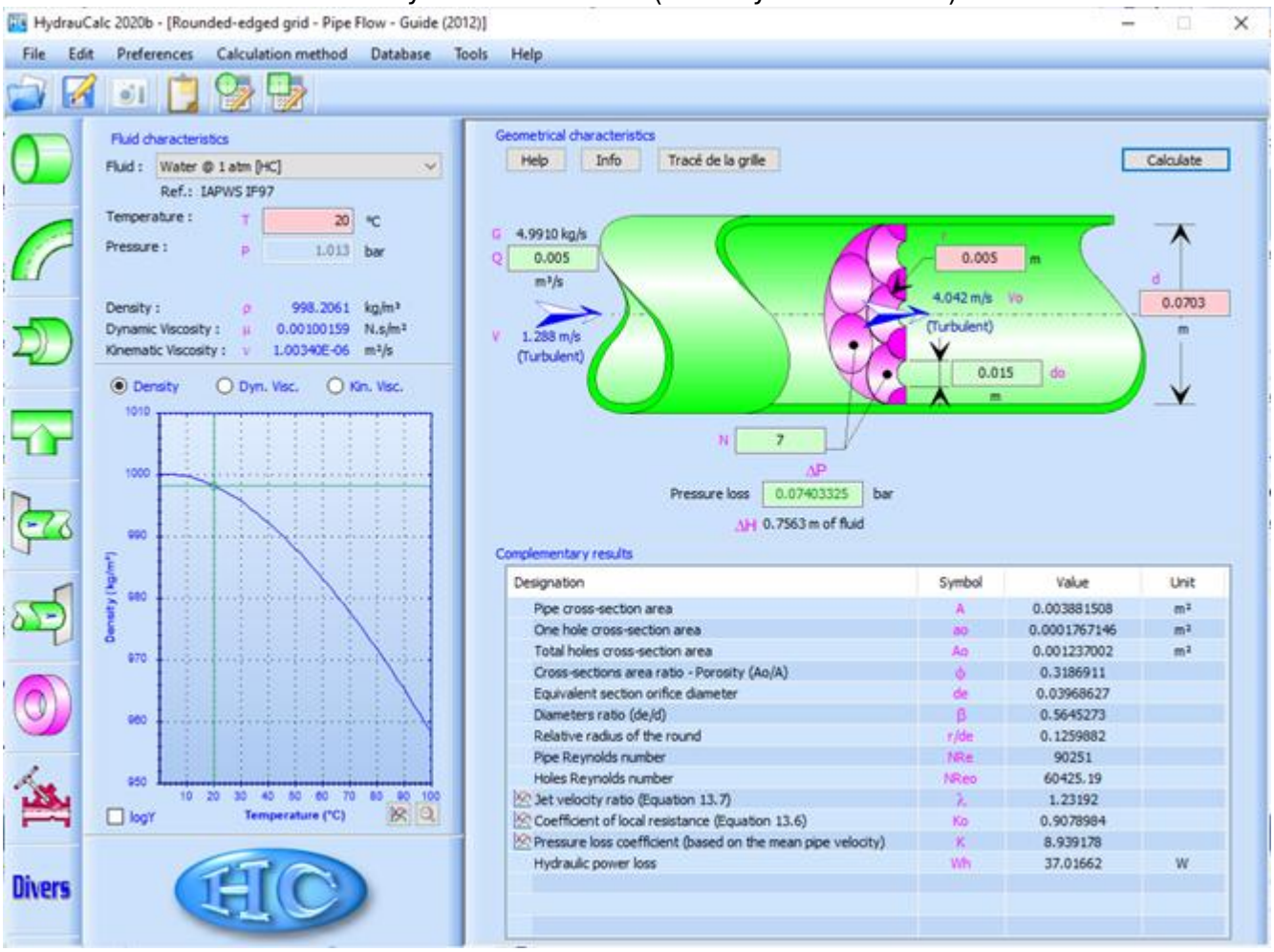
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in holes ($NRe_o \geq 10^4$)
- stabilized flow upstream of the grid

Example of application:

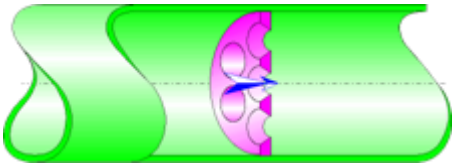


References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

2.8.4 Bevel-edged grid

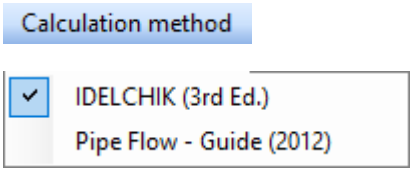
Circular Cross-Section



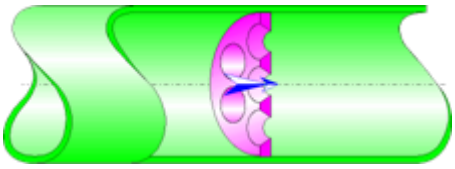
For the calculation of the pressure loss coefficient of bevel-edged grid, the user can choose from one of the methods described in the following two reference documents:

- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Pipe Flow - A Practical and Comprehensive Guide - Rennels and Hudson (2012)

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.8.4.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a bevel-edged grid (perforated plate) installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D_h = D_0$$

Pipe cross-section area (m²):

$$F_1 = \pi \cdot \frac{D_1^2}{4}$$

Cross-section area of one hole (m²):

$$f_0 = \pi \cdot \frac{D_0^2}{4}$$

Clear cross-sectional area of the grid (m²):

$$F_0 = f_0 \cdot N$$

Mean velocity in pipe (m/s):

$$w_1 = \frac{Q}{F_1}$$

Mean velocity in holes (m/s):

$$w_0 = \frac{Q}{F_0}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in pipe:

$$\mathrm{Re}_1 = \frac{w_1 \cdot D_1}{\nu}$$

Reynolds number in holes:

$$\mathrm{Re}_0 = \frac{w_0 \cdot D_0}{\nu}$$

Local resistance coefficient:

- $\mathrm{Re}_0 \geq 10^5$

$$\zeta_1 = \left[\sqrt{\zeta'} \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375} + \left(1 - \frac{F_0}{F_1}\right) \right]^2 \cdot \left(\frac{F_1}{F_0}\right)^2$$

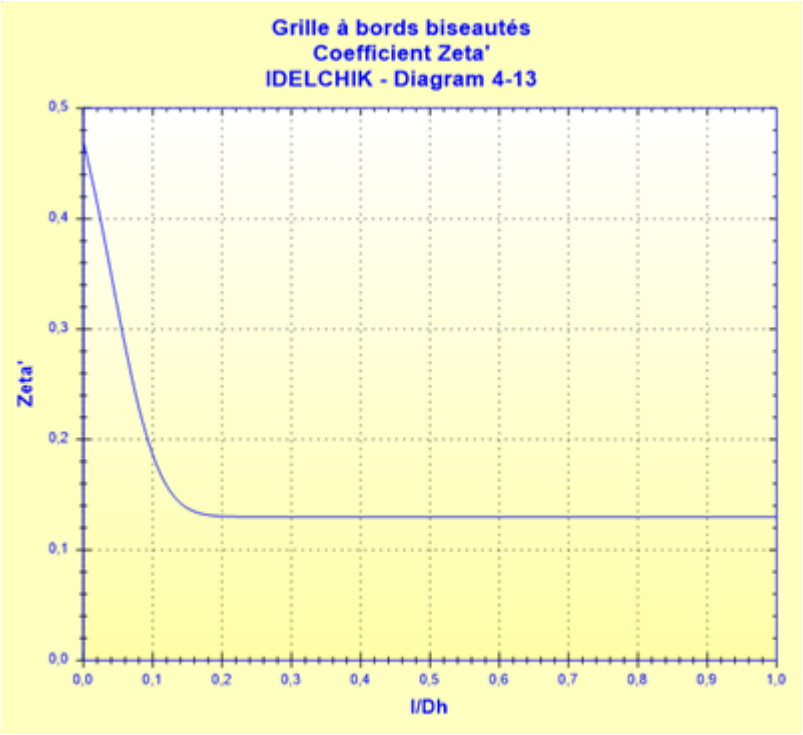
([1] diagram 8-2)

with :

Coefficient of effect of the orifice thickness:

$$\zeta' = 0.13 + 0.34 \cdot 10^{-\left(3.4\frac{l}{D_h} + 88.4\left(\frac{l}{D_h}\right)^{2.3}\right)}$$

([1] diagram 4-13)



■ $Re_0 \leq 10^5$

Quadratic local resistance coefficient:

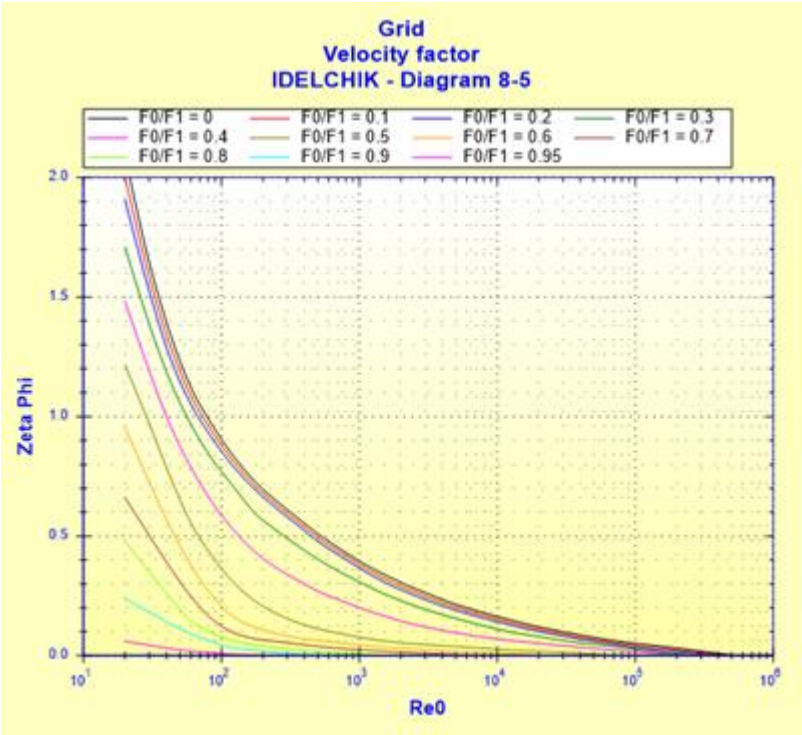
$$\zeta_{1quad} = \left[\sqrt{\zeta'} \cdot \left(1 - \frac{F_0}{F_1}\right)^{0.375} + \left(1 - \frac{F_0}{F_1}\right) \right]^2 \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 8-2)

Velocity factor:

$$\zeta_\varphi = f\left(\mathrm{Re}_0, \frac{F_0}{F_1}\right)$$

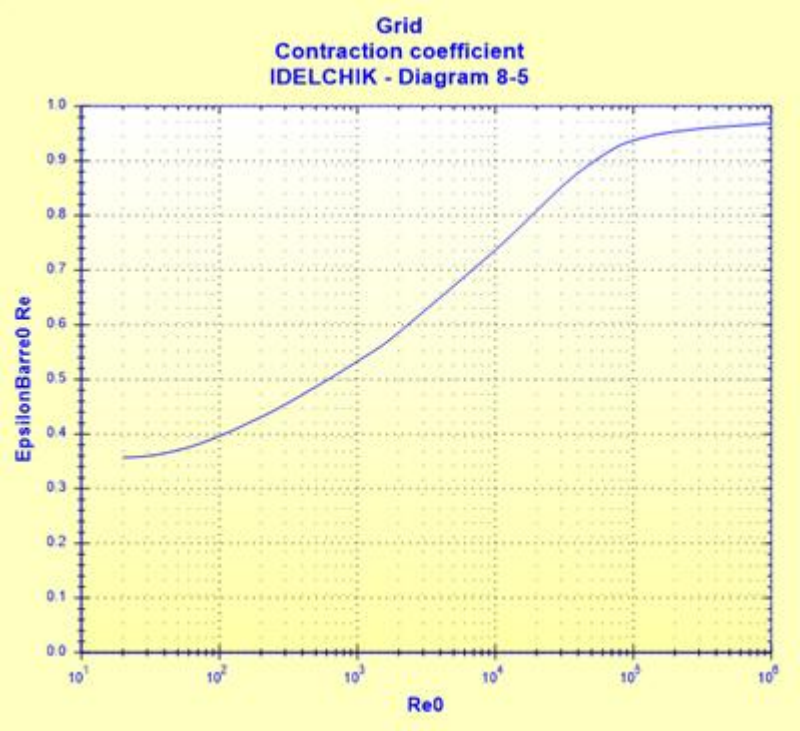
([1] diagram 8-5)



Contraction factor:

$$\bar{\varepsilon}_{0\mathrm{Re}} = f(\mathrm{Re}_0)$$

([1] diagram 8-5)



Coefficient of local resistance:

- $30 < Re_0 < 10^5$

$$\zeta_1 = \zeta_\varphi \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 8-5)

- $10 < Re_0 \leq 30$

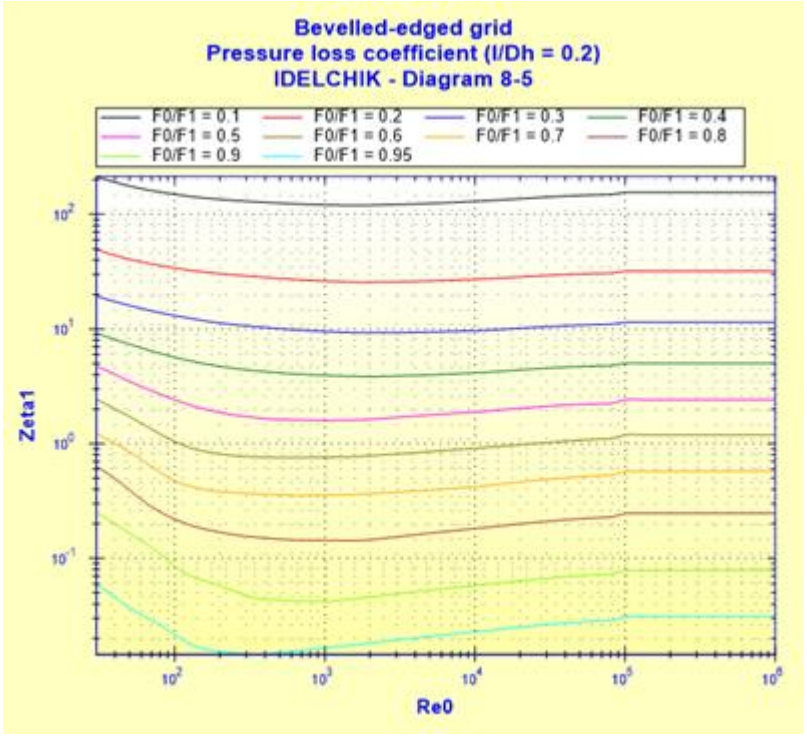
$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2 + \overline{\varepsilon}_{0Re} \cdot \zeta_{1quad}$$

([1] diagram 8-5)

- $Re_0 \leq 10$

$$\zeta_1 = \frac{33}{Re_0} \cdot \left(\frac{F_1}{F_0}\right)^2$$

([1] diagram 8-5)



([1] diagram 8-5 with l/Dh = 0.2)

Pressure loss coefficient (based on the mean pipe velocity):

$$\zeta = \zeta_1$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{W_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D_h	Hydraulic diameter (m)
D_1	Pipe internal diameter (m)

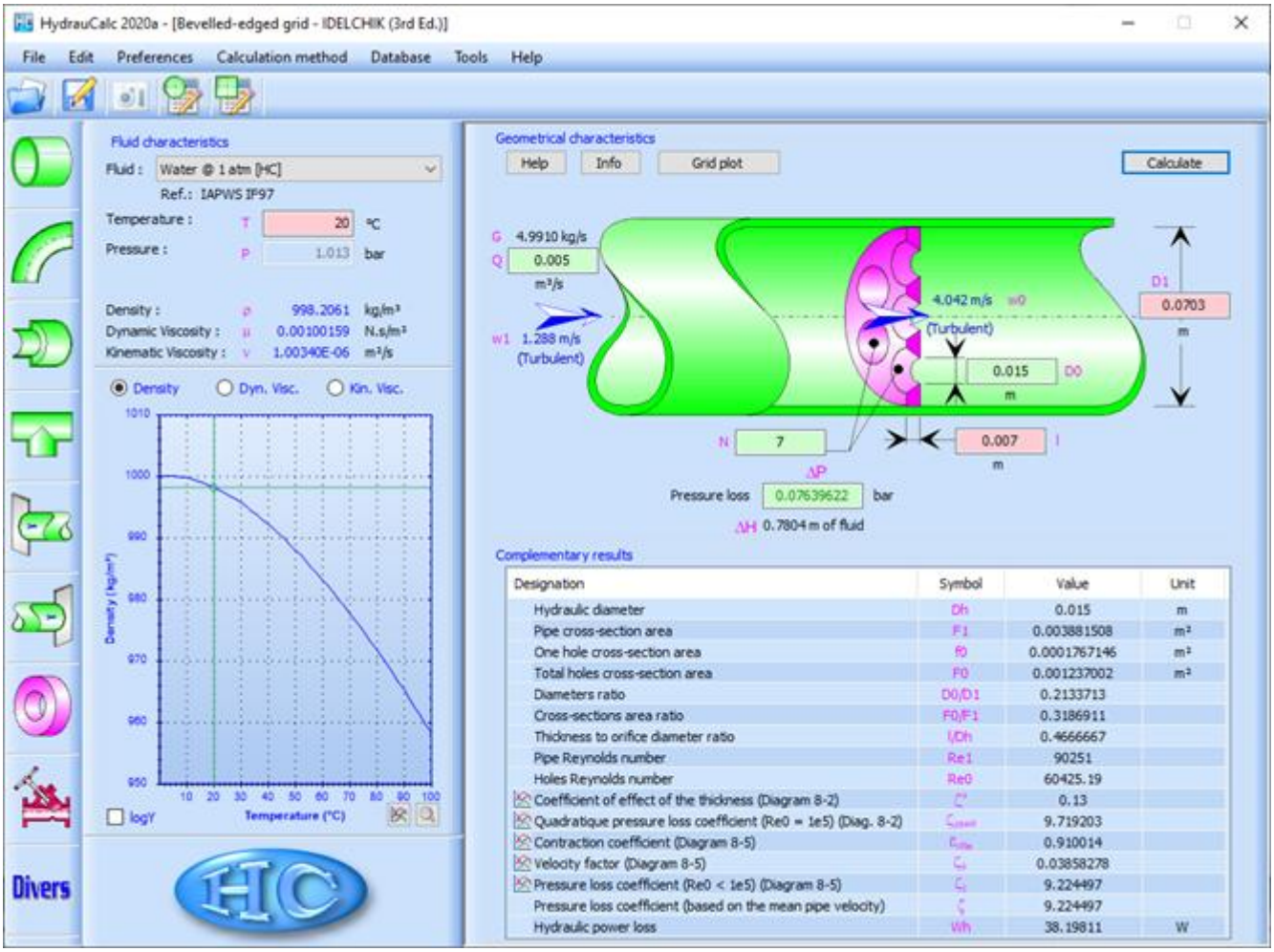
F_1	Pipe cross-sectional area (m^2)
N	Holes number ()
D_0	Holes diameter (m)
F_0	Clear cross-sectional area of the grid (m^2)
f_0	Cross-section area of one hole (m^2)
Q	Volume flow rate (m^3/s)
w_1	Mean velocity in pipe (m/s)
w_0	Mean velocity in holes (m/s)
G	Mass flow rate (kg/s)
l	Grid thickness (m)
Re_1	Reynolds number in pipe ()
Re_0	Reynolds number in holes ()
ζ_{1quad}	Quadratic pressure loss coefficient determined as Re = 10^5 ()
ζ_φ	Velocity factor ()
$\bar{\varepsilon}_{0Re}$	Contraction factor ()
ζ_1	Coefficient of local resistance ()
ζ	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- any flow regime: laminar and turbulent

- stabilized flow upstream of the grid
- thickness to hole diameter ratio (l/D_0) greater than 0.015
- top angle of the holes between 40° and 90°

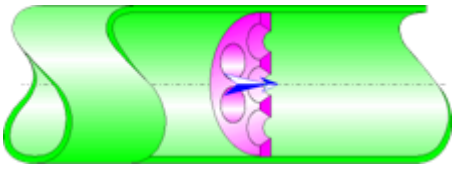
Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

2.8.4.2 Pipe Flow - Guide



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a bevel-edged grid (perforated plate) installed in a straight pipe.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Pipe cross-sectional area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Cross-sectional area of one hole (m^2):

$$a_o = \pi \cdot \frac{d_o^2}{4}$$

Clear cross-sectional area of the grid (m^2):

$$A_0 = a_0 \cdot N$$

Porosity:

$$\phi = \frac{A_0}{A}$$

Equivalent section orifice diameter (m):

$$d_e = \sqrt{\frac{4 \cdot A_0}{\pi}}$$

Ratio between the diameters of the equivalent section orifice and the pipe:

$$\beta = \frac{d_e}{d}$$

Pipe velocity (m/s):

$$V = \frac{Q}{A}$$

Holes velocity (m/s):

$$V_o = \frac{Q}{A_o}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

$$N_{Re} = \frac{V \cdot d}{\nu}$$

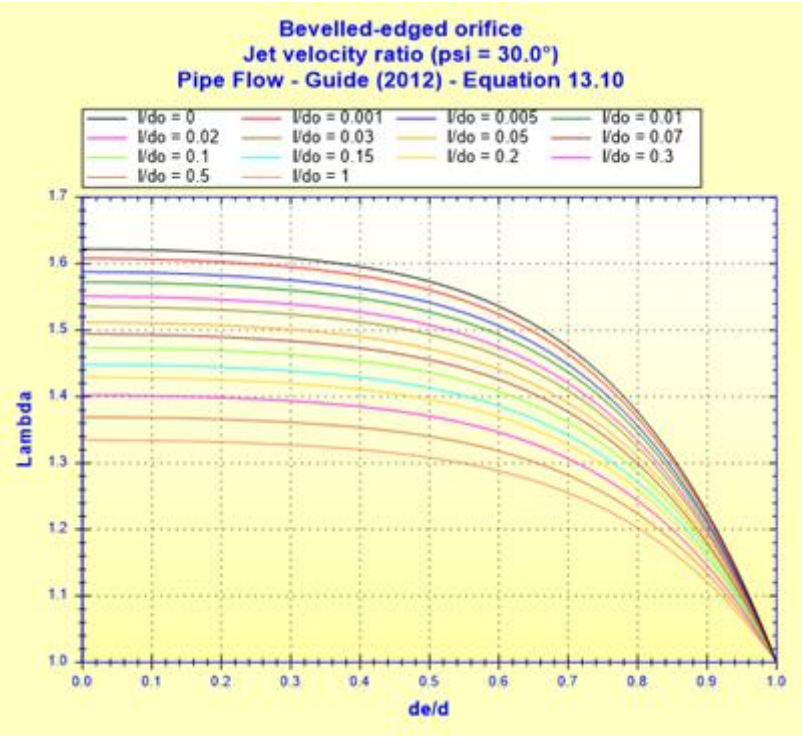
Reynolds number in holes:

$$N_{Re_O} = \frac{V_O \cdot d_O}{\nu}$$

Jet velocity ratio:

$$\lambda = 1 + 0.622 \cdot \left[1 - C_b \cdot \left(\frac{l}{d_0} \right)^{\frac{1-\sqrt{1/c_b}}{2}} \right] \cdot \left(1 - 0.215 \cdot \beta^2 - 0.785 \cdot \beta^5 \right)$$

([1] equation 13.10)



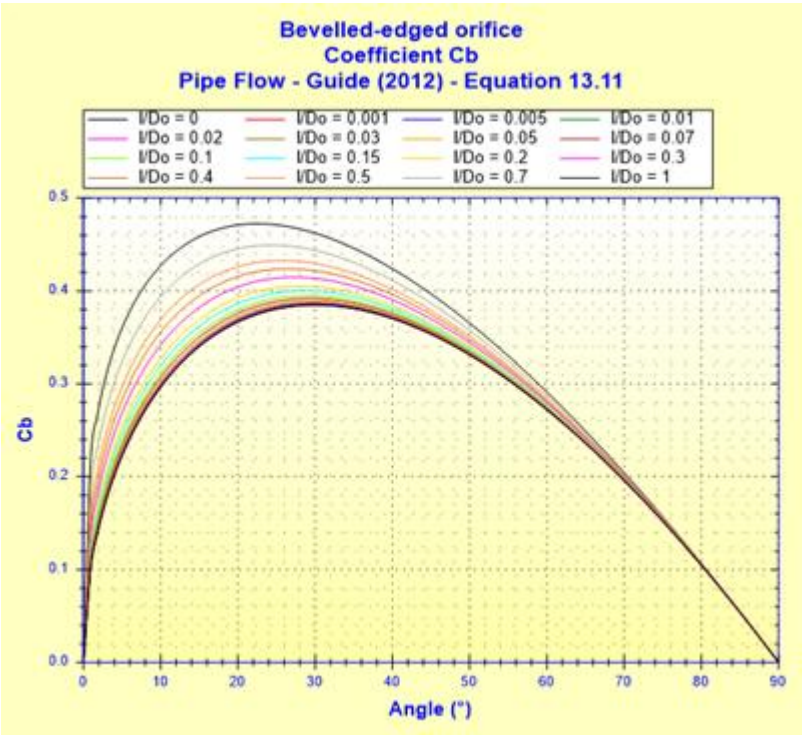
([1] equation 13.10 with psi = 30°)

with:

Coefficient of effect of the bevel angle:

$$C_b = \left(1 - \frac{\Psi}{90}\right) \cdot \left(\frac{\Psi}{90}\right)^{\frac{1}{2+l/d_0}}$$

([1] equation 13.11)



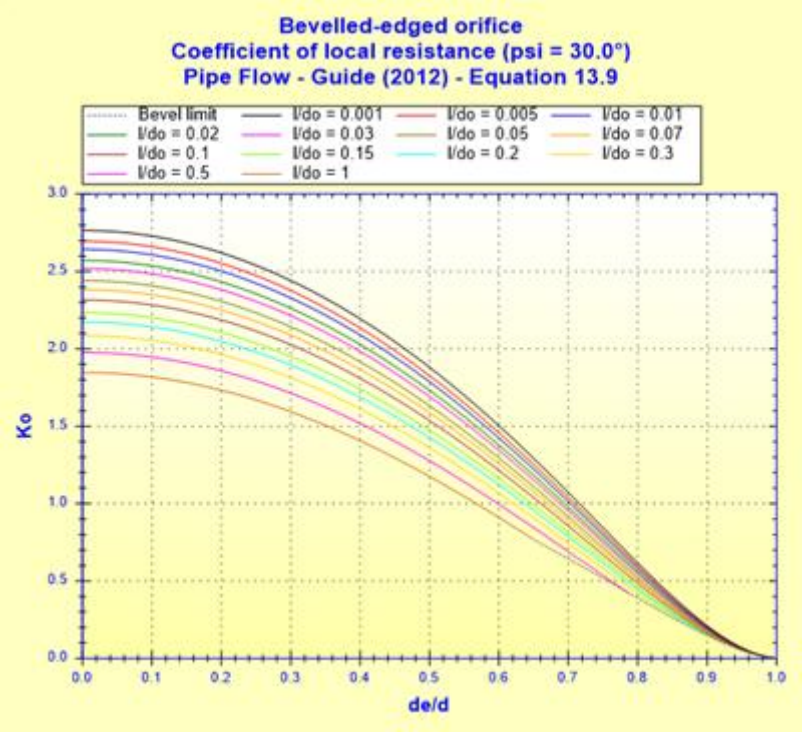
Velocity in vena contracta:

$$V_c = V_0 \cdot \lambda$$

Coefficient of local resistance:

$$K_o = 0.0696 \cdot \left(1 - C_b \cdot \frac{l}{d_0}\right) \cdot \left(1 - 0.42 \cdot \sqrt{\frac{l}{d_0}} \cdot \beta^2\right) \cdot \left(1 - \beta^5\right) \cdot \lambda^2 + \left(\lambda - \beta^2\right)^2$$

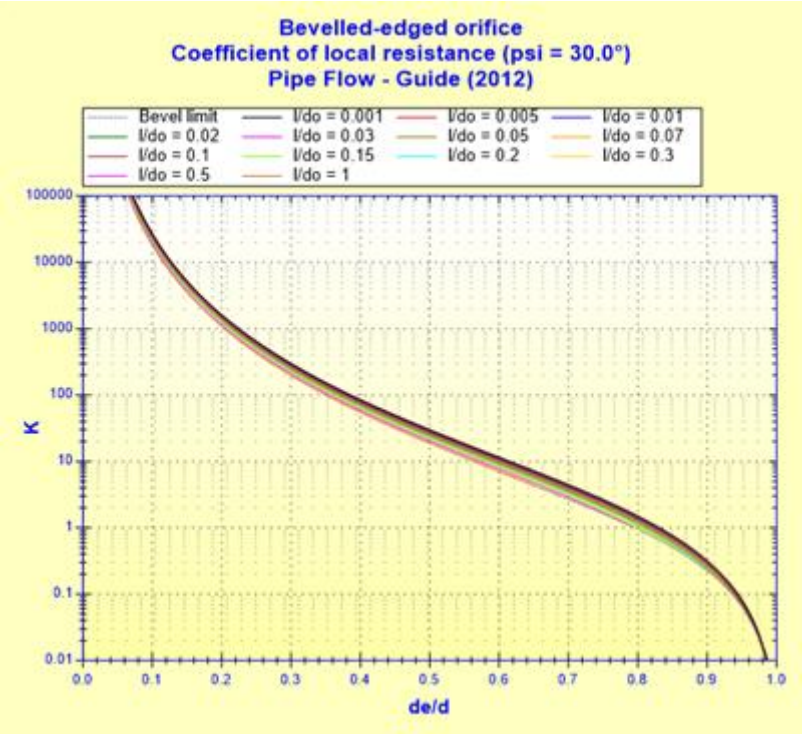
([1] equation 13.9)



([1] equation 13.9 with ψ = 30°)

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_o \cdot \left(\frac{A}{A_0}\right)^2$$



(with ψ = 30°)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

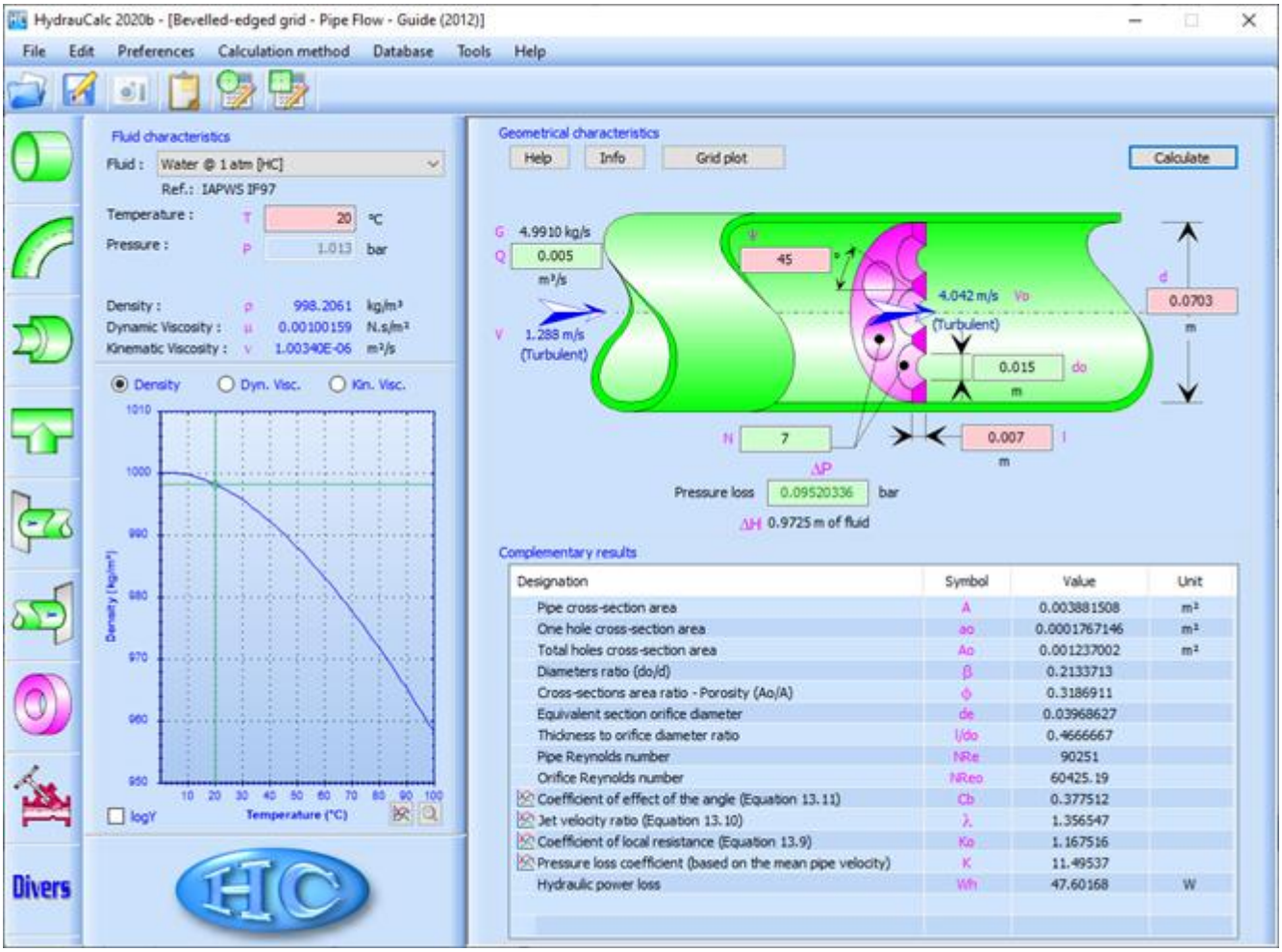
d	Internal pipe diameter (m)
A	Pipe cross-sectional area (m^2)
d_0	Holes diameter (m)
a_o	Cross-sectional area of one hole (m^2)
N	Holes number ()

A_0	Clear cross-sectional area of the grid (m^2)
ϕ	Porosity ()
d_e	Equivalent section orifice diameter (m)
β	Ratio between the diameters of the equivalent section orifice and the pipe ()
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V_o	Mean velocity in holes (m/s)
V	Mean velocity in pipe (m/s)
NRe_o	Reynolds number in holes ()
NRe	Reynolds number in pipe ()
λ	Jet velocity ratio ()
l	Thickness grid (m)
K_o	Coefficient of local resistance ()
ψ	Bevel angle ()
Cb	Coefficient of effect of the bevel angle ()
K	Total pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in holes ($NRe_o \geq 10^4$)
- stabilized flow upstream of the grid

Example of application:



References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)

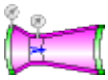
2.9 Flowmeters

This subsection regroups the set of flowmeters that can be modeled and calculated. The types of flowmeter available are:

- Orifice plate flowmeter

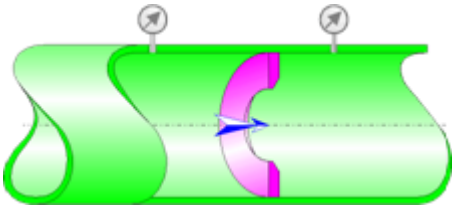
- Nozzle and Venturi nozzle flowmeter

- Venturi tube flowmeter



2.9.1 Orifice plate flowmeter

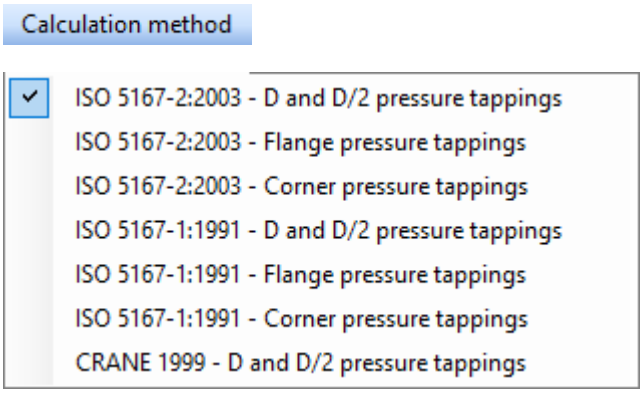
Square-Edge Orifice Flowmeter



For the determination of the fluid flow through a square-edge orifice flowmeter, the user can choose from one of the methods described in the following three reference documents:

- ISO 5167-2:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
  Part 1: General principles and requirements
  Part 2: Orifice plates
- ISO 5167-1:1991 - Measurement of fluid flow by means of pressure differential devices
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999

The calculation method is selected using the "Calculation method" menu. The default option is "ISO 5167-2:2003 – D and D/2 pressure tappings"

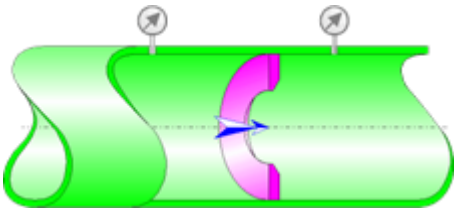


2.9.1.1 ISO 5167-2:2003 - D and D/2 pressure tappings

Square-Edge Orifice Flowmeter

D and D/2 pressure tappings

(ISO 5167-2:2003)



Model description:

This model of component determines the fluid flow through a square-edge orifice flowmeter with D & D/2 pressure tappings, according to the international standard "ISO-5167-2:2003".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

Reynolds number referred to internal pipe diameter:

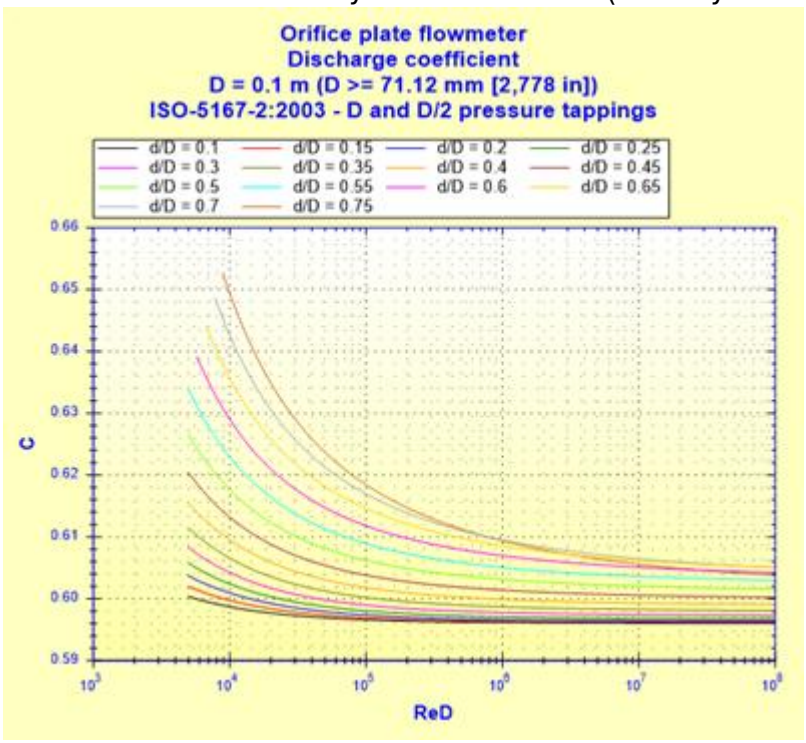
$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient (Reader-Harris/Gallagher (1998) equation):

- D ≥ 71.12 mm (2.8 in)

$$C = 0.5961 + 0.0261 \cdot \beta^2 - 0.216 \cdot \beta^8 + 0.000521 \cdot \left(\frac{10^6 \cdot \beta}{\mathrm{Re}_D}\right)^{0.7} + (0.0188 + 0.0063 \cdot A) \cdot \beta^{3.5} \cdot \left(\frac{10^6}{\mathrm{Re}_D}\right)^{0.3} + \left(0.043 + 0.08 \cdot e^{-10 \cdot L1} - 0.123 \cdot e^{-7 \cdot L1}\right) \cdot (1 - 0.11 \cdot A) \cdot \frac{\beta^4}{1 - \beta^4} - 0.031 \cdot \left(M'_2 - 0.8 \cdot M'^{1.1}_2\right) \cdot \beta^{1.3}$$

([2] § 5.3.2.1 eq. 4)



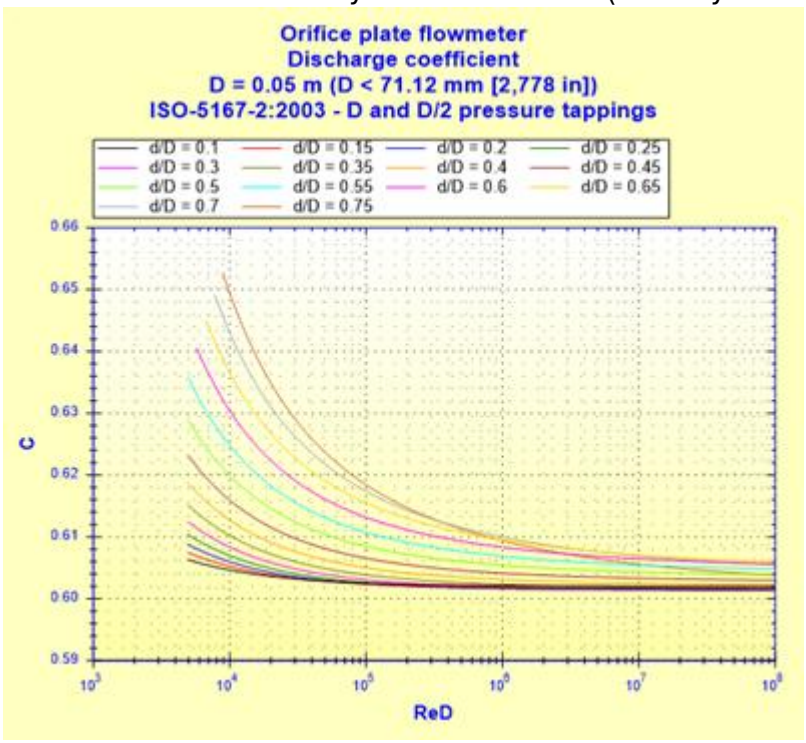
with D = 100 mm

■ D < 71.12 mm (2.8 in)

$$C = 0.5961 + 0.0261 \cdot \beta^2 - 0.216 \cdot \beta^8 + 0.000521 \cdot \left(\frac{10^6 \cdot \beta}{\mathrm{Re}_D}\right)^{0.7}$$
$$+ (0.0188 + 0.0063 \cdot A) \cdot \beta^{3.5} \cdot \left(\frac{10^6}{\mathrm{Re}_D}\right)^{0.3}$$
$$+ \left(0.043 + 0.08 \cdot e^{-10 \cdot L1} - 0.123 \cdot e^{-7 \cdot L1}\right) \cdot (1 - 0.11 \cdot A) \cdot \frac{\beta^4}{1 - \beta^4}$$
$$- 0.031 \cdot \left(M'_2 - 0.8 \cdot M'^{1.1}_2\right) \cdot \beta^{1.3}$$
$$+ 0.011 \cdot (0.75 - \beta) \cdot \left(2.8 - \frac{D}{25.4}\right)$$

([2] § 5.3.2.1 eq. 4)

Where D is the pipe diameter in mm



with D = 50 mm

where:

$$M'_2 = \frac{2 \cdot L'_2}{1-\beta}$$

$$A = \left(\frac{19000 \cdot \beta}{Re_D} \right)^{0.8}$$

The values of L_1 and L'_2 to be used in this equations are as follows:

$$L_1 = 1$$

$$L'_2 = 0.47$$

Expansibility factor:

$$\varepsilon = 1$$

([1] §3.3.6) for incompressible fluid (liquid)

Mass flow rate (kg/s):

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$

([2] § 4 eq. 1)

Volume flow rate (m^3/s):

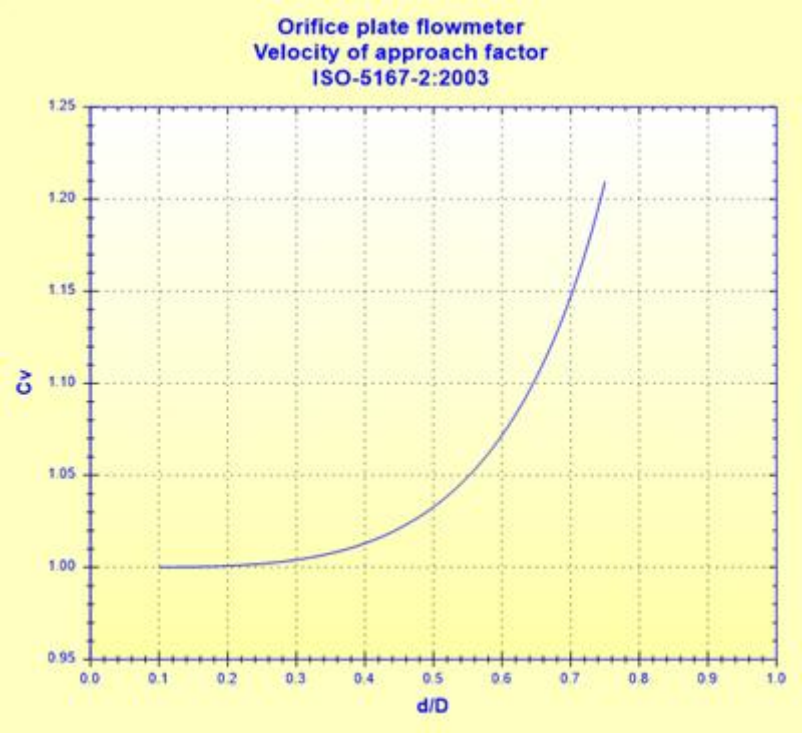
$$q_v = \frac{q_m}{\rho}$$

([2] § 4 eq. 2)

Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$

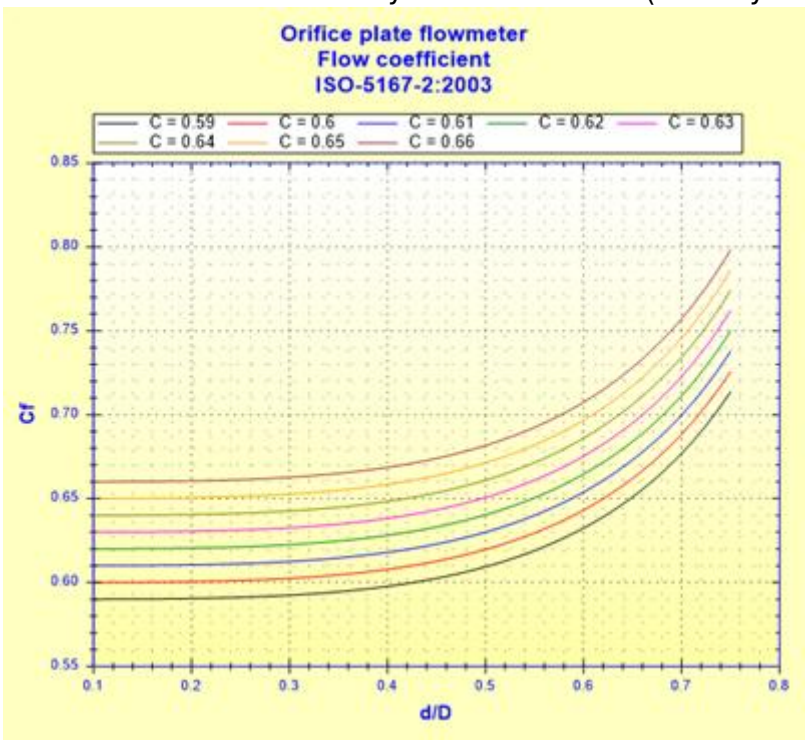
([1] §3.3.5)

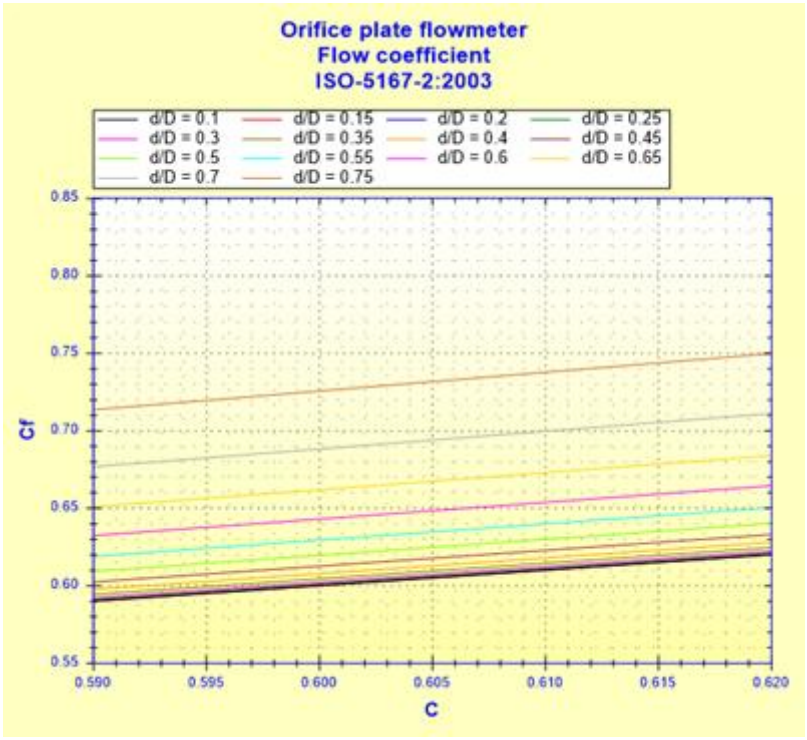


Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$

([1] §3.3.5)





Pressure loss coefficient of orifice (based on the mean pipe velocity):

$$K = \left(\frac{\sqrt{1 - \beta^4 \cdot \left(1 - C^2\right)}}{C \cdot \beta^2} - 1 \right)^2$$

([2] § 5.4.3)

Net pressure loss (Pa):

$$\Delta\varpi = \frac{\sqrt{1-\beta^4\cdot\left(1-C^2\right)}-C\cdot\beta^2}{\sqrt{1-\beta^4\cdot\left(1-C^2\right)}+C\cdot\beta^2}\cdot\Delta p$$

([2] § 5.4.1)

Net head loss (m):

$$\Delta h = \frac{\Delta\varpi}{\rho\cdot g}$$

Net hydraulic power loss (W):

$$Wh = \Delta\varpi\cdot q_V$$

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho\cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()
Re_D	Reynolds number referred to pipe ()
C	Discharge coefficient ()
L_1	Upstream relative pressure tapping spacing from the upstream face ()

L'_2 Downstream relative pressure tapping spacing from the downstream face ()

ε Expansibility factor ()

q_m Mass flow rate (kg/s)

C_v Velocity of approach factor ()

C_f Flow coefficient ()

K Pressure loss coefficient of orifice ()

$\Delta\varpi$ Net pressure loss (Pa)

ΔP Measured pressure loss (Pa)

Δh Net head loss of fluid (m)

Wh Hydraulic power loss (W)

ΔH Measured head loss of fluid (m)

ρ Fluid density (kg/m³)

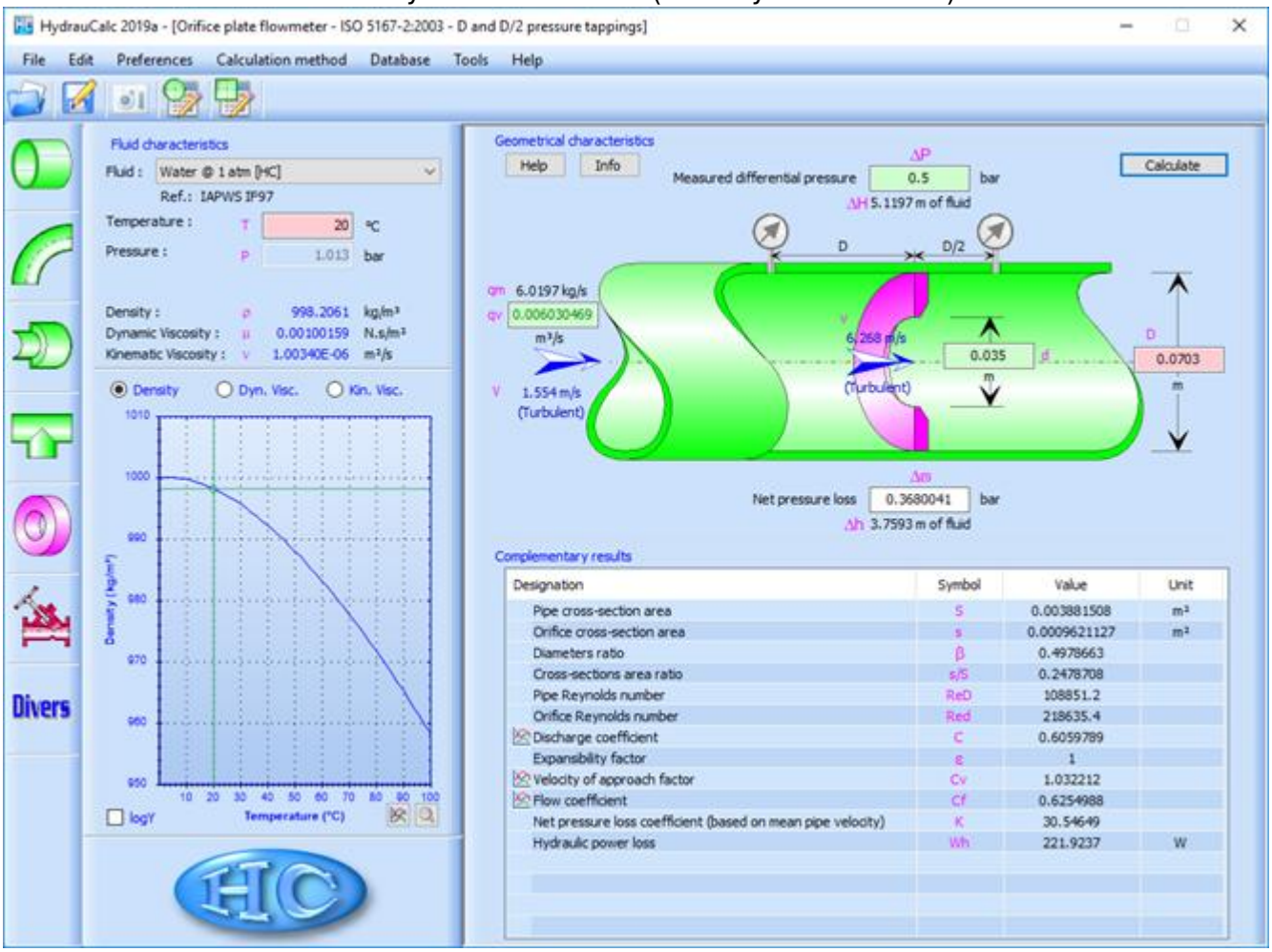
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Limit of use:

- $d \geq 12.5$ mm
- $50 \text{ mm} \leq D \leq 1\,000$ mm
- $0.1 \leq \beta \leq 0.75$
- $Re_D \geq 5\,000$ for $0.1 \leq \beta \leq 0.559$
- $Re_D \geq 16\,000\,\beta^2$ for $\beta > 0.559$

Example of application:



References:

[1] ISO 5167-1:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 1: General principles and requirements

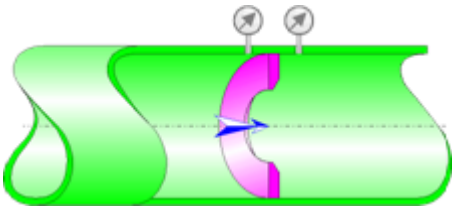
[2] ISO 5167-2:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 2: Orifice plates

2.9.1.2 ISO 5167-2:2003 - Flange pressure tappings

Square-Edge Orifice Flowmeter

Flange pressure tappings

(ISO 5167-2:2003)



Model description:

This model of component determines the fluid flow through a square-edge orifice flowmeter with flange pressure tappings, according to the international standard "ISO-5167-2:2003".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

Reynolds number referred to internal pipe diameter:

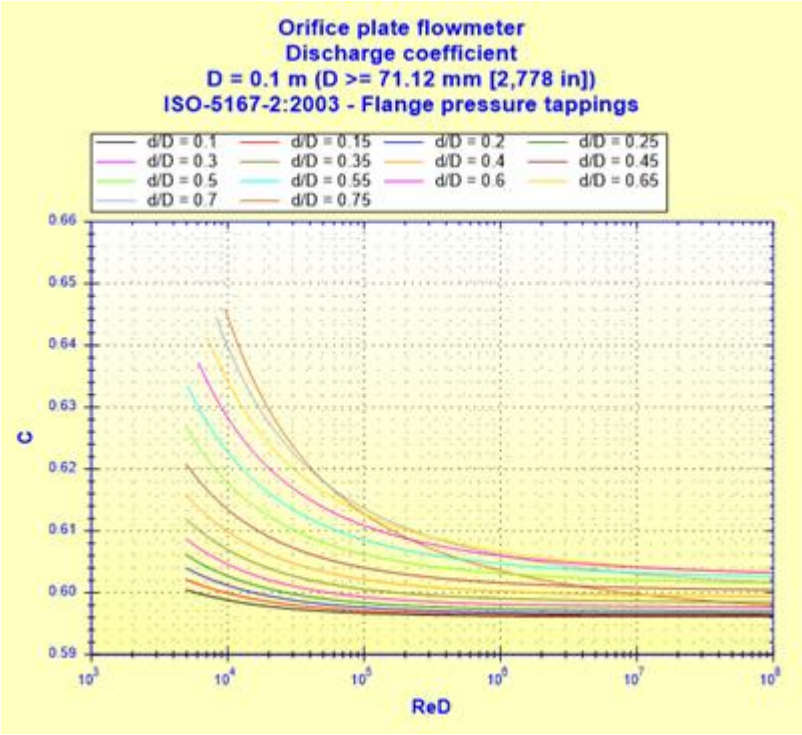
$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient (Reader-Harris/Gallagher (1998) equation):

- D ≥ 71.12 mm (2.8 in)

$$C = 0.5961 + 0.0261 \cdot \beta^2 - 0.216 \cdot \beta^8 + 0.000521 \cdot \left(\frac{10^6 \cdot \beta}{\mathrm{Re}_D}\right)^{0.7} + (0.0188 + 0.0063 \cdot A) \cdot \beta^{3.5} \cdot \left(\frac{10^6}{\mathrm{Re}_D}\right)^{0.3} + \left(0.043 + 0.08 \cdot e^{-10 \cdot L1} - 0.123 \cdot e^{-7 \cdot L1}\right) \cdot (1 - 0.11 \cdot A) \cdot \frac{\beta^4}{1 - \beta^4} - 0.031 \cdot \left(M'_2 - 0.8 \cdot M'^{1.1}_2\right) \cdot \beta^{1.3}$$

([2] § 5.3.2.1 eq. 4)



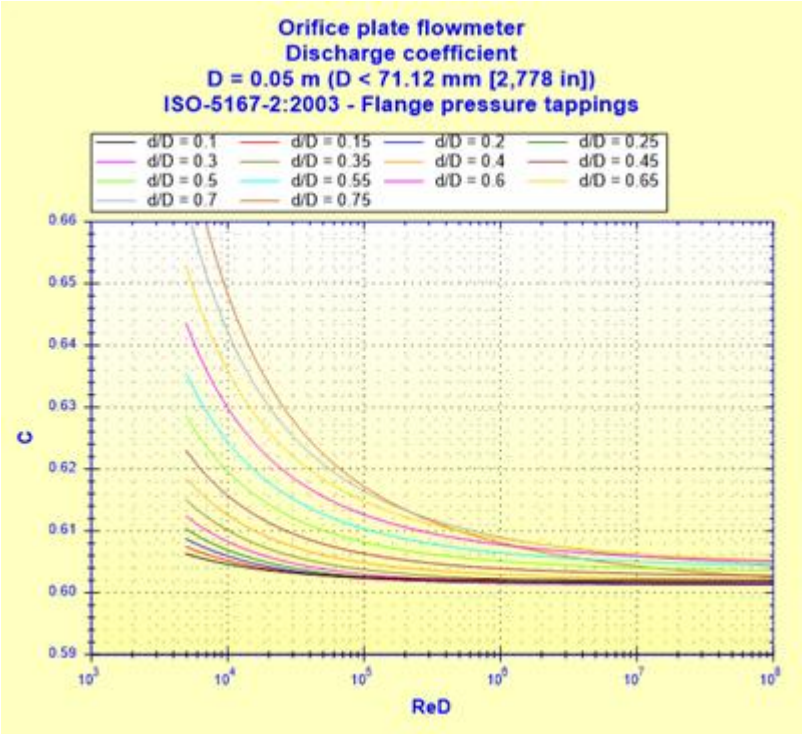
with D = 100 mm

■ D < 71.12 mm (2.8 in)

$$C = 0.5961 + 0.0261 \cdot \beta^2 - 0.216 \cdot \beta^8 + 0.000521 \cdot \left(\frac{10^6 \cdot \beta}{\mathrm{Re}_D}\right)^{0.7}$$
$$+ (0.0188 + 0.0063 \cdot A) \cdot \beta^{3.5} \cdot \left(\frac{10^6}{\mathrm{Re}_D}\right)^{0.3}$$
$$+ \left(0.043 + 0.08 \cdot e^{-10 \cdot L1} - 0.123 \cdot e^{-7 \cdot L1}\right) \cdot (1 - 0.11 \cdot A) \cdot \frac{\beta^4}{1 - \beta^4}$$
$$- 0.031 \cdot \left(M'_2 - 0.8 \cdot M'^{1.1}_2\right) \cdot \beta^{1.3}$$
$$+ 0.011 \cdot (0.75 - \beta) \cdot \left(2.8 - \frac{D}{25.4}\right)$$

([2] § 5.3.2.1 eq. 4)

Where D is the pipe diameter in mm



with D = 50 mm

where:

$$M'_2 = \frac{2 \cdot L'_2}{1-\beta}$$

$$A = \left(\frac{19000 \cdot \beta}{\mathrm{Re}_D} \right)^{0.8}$$

The values of L_1 and L'_2 to be used in this equations are as follows:

$$L_1 = L'_2 = \frac{25.4}{D}$$

where D is expressed in millimetres

Expansibility factor:

$$\varepsilon = 1$$

([1] §3.3.6) for incompressible fluid (liquid)

Mass flow rate (kg/s):

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$

([2] § 4 eq. 1)

Volume flow rate (m^3/s):

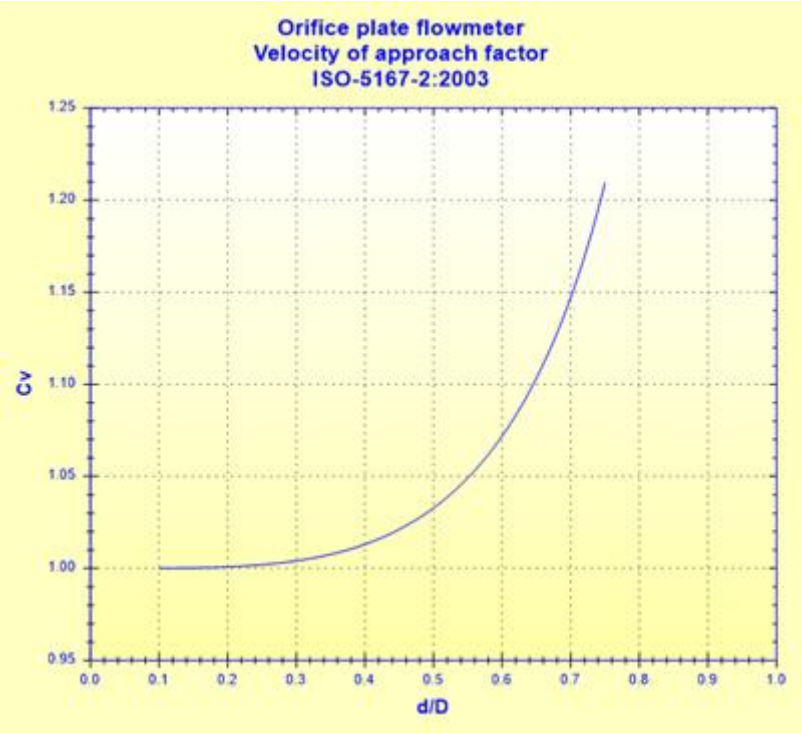
$$q_v = \frac{q_m}{\rho}$$

([2] § 4 eq. 2)

Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$

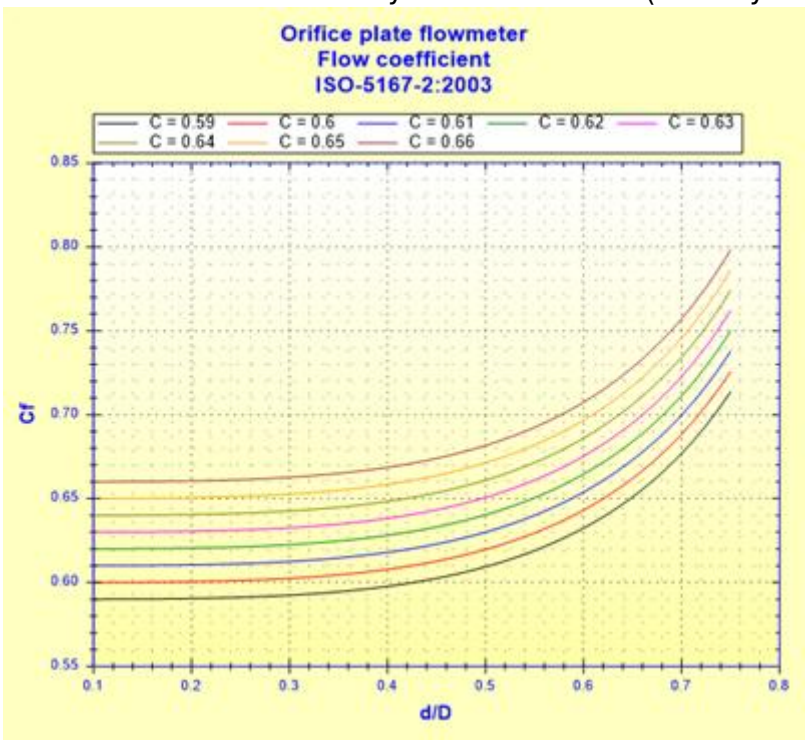
([1] §3.3.5)

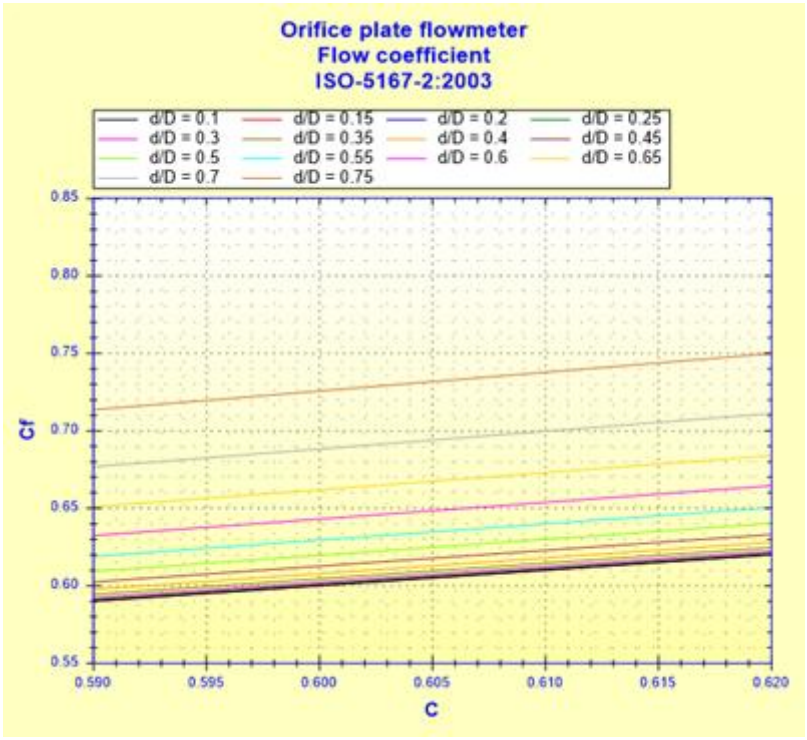


Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$

([1] §3.3.5)





Pressure loss coefficient of orifice (based on the mean pipe velocity):

$$K = \left(\frac{\sqrt{1 - \beta^4 \cdot \left(1 - C^2\right)}}{C \cdot \beta^2} - 1 \right)^2$$

([2] § 5.4.3)

Net pressure loss (Pa):

$$\Delta\varpi = \frac{\sqrt{1-\beta^4\cdot\left(1-C^2\right)}-C\cdot\beta^2}{\sqrt{1-\beta^4\cdot\left(1-C^2\right)}+C\cdot\beta^2}\cdot\Delta p$$

([2] § 5.4.1)

Net head loss (m):

$$\Delta h = \frac{\Delta\varpi}{\rho\cdot g}$$

Net hydraulic power loss (W):

$$Wh = \Delta\varpi\cdot q_V$$

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho\cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()
Re_D	Reynolds number referred to pipe ()
C	Discharge coefficient ()
L_1	Upstream relative pressure tapping spacing from the upstream face ()

L'_2 Downstream relative pressure tapping spacing from the downstream face ()

ε Expansibility factor ()

q_m Mass flow rate (kg/s)

C_v Velocity of approach factor ()

C_f Flow coefficient ()

K Pressure loss coefficient of orifice (based on the mean pipe velocity) ()

$\Delta\varpi$ Net pressure loss (Pa)

ΔP Measured pressure loss (Pa)

Δh Net head loss of fluid (m)

Wh Hydraulic power loss (W)

ΔH Measured head loss of fluid (m)

ρ Fluid density (kg/m^3)

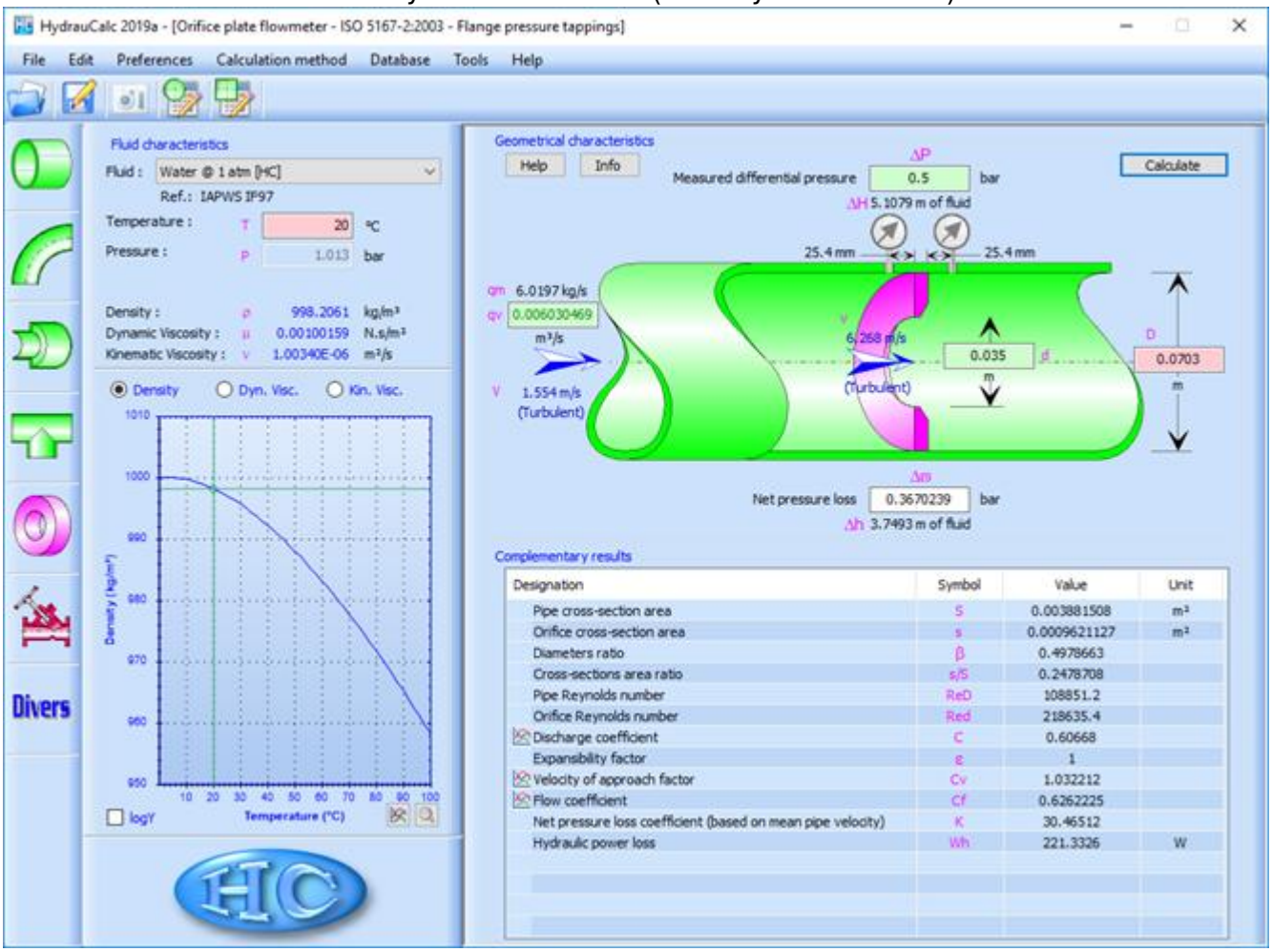
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Limit of use:

- $d \geq 12.5$ mm
- $50 \text{ mm} \leq D \leq 1\,000$ mm
- $0.1 \leq \beta \leq 0.75$
- both $Re_D \geq 5\,000$ and $Re_D \geq 170\ \beta^2\ D$
  where D is expressed in millimetres

Example of application:



References:

[1] ISO 5167-1:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 1: General principles and requirements

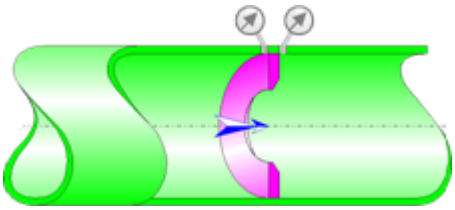
[2] ISO 5167-2:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 2: Orifice plates

2.9.1.3 ISO 5167-2:2003 - Corner pressure tappings

Square-Edge Orifice Flowmeter

Corner pressure tappings

(ISO 5167-2:2003)



Model description:

This model of component determines the fluid flow through a square-edge orifice flowmeter with corner pressure tappings, according to the international standard "ISO-5167-2:2003".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

Reynolds number referred to internal pipe diameter:

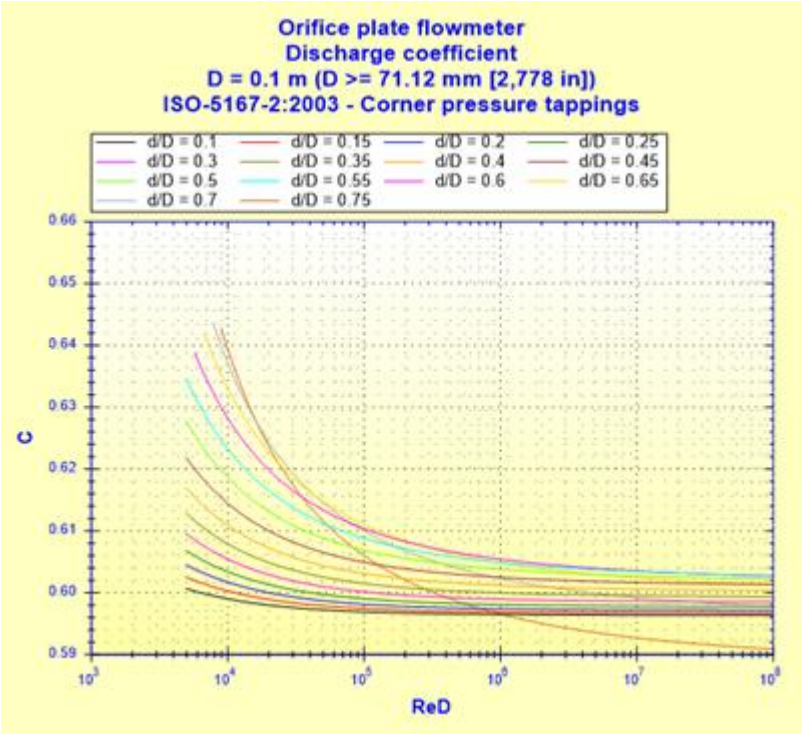
$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient (Reader-Harris/Gallagher (1998) equation):

- D ≥ 71.12 mm (2.8 in)

$$C = 0.5961 + 0.0261 \cdot \beta^2 - 0.216 \cdot \beta^8 + 0.000521 \cdot \left(\frac{10^6 \cdot \beta}{\mathrm{Re}_D}\right)^{0.7} + (0.0188 + 0.0063 \cdot A) \cdot \beta^{3.5} \cdot \left(\frac{10^6}{\mathrm{Re}_D}\right)^{0.3} + \left(0.043 + 0.08 \cdot e^{-10 \cdot L1} - 0.123 \cdot e^{-7 \cdot L1}\right) \cdot (1 - 0.11 \cdot A) \cdot \frac{\beta^4}{1 - \beta^4} - 0.031 \cdot \left(M'_2 - 0.8 \cdot M'^{1.1}_2\right) \cdot \beta^{1.3}$$

([2] § 5.3.2.1 eq. 4)



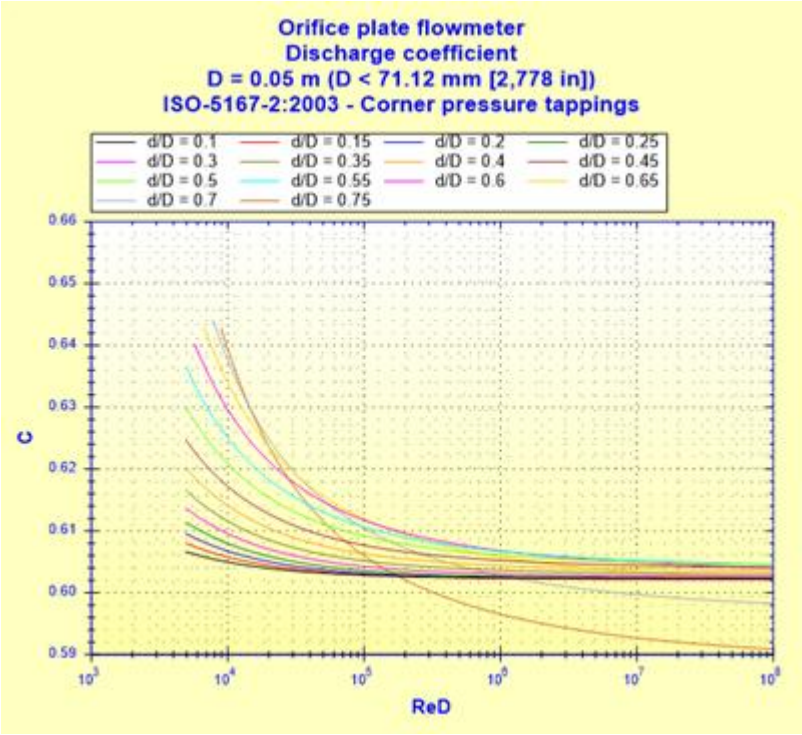
with D = 100 mm

■ D < 71.12 mm (2.8 in)

$$C = 0.5961 + 0.0261 \cdot \beta^2 - 0.216 \cdot \beta^8 + 0.000521 \cdot \left(\frac{10^6 \cdot \beta}{\mathrm{Re}_D}\right)^{0.7}$$
$$+ (0.0188 + 0.0063 \cdot A) \cdot \beta^{3.5} \cdot \left(\frac{10^6}{\mathrm{Re}_D}\right)^{0.3}$$
$$+ \left(0.043 + 0.08 \cdot e^{-10 \cdot L1} - 0.123 \cdot e^{-7 \cdot L1}\right) \cdot (1 - 0.11 \cdot A) \cdot \frac{\beta^4}{1 - \beta^4}$$
$$- 0.031 \cdot \left(M'_2 - 0.8 \cdot M'^{1.1}_2\right) \cdot \beta^{1.3}$$
$$+ 0.011 \cdot (0.75 - \beta) \cdot \left(2.8 - \frac{D}{25.4}\right)$$

([2] § 5.3.2.1 eq. 4)

Where D is the pipe diameter in mm



with D = 50 mm

where:

$$M'_2 = \frac{2 \cdot L'_2}{1-\beta}$$

$$A = \left(\frac{19000 \cdot \beta}{Re_D} \right)^{0.8}$$

The values of L_1 and L'_2 to be used in this equations are as follows:

$$L_1 = L'_2 = 0$$

Expansibility factor:

$$\varepsilon = 1$$ ([1] §3.3.6) for incompressible fluid (liquid)

Mass flow rate (kg/s):

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$ ([2] § 4 eq. 1)

Volume flow rate (m^3/s):

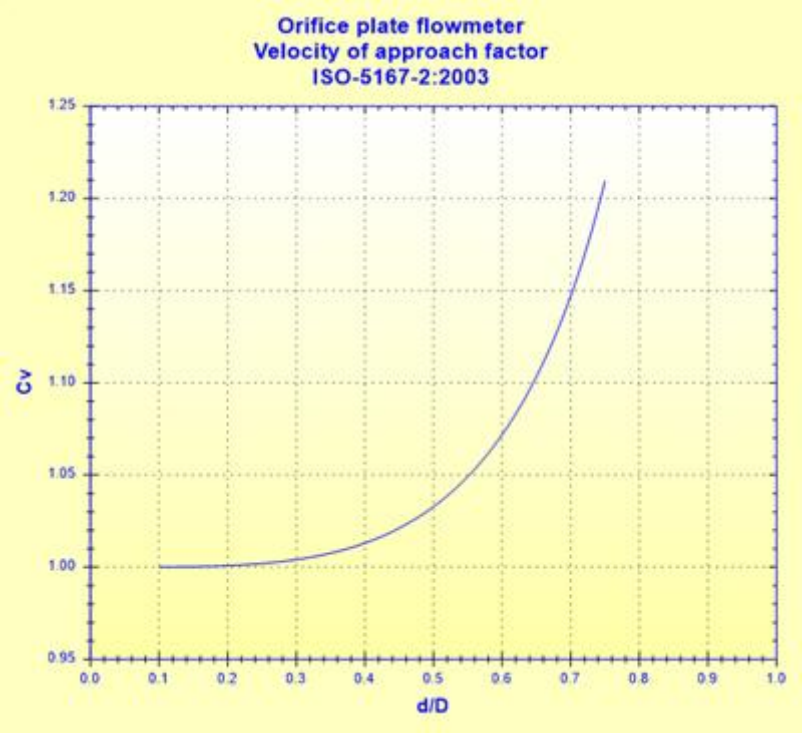
$$q_v = \frac{q_m}{\rho}$$

([2] § 4 eq. 2)

Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$

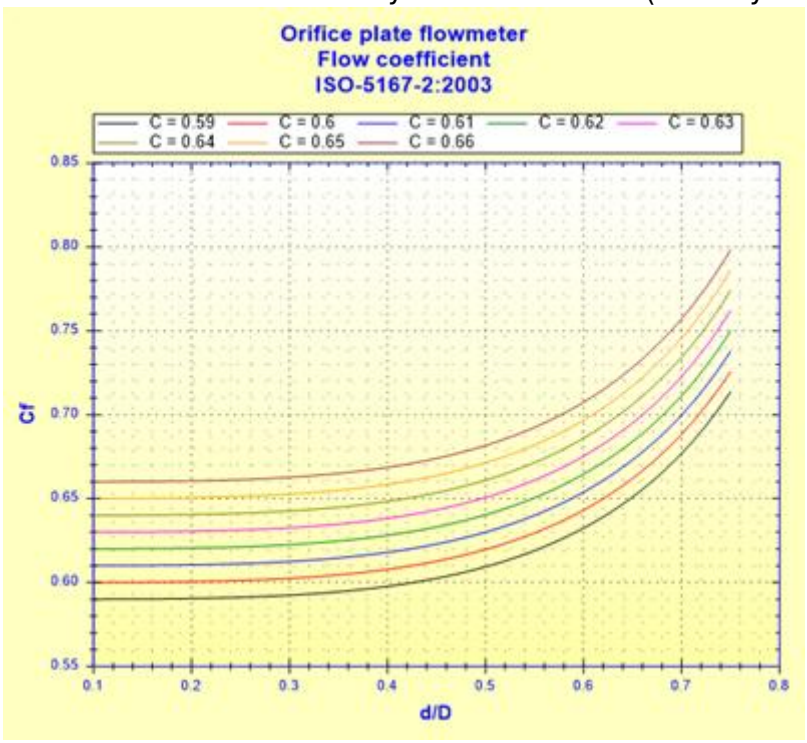
([1] §3.3.5)

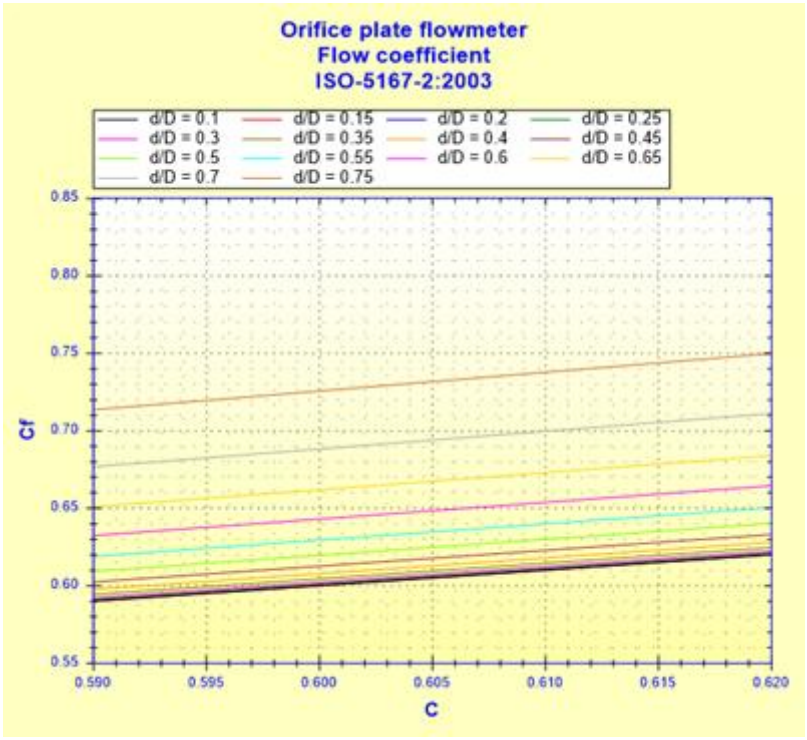


Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$

([1] §3.3.5)





Pressure loss coefficient of orifice (based on the mean pipe velocity):

$$K = \left(\frac{\sqrt{1 - \beta^4 \cdot \left(1 - C^2\right)}}{C \cdot \beta^2} - 1 \right)^2$$

([2] § 5.4.3)

Net pressure loss (Pa):

$$\Delta\varpi = \frac{\sqrt{1-\beta^4\cdot\left(1-C^2\right)}-C\cdot\beta^2}{\sqrt{1-\beta^4\cdot\left(1-C^2\right)}+C\cdot\beta^2}\cdot\Delta p$$

([2] § 5.4.1)

Net head loss (m):

$$\Delta h = \frac{\Delta\varpi}{\rho\cdot g}$$

Net hydraulic power loss (W):

$$Wh = \Delta\varpi\cdot q_V$$

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho\cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()
Re_D	Reynolds number referred to pipe ()
C	Discharge coefficient ()
L_1	Upstream relative pressure tapping spacing from the upstream face ()

L'_2 Downstream relative pressure tapping spacing from the downstream face ()

ε Expansibility factor ()

q_m Mass flow rate (kg/s)

C_v Velocity of approach factor ()

C_f Flow coefficient ()

K Pressure loss coefficient of orifice (based on the mean pipe velocity) ()

$\Delta\varpi$ Net pressure loss (Pa)

ΔP Measured pressure loss (Pa)

Δh Net head loss of fluid (m)

Wh Hydraulic power loss (W)

ΔH Measured head loss of fluid (m)

ρ Fluid density (kg/m^3)

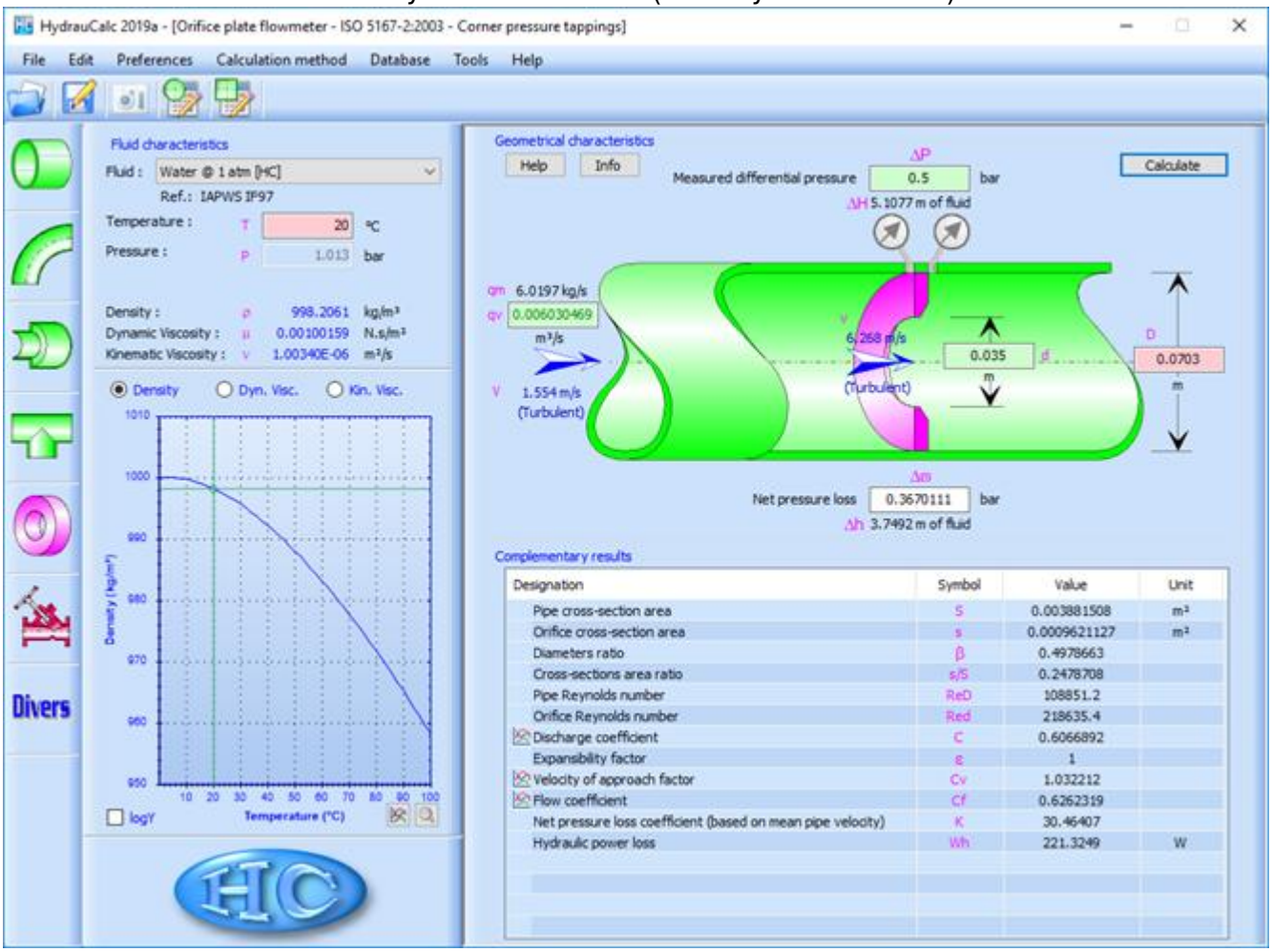
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Limit of use:

- $d \geq 12.5$ mm
- $50 \text{ mm} \leq D \leq 1\,000$ mm
- $0.1 \leq \beta \leq 0.75$
- $Re_D \geq 5\,000$ for $0.1 \leq \beta \leq 0.559$
- $Re_D \geq 16\,000\ \beta^2$ for $\beta > 0.559$

Example of application:



References:

[1] ISO 5167-1:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 1: General principles and requirements

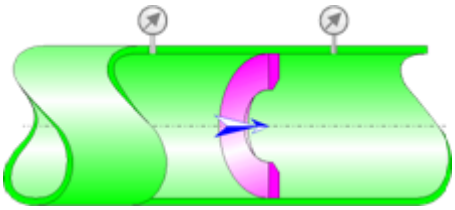
[2] ISO 5167-2:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 2: Orifice plates

2.9.1.4 ISO 5167-1:1991 - D and D/2 pressure tappings

Square-Edge Orifice Flowmeter

D and D/2 pressure tappings

(ISO 5167-1:1991)



Model description:

This model of component determines the fluid flow through a square-edge orifice flowmeter with D & D/2 pressure tappings, according to the international standard "ISO-5167-1:1991".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

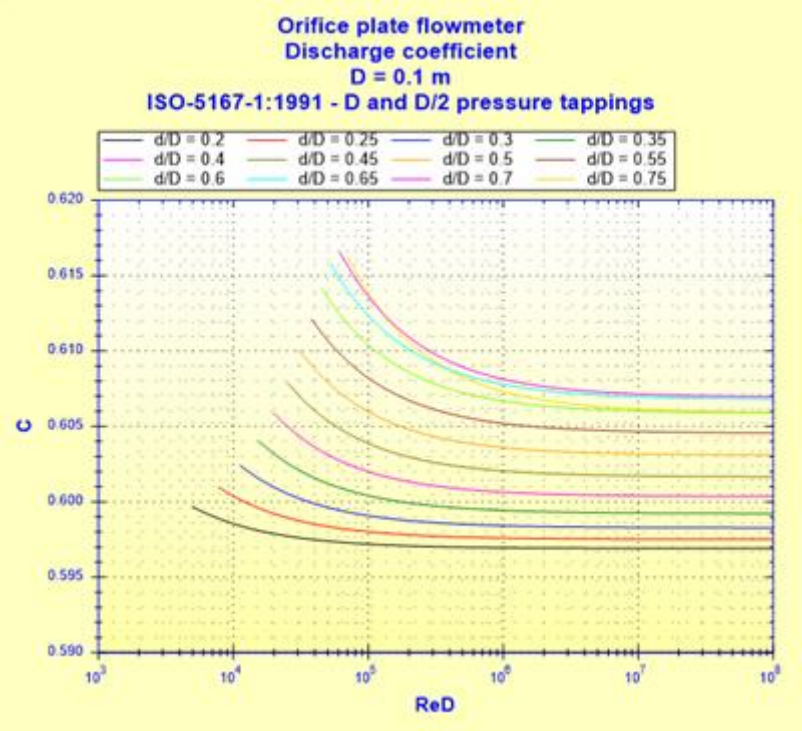
Reynolds number referred to internal pipe diameter:

$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient (Stolz equation):

$$C = 0.5959 + 0.0312 \cdot \beta^{2.1} - 0.184 \cdot \beta^{8} + 0.0029 \cdot \beta^{2.5} \cdot \left(\frac{10^6}{\mathrm{Re}_D}\right)^{0.75} + 0.09 \cdot L_1 \cdot \beta^4 \cdot \left(1-\beta^4\right)^{-1} - 0.0337 \cdot L'_2 \cdot \beta^3$$

([1] § 8.3.2.1)



with D = 100 mm

The values of L_1 and L'_2 to be used in this equation are as follows:

$$L_1 = 1$$

$$L'_2 = 0.47$$

Note: for L1 > 0.039/0.09 (=0.4333), take 0.039 as value of coefficient $\beta^4(1-\beta^4)^{-1}$

Expansibility factor:

$$\varepsilon = 1$$

([1] §3.3.5) for incompressible fluid (liquid)

Mass flow rate (kg/s):

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$

([1] § 5.1 eq. 1)

Volume flow rate (m^3/s):

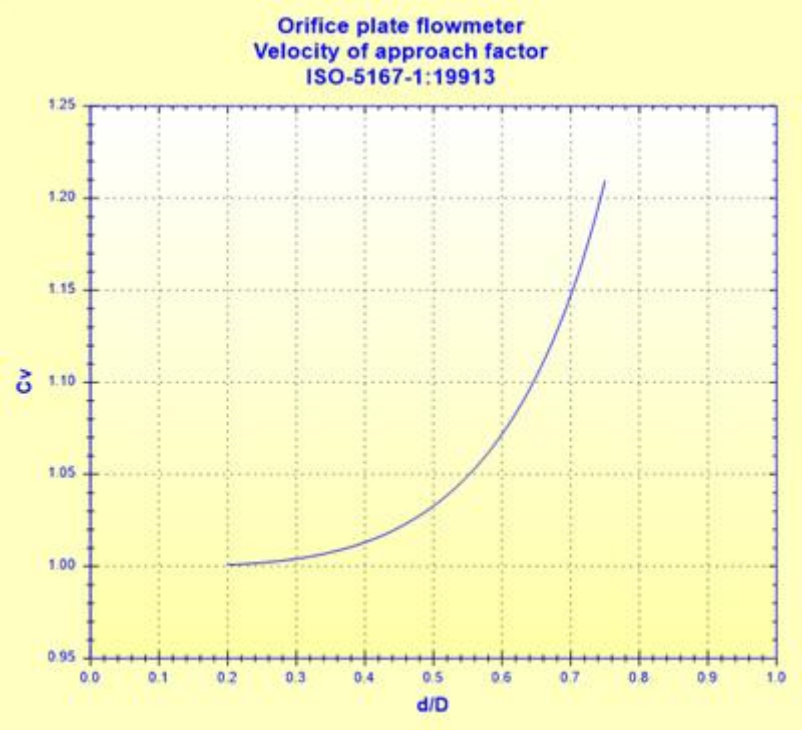
$$q_v = \frac{q_m}{\rho}$$

([1] § 5.1 eq. 3)

Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$

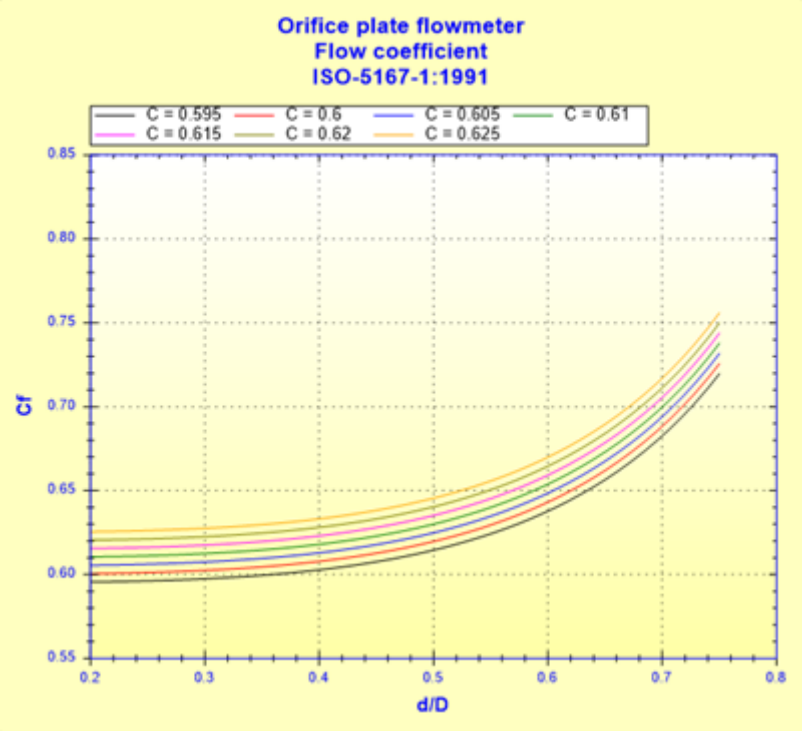
([1] §3.3.4)

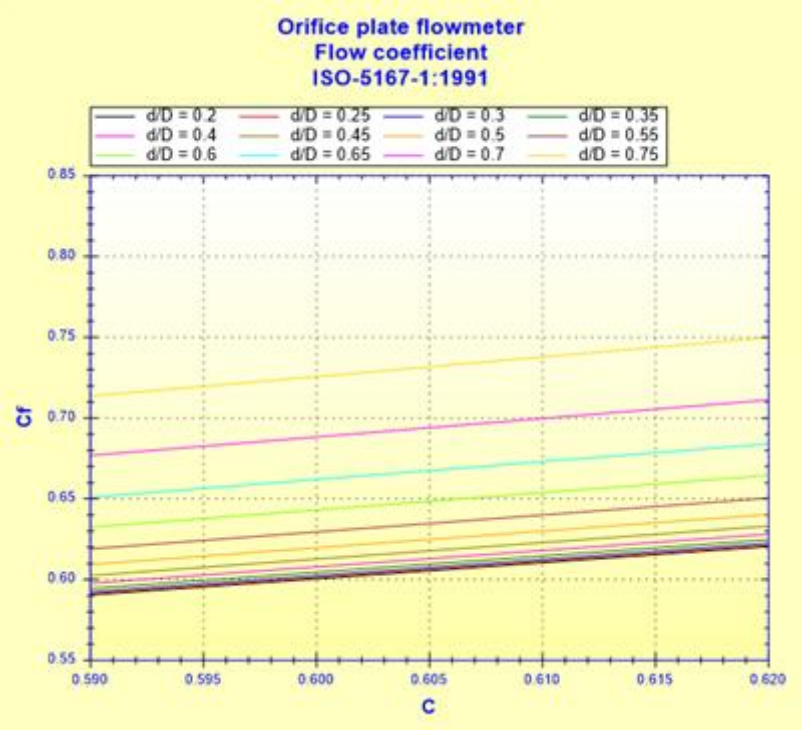


Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$

([1] §3.3.4)





Net pressure loss (Pa):

$$\Delta \varpi = \frac{\sqrt{1-\beta^4} - C \cdot \beta^2}{\sqrt{1-\beta^4} + C \cdot \beta^2} \cdot \Delta p$$

([1] § 8.4.1)

Net pressure loss coefficient (based on the mean pipe velocity):

$$K = \frac{\Delta \varpi}{0.5 \cdot \rho \cdot V^2}$$

Net head loss (m):

$$\Delta h = \frac{\Delta \varpi}{\rho \cdot g}$$

Net hydraulic power loss (W):

$$Wh = \Delta \varpi \cdot q$$

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()
Re_D	Reynolds number referred to pipe ()
C	Discharge coefficient ()
L_1	Upstream relative pressure tapping spacing from the upstream face ()
L'_2	Downstream relative pressure tapping spacing from the downstream face ()
ε	Expansibility factor ()

q_m Mass flow rate (kg/s)

C_v Velocity of approach factor ()

C_f Flow coefficient ()

$\Delta\varpi$ Net pressure loss (Pa)

ΔP Measured pressure loss (Pa)

K Net pressure loss coefficient (based on the mean pipe velocity) ()

Δh Net head loss of fluid (m)

Wh Hydraulic power loss (W)

ΔH Measured head loss of fluid (m)

ρ Fluid density (kg/m³)

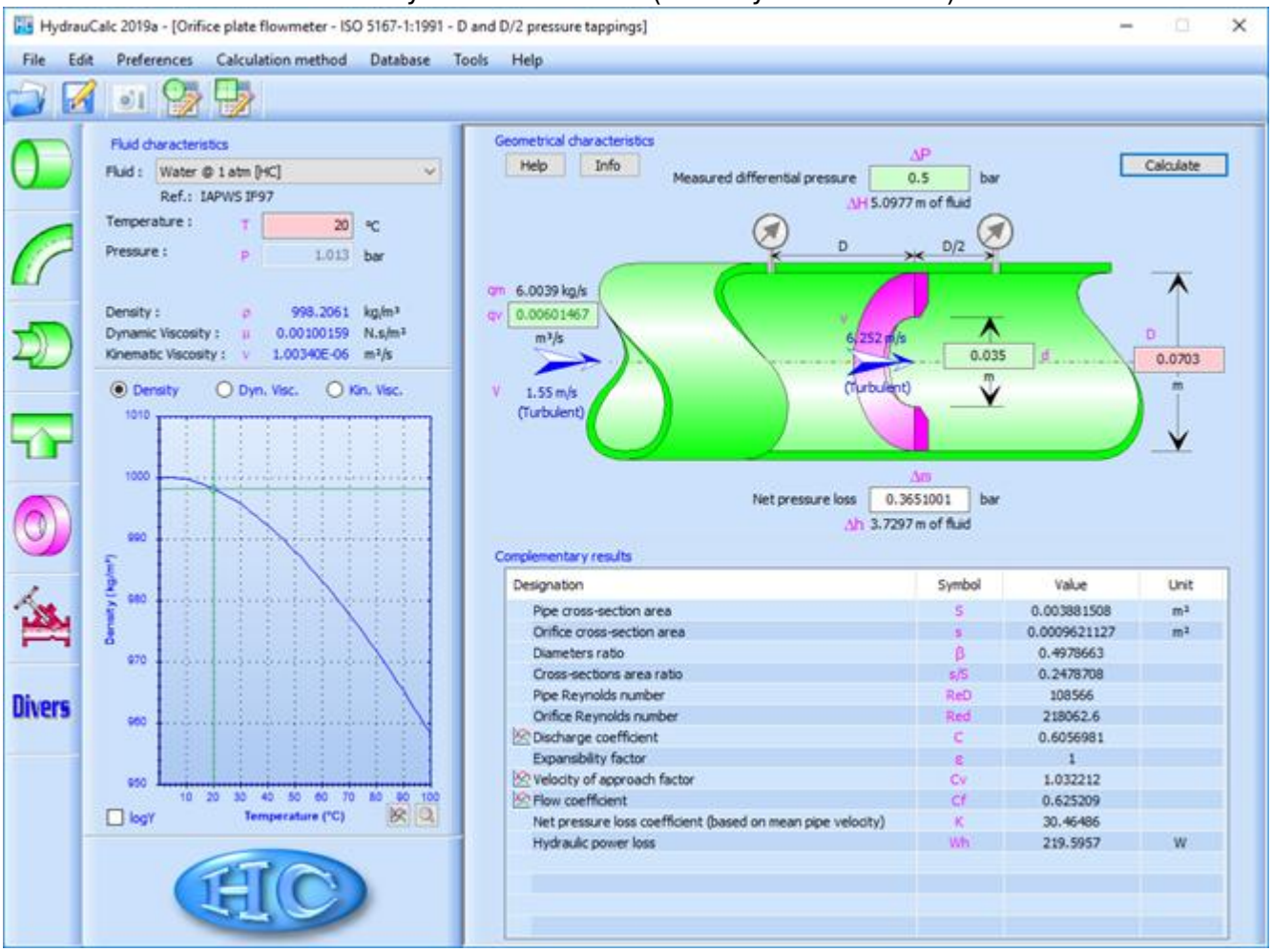
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Limit of use:

- $d > 12{,}5$ mm
- $50 \text{ mm} < D < 1\,000$ mm
- $0{,}2 < \beta < 0{,}75$
- $Re_D > 1260\ \beta^2 D$
  where D is expressed in millimetres

Example of application:



References:

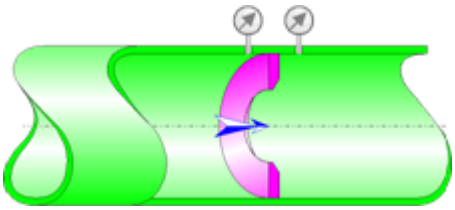
[1] ISO 5167-1:1991 - Measurement of fluid flow by means of pressure differential devices

2.9.1.5 ISO 5167-1:1991 - Flange pressure tappings

Square-Edge Orifice Flowmeter

Flange pressure tappings

(ISO 5167-1:1991)



Model description:

This model of component determines the fluid flow through a square-edge orifice flowmeter with flange pressure tappings, according to the international standard "ISO-5167-1:1991".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

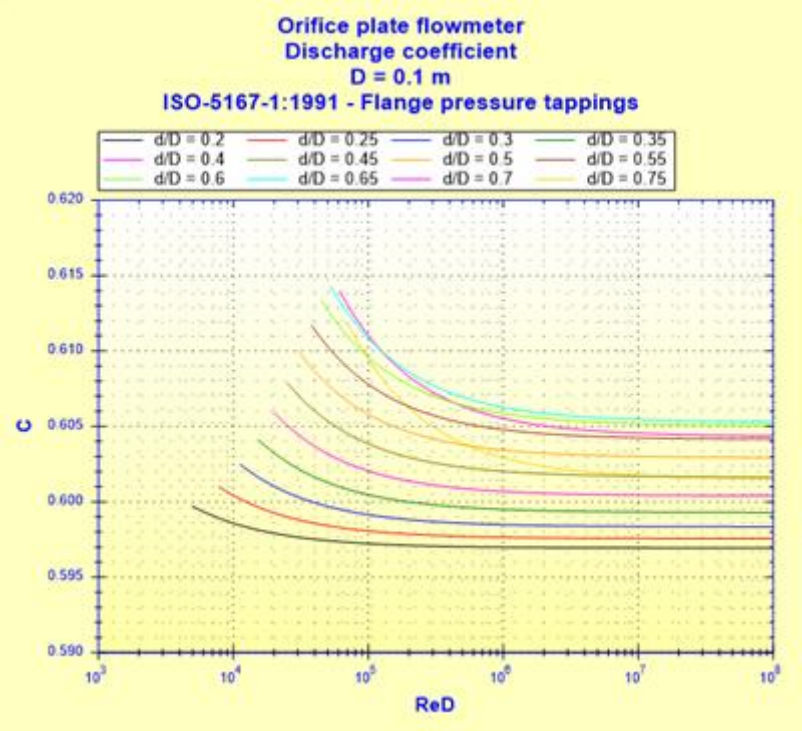
Reynolds number referred to internal pipe diameter:

$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient (Stolz equation):

$$C = 0.5959 + 0.0312 \cdot \beta^{2.1} - 0.184 \cdot \beta^{8} + 0.0029 \cdot \beta^{2.5} \cdot \left(\frac{10^6}{\mathrm{Re}_D}\right)^{0.75} + 0.09 \cdot L_1 \cdot \beta^4 \cdot \left(1-\beta^4\right)^{-1} - 0.0337 \cdot L'_2 \cdot \beta^3$$

([1] § 8.3.2.1)



with D = 100 mm

The values of L_1 and L'_2 to be used in this equations are as follows:

$$L_1 = L'_2 = \frac{25.4}{D}$$

where D is expressed in millimetres
Note: for L1 > 0.039/0.09 (=0.4333), take 0.039 as value of coefficient $\beta^4(1-\beta^4)^{-1}$

Expansibility factor:

$$\varepsilon = 1$$

([1] §3.3.5) for incompressible fluid (liquid)

Mass flow rate (kg/s):

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$

([1] § 5.1 eq. 1)

Volume flow rate (m^3/s):

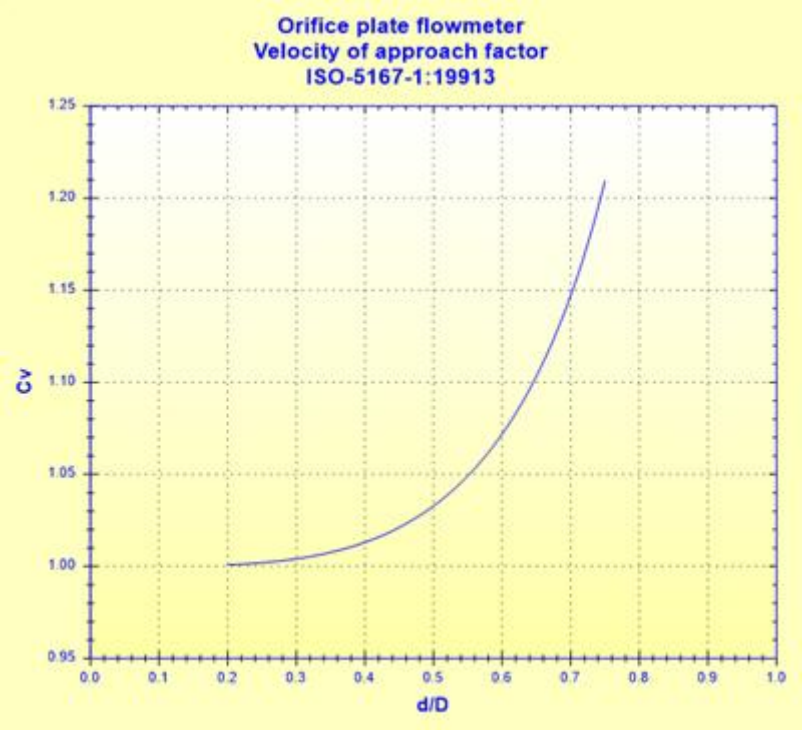
$$q_v = \frac{q_m}{\rho}$$

([1] § 5.1 eq. 3)

Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$

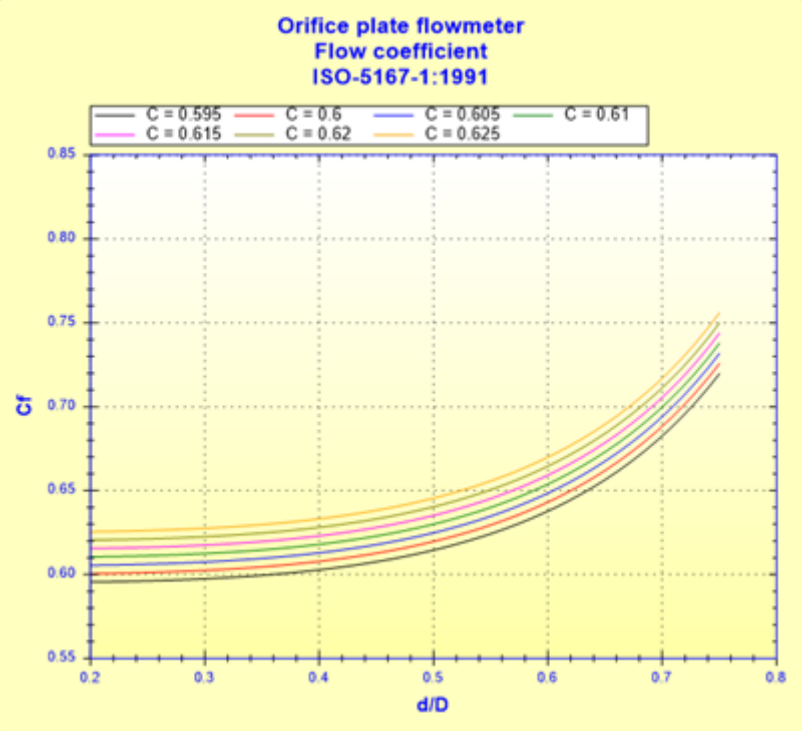
([1] §3.3.4)

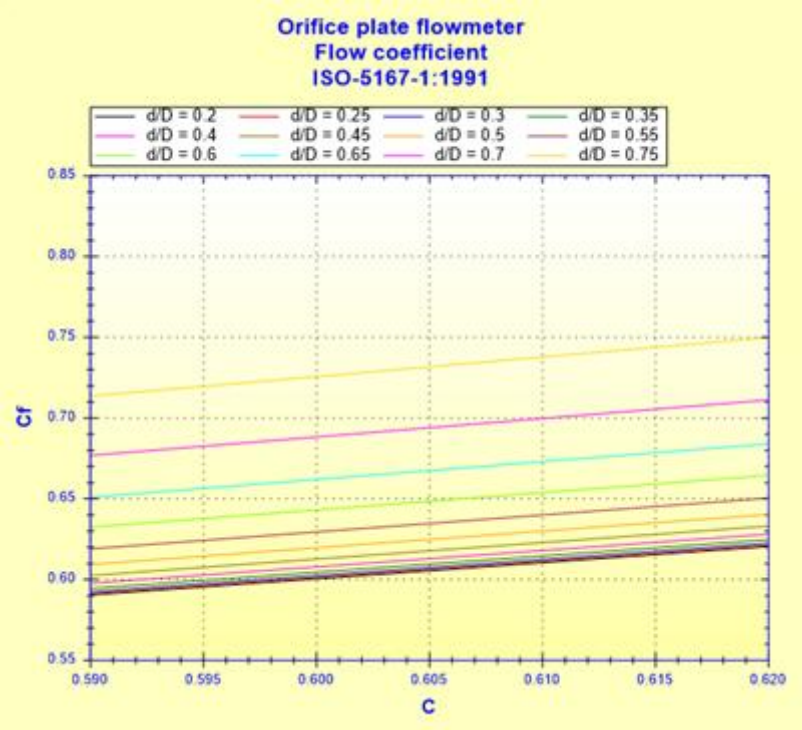


Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$

([1] §3.3.4)





Net pressure loss (Pa):

$$\Delta \varpi = \frac{\sqrt{1-\beta^4} - C \cdot \beta^2}{\sqrt{1-\beta^4} + C \cdot \beta^2} \cdot \Delta p$$

([1] § 8.4.1)

Net pressure loss coefficient (based on the mean pipe velocity):

$$K = \frac{\Delta \varpi}{0.5 \cdot \rho \cdot V^2}$$

Net head loss (m):

$$\Delta h = \frac{\Delta \varpi}{\rho \cdot g}$$

Net hydraulic power loss (W):

$$Wh = \Delta \varpi \cdot q$$

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()
Re_D	Reynolds number referred to pipe ()
C	Discharge coefficient ()
L_1	Upstream relative pressure tapping spacing from the upstream face ()
L'_2	Downstream relative pressure tapping spacing from the downstream face ()
ε	Expansibility factor ()

q_m Mass flow rate (kg/s)

C_v Velocity of approach factor ()

C_f Flow coefficient ()

$\Delta\varpi$ Net pressure loss (Pa)

ΔP Measured pressure loss (Pa)

K Net pressure loss coefficient (based on the mean pipe velocity) ()

Δh Net head loss of fluid (m)

Wh Hydraulic power loss (W)

ΔH Measured head loss of fluid (m)

ρ Fluid density (kg/m³)

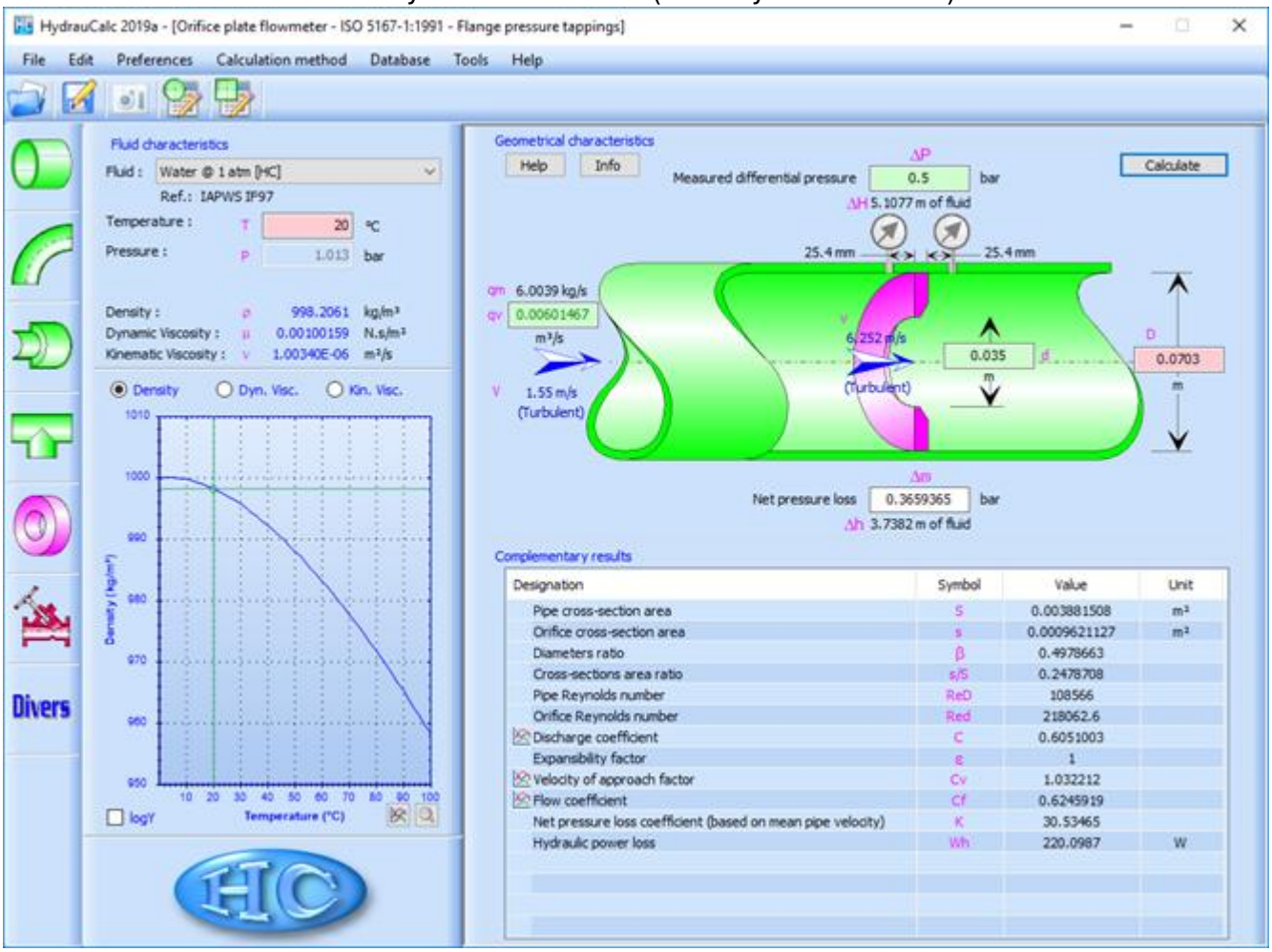
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Limit of use:

- $d > 12{,}5$ mm
- $50 \text{ mm} < D < 1\,000$ mm
- $0{,}2 < \beta < 0{,}75$
- $Re_D > 1260\ \beta^2\ D$
  where D is expressed in millimetres

Example of application:



References:

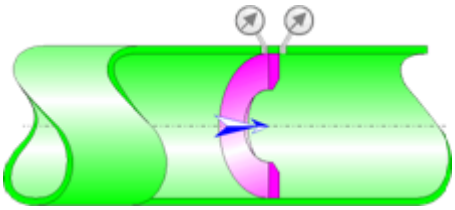
[1] ISO 5167-1:1991 - Measurement of fluid flow by means of pressure differential devices

2.9.1.6 ISO 5167-1:1991 - Corner pressure tappings

Square-Edge Orifice Flowmeter

Corner pressure tappings

(ISO 5167-1:1991)



Model description:

This model of component determines the fluid flow through a square-edge orifice flowmeter with corner pressure tappings, according to the international standard "ISO-5167-1:1991".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

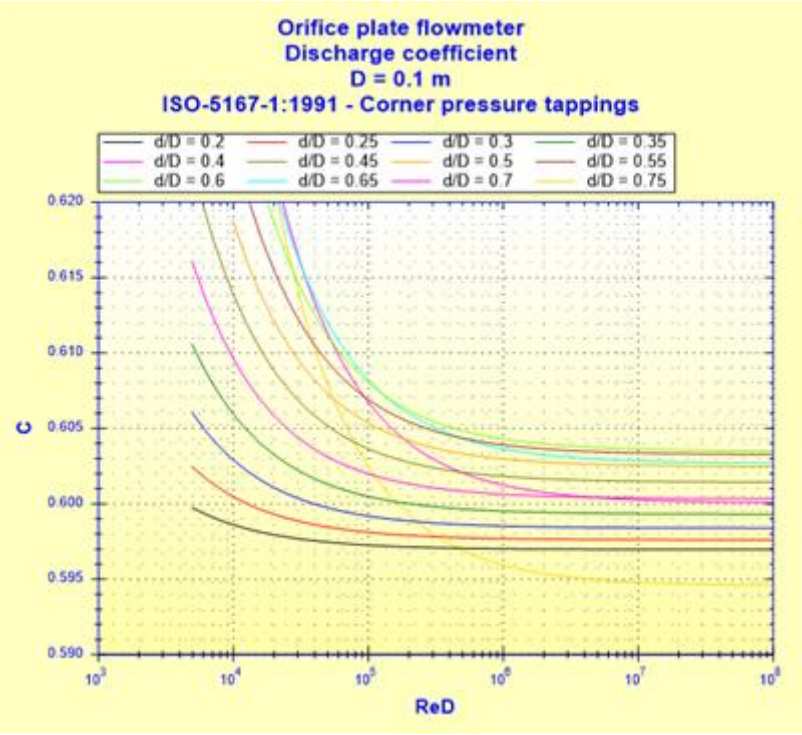
Reynolds number referred to internal pipe diameter:

$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient (Stolz equation):

$$C = 0.5959 + 0.0312 \cdot \beta^{2.1} - 0.184 \cdot \beta^{8} + 0.0029 \cdot \beta^{2.5} \cdot \left(\frac{10^6}{\mathrm{Re}_D}\right)^{0.75} + 0.09 \cdot L_1 \cdot \beta^4 \cdot \left(1-\beta^4\right)^{-1} - 0.0337 \cdot L'_2 \cdot \beta^3$$

([1] § 8.3.2.1)



with D = 100 mm

The values of L_1 and L'_2 to be used in this equations are as follows:

$$L_1 = L'_2 = 0$$

Expansibility factor:

$$\varepsilon = 1$$ ([1] §3.3.5) for incompressible fluid (liquid)

Mass flow rate (kg/s):

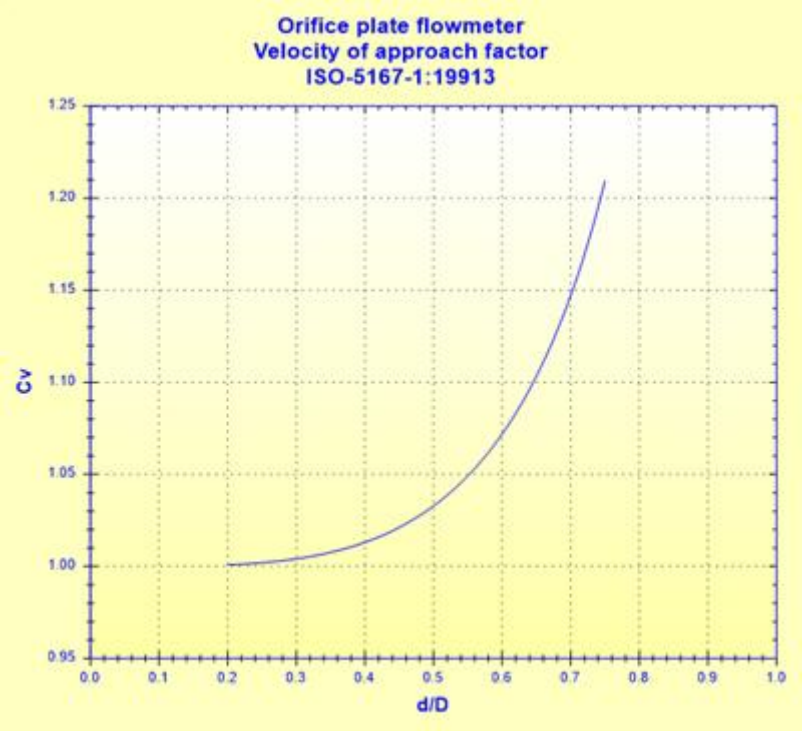
$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$ ([1] § 5.1 eq. 1)

Volume flow rate (m^3/s):

$$q_v = \frac{q_m}{\rho}$$ ([1] § 5.1 eq. 3)

Velocity of approach factor:

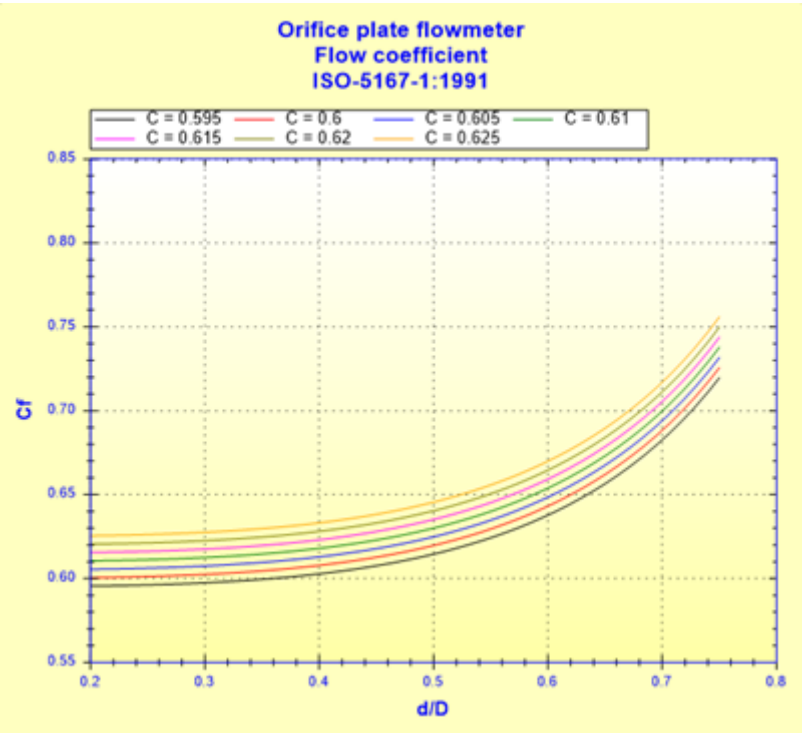
$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.4)

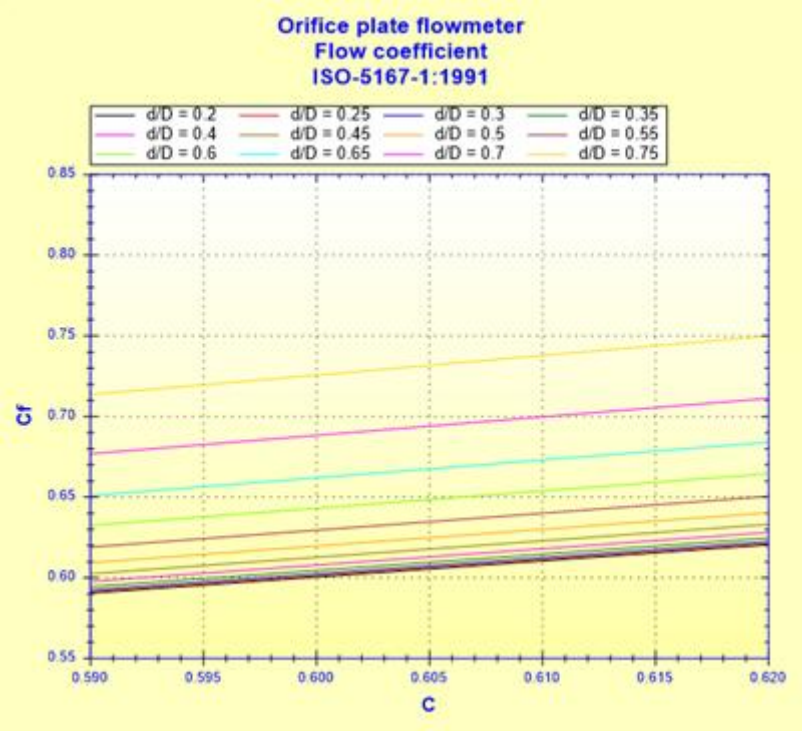


Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$

([1] §3.3.4)





Net pressure loss (Pa):

$$\Delta\varpi = \frac{\sqrt{1-\beta^4} - C\cdot\beta^2}{\sqrt{1-\beta^4} + C\cdot\beta^2}\cdot\Delta p$$

([1] § 8.4.1)

Net pressure loss coefficient (based on the mean pipe velocity):

$$K = \frac{\Delta\varpi}{0.5\cdot\rho\cdot V^2}$$

Net head loss (m):

$$\Delta h = \frac{\Delta\varpi}{\rho\cdot g}$$

Net hydraulic power loss (W):

$$Wh = \Delta\varpi\cdot q$$

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho\cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()
Re_D	Reynolds number referred to pipe ()
C	Discharge coefficient ()
L_1	Upstream relative pressure tapping spacing from the upstream face ()
L'_2	Downstream relative pressure tapping spacing from the downstream face ()
ε	Expansibility factor ()
q_m	Mass flow rate (kg/s)
C_v	Velocity of approach factor ()
C_f	Flow coefficient ()
$\Delta\varpi$	Net pressure loss (Pa)
ΔP	Measured pressure loss (Pa)
K	Net pressure loss coefficient (based on the mean pipe velocity) ()
Δh	Net head loss of fluid (m)
Wh	Hydraulic power loss (W)
ΔH	Measured head loss of fluid (m)
ρ	Fluid density (kg/m^3)

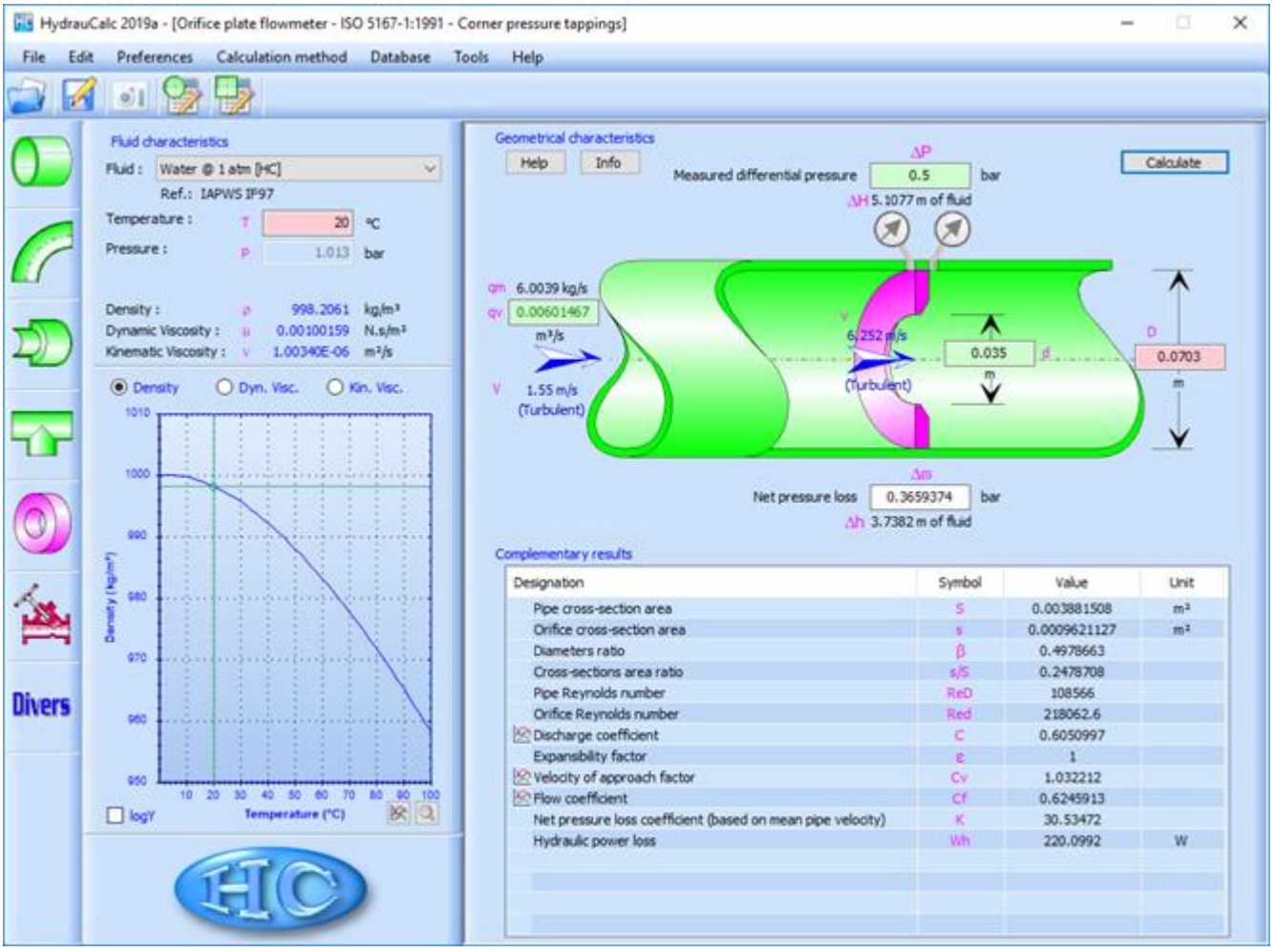
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Limit of use:

- $d > 12{,}5$ mm
- 50 mm $< D < 1\,000$ mm
- $0{,}2 < \beta < 0{,}75$
- $Re_D > 5\,000$ for $0.2 < \beta < 0.45$
- $Re_D > 10\,000$ for $\beta > 0.45$

Example of application:



References:

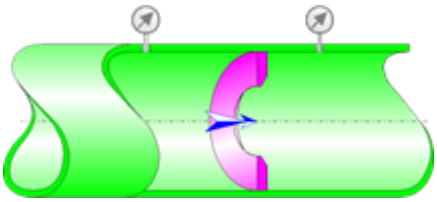
[1] ISO 5167-1:1991 - Measurement of fluid flow by means of pressure differential devices

2.9.1.7 CRANE - D and D/2 pressure tappings

Square-Edge Orifice Flowmeter

D and D/2 pressure tapings

(CRANE)



Model description:

This model of component determines the fluid flow through a square-edge orifice flowmeter with D & D/2 pressure tappings, according to the reference document [1].

Model formulation:

Diameter ratio:

$$\beta = \frac{D_1}{D_2}$$

Orifice cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Pipe cross-sectional area (m^2):

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity in orifice (m/s):

$$v_1 = \frac{q}{A_1}$$

Mean velocity in pipe (m/s):

$$v_2 = \frac{q}{A_2}$$

Reynolds number in orifice:

$$\mathrm{Re}_1 = \frac{v_1 \cdot D_1}{\nu}$$

Reynolds number in pipe:

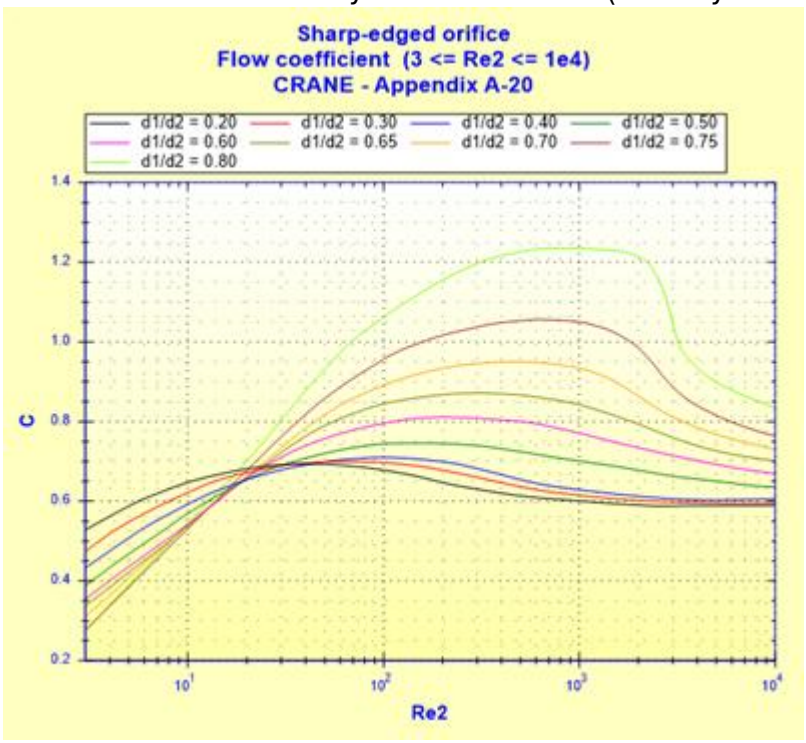
$$\mathrm{Re}_2 = \frac{v_2 \cdot D_2}{\nu}$$

Flow coefficient:

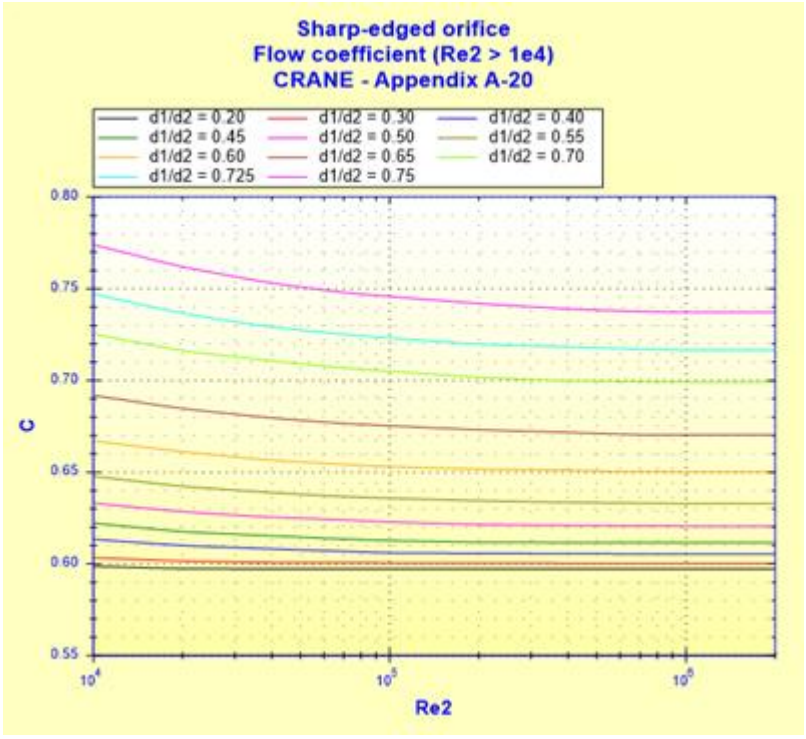
$$C = f\left(\mathrm{Re}_2, \frac{d_1}{d_2}\right)$$

([1] appendix A-20)

- $3 \leq \mathrm{Re}_2 \leq 10^4$



■ $Re_2 > 10^4$



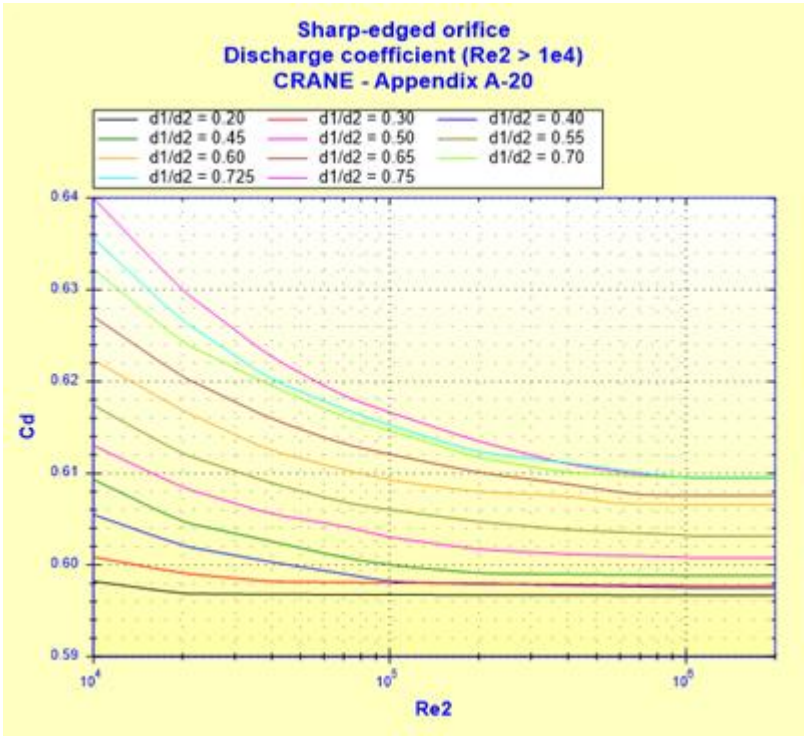
Discharge coefficient:

$$C_d = C \cdot \sqrt{1-\beta^4}$$

([1] appendix A-20)

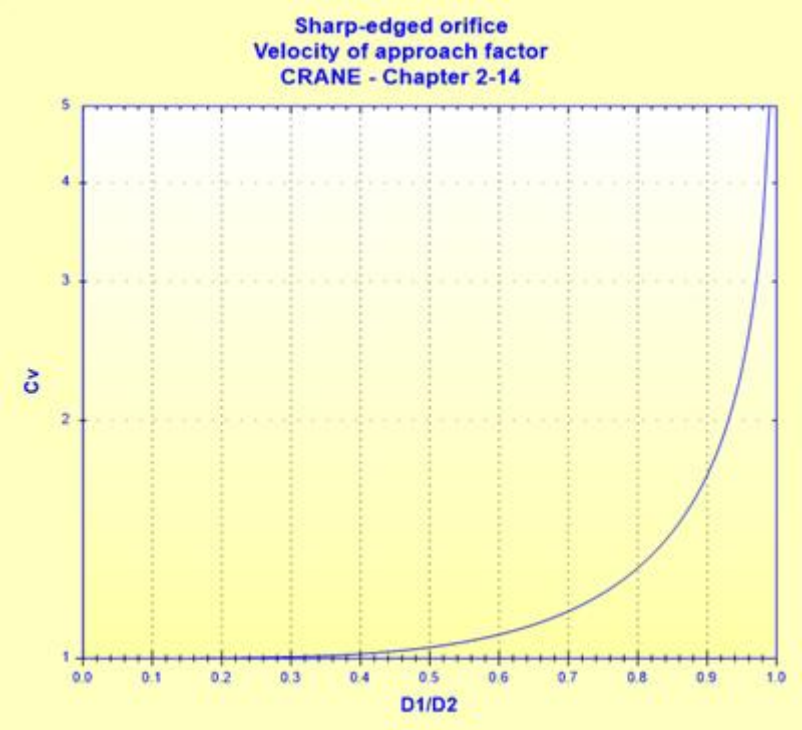
■ $3 \leq Re_2 \leq 10^4$

■ $Re_2 > 10^4$



Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$ ([1] 2-14)



Volume flow rate (m^3/s):

$$q = A_1 \cdot C \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}$$ ([1] Equation 2-23)

Mass flow rate (kg/s):

$$W = q \cdot \rho$$

Resistance coefficient of orifice (based on the mean pipe velocity):

$$K_o = \frac{1-\beta^2}{C^2 \cdot \beta^4}$$ ([1] appendix A-20)

Net pressure loss (Pa):

$$\Delta \varpi = K_o \cdot \frac{\rho \cdot v_2^2}{2}$$

Net head loss (m):

$$\Delta h = K_o \cdot \frac{v_2^2}{2 \cdot g}$$

Net hydraulic power loss (W):

$$Wh = \Delta w \cdot q$$

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

Symbols, Definitions, SI Units:

D_1	Orifice diameter (m)
D_2	Internal pipe diameter (m)
β	Diameter ratio ()
A_1	Orifice cross-sectional area (m^2)
A_2	Pipe cross-sectional area (m^2)
v_1	Mean velocity in orifice (m/s)
v_2	Mean velocity in pipe (m/s)
Re_1	Reynolds number in orifice ()
Re_2	Reynolds number in pipe ()
C	Flow coefficient ()
C_d	Discharge coefficient ()
C_v	Velocity of approach factor ()
q	Volume flow rate (m^3/s)
ΔP	Measured pressure loss (Pa)
w	Mass flow rate (kg/s)
K_o	Resistance coefficient of orifice (based on the mean pipe velocity) ()
$\Delta\varpi$	Net pressure loss (Pa)

Δh Net head loss of fluid (m)

Wh Hydraulic power loss (W)

ΔH Measured head loss of fluid (m)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Notation of equations according to sources.

Validity range:

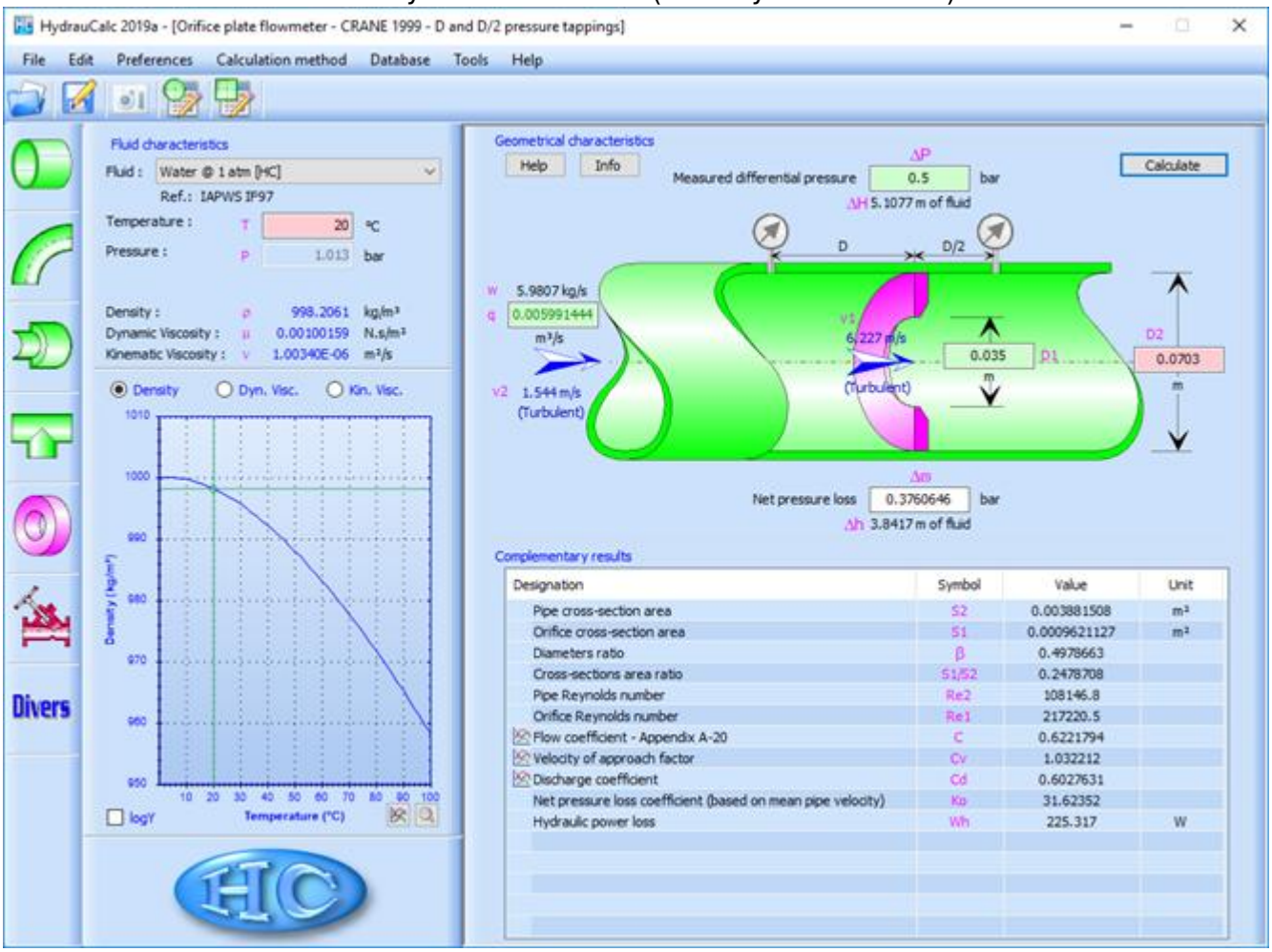
- any flow regime: laminar and turbulent
- stabilized flow upstream of the orifice

note: 1) for Reynolds number "Re_2" between 3 and 10^4, and diameter ratio "D_1/ D_2" lower than 0.2 or greater than 0.8, the flow coefficient "*C*" is extrapolated

2) for Reynolds number "Re_2" between 10^4 and 2.10^6, and diameter ratio "D_1/ D_2" lower than 0.2 or greater than 0.75, the flow coefficient "*C*" is extrapolated

---

Example of application:

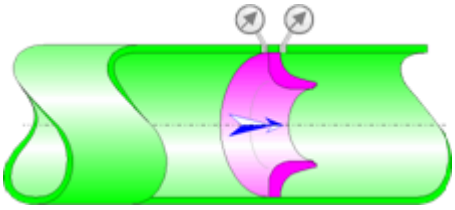


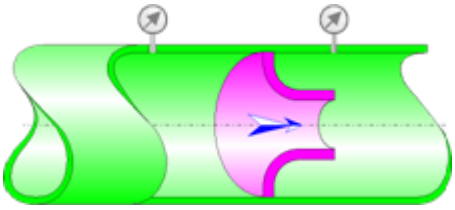
References:

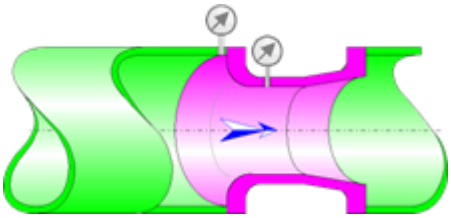
[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 – Edition 1999

2.9.2 Nozzle and Venturi nozzle flowmeter

Nozzles and Venturi nozzles





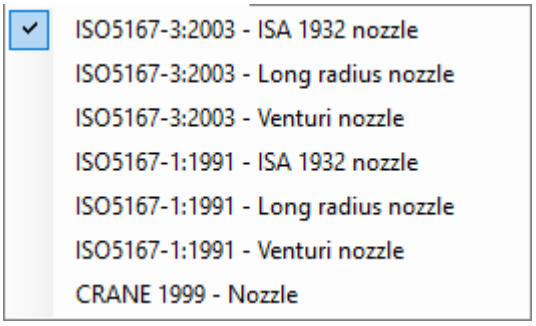


For the determination of the fluid flow through a nozzle or Venturi nozzle flowmeter, the user can choose from one of the methods described in the following three reference documents:

- ISO 5167:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
  Part 1: General principles and requirements
  Part 3: Nozzles and Venturi nozzles
- ISO 5167:1991 - Measurement of fluid flow by means of pressure differential devices
- CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999

The calculation method is selected using the "Calculation method" menu. The default option is "ISO 5167-3:2003 – ISA 1932 nozzle"

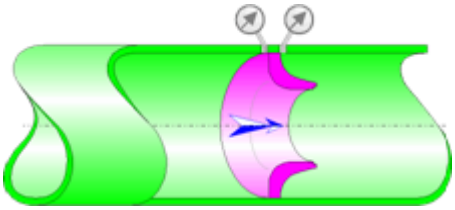
Calculation method



2.9.2.1 ISO 5167-3:2003 - ISA 1932 nozzle

ISA 1932 nozzle

(ISO 5167-3:2003)



Model description:

This model of component determines the fluid flow through a ISA 1932 nozzle flowmeter, according to the international standard "ISO-5167-3:2003".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

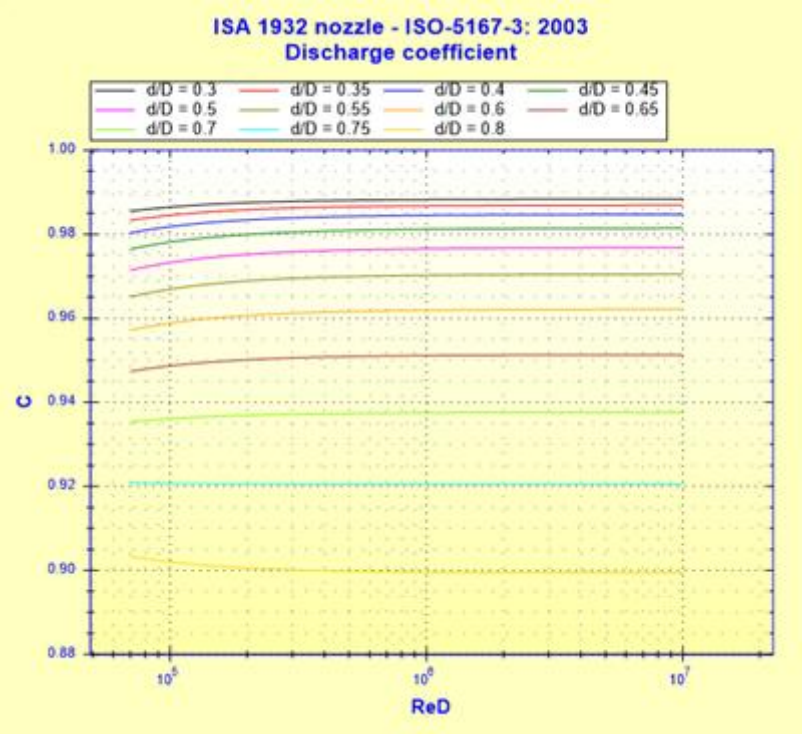
Reynolds number referred to internal pipe diameter:

$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient:

$$C = 0.99 - 0.2262 \cdot \beta^{4.1} - \left(0.00175 \cdot \beta^2 - 0.0033 \cdot \beta^{4.15}\right) \cdot \left(\frac{10^6}{\mathrm{Re}_D}\right)^{1.15}$$

([2] §5.1.6.2 eq. 3)



Expansibility factor:

$$\varepsilon = 1$$ ([1] §3.3.6) for incompressible fluid (liquid)

Mass flow rate (kg/s):

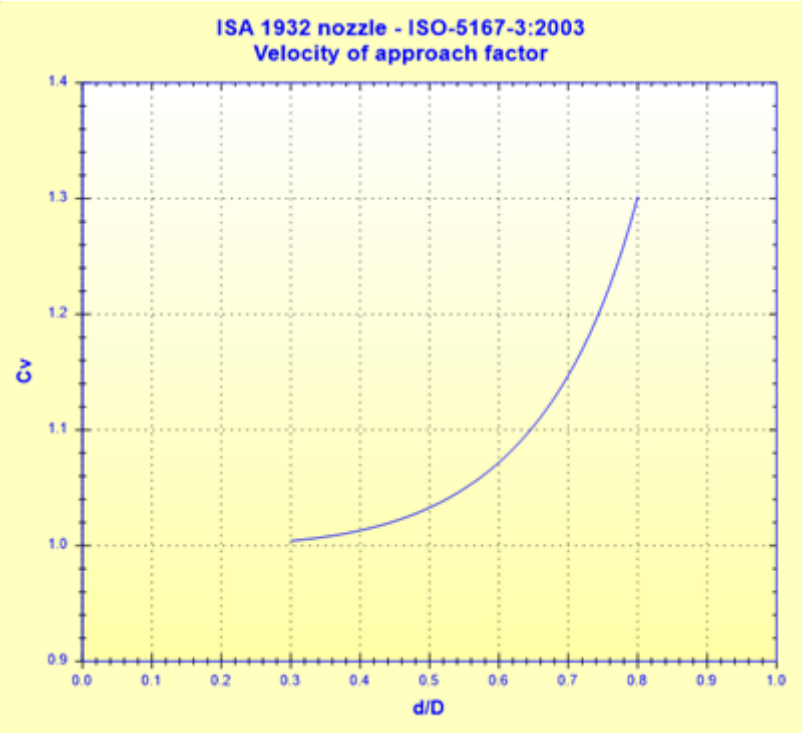
$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$ ([1] §5.1 eq. 1 and [2] §4 eq. 1))

Volume flow rate (m^3/s):

$$q_v = \frac{q_m}{\rho}$$ ([1] §5.1 eq. 3 and [2] §4 eq. 2))

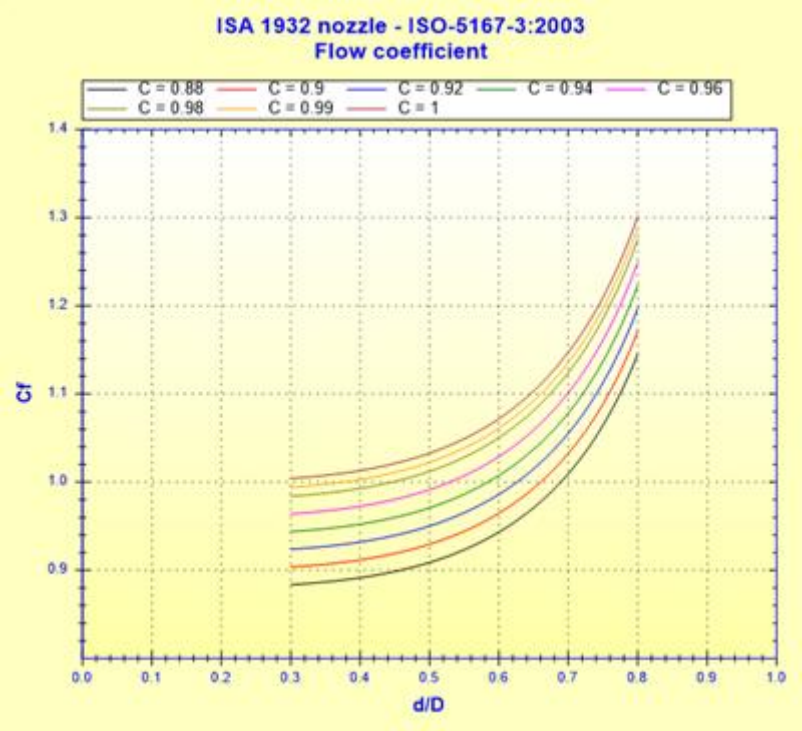
Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.5)



Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.5)



Net pressure loss (Pa):

$$\Delta\varpi = \frac{\sqrt{1-\beta^4} - C\cdot\beta^2}{\sqrt{1-\beta^4} + C\cdot\beta^2}\cdot\Delta p$$

([1] § 5.1.8 eq. 5)

Net pressure loss coefficient (based on the mean pipe velocity):

$$K = \frac{\Delta\varpi}{0.5\cdot\rho\cdot V^2}$$

([1] § 5.1.8 eq. 7)

Net head loss (m):

$$\Delta h = \frac{\Delta\varpi}{\rho\cdot g}$$

Net hydraulic power loss (W):

$$Wh = \Delta\varpi\cdot q$$

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho\cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()
Re_D	Reynolds number referred to pipe ()
C	Discharge coefficient ()
ε	Expansibility factor ()
q_m	Mass flow rate (kg/s)
C_v	Velocity of approach factor ()
C_f	Flow coefficient ()
$\Delta\varpi$	Net pressure loss (Pa)
ΔP	Measured pressure loss (Pa)
K	Net pressure loss coefficient (based on the mean pipe velocity) ()
Δh	Net head loss of fluid (m)
Wh	Net hydraulic power loss (W)
ΔH	Measured head loss of fluid (m)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

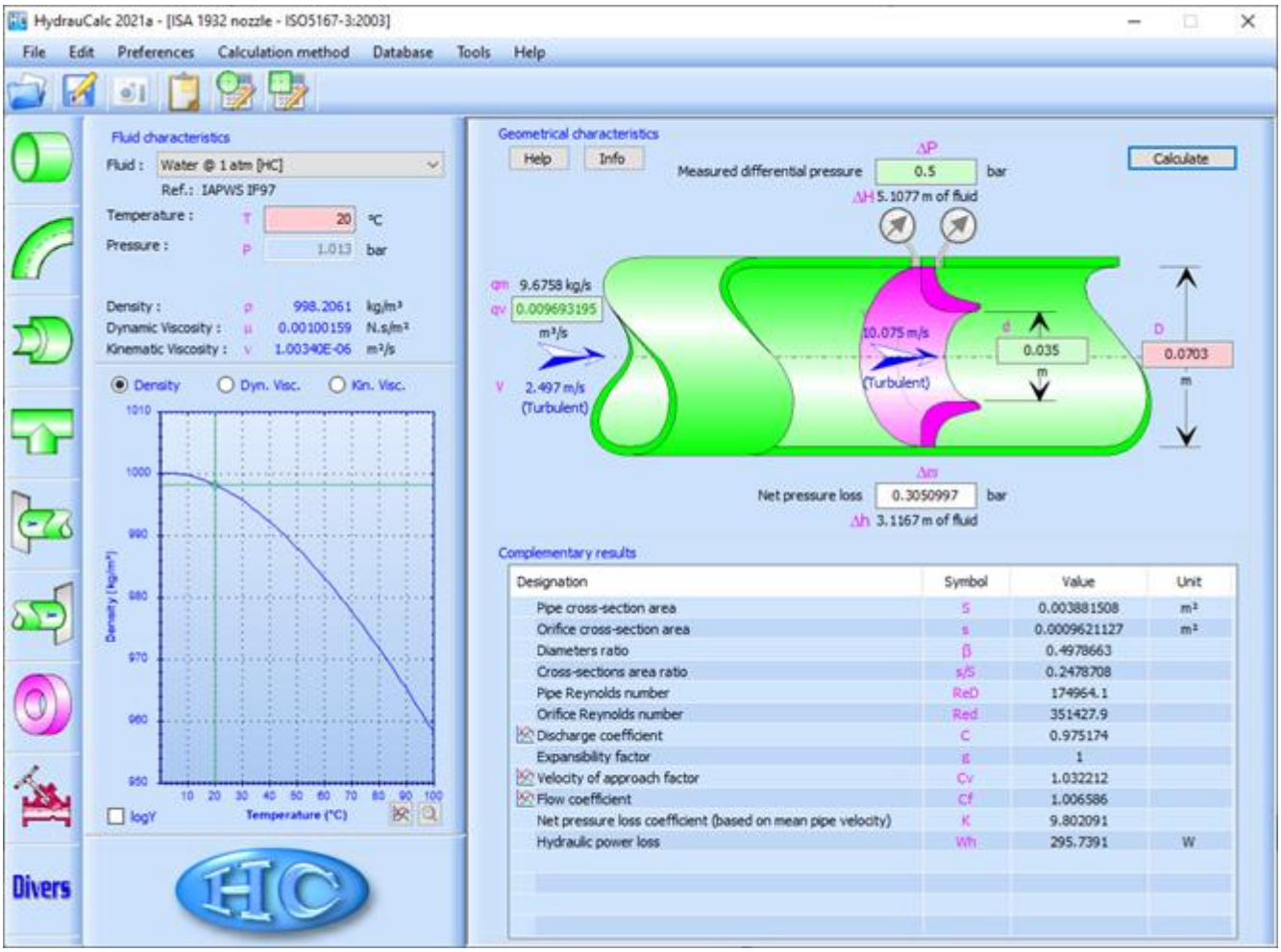
Limit of use ([2] §5.1.6.1):

- 50 mm ≤ D ≤ 500 mm
- $0.3 \leq \beta \leq 0.8$

  $0.3 \leq \beta < 0.44$ for $7 \cdot 10^4 \leq Re_D \leq 10^7$

  $0.44 \leq \beta \leq 0.8$ for $2 \cdot 10^4 \leq Re_D \leq 10^7$

Example of application:



References:

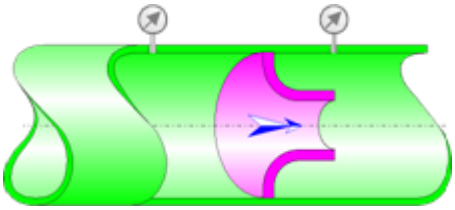
[1] ISO 5167-1:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 1: General principles and requirements

[2] ISO 5167-3:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 3: Nozzles and Venturi nozzles

2.9.2.2 ISO 5167-3:2003 - Long radius nozzle

Long radius nozzle

(ISO 5167-3:2003)



Model description:

This model of component determines the fluid flow through a long radius nozzle flowmeter, according to the international standard "ISO-5167-3:2003".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$V = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

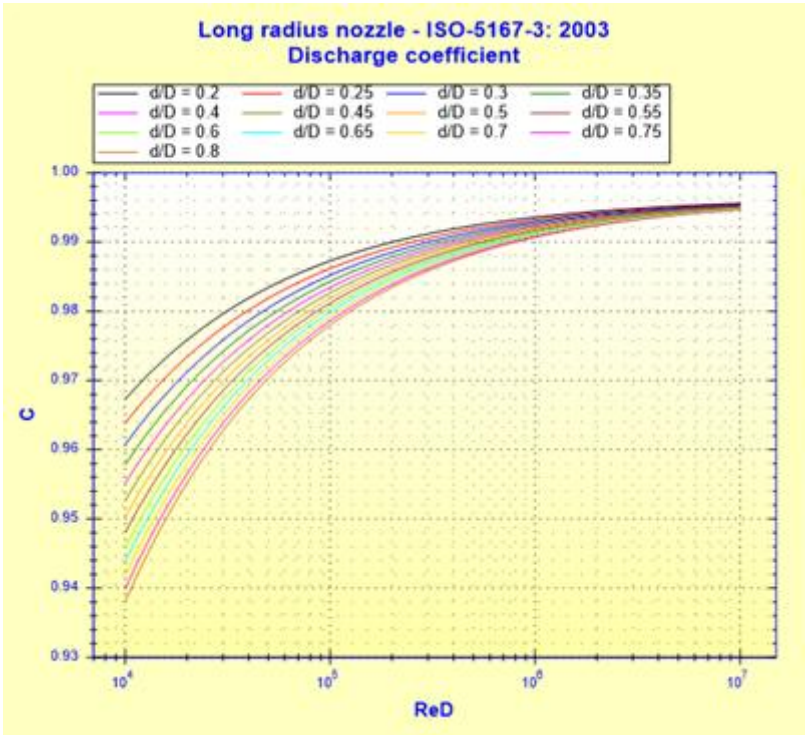
$$\mathrm{Re}_d = \frac{V \cdot d}{\nu}$$

Reynolds number referred to internal pipe diameter:

$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient:

$$C = 0.9965 - 0.00653 \cdot \sqrt{\frac{10^6 \cdot \beta}{\mathrm{Re}_D}}$$ ([2] §5.2.6.2 eq. 8)



Expansibility factor:

$$\varepsilon = 1$$

([1] §3.3.6) for incompressible fluid (liquid)

Mass flow rate (kg/s):

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$

([1] §5.1 eq. 1 and [2] §4 eq. 1)

Volume flow rate (m^3/s):

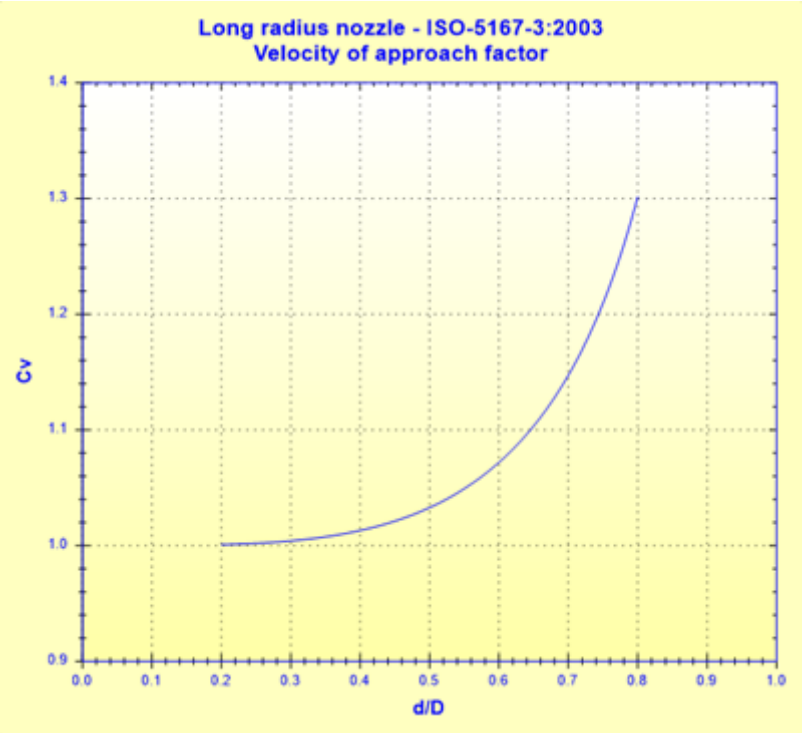
$$q_v = \frac{q_m}{\rho}$$

([1] §5.1 eq. 3 and [2] §4 eq. 2)

Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$

([1] §3.3.4)



Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$

([1] §3.3.5)

Net pressure loss (Pa):

$$\Delta\varpi = \frac{\sqrt{1-\beta^4} - C\cdot\beta^2}{\sqrt{1-\beta^4} + C\cdot\beta^2}\cdot\Delta p$$

([1] § 5.1.8 eq. 5)

Net pressure loss coefficient (based on the mean pipe velocity):

$$K = \frac{\Delta\varpi}{0.5\cdot\rho\cdot V^2}$$

([1] § 5.1.8 eq. 7)

Net head loss (m):

$$\Delta h = \frac{\Delta\varpi}{\rho\cdot g}$$

Net hydraulic power loss (W):

$$Wh = \Delta\varpi\cdot q$$

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho\cdot g}$$

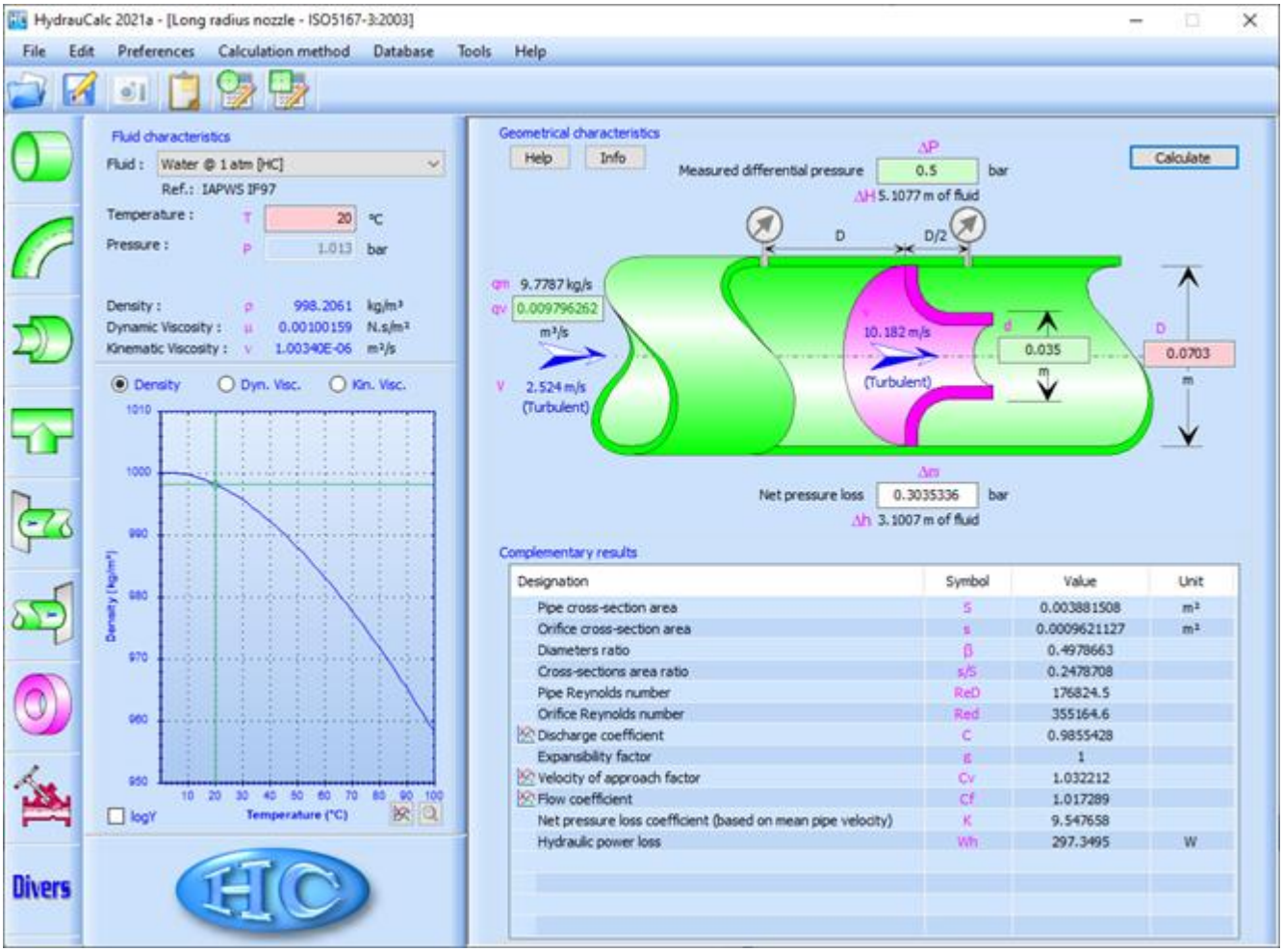
Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()
Re_D	Reynolds number referred to pipe ()
C	Discharge coefficient ()
ε	Expansibility factor ()
q_m	Mass flow rate (kg/s)
C_v	Velocity of approach factor ()
C_f	Flow coefficient ()
$\Delta\varpi$	Net pressure loss (Pa)
ΔP	Measured pressure loss (Pa)
K	Net pressure loss coefficient (based on the mean pipe velocity) ()
Δh	Net head loss of fluid (m)
Wh	Net hydraulic power loss (W)
ΔH	Measured head loss of fluid (m)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Limit of use ([2] §5.2.6.1):

- $50\ mm \leq D \leq 630\ mm$
- $0.2 \leq \beta \leq 0.8$
- $10^4 \leq Re_D \leq 10^7$

Example of application:



References:

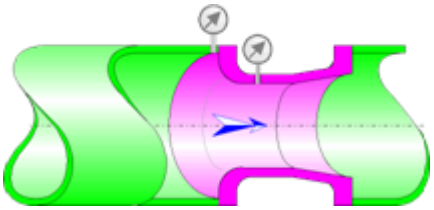
[1] ISO 5167-1:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 1: General principles and requirements

[2] ISO 5167-3:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 3: Nozzles and Venturi nozzles

2.9.2.3 ISO 5167-3:2003 - Venturi nozzle

Venturi nozzle

(ISO 5167-3:2003)



Model description:

This model of component determines the fluid flow through a Venturi nozzle flowmeter, according to the international standard "ISO-5167-3:2003".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

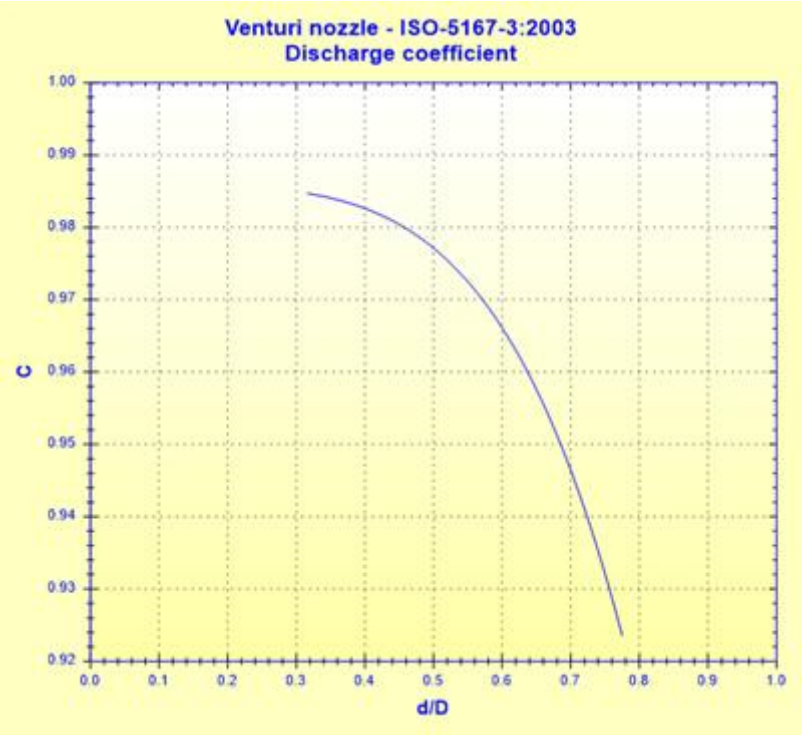
$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

Reynolds number referred to internal pipe diameter:

$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient:

$$C = 0.9858 - 0.196 \cdot \beta^{4.5}$$ ([2] § 5.3.4.2)



Expansibility factor:

$\varepsilon = 1$ ([1] §3.3.6) for incompressible fluid (liquid)

Mass flow rate (kg/s):

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$

([1] §5.1 eq. 1 and [2] §4 eq. 1)

Volume flow rate (m^3/s):

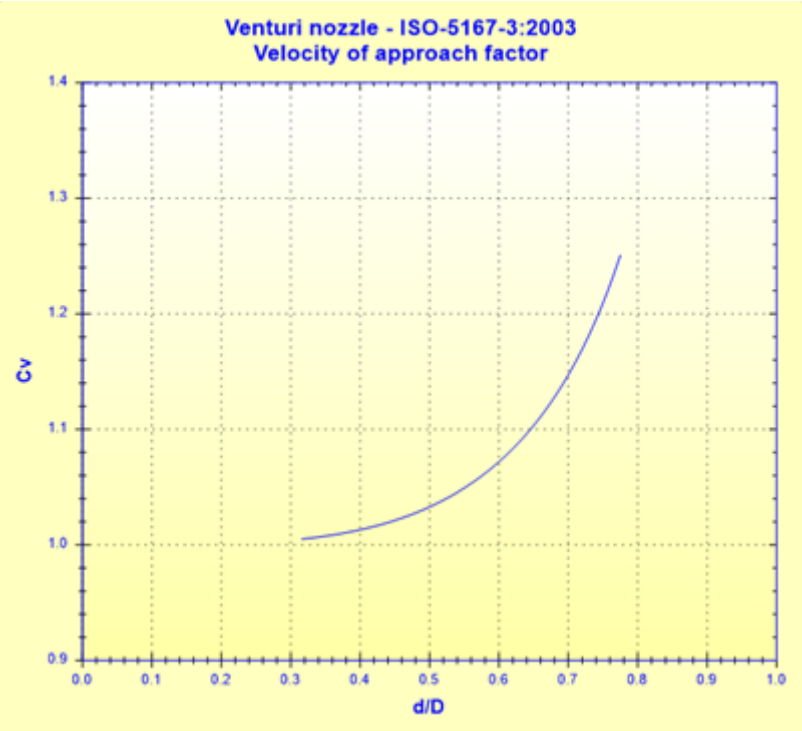
$$q_v = \frac{q_m}{\rho}$$

([1] §5.1 eq. 3 and [2] §4 eq. 2)

Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$

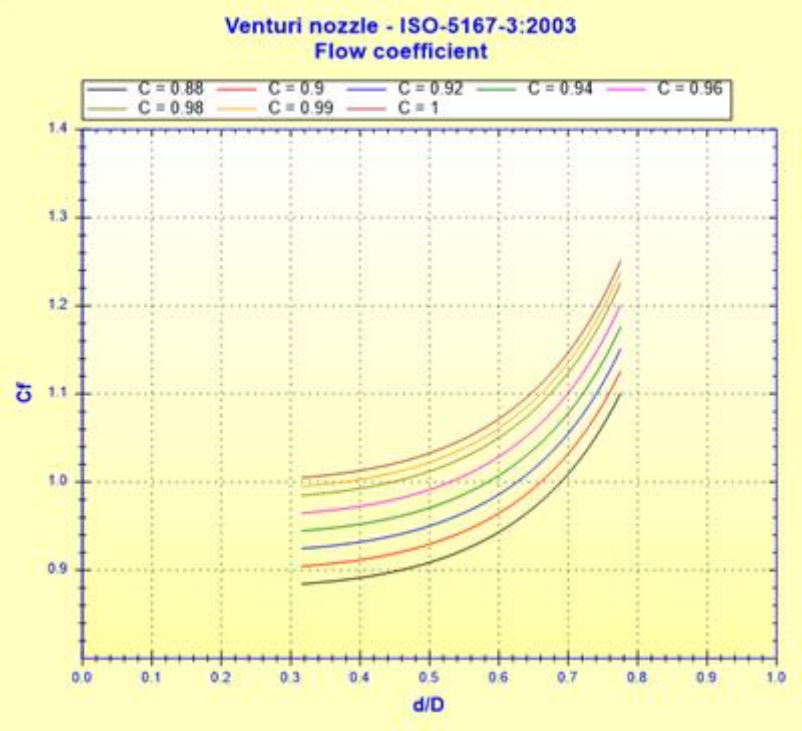
([1] §3.3.4)



Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$

([1] §3.3.5)



Net pressure loss (Pa):

The net pressure loss is not formulated in the reference document [2]

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()

Re_D Reynolds number referred to pipe ()

C Discharge coefficient ()

ε Expansibility factor ()

q_m Mass flow rate (kg/s)

C_v Velocity of approach factor ()

C_f Flow coefficient ()

ΔP Measured pressure loss (Pa)

ΔH Measured head loss of fluid (m)

ρ Fluid density (kg/m³)

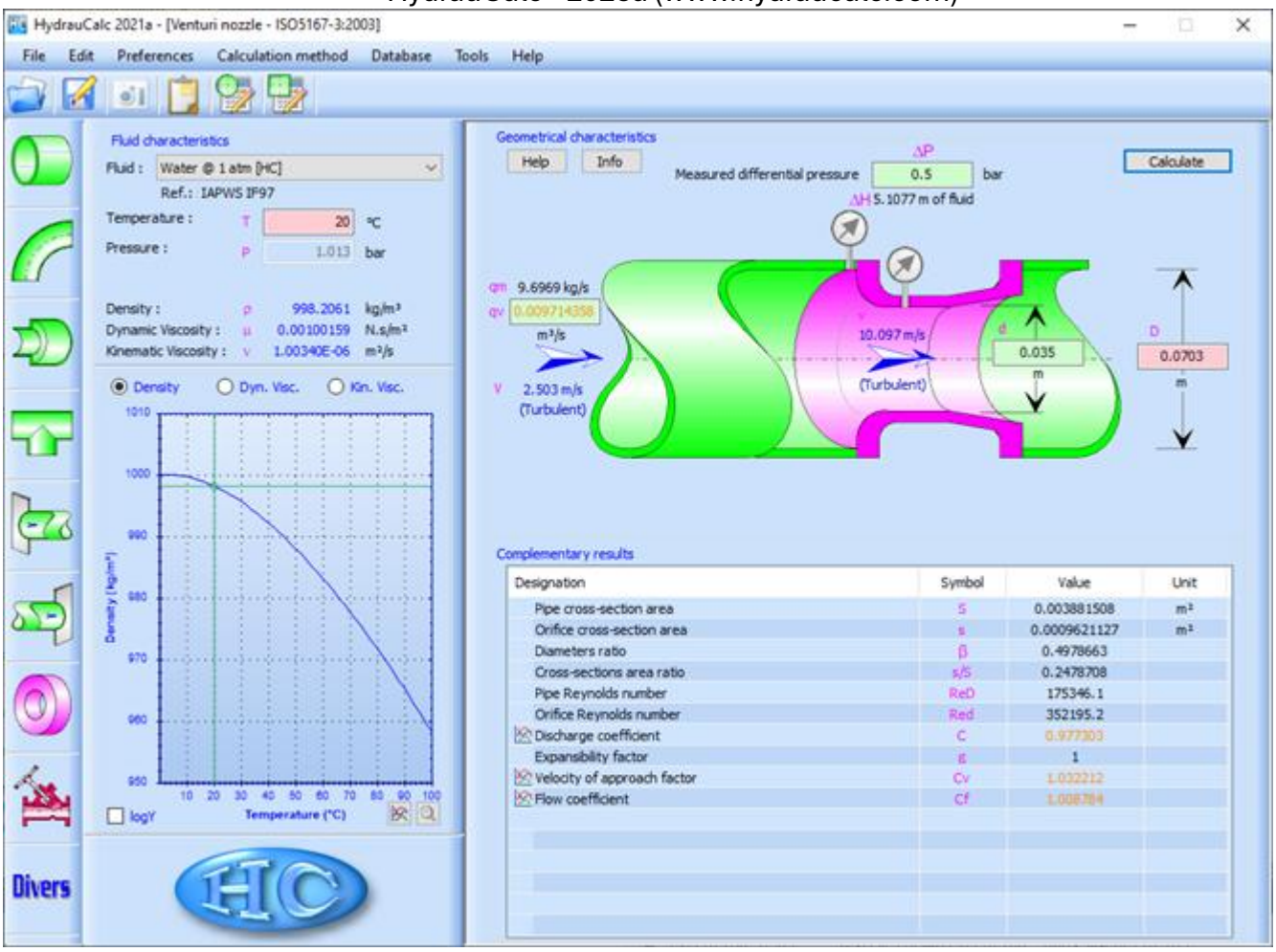
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Limit of use ([2] §5.3.4.1) :

- $65\ mm \leq D \leq 500\ mm$
- $d \geq 50\ mm$
- $0.316 \leq \beta \leq 0.775$
- $1.5 \cdot 10^5 \leq Re_D \leq 2 \cdot 10^6$

Example of application:



References:

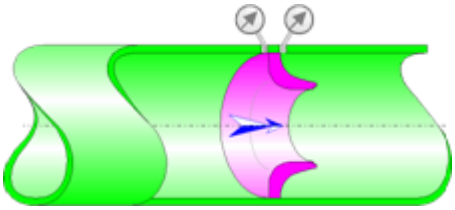
[1] ISO 5167-1:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 1: General principles and requirements

[2] ISO 5167-3:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 3: Nozzles and Venturi nozzles

2.9.2.4 ISO 5167-1:1991 - ISA 1932 nozzle

ISA 1932 nozzle

(ISO 5167-1:1991)



Model description:

This model of component determines the fluid flow through a ISA 1932 nozzle flowmeter, according to the international standard "ISO-5167-1:1991".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

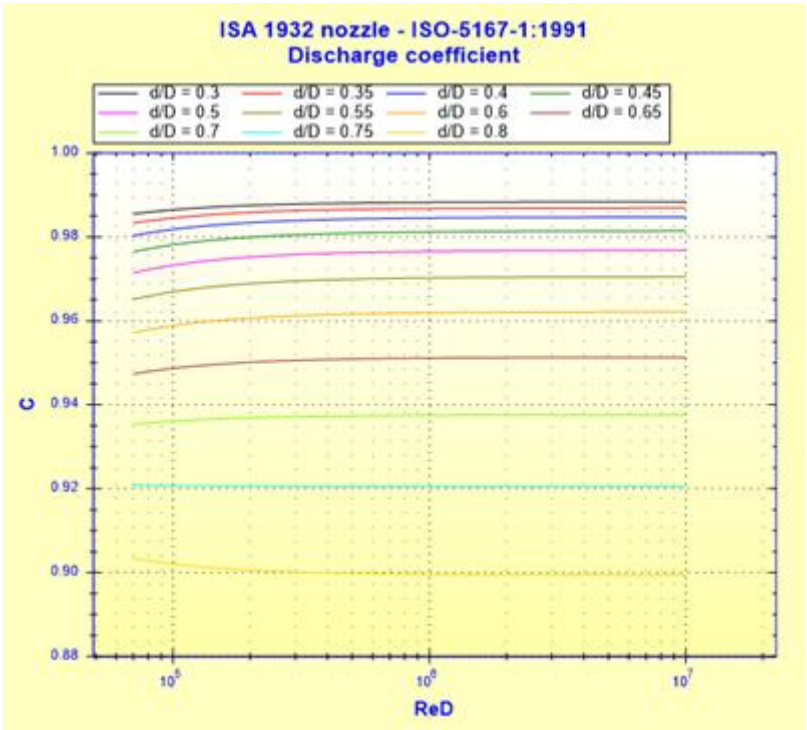
Reynolds number referred to internal pipe diameter:

$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient:

$$C = 0.99 - 0.2262 \cdot \beta^{4.1} - \left(0.00175 \cdot \beta^2 - 0.0033 \cdot \beta^{4.15}\right) \cdot \left(\frac{10^6}{\mathrm{Re}_D}\right)^{1.15}$$

([1] §9.1.6.2)



Expansibility factor:

$\varepsilon = 1$ ([1] §3.3.5) for incompressible fluid (liquid)

Mass flow rate (kg/s):

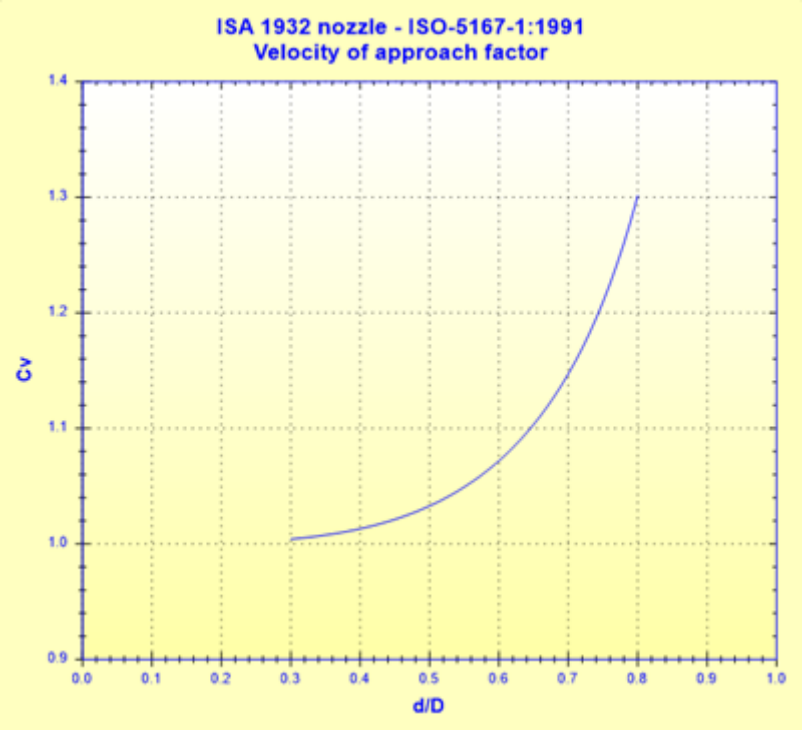
$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$ ([1] §5.1 eq. 1)

Volume flow rate (m^3/s):

$$q_v = \frac{q_m}{\rho}$$ ([1] §5.1 eq. 3)

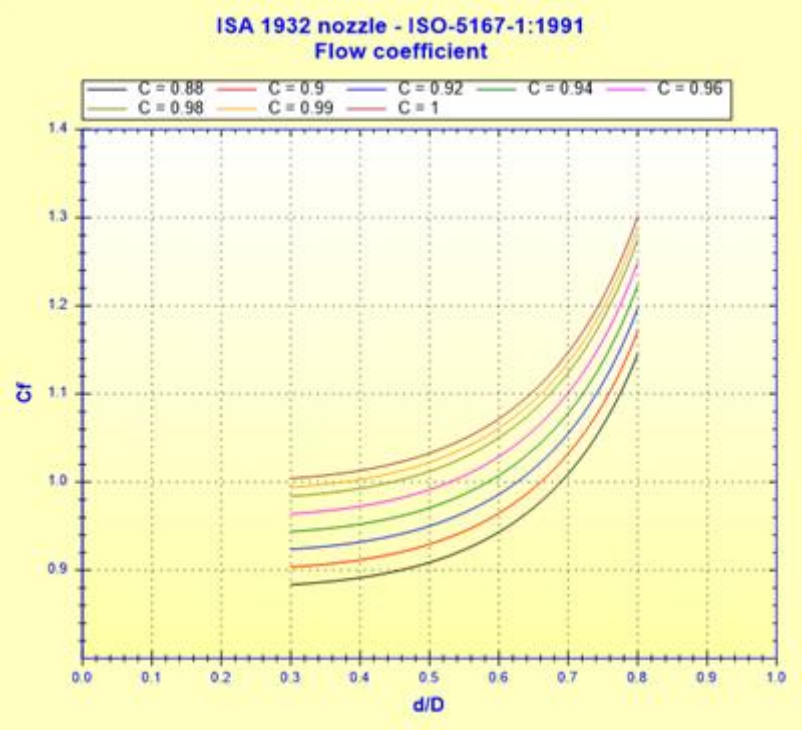
Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.4)



Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.4)



Net pressure loss (Pa):

$$\Delta\varpi = \frac{\sqrt{1-\beta^4} - C \cdot \beta^2}{\sqrt{1-\beta^4} + C \cdot \beta^2} \cdot \Delta p$$ ([1] §8.4.1)

Net pressure loss coefficient (based on the mean pipe velocity):

$$K = \frac{\Delta\varpi}{0.5 \cdot \rho \cdot V^2}$$

Net head loss (m):

$$\Delta h = \frac{\Delta\varpi}{\rho \cdot g}$$

Net hydraulic power loss (W):

$$Wh = \Delta\varpi \cdot q$$

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()
Re_D	Reynolds number referred to pipe ()
C	Discharge coefficient ()
ε	Expansibility factor ()
q_m	Mass flow rate (kg/s)
C_v	Velocity of approach factor ()
C_f	Flow coefficient ()
$\Delta\varpi$	Net pressure loss (Pa)
ΔP	Measured pressure loss (Pa)
K	Net pressure loss coefficient (based on the mean pipe velocity) ()
Δh	Net head loss of fluid (m)
Wh	Net hydraulic power loss (W)
ΔH	Measured head loss of fluid (m)
ρ	Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

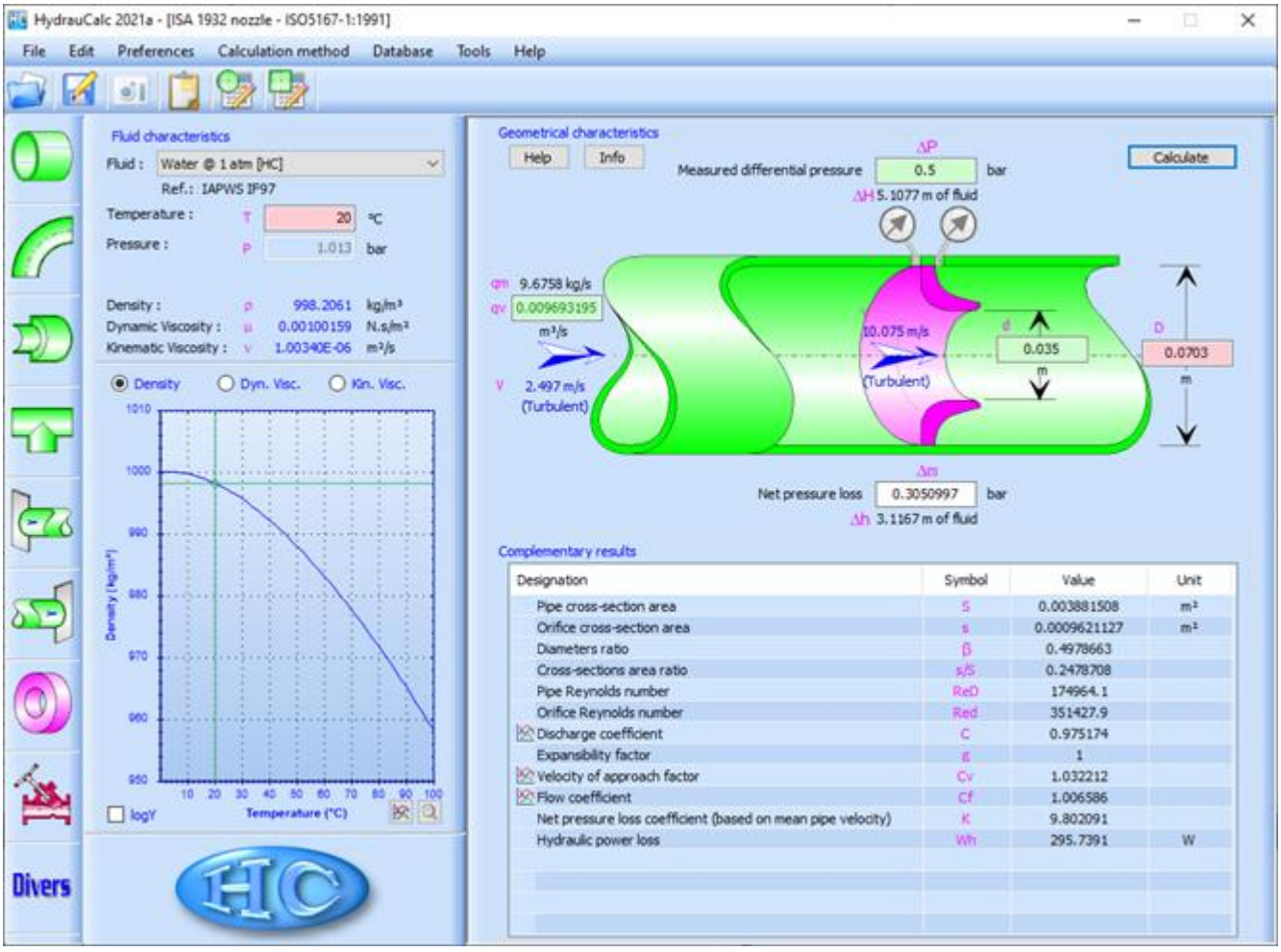
Limit of use ([1] §9.1.6.1):

- $50\ mm \leq D \leq 500\ mm$
- $0.3 \leq \beta \leq 0.8$

  $0.3 \leq \beta < 0.44$ for $7 \cdot 10^4 \leq Re_D \leq 10^7$

  $0.44 \leq \beta \leq 0.8$ for $2 \cdot 10^4 \leq Re_D \leq 10^7$

Example of application:



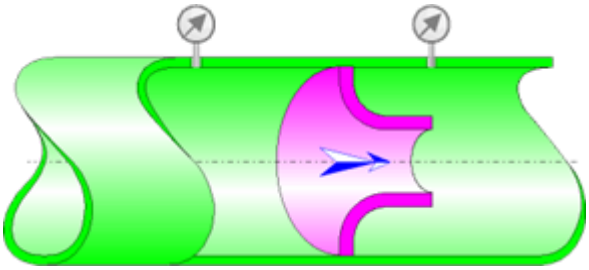
References:

[1] ISO 5167-1:1991 - Measurement of fluid flow by means of pressure differential devices

2.9.2.5 ISO 5167-1:1991 - Long radius nozzle

Long radius nozzle

(ISO 5167-1:1991)



Model description:

This model of component determines the fluid flow through a long radius nozzle flowmeter, according to the international standard "ISO-5167-1:1991".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

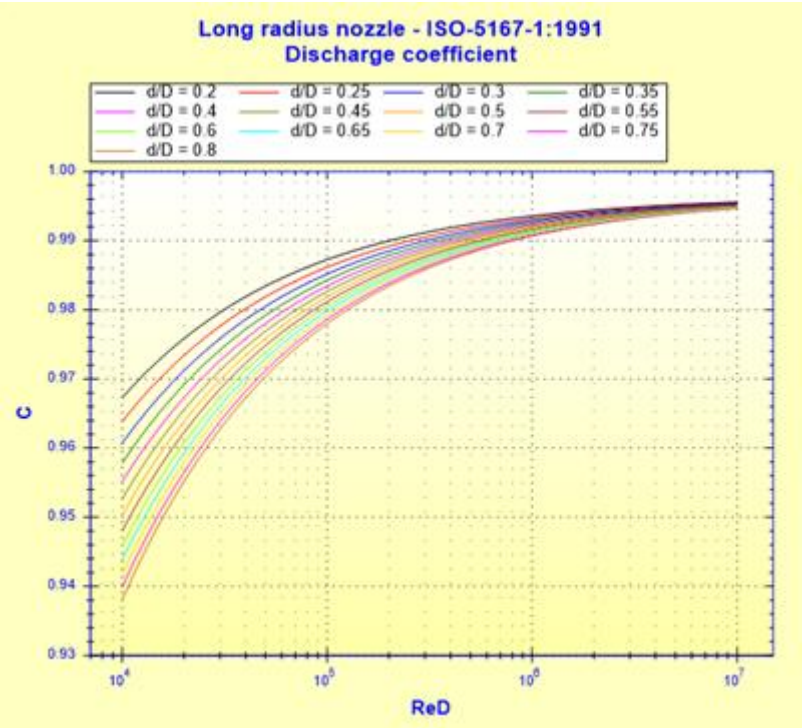
$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

Reynolds number referred to internal pipe diameter:

$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient:

$$C = 0.9965 - 0.00653 \cdot \sqrt{\frac{10^6 \cdot \beta}{\mathrm{Re}_D}}$$ ([1] §9.2.6.2)



Expansibility factor:

$$\varepsilon = 1$$ ([1] §3.3.5) for incompressible fluid (liquid)

Mass flow rate (kg/s):

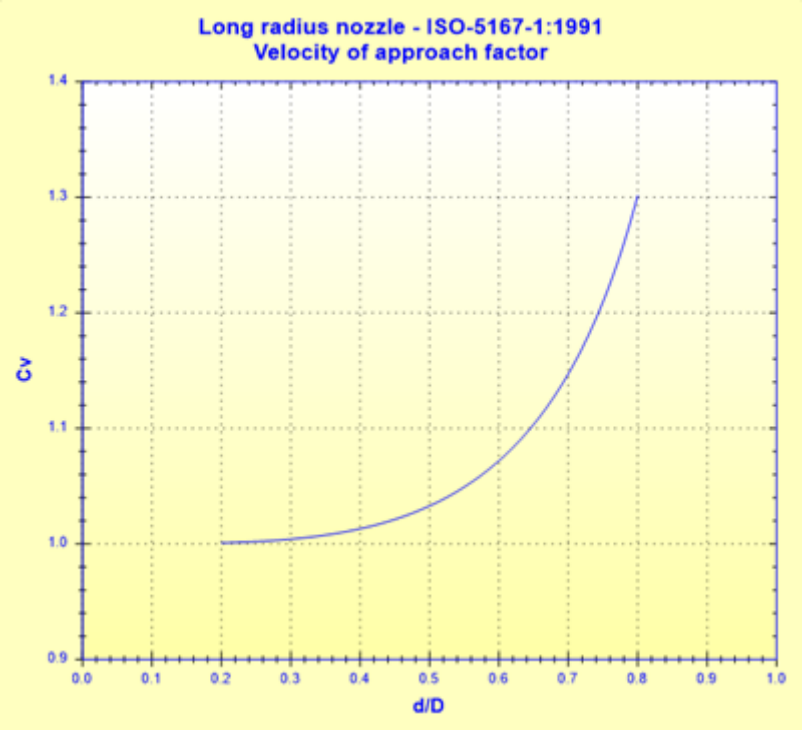
$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$ ([1] §5.1 eq. 1)

Volume flow rate (m^3/s):

$$q_v = \frac{q_m}{\rho}$$ ([1] §5.1 eq. 3)

Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.4)



Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.4)

Net pressure loss (Pa):

$$\Delta\varpi = \frac{\sqrt{1-\beta^4} - C \cdot \beta^2}{\sqrt{1-\beta^4} + C \cdot \beta^2} \cdot \Delta p$$ ([1] §8.4.1)

Net pressure loss coefficient (based on the mean pipe velocity):

$$K = \frac{\Delta\varpi}{0.5 \cdot \rho \cdot V^2}$$

Net head loss (m):

$$\Delta h = \frac{\Delta\varpi}{\rho \cdot g}$$

Net hydraulic power loss (W):

$$Wh = \Delta\varpi \cdot q$$

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()
Re_D	Reynolds number referred to pipe ()
C	Discharge coefficient ()
ε	Expansibility factor ()
q_m	Mass flow rate (kg/s)
C_v	Velocity of approach factor ()
C_f	Flow coefficient ()
$\Delta\varpi$	Net pressure loss (Pa)
ΔP	Measured pressure loss (Pa)
K	Net pressure loss coefficient (based on the mean pipe velocity) ()
Δh	Net head loss of fluid (m)
Wh	Net hydraulic power loss (W)
ΔH	Measured head loss of fluid (m)
ρ	Fluid density (kg/m^3)

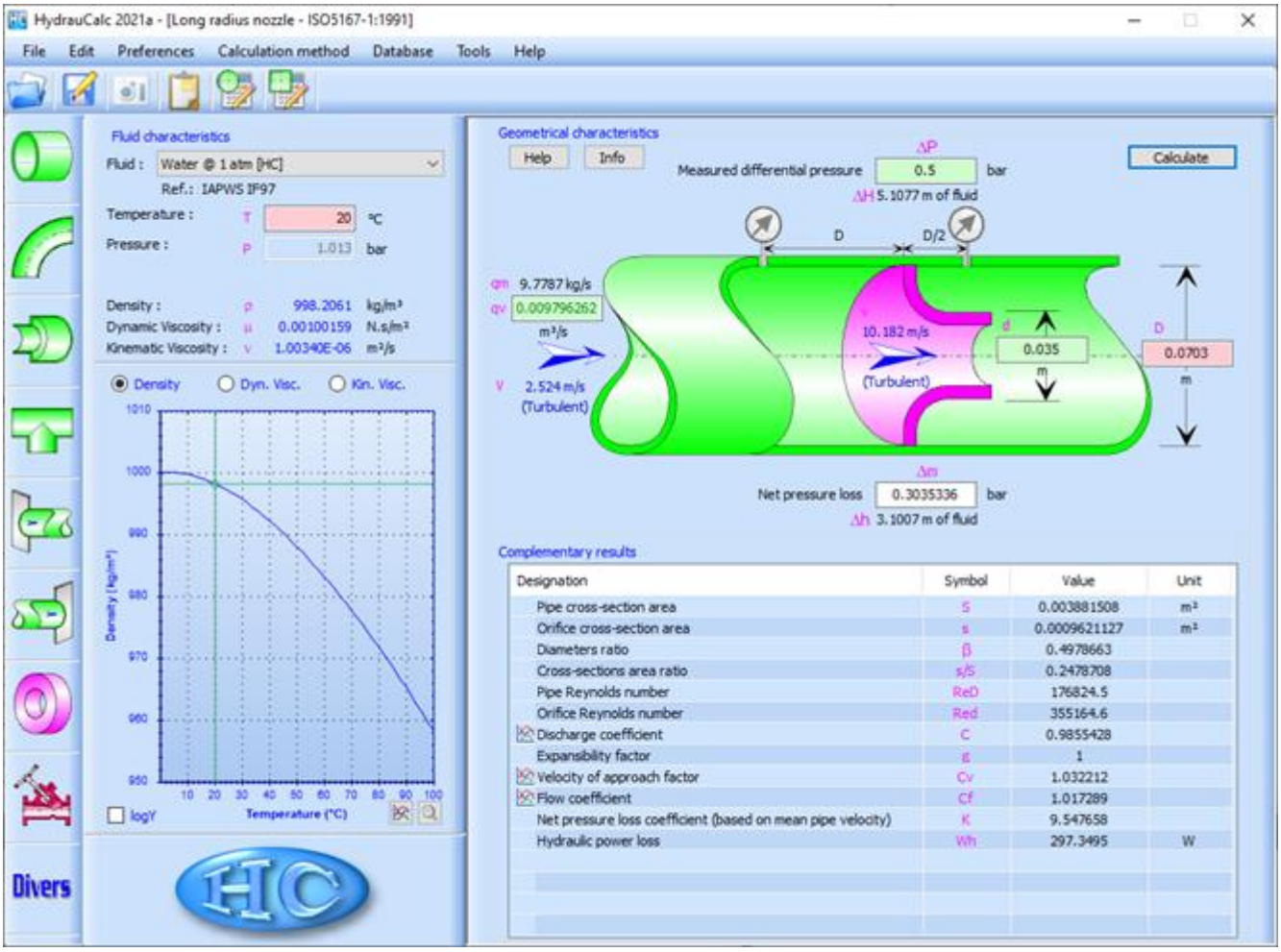
ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Limit of use ([1] §9.2.6.1):

- $50\ mm \leq D \leq 630\ mm$
- $0.2 \leq \beta \leq 0.8$
- $10^4 \leq Re_D \leq 10^7$

Example of application:



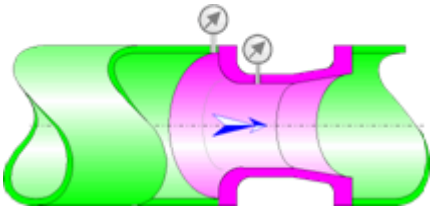
References:

[1] ISO 5167-1:1991 - Measurement of fluid flow by means of pressure differential devices

2.9.2.6 ISO 5167-1:1991 - Venturi nozzle

Venturi nozzle

(ISO 5167-1:1991)



Model description:

This model of component determines the fluid flow through a Venturi nozzle flowmeter, according to the international standard "ISO-5167-1:1991".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

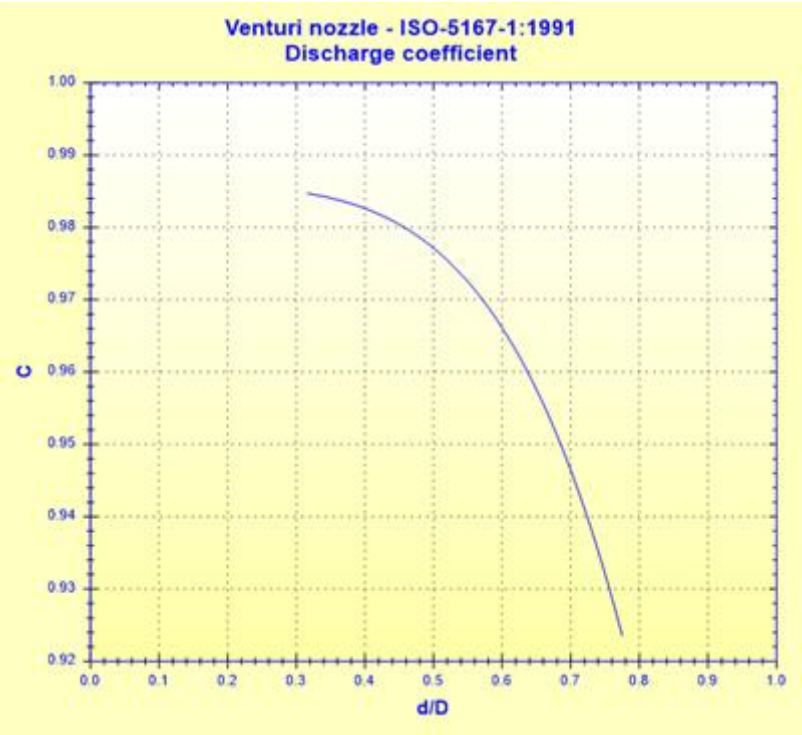
$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

Reynolds number referred to internal pipe diameter:

$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient:

$$C = 0.9858 - 0.196 \cdot \beta^{4.5}$$ ([1] §10.2.4.2)



Expansibility factor:

$$\varepsilon = 1$$

([1] §3.3.5) for incompressible fluid (liquid)

Mass flow rate (kg/s):

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$

([1] §5.1 eq. 1)

Volume flow rate (m^3/s):

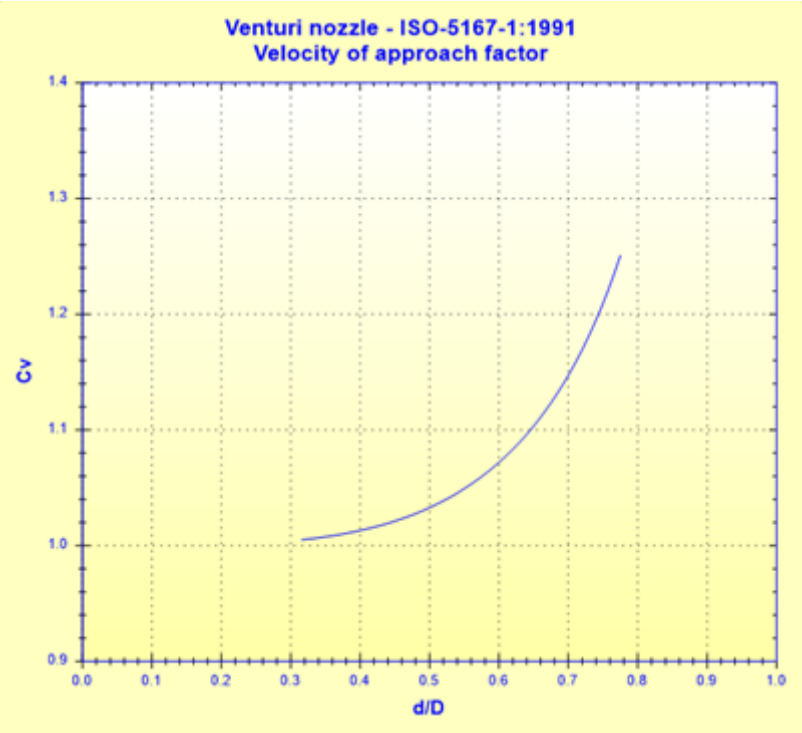
$$q_v = \frac{q_m}{\rho}$$

([1] §5.1 eq. 3)

Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$

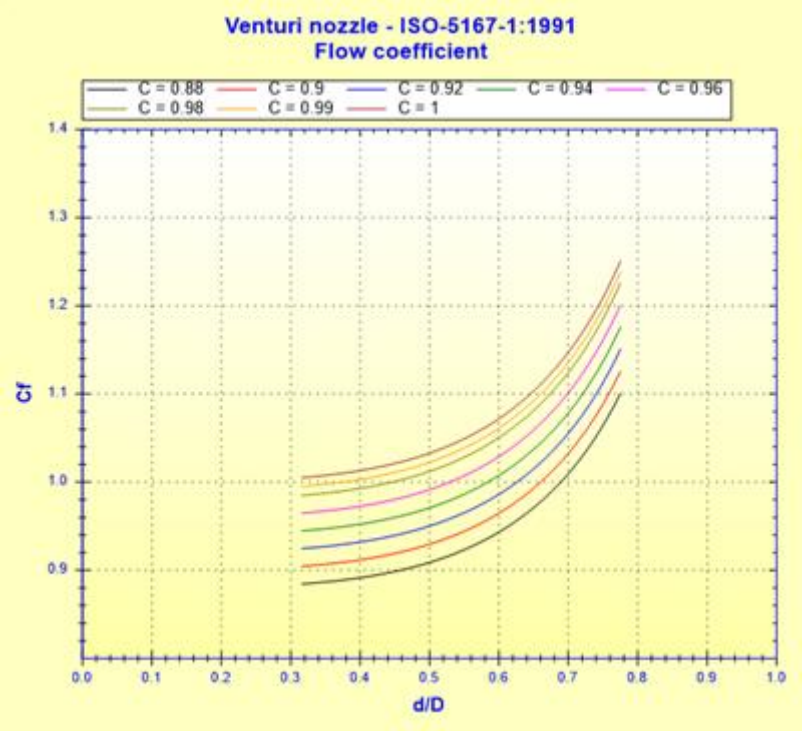
([1] §3.3.4)



Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$

([1] §3.3.4)



Net pressure loss (Pa):

The net pressure loss is not formulated in the reference document [1]

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()

Re_D Reynolds number referred to pipe ()

C Discharge coefficient ()

ε Expansibility factor ()

q_m Mass flow rate (kg/s)

C_v Velocity of approach factor ()

C_f Flow coefficient ()

ΔP Measured pressure loss (Pa)

ΔH Measured head loss of fluid (m)

ρ Fluid density (kg/m³)

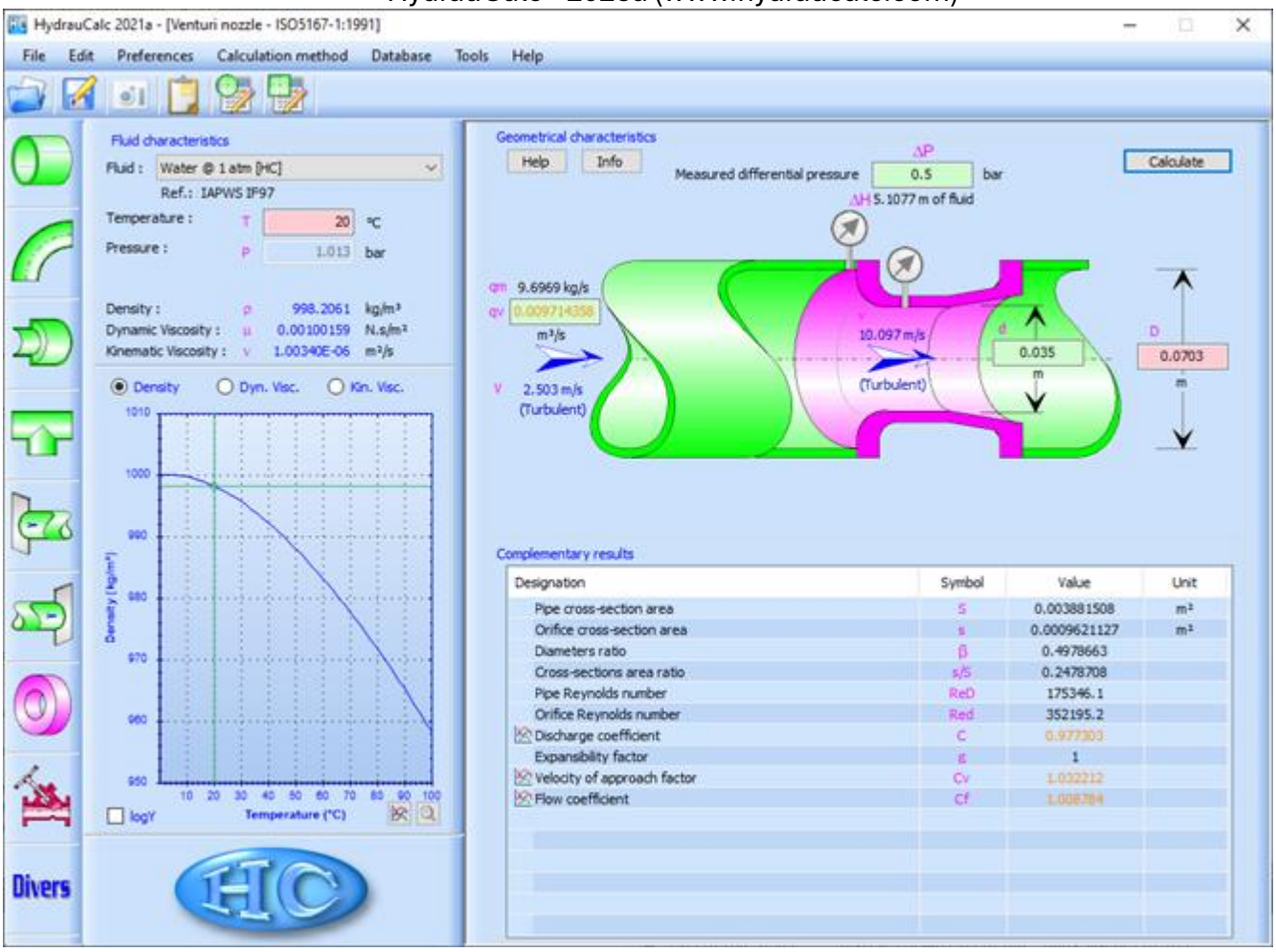
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Limit of use ([1] §10.2.4.1):

- $65\ mm \leq D \leq 500\ mm$
- $d \geq 50\ mm$
- $0.316 \leq \beta \leq 0.775$
- $1.5 \cdot 10^5 \leq Re_D \leq 2 \cdot 10^6$

Example of application:



References:

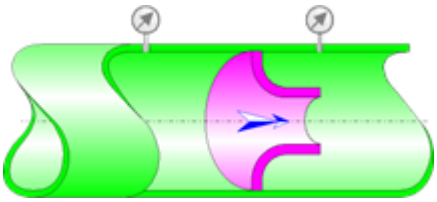
[1] ISO 5167-1:1991 - Measurement of fluid flow by means of pressure differential devices

2.9.2.7 CRANE - Nozzle

Long radius nozzle

D and D/2 pressure tapings

(CRANE)



Model description:

This model of component determines the fluid flow through a long radius nozzle flowmeter with D & D/2 pressure tappings, according to the reference document [1].

Model formulation:

Diameter ratio:

$$\beta = \frac{D_1}{D_2}$$

Orifice cross-sectional area (m^2):

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

Pipe cross-sectional area (m^2):

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity in orifice (m/s):

$$v_1 = \frac{q}{A_1}$$

Mean velocity in pipe (m/s):

$$v_2 = \frac{q}{A_2}$$

Reynolds number in orifice:

$$\mathrm{Re}_1 = \frac{v_1 \cdot D_1}{\nu}$$

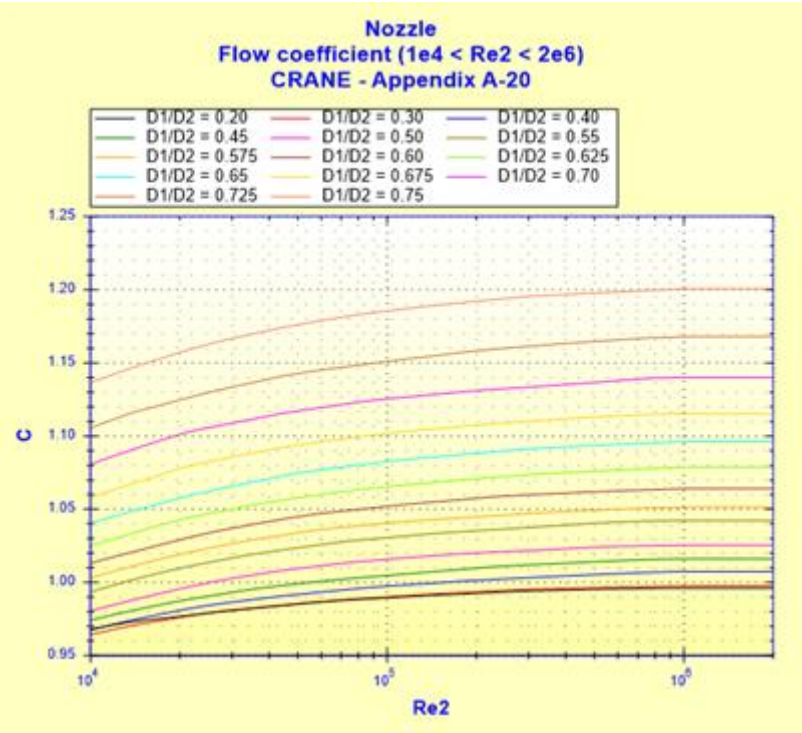
Reynolds number in pipe:

$$\mathrm{Re}_2 = \frac{v_2 \cdot D_2}{\nu}$$

Flow coefficient:

$$C = f\left(\mathrm{Re}_2, \frac{d_1}{d_2}\right)$$

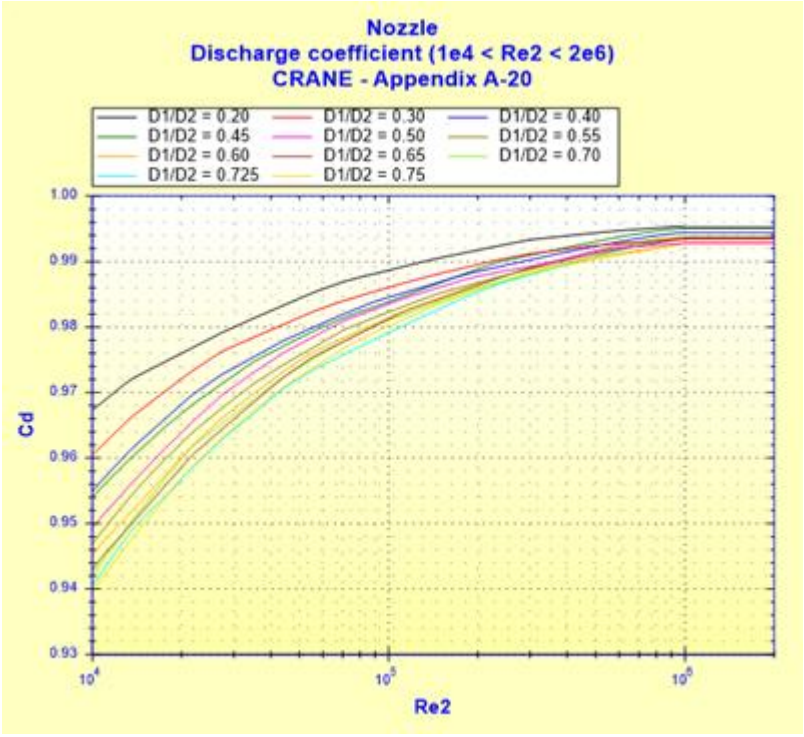
([1] appendix A-20)



Discharge coefficient:

$$C_d = C \cdot \sqrt{1-\beta^4}$$

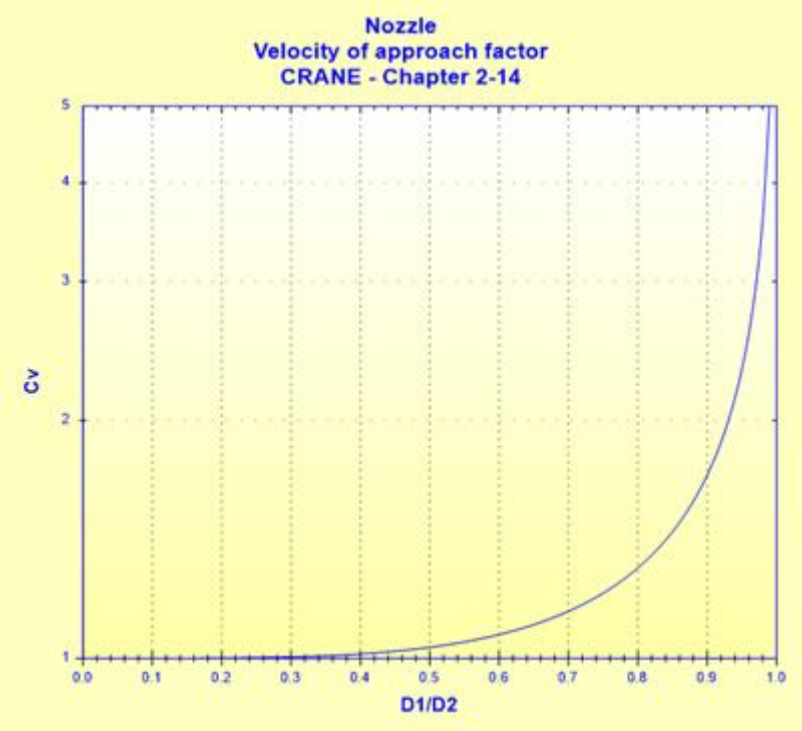
([1] appendix A-20)



Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$

([1] 2-14)



Volume flow rate (m^3/s):

$$q = A_1 \cdot C \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}$$ ([1] Equation 2-23)

Mass flow rate (kg/s):

$$W = q \cdot \rho$$

Net pressure loss (Pa):

$$\Delta \varpi = \frac{\sqrt{1-\beta^4} - C \cdot \beta^2}{\sqrt{1-\beta^4} + C \cdot \beta^2} \cdot \Delta p$$ ([2] § 5.2.8)

Net pressure loss coefficient (based on the mean pipe velocity):

$$K = \frac{\Delta \varpi}{0.5 \cdot \rho \cdot V^2}$$ ([2] § 5.2.8)

Net head loss (m):

$$\Delta h = K_o \cdot \frac{v_2^2}{2 \cdot g}$$

Net hydraulic power loss (W):

$$Wh = \Delta w \cdot q$$

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

Symbols, Definitions, SI Units:

D_1	Orifice diameter (m)
D_2	Internal pipe diameter (m)
β	Diameter ratio ()
A_1	Orifice cross-sectional area (m^2)
A_2	Pipe cross-sectional area (m^2)
q	Volume flow rate (m^3/s)
v_1	Mean velocity in orifice (m/s)
v_2	Mean velocity in pipe (m/s)
Re_1	Reynolds number in orifice ()
Re_2	Reynolds number in pipe ()
C	Flow coefficient ()
C_d	Discharge coefficient ()
C_v	Velocity of approach factor ()
ΔP	Measured pressure loss (Pa)
w	Mass flow rate (kg/s)
$\Delta \varpi$	Net pressure loss (Pa)
K_o	Resistance coefficient (based on the mean pipe velocity) ()
Δh	Net head loss of fluid (m)
Wh	Hydraulic power loss (W)

ΔH Measured head loss of fluid (m)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Notation of equations according to sources.

Validity range:

- turbulent flow regime ($10^4 < Re_2 < 2 \cdot 10^6$)
- stabilized flow upstream of the orifice

Example of application:

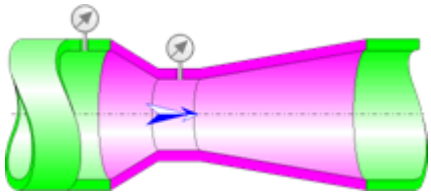
References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 – Edition 1999

[2] ISO 5167-2:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 3: Nozzles and Venturi nozzles

2.9.3 Classical Venturi tube flowmeter

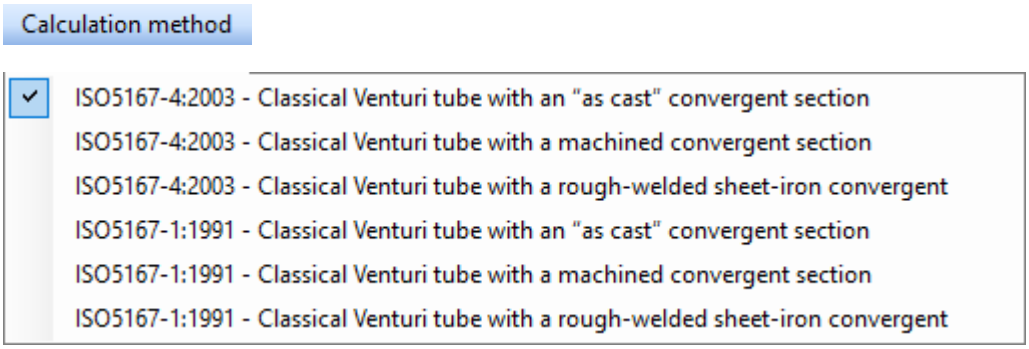
Classical Venturi tube



For the determination of the fluid flow through a classical Venturi tube flowmeter, the user can choose from one of the methods described in the following two reference documents:

- ISO 5167:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
  Part 1: General principles and requirements
  Part 4: Venturi tubes
- ISO 5167:1991 - Measurement of fluid flow by means of pressure differential devices

The calculation method is selected using the "Calculation method" menu. The default option is "ISO 5167-4:2003 – Classical Venturi tube with an “as cast” convergent section"

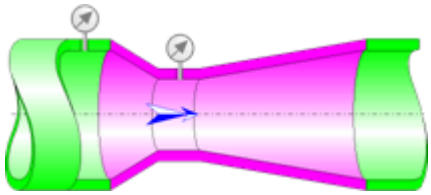


2.9.3.1 ISO 5167-4:2003 - Classical Venturi tube with an 'as cast' convergent section

Classical Venturi tube

with an "as cast" convergent section

(ISO 5167-4:2003)



Model description:

This model of component determines the fluid flow through a classical Venturi tube with an "as cast" convergent section, according to the international standard "ISO-5167-4:2003".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

Reynolds number referred to internal pipe diameter:

$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient:

$$C = 0.984$$ ([2] §5.5.2)

Expansibility factor:

$$\varepsilon = 1$$ ([1] §3.3.6) for incompressible fluid (liquid)

Mass flow rate (kg/s):

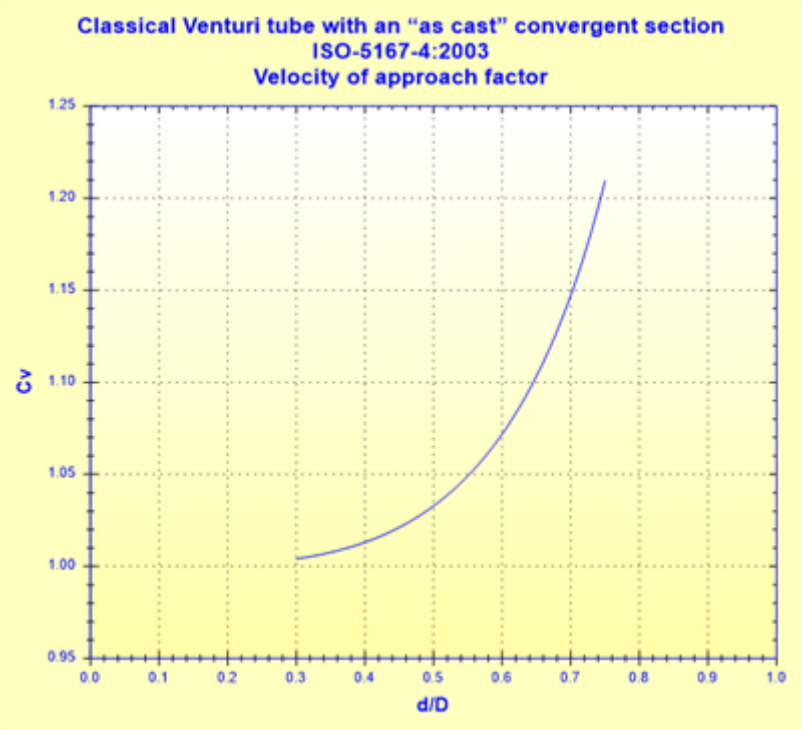
$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$ ([1] §5.1 eq. 1 and [2] §4 eq. 1)

Volume flow rate (m^3/s):

$$q_v = \frac{q_m}{\rho}$$ ([1] §5.1 eq. 3 and [2] §4 eq. 2)

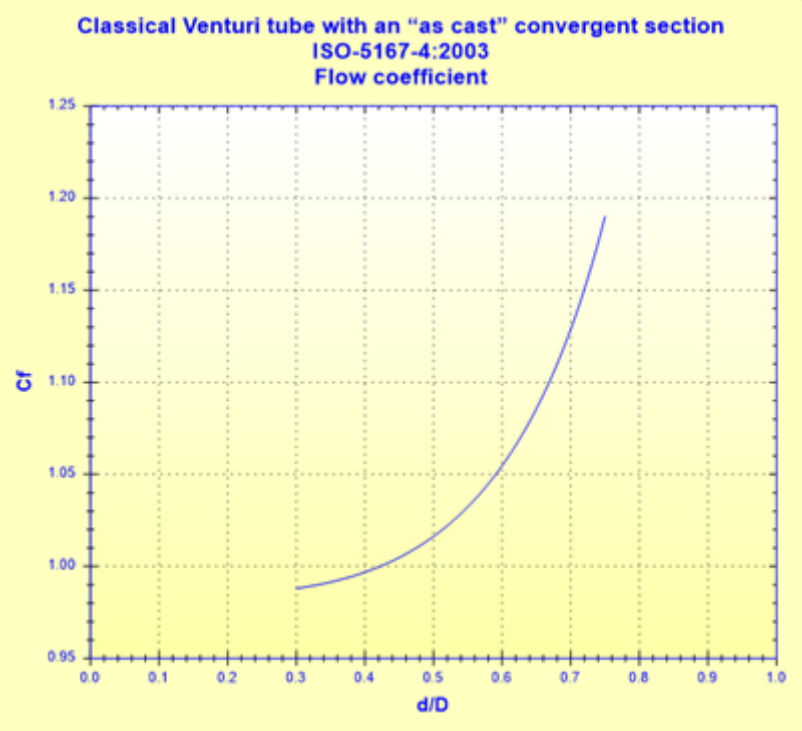
Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.5)



Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.5)



Net pressure loss:

The net pressure loss is not formulated in the reference document [2]

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()

Re_D Reynolds number referred to pipe ()

C Discharge coefficient ()

ε Expansibility factor ()

q_m Mass flow rate (kg/s)

C_v Velocity of approach factor ()

C_f Flow coefficient ()

ΔP Measured pressure loss (Pa)

ΔH Measured head loss of fluid (m)

ρ Fluid density (kg/m³)

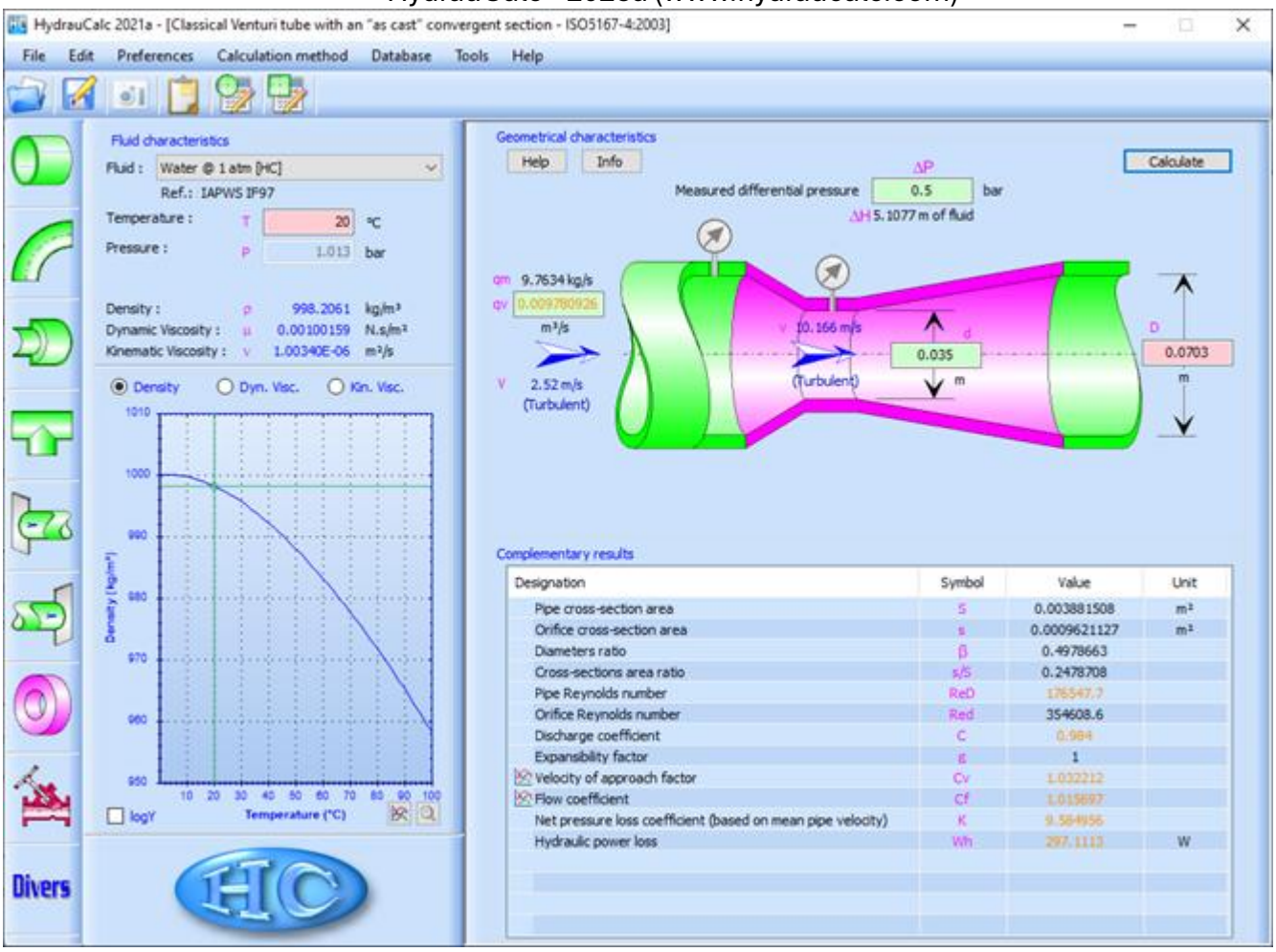
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Limit of use ([2] §5.5.2):

- $100\ mm \leq D \leq 800\ mm$
- $0,3 \leq \beta \leq 0,75$
- $2 \cdot 10^5 \leq Re_D \leq 2 \cdot 10^6$

Example of application:



References:

[1] ISO 5167-1:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 1: General principles and requirements

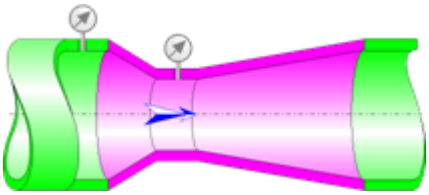
[2] ISO 5167-4:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 4: Venturi tubes

2.9.3.2 ISO 5167-4:2003 - Classical Venturi tube with a machined convergent section

Classical Venturi tube

with a machined convergent section

(ISO 5167-4:2003)



Model description:

This model of component determines the fluid flow through a classical Venturi tube with a machined convergent section, according to the international standard "ISO-5167-4:2003".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

Reynolds number referred to internal pipe diameter:

$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient:

$$C = 0.995$$ ([2] §5.5.3)

Expansibility factor:

$$\varepsilon = 1$$ ([1] §3.3.6) for incompressible fluid (liquid)

Mass flow rate (kg/s):

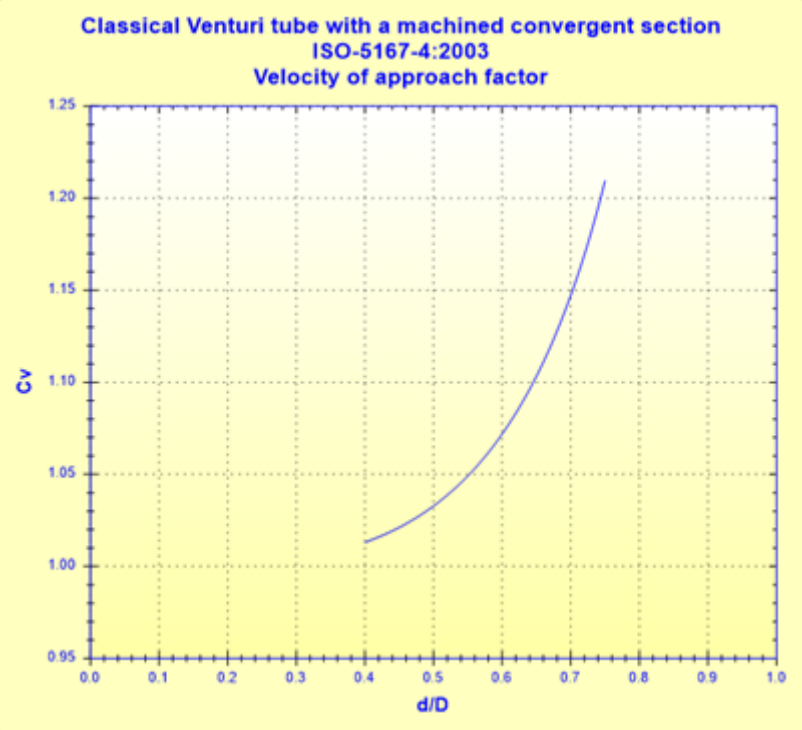
$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$ ([1] §5.1 eq. 1 and [2] §4 eq. 1)

Volume flow rate (m^3/s):

$$q_v = \frac{q_m}{\rho}$$ ([1] §5.1 eq. 3 and [2] §4 eq. 2)

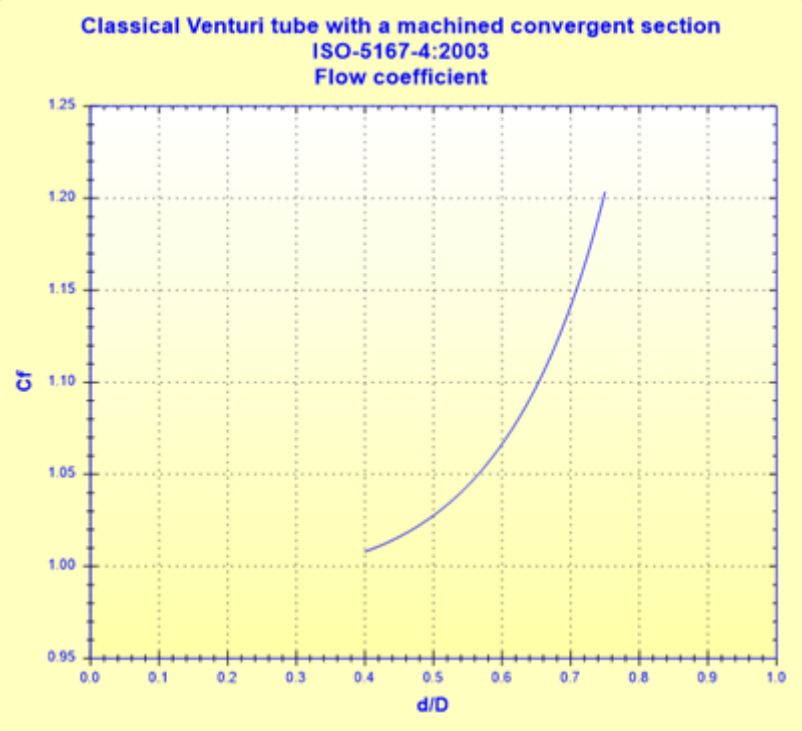
Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.5)



Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.5)



Net pressure loss:

The net pressure loss is not formulated in the reference document [2]

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()

Re_D Reynolds number referred to pipe ()

C Discharge coefficient ()

ε Expansibility factor ()

q_m Mass flow rate (kg/s)

C_v Velocity of approach factor ()

C_f Flow coefficient ()

ΔP Measured pressure loss (Pa)

ΔH Measured head loss of fluid (m)

ρ Fluid density (kg/m³)

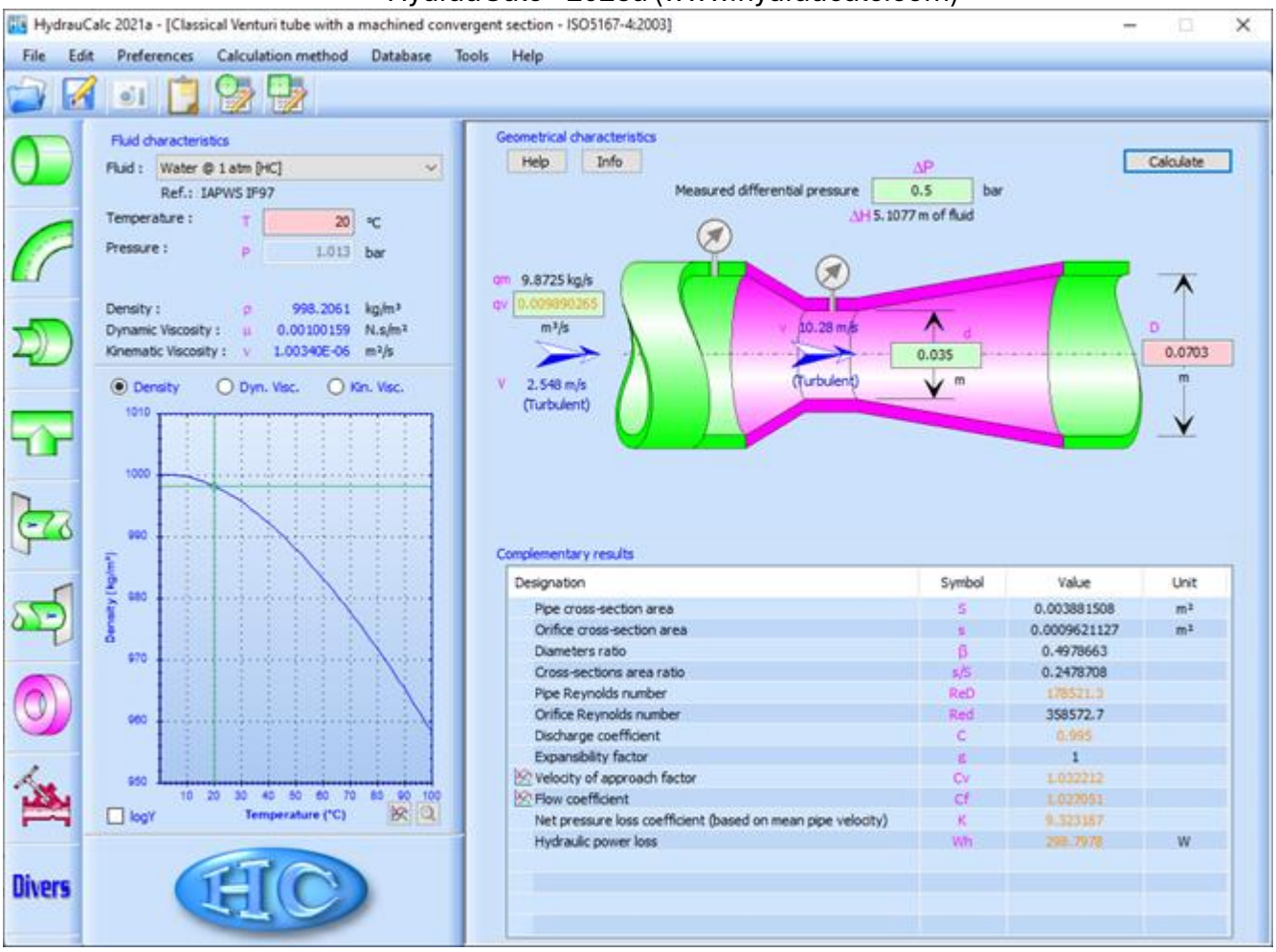
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Limit of use ([2] §5.5.3):

- $50\ mm \leq D \leq 250\ mm$
- $0,4 \leq \beta \leq 0,75$
- $2 \cdot 10^5 \leq Re_D \leq 1 \cdot 10^6$

Example of application:



References:

[1] ISO 5167-1:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 1: General principles and requirements

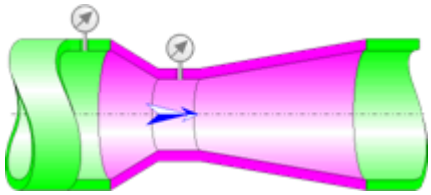
[2] ISO 5167-4:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 4: Venturi tubes

2.9.3.3 ISO 5167-4:2003 - Classical Venturi tube with a rough-welded sheet-iron convergent

Classical Venturi tube

with a rough-welded sheet-iron convergent

(ISO 5167-4:2003)



Model description:

This model of component determines the fluid flow through a classical Venturi tube with a rough-welded sheet-iron convergent, according to the international standard "ISO-5167-4:2003".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

Reynolds number referred to internal pipe diameter:

$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient:

$$C = 0.985$$ ([2] §5.5.4)

Expansibility factor:

$$\varepsilon = 1$$ ([1] §3.3.6) for incompressible fluid (liquid)

Mass flow rate (kg/s):

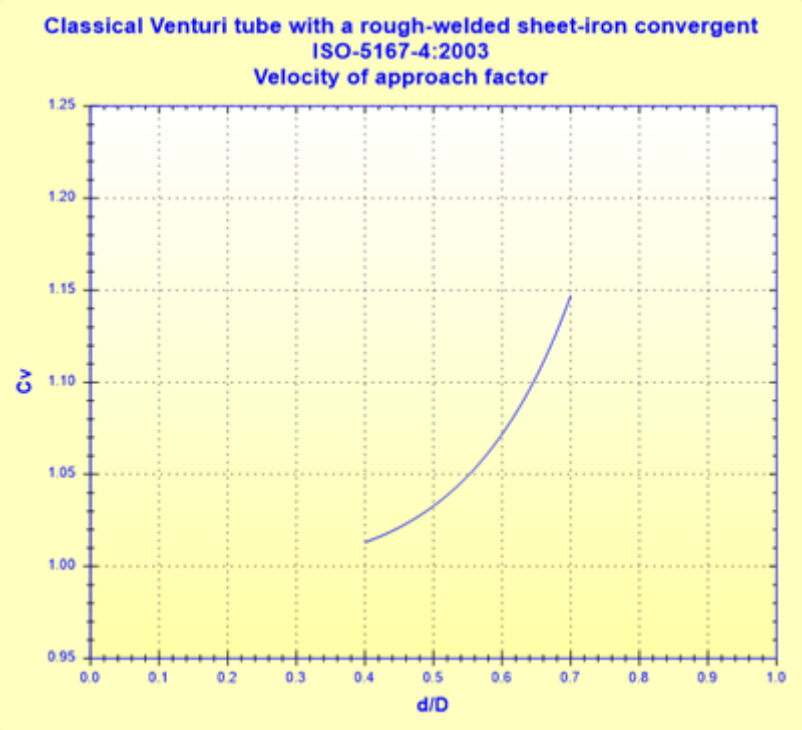
$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$ ([1] §5.1 eq. 1 and [2] §4 eq. 1)

Volume flow rate (m^3/s):

$$q_v = \frac{q_m}{\rho}$$ ([1] §5.1 eq. 3 and [2] §4 eq. 2)

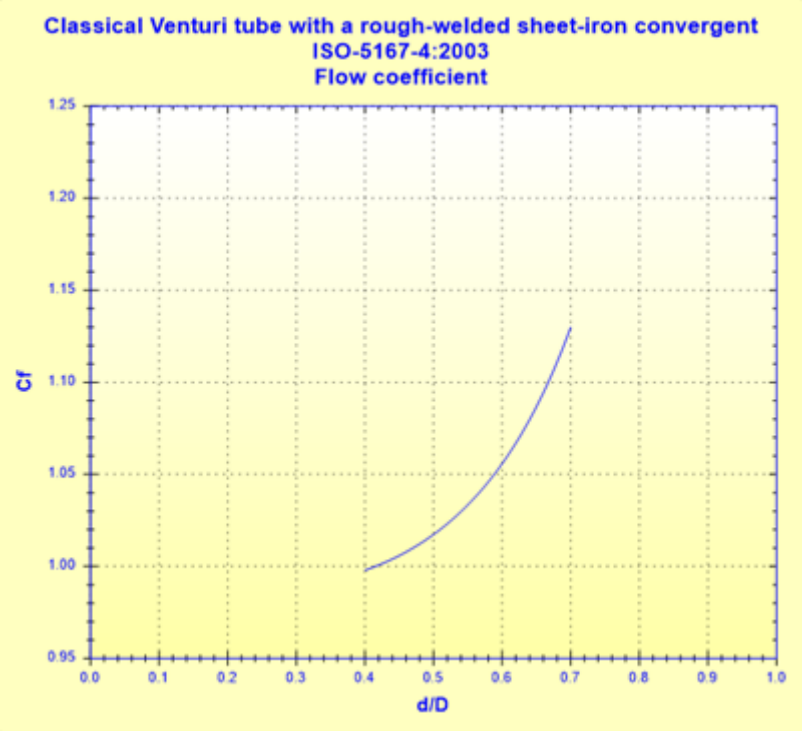
Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.5)



Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.5)



Net pressure loss:

The net pressure loss is not formulated in the reference document [2]

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()

Re_D Reynolds number referred to pipe ()

C Discharge coefficient ()

ε Expansibility factor ()

q_m Mass flow rate (kg/s)

C_v Velocity of approach factor ()

C_f Flow coefficient ()

ΔP Measured pressure loss (Pa)

ΔH Measured head loss of fluid (m)

ρ Fluid density (kg/m³)

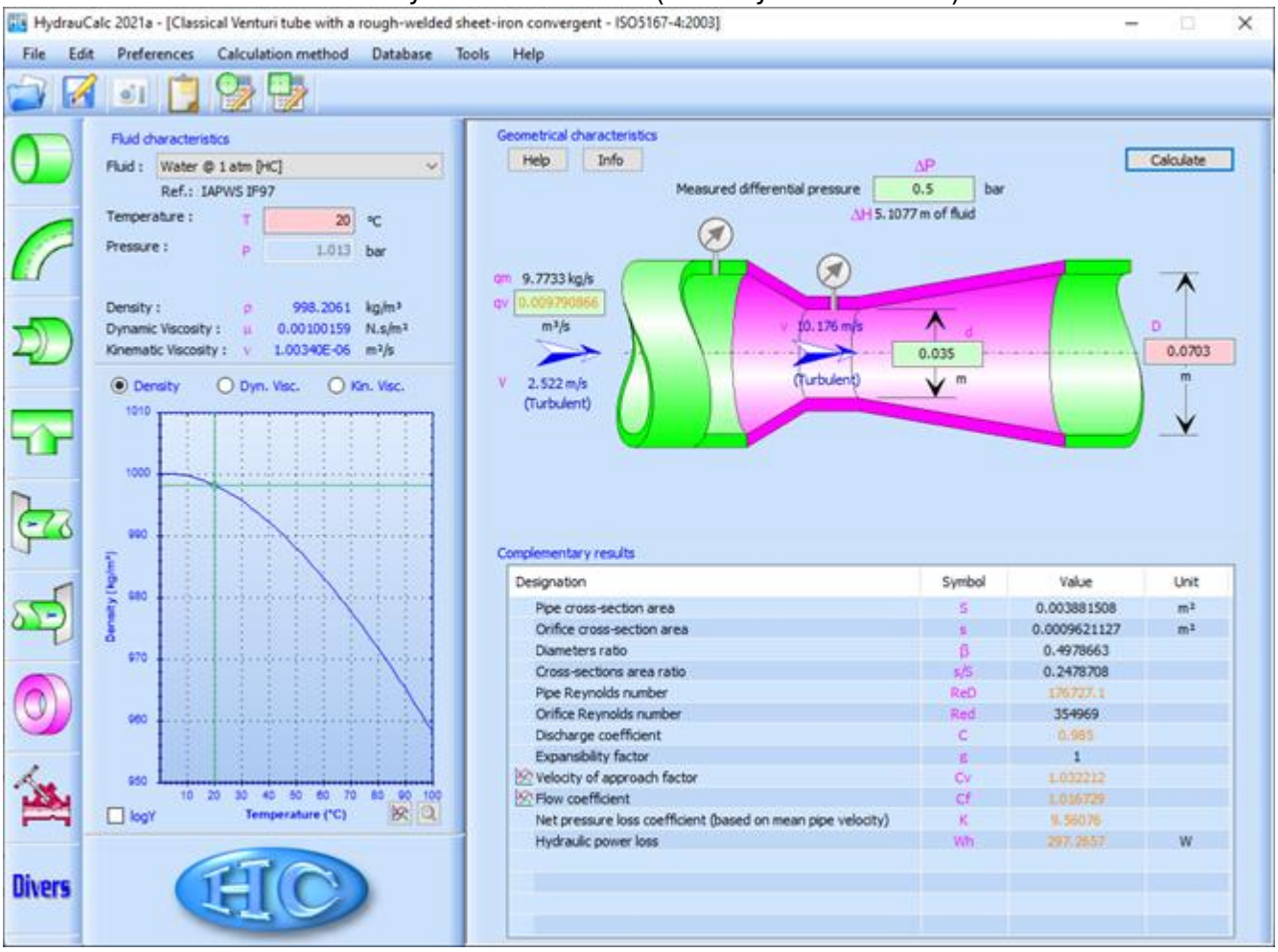
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Limit of use ([2] §5.5.4):

- $200\ mm \leq D \leq 1200\ mm$
- $0,4 \leq \beta \leq 0,7$
- $2 \cdot 10^5 \leq Re_D \leq 2 \cdot 10^6$

Example of application:



References:

[1] ISO 5167-1:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 1: General principles and requirements

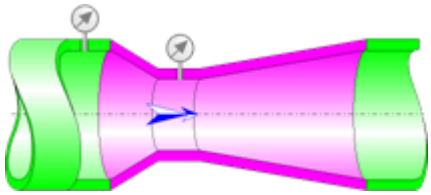
[2] ISO 5167-4:2003 - Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full
Part 4: Venturi tubes

2.9.3.4 ISO 5167-1:1991 - Classical Venturi tube with an 'as cast' convergent section

Classical Venturi tube

with an "as cast" convergent section

(ISO 5167-1:1991)



Model description:

This model of component determines the fluid flow through a classical Venturi tube with an "as cast" convergent section, according to the international standard "ISO-5167-1:1991".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

Reynolds number referred to internal pipe diameter:

$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient:

$$C = 0.984$$ ([1] § 10.1.5.2)

Expansibility factor:

$$\varepsilon = 1$$ ([1] §3.3.5) for incompressible fluid (liquid)

Mass flow rate (kg/s):

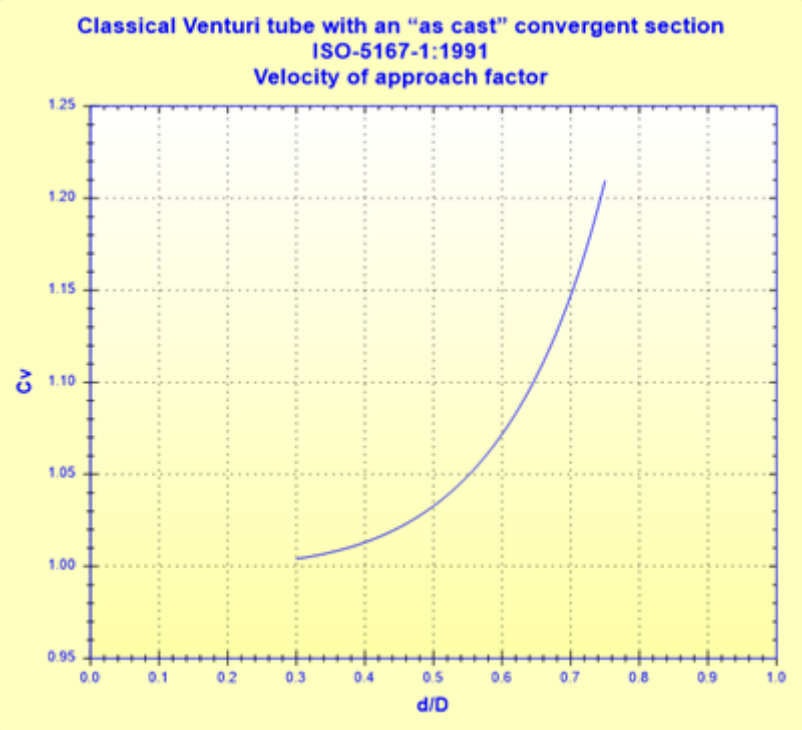
$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$ ([1] § 5.1 eq. 1)

Volume flow rate (m^3/s):

$$q_v = \frac{q_m}{\rho}$$ ([1] § 5.1 eq. 3)

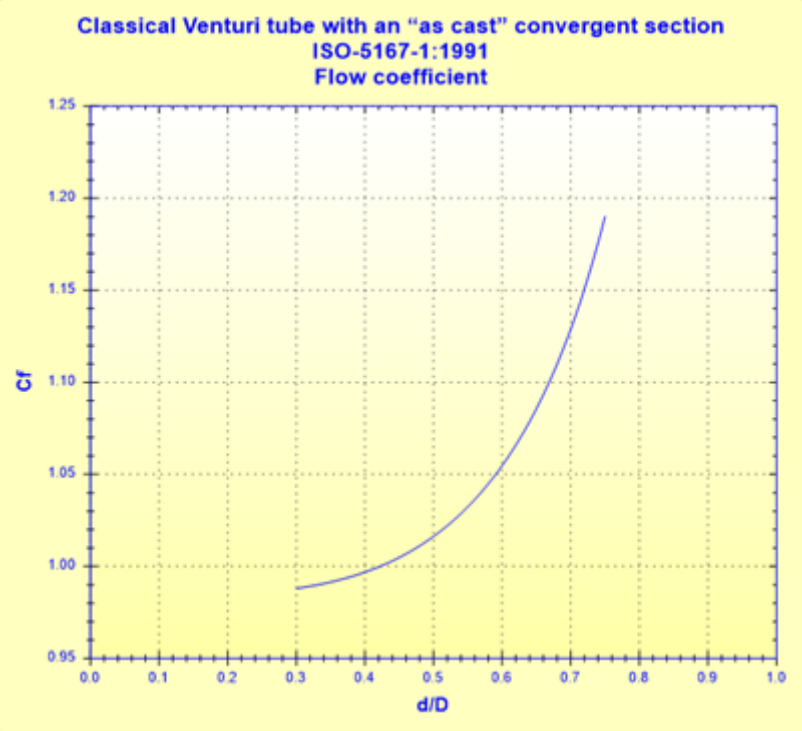
Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.4)



Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.4)



Net pressure loss:

The net pressure loss is not formulated in the reference document [1]

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()

Re_D Reynolds number referred to pipe ()

C Discharge coefficient ()

ε Expansibility factor ()

q_m Mass flow rate (kg/s)

C_v Velocity of approach factor ()

C_f Flow coefficient ()

ΔP Measured pressure loss (Pa)

ΔH Measured head loss of fluid (m)

ρ Fluid density (kg/m³)

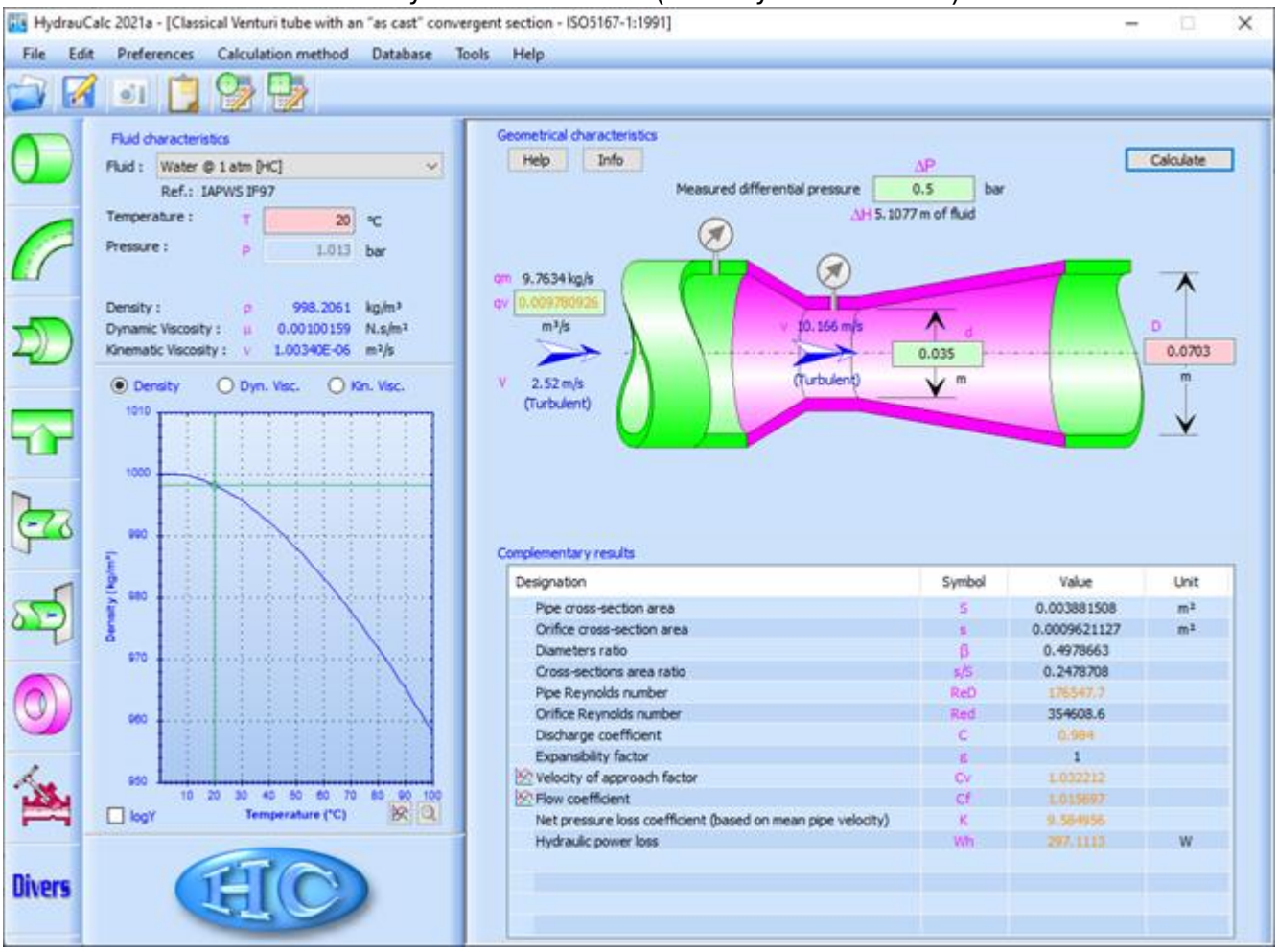
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Limit of use ([1] §10.1.5.2):

- $100\ mm \leq D \leq 800\ mm$
- $0,3 \leq \beta \leq 0,75$
- $2 \cdot 10^5 \leq Re_D \leq 2 \cdot 10^6$

Example of application:



References:

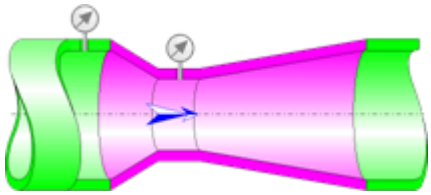
[1] ISO 5167-1:1991 - Measurement of fluid flow by means of pressure differential devices

2.9.3.5 ISO 5167-1:1991 - Classical Venturi tube with a machined convergent section

Classical Venturi tube

with a machined convergent section

(ISO 5167-1:1991)



Model description:

This model of component determines the fluid flow through a classical Venturi tube with a machined convergent section, according to the international standard "ISO-5167-1:1991".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

Reynolds number referred to internal pipe diameter:

$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient:

$$C = 0.995$$ ([1] §10.1.5.3)

Expansibility factor:

$$\varepsilon = 1$$ ([1] §3.3.5) for incompressible fluid (liquid)

Mass flow rate (kg/s):

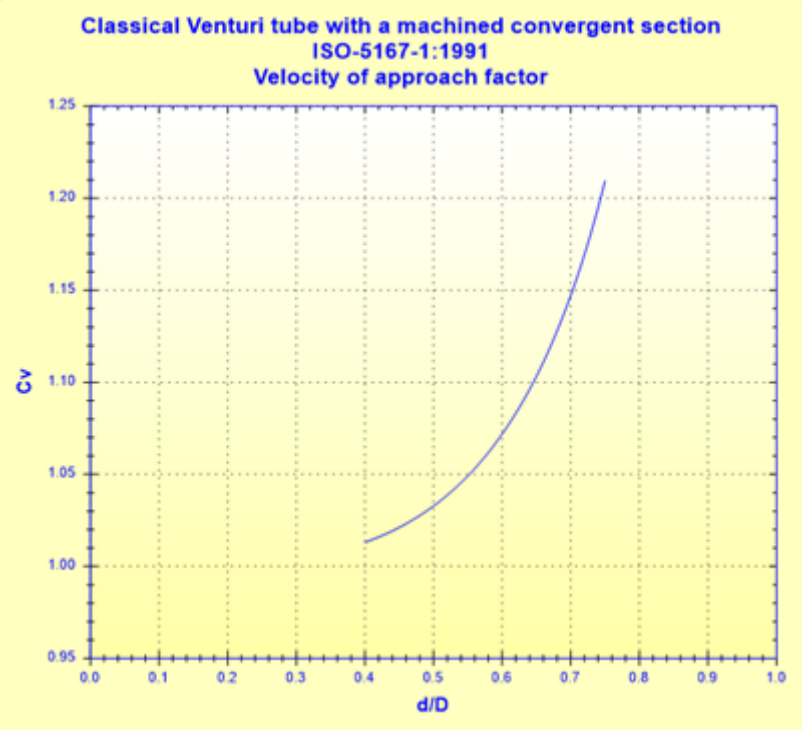
$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$ ([1] §5.1 eq. 1)

Volume flow rate (m^3/s):

$$q_v = \frac{q_m}{\rho}$$ ([1] §5.1 eq. 3)

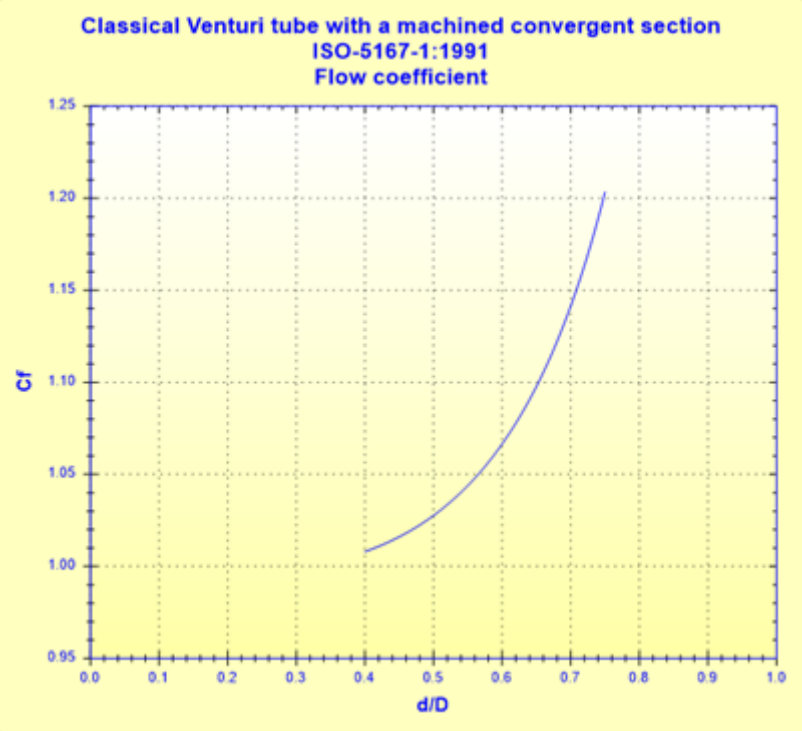
Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.4)



Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.4)



Net pressure loss:

The net pressure loss is not formulated in the reference document [1]

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()

Re_D Reynolds number referred to pipe ()

C Discharge coefficient ()

ε Expansibility factor ()

q_m Mass flow rate (kg/s)

C_v Velocity of approach factor ()

C_f Flow coefficient ()

ΔP Measured pressure loss (Pa)

ΔH Measured head loss of fluid (m)

ρ Fluid density (kg/m³)

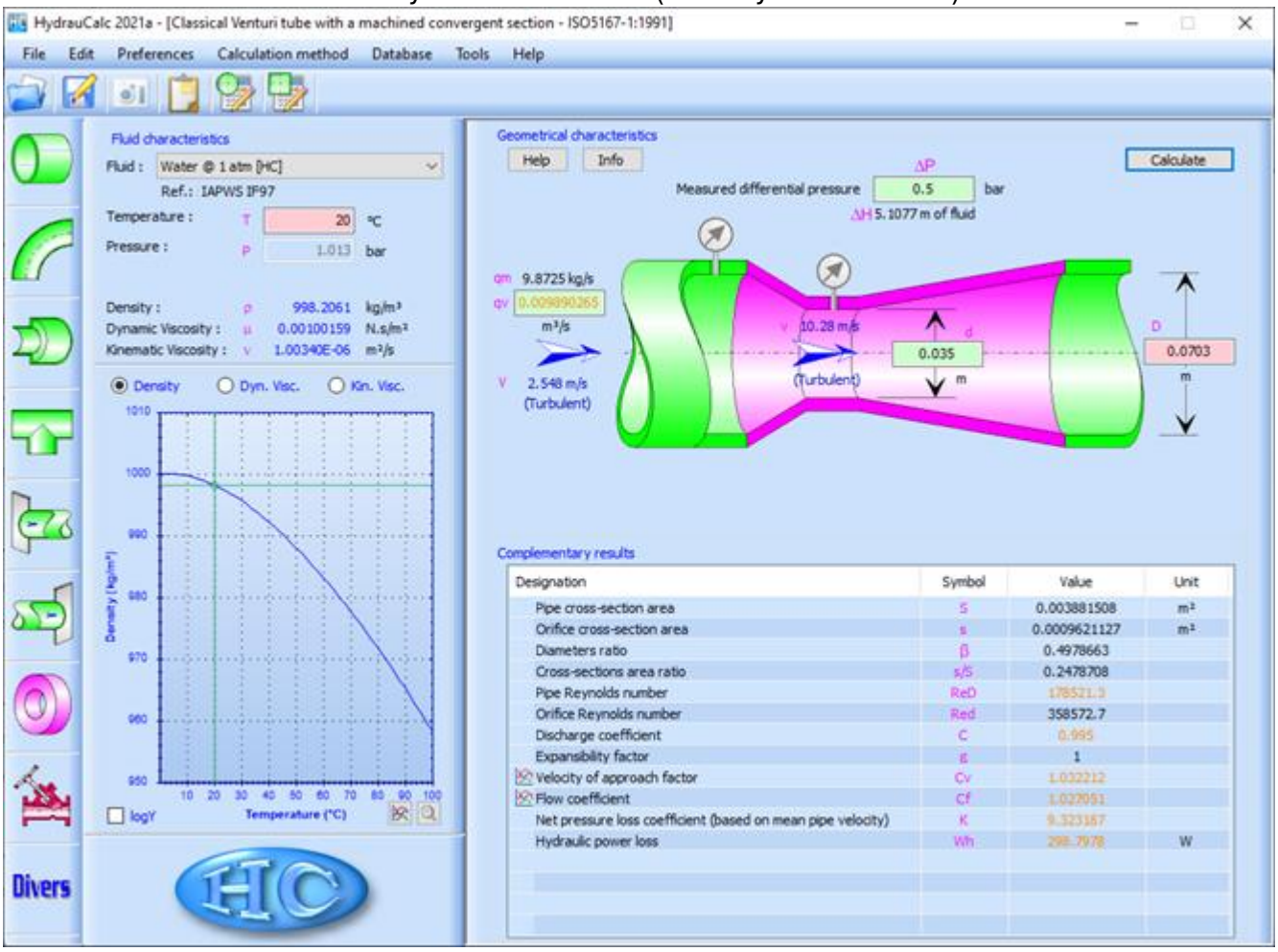
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Limit of use ([1] §10.1.5.3):

- $50\ mm \leq D \leq 250\ mm$
- $0,4 \leq \beta \leq 0,75$
- $2 \cdot 10^5 \leq Re_D \leq 1 \cdot 10^6$

Example of application:



References:

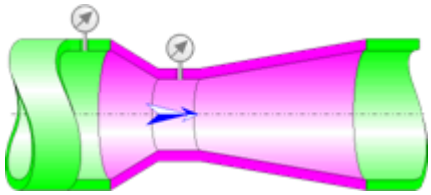
[1] ISO 5167-1:1991 - Measurement of fluid flow by means of pressure differential devices

2.9.3.6 ISO 5167-1:1991 - Classical Venturi tube with a rough-welded sheet-iron convergent

Classical Venturi tube

with a rough-welded sheet-iron convergent

(ISO 5167-1:1991)



Model description:

This model of component determines the fluid flow through a classical Venturi tube with a rough-welded sheet-iron convergent, according to the international standard "ISO-5167-1:1991".

Model formulation:

Diameter ratio:

$$\beta = \frac{d}{D}$$

Orifice cross-sectional area (m^2):

$$s = \pi \cdot \frac{d^2}{4}$$

Pipe cross-sectional area (m^2):

$$S = \pi \cdot \frac{D^2}{4}$$

Mean velocity in orifice (m/s):

$$v = \frac{q_v}{s}$$

Mean velocity in pipe (m/s):

$$V = \frac{q_v}{S}$$

Reynolds number referred to orifice diameter:

$$\mathrm{Re}_d = \frac{v \cdot d}{\nu}$$

Reynolds number referred to internal pipe diameter:

$$\mathrm{Re}_D = \frac{V \cdot D}{\nu}$$

Discharge coefficient:

$$C = 0.985$$ ([1] §10.1.5.4)

Expansibility factor:

$$\varepsilon = 1$$ ([1] §3.3.5) for incompressible fluid (liquid)

Mass flow rate (kg/s):

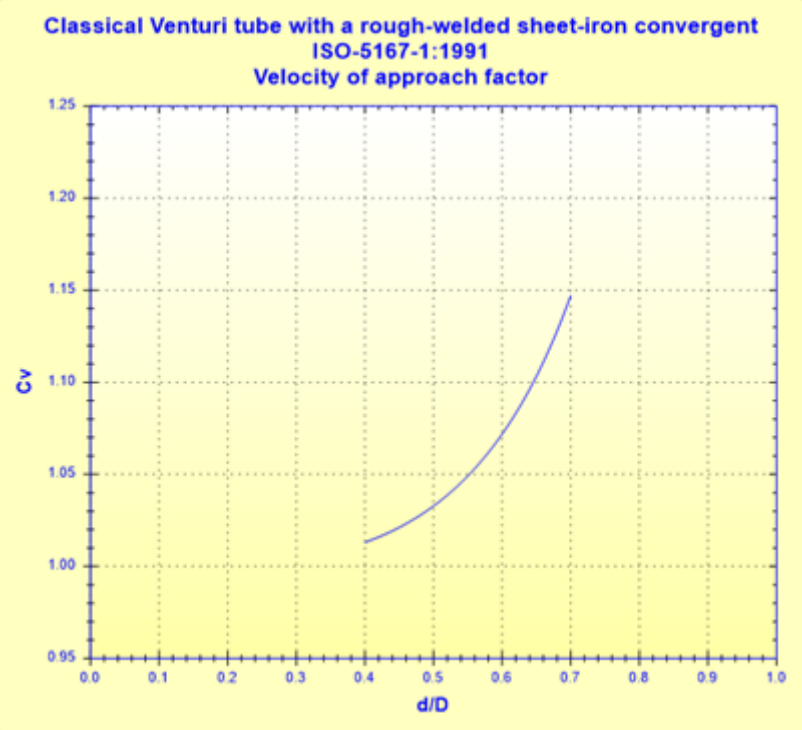
$$q_m = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho}$$ ([1] §5.1 eq. 1)

Volume flow rate (m^3/s):

$$q_v = \frac{q_m}{\rho}$$ ([1] §5.1 eq. 3)

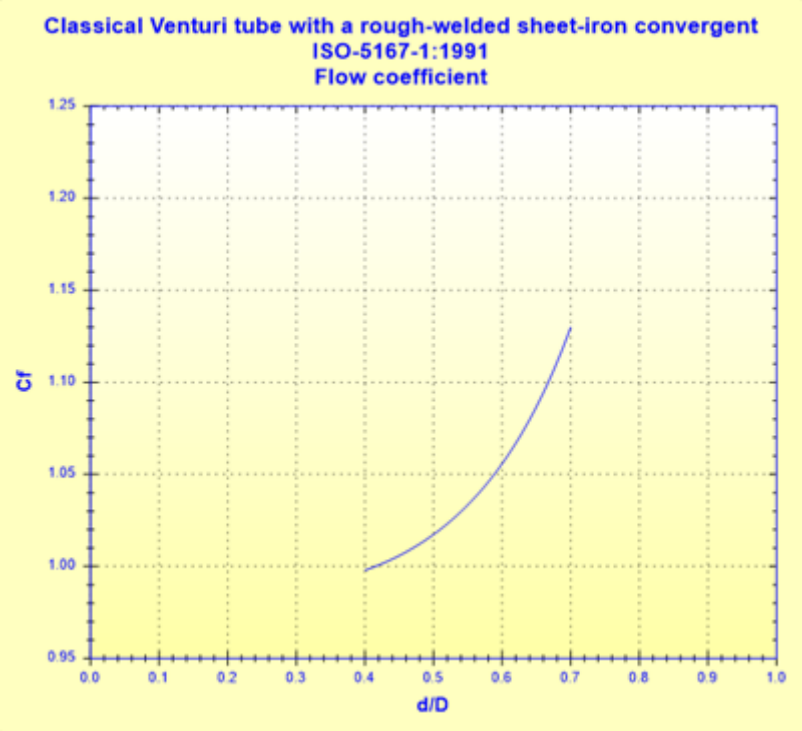
Velocity of approach factor:

$$C_v = \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.4)



Flow coefficient:

$$C_f = C \cdot \frac{1}{\sqrt{1-\beta^4}}$$ ([1] §3.3.4)



Net pressure loss:

The net pressure loss is not formulated in the reference document [1]

Measured head loss (m):

$$\Delta H = \frac{\Delta P}{\rho \cdot g}$$

Symbols, Definitions, SI Units:

d	Orifice diameter (m)
D	Internal pipe diameter (m)
β	Diameter ratio ()
s	Orifice cross-sectional area (m^2)
S	Pipe cross-sectional area (m^2)
q_v	Volume flow rate (m^3/s)
v	Mean velocity in orifice (m/s)
V	Mean velocity in pipe (m/s)
Re_d	Reynolds number referred to orifice ()

Re_D Reynolds number referred to pipe ()

C Discharge coefficient ()

ε Expansibility factor ()

q_m Mass flow rate (kg/s)

C_v Velocity of approach factor ()

C_f Flow coefficient ()

ΔP Measured pressure loss (Pa)

ΔH Measured head loss of fluid (m)

ρ Fluid density (kg/m³)

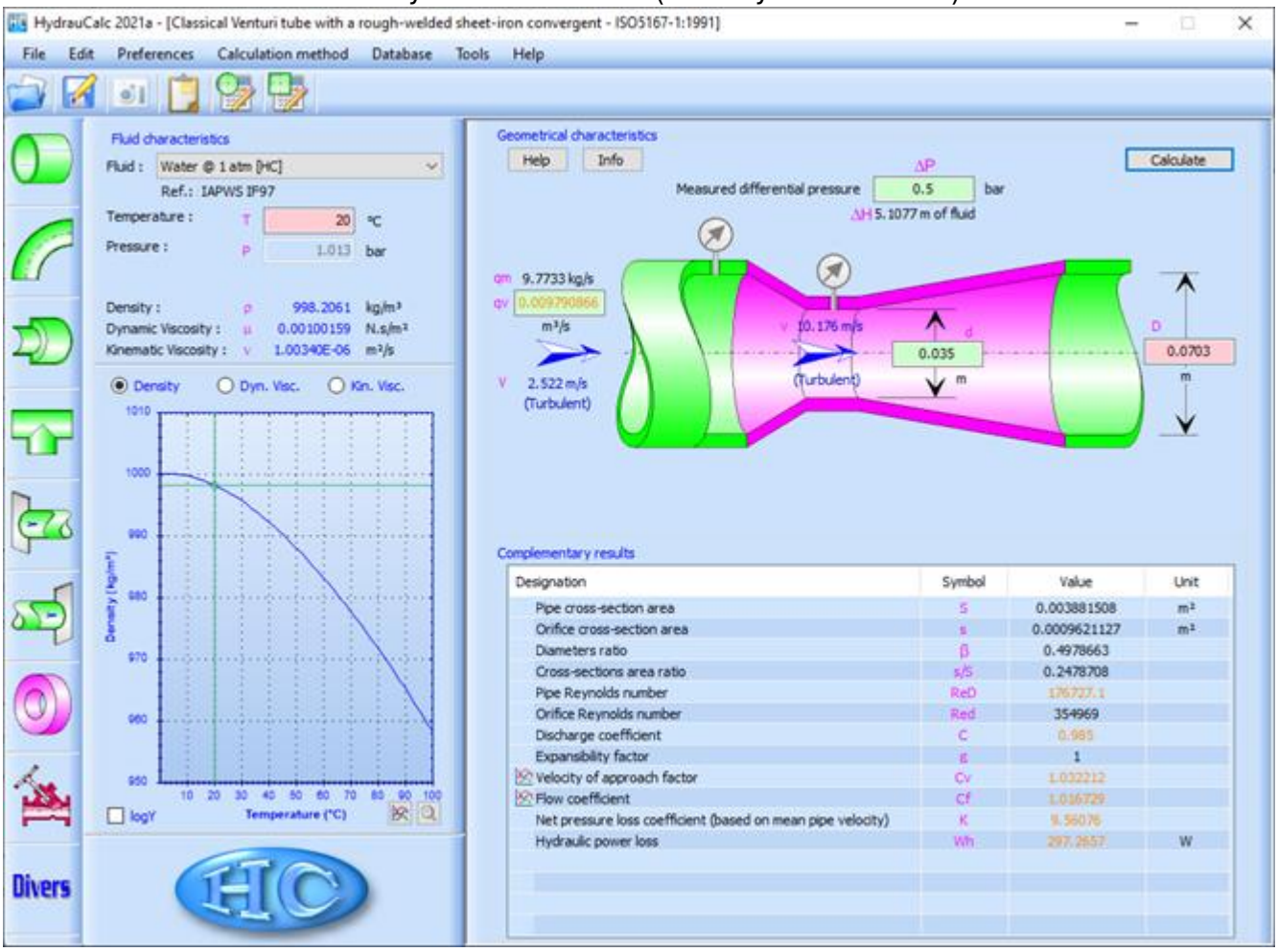
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Limit of use ([1] §10.1.5.4):

- $200\ mm \leq D \leq 1200\ mm$
- $0,4 \leq \beta \leq 0,7$
- $2 \cdot 10^5 \leq Re_D \leq 2 \cdot 10^6$

Example of application:



References:

[1] ISO 5167-1:1991 - Measurement of fluid flow by means of pressure differential devices

2.10 Valves

This subsection regroups the set of valves that can be modeled and calculated. The types of valves available are:

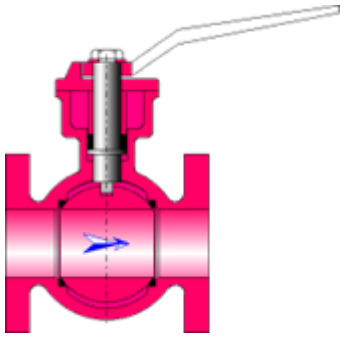
- Ball Valve

- Butterfly Valve

- Y Globe Valve

- Globe Valve

2.10.1 Ball valve

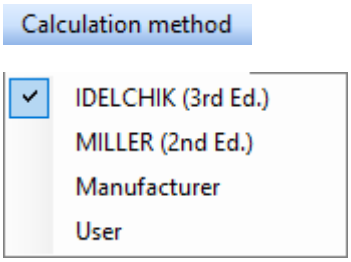


For the calculation of the pressure loss coefficient of ball valves, the user can choose from one of the methods described in the following two reference documents:

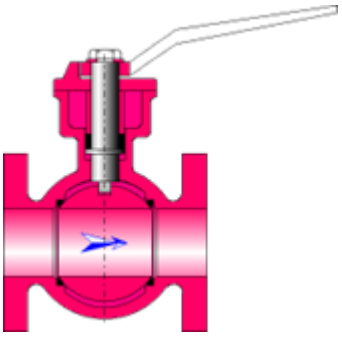
- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

It can also select a valve from a list of valves offered by manufacturers or define its own valve.

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.10.1.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a ball valve installed in a straight pipe.

Model formulation:

Cross-sectional area (m^2):

$$F = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$w = \frac{Q}{F}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

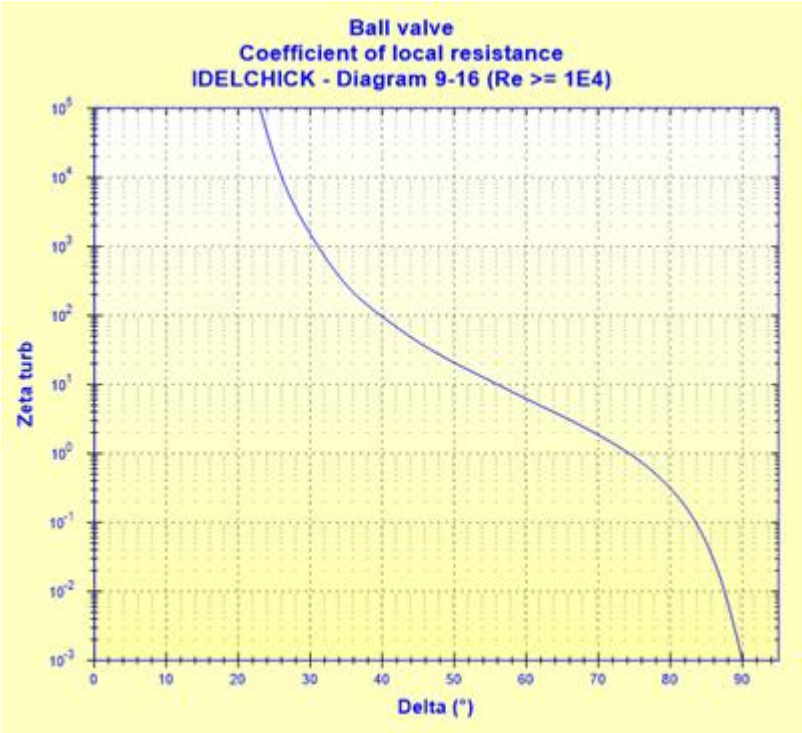
Reynolds number:

$$\mathrm{Re} = \frac{w \cdot D}{\nu}$$

Local resistance coefficient:

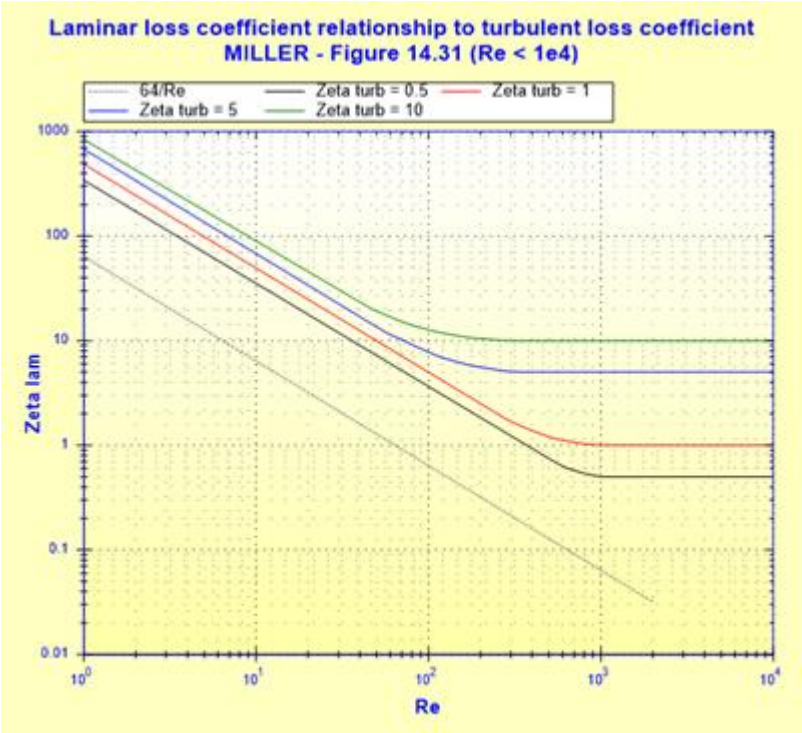
- Re ≥ 10^4 (turbulent flow)

$$\zeta_{turb} = f(\delta)$$ ([1] diagram 9-16 curve 1)



- Re < 10^4 (laminar flow)

$$\zeta_{lam} = f(\zeta_{turb}, \mathrm{Re})$$ ([2] figure 14.31)



Reynolds Number Correction ($Re < 10^4$):

$$C_{Re} = \frac{\zeta_{lam}}{\zeta_{turb}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$\zeta = \zeta_{turb}$$

- laminar flow ($Re < 10^4$):

$$\zeta = \zeta_{lam}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{w^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
F	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w	Mean velocity (m/s)
Re	Reynolds number ()
δ	Opening angle (°)
ζ_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
ζ_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
ζ	Pressure loss coefficient (based on the mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

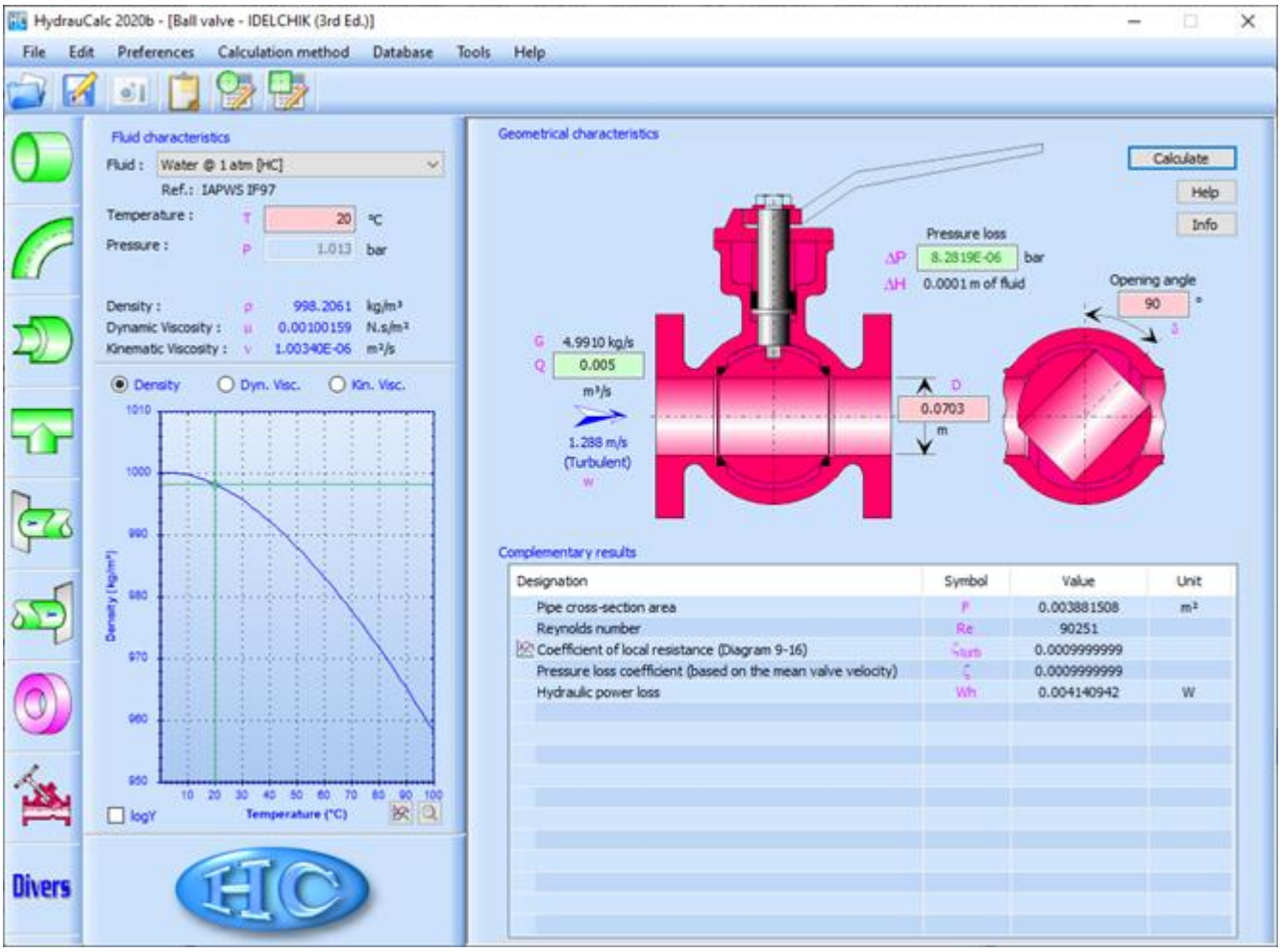
Validity range:

- any flow regime: laminar and turbulent

note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "ζ_{lam}" is estimated

---

Example of application:

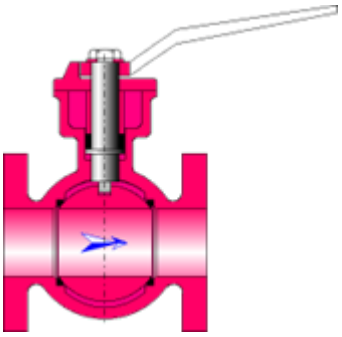


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

[2] Internal Flow System, Second Edition, D.S. Miller

2.10.1.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a ball valve installed in a straight pipe.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

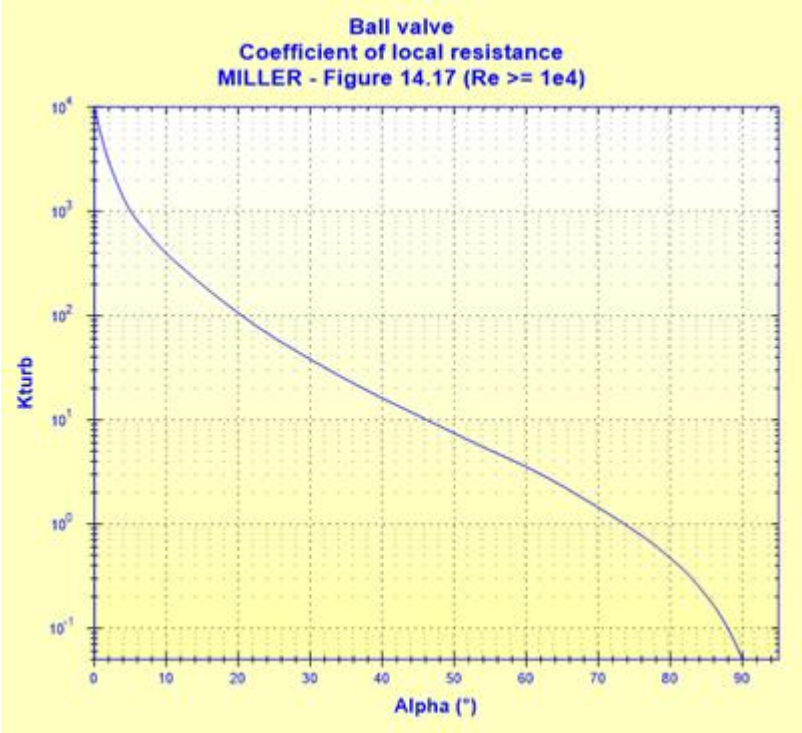
Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

Local resistance coefficient:

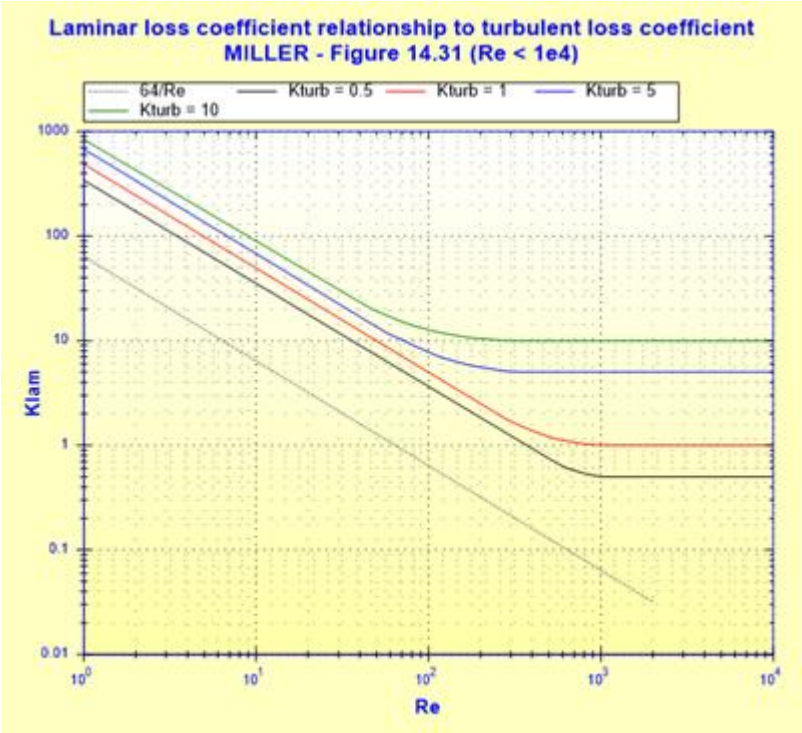
- Re ≥ 10^4 (turbulent flow)

$$K_{turb} = f(\alpha)$$ ([1] figure 14.17)



- Re < 10^4 (laminar flow)

$$K_{lam} = f(K_{turb}, \mathrm{Re})$$ ([1] figure 14.31)



Reynolds Number Correction ($Re < 10^4$):

$$C_{Re} = \frac{K_{lam}}{K_{turb}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$K = K_{turb}$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
Re	Reynolds number ()
α	Opening angle (°)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

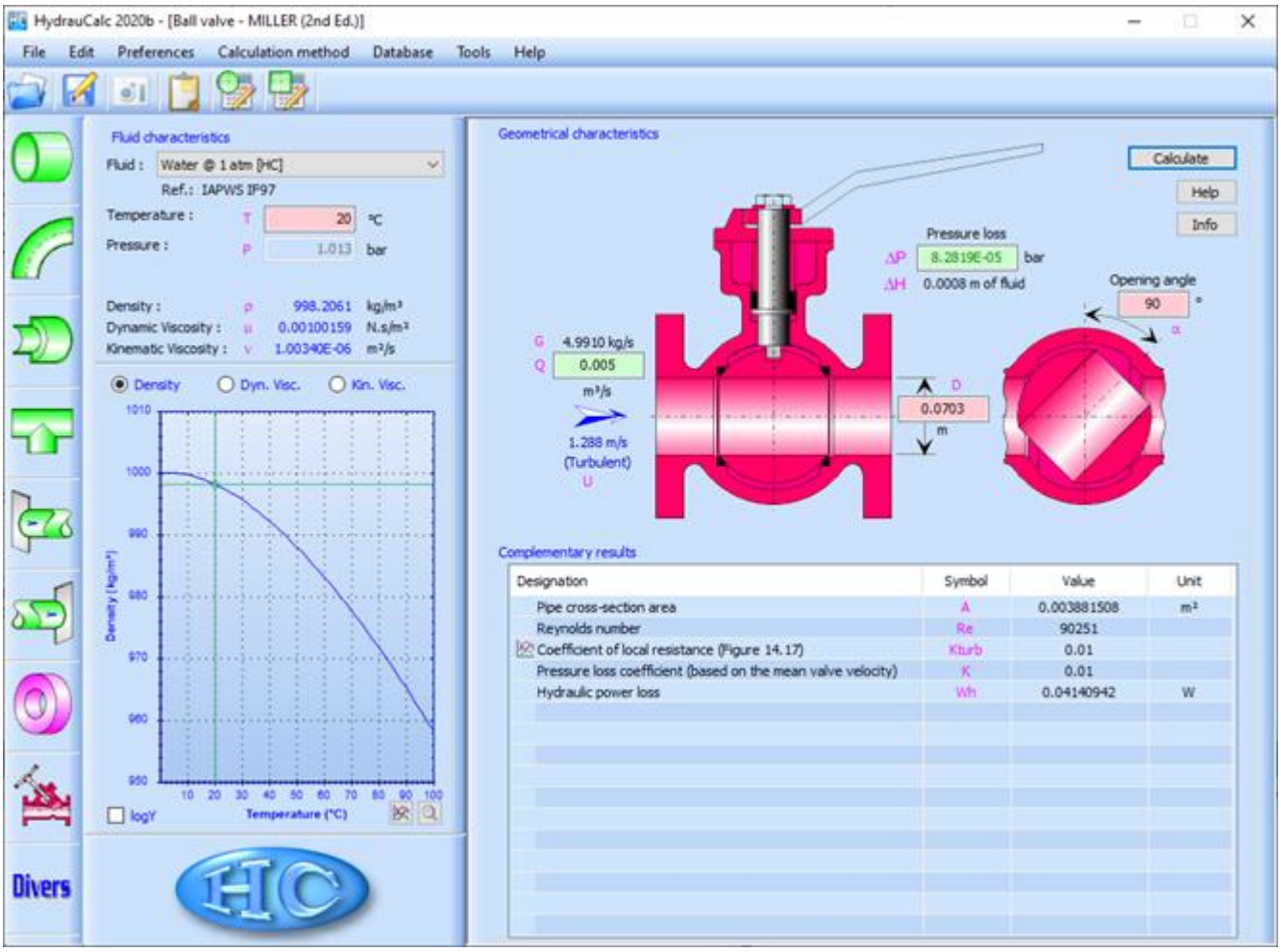
Validity range:

- any flow regime: laminar and turbulent

note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

---

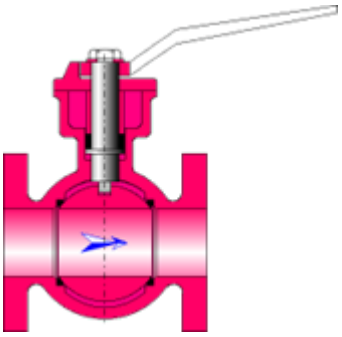
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.10.1.3 Manufacturer



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a ball valve installed in a straight pipe.

The valve characteristics are defined by valves manufacturers. The pressure drop of the valve is characterized by a flow coefficient "Kv", "Cv" or "Av" at full opening, and a law of flow coefficient evolution according the valve opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

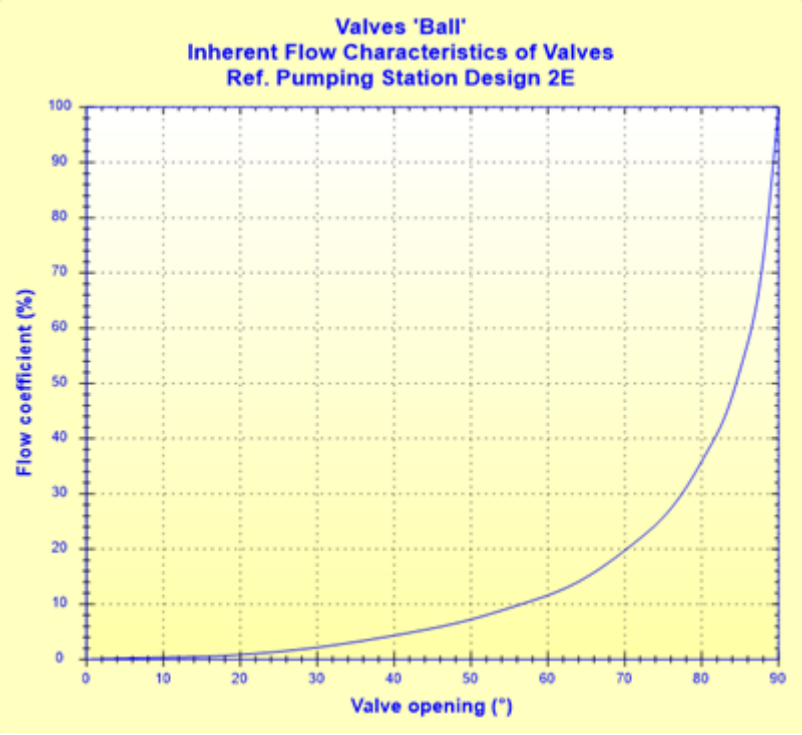
$$Re = \frac{U \cdot D}{\nu}$$

Evolution of the flow coefficients according to the valve opening:

$$Kv = Kvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Cv = Cvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Av = Avs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$



$F_{low}C_{oef}(V_{alve}O_{pening})$ ([1] Figure 5-2)

Local resistance coefficient (Pa):

- Re ≥ 10^4 (turbulent flow)

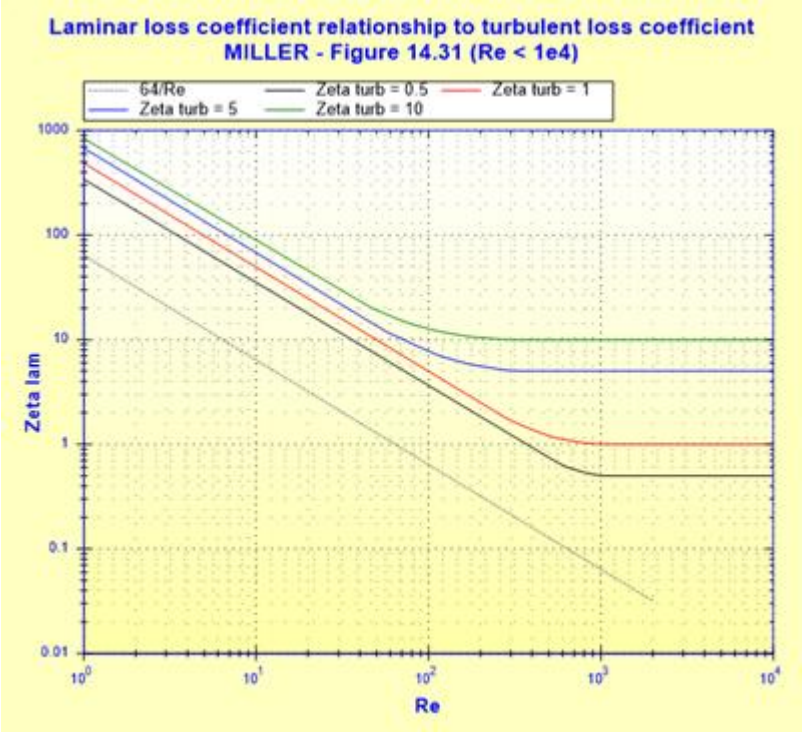
$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv/36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv / 41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

■ Re < 10^4 (laminar flow)

$$K_{lam} = f(K_{turb}, \mathrm{Re})$$ ([2] figure 14.31)



Reynolds Number Correction (Re < 10^4):

$$C_{\mathrm{Re}} = \frac{K_{lam}}{K_{turb}}$$

Corrected flow coefficient in laminar flow (Re < 10^4):

$$Kv_c = \frac{Kv}{\sqrt{C_{Re}}}$$

$$Cv_c = \frac{Cv}{\sqrt{C_{Re}}}$$

$$Av_c = \frac{Av}{\sqrt{C_{Re}}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$K = K_{turb}$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
Re	Reynolds number ()
α	Opening angle (°)
Kvs	Full opening flow coefficient (m^3/h)

Cvs	Full opening flow coefficient (USG/min)
Avs	Full opening flow coefficient (m^2)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
Kv_c	Corrected flow coefficient in laminar flow (m^3/h)
Cv_c	Corrected flow coefficient in laminar flow (USG/min)
Av_c	Corrected flow coefficient in laminar flow (m^2)
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

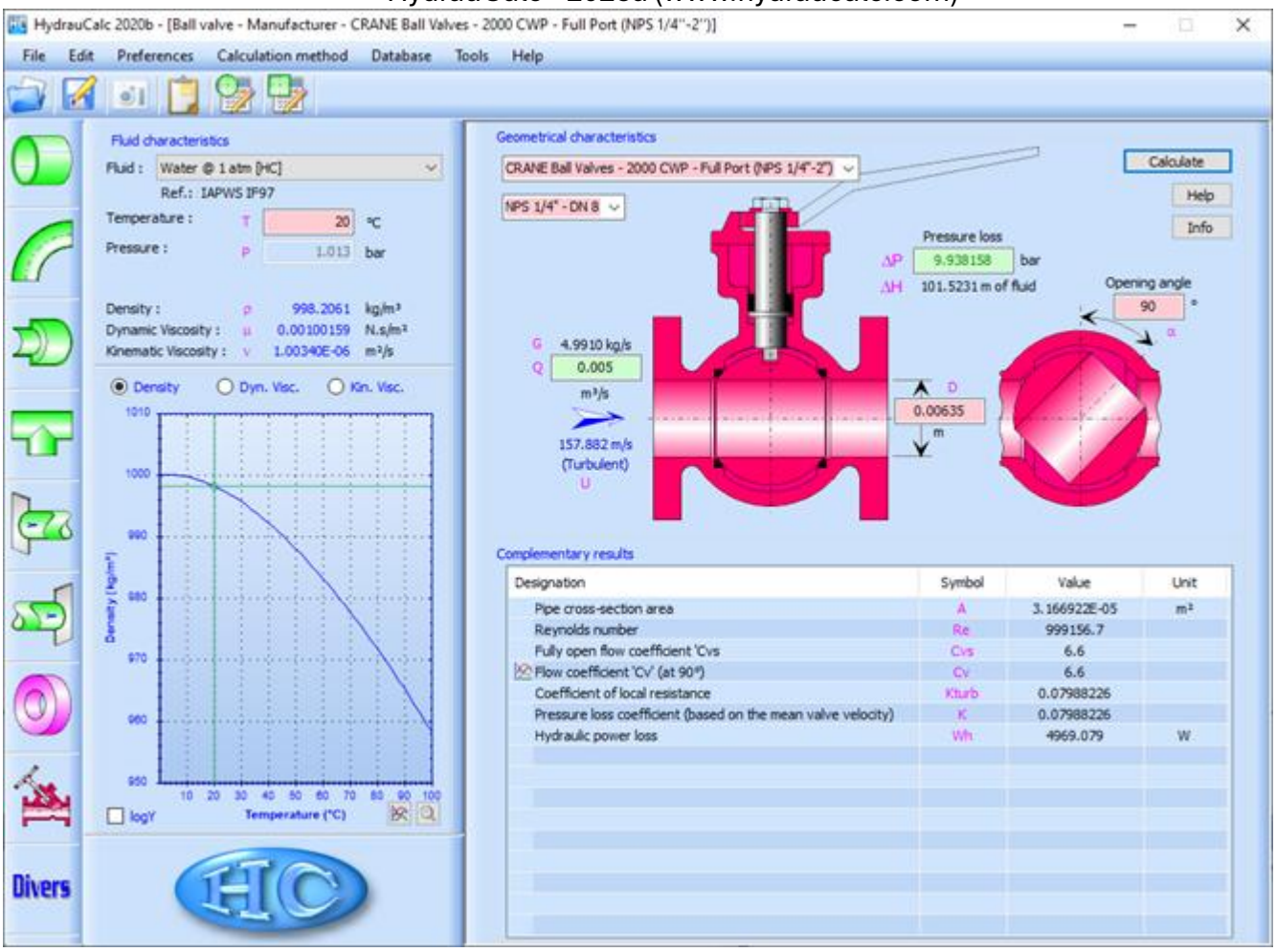
Validity range:

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

---

Example of application:



References:

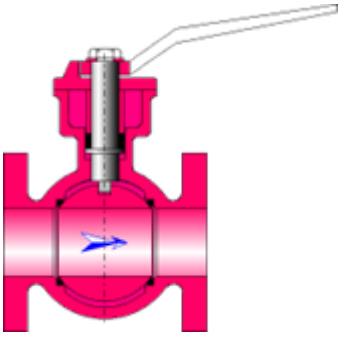
[1] Pumping Station Design, Second Edition, Garr M. Jones

[2] Internal Flow System, Second Edition, D.S. Miller

2.10.1.4 User

Ball valve

(User defined by a flow coefficient)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a ball valve installed in a straight pipe.

The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening, and a law of flow coefficient evolution according the valve opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

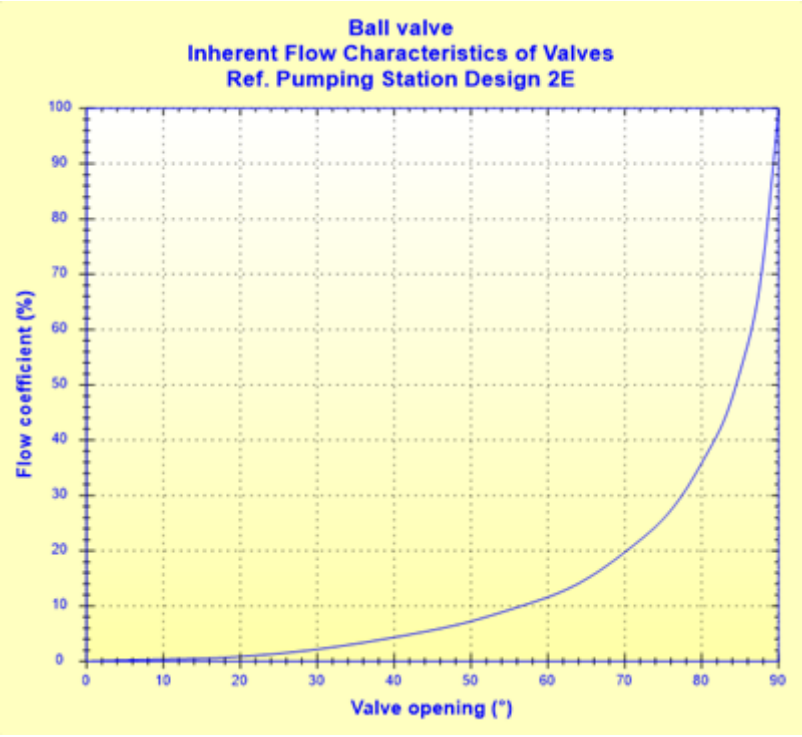
$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Evolution of the flow coefficients according to the valve opening:

$$Kv = Kvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Cv = Cvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Av = Avs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$



$F_{low}C_{oef}(V_{alve}O_{pening})$ ([1] Figure 5-2)

Local resistance coefficient (Pa):

- Re ≥ 10^4 (turbulent flow)

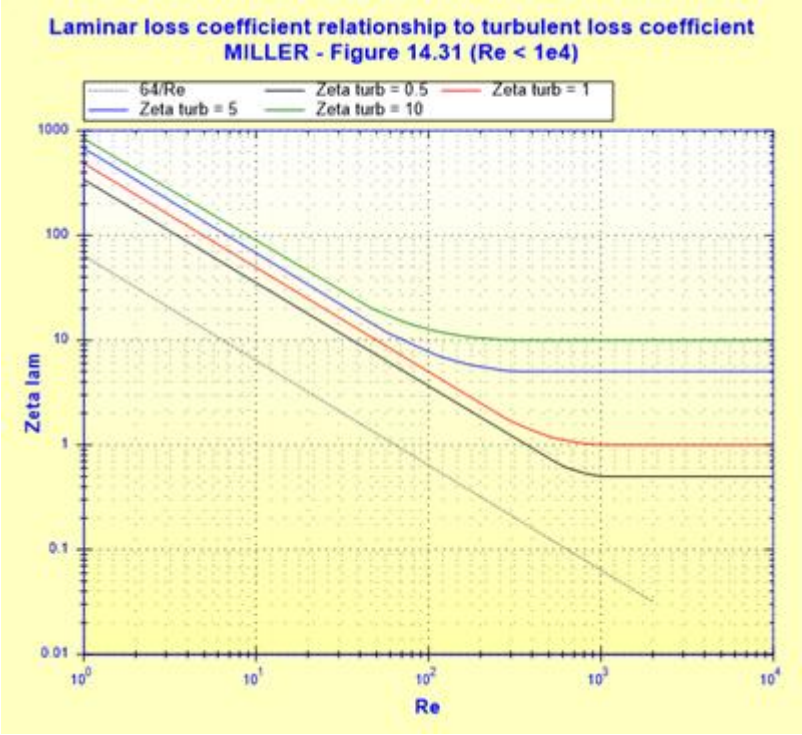
$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv / 36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv / 41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

■ Re < 10^4 (laminar flow)

$$K_{lam} = f(K_{turb}, \mathrm{Re})$$ ([2] figure 14.31)



Reynolds Number Correction (Re < 10^4):

$$C_{\mathrm{Re}} = \frac{K_{lam}}{K_{turb}}$$

Corrected flow coefficient in laminar flow (Re < 10^4):

$$Kv_c = \frac{Kv}{\sqrt{C_{Re}}}$$

$$Cv_c = \frac{Cv}{\sqrt{C_{Re}}}$$

$$Av_c = \frac{Av}{\sqrt{C_{Re}}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$K = K_{turb}$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
Re	Reynolds number ()

α	Opening angle (°)
Kvs	Full opening flow coefficient (m^3/h)
Cvs	Full opening flow coefficient (USG/min)
Avs	Full opening flow coefficient (m^2)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
Kv_c	Corrected flow coefficient in laminar flow (m^3/h)
Cv_c	Corrected flow coefficient in laminar flow (USG/min)
Av_c	Corrected flow coefficient in laminar flow (m^2)
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

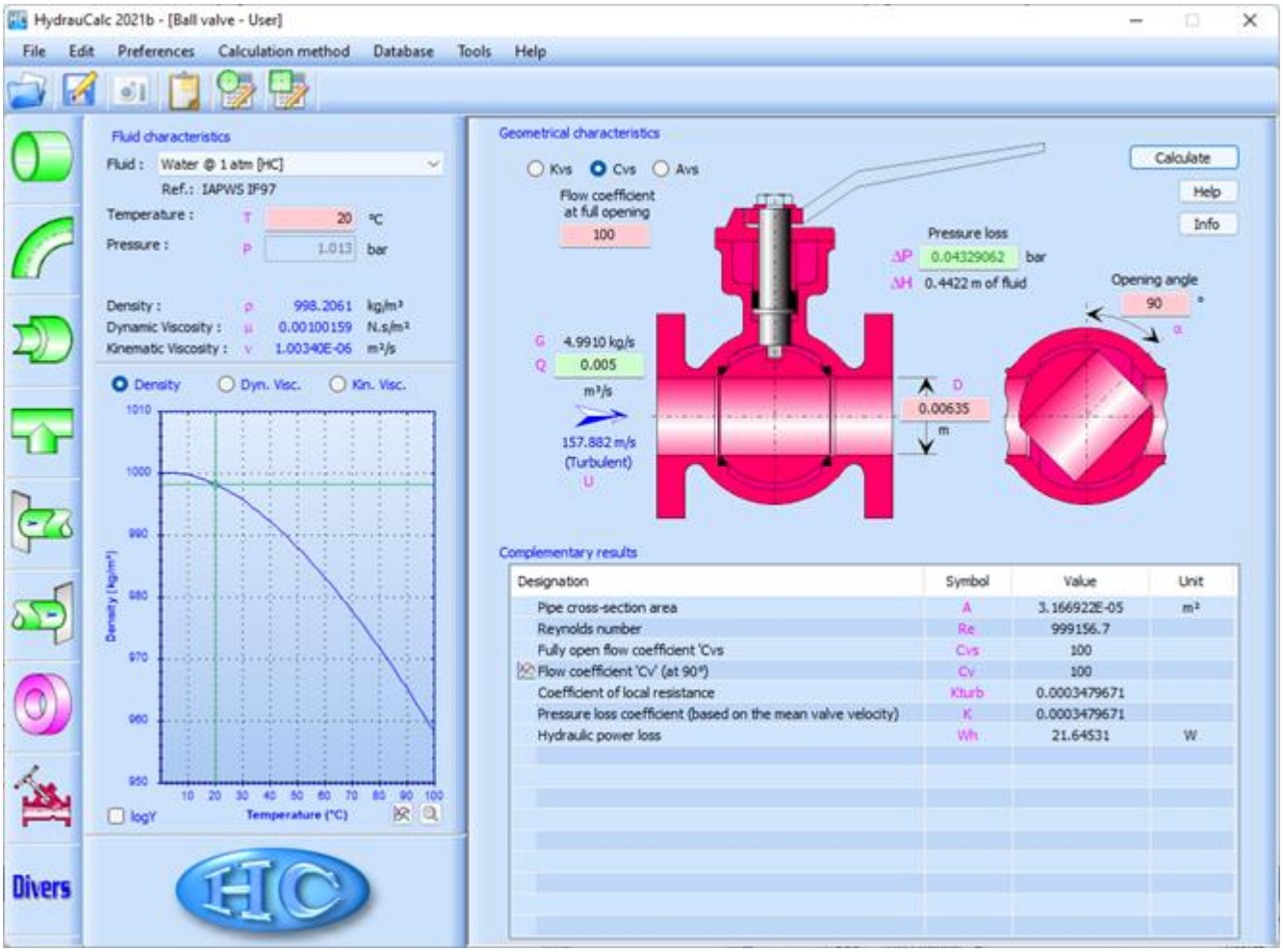
Validity range:

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

---

Example of application:

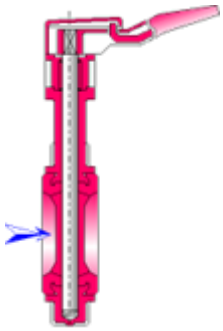


References:

[1] Pumping Station Design, Second Edition, Garr M. Jones

[2] Internal Flow System, Second Edition, D.S. Miller

2.10.2 Butterfly valve

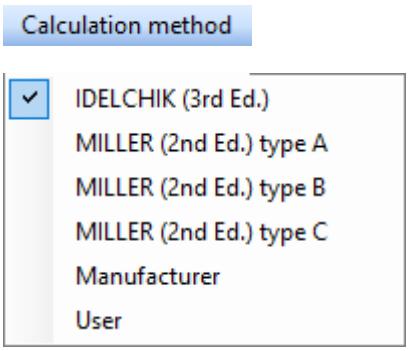


For the calculation of the pressure loss coefficient of butterfly valves, the user can choose from one of the methods described in the following two reference documents:

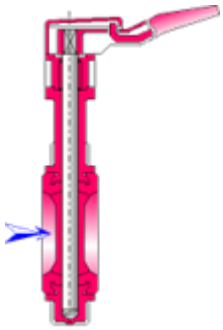
- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

It can also select a valve from a list of valves offered by manufacturers or define its own valve.

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.10.2.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a butterfly valve installed in a straight pipe.

Model formulation:

Cross-sectional area (m^2):

$$F = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$w = \frac{Q}{F}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

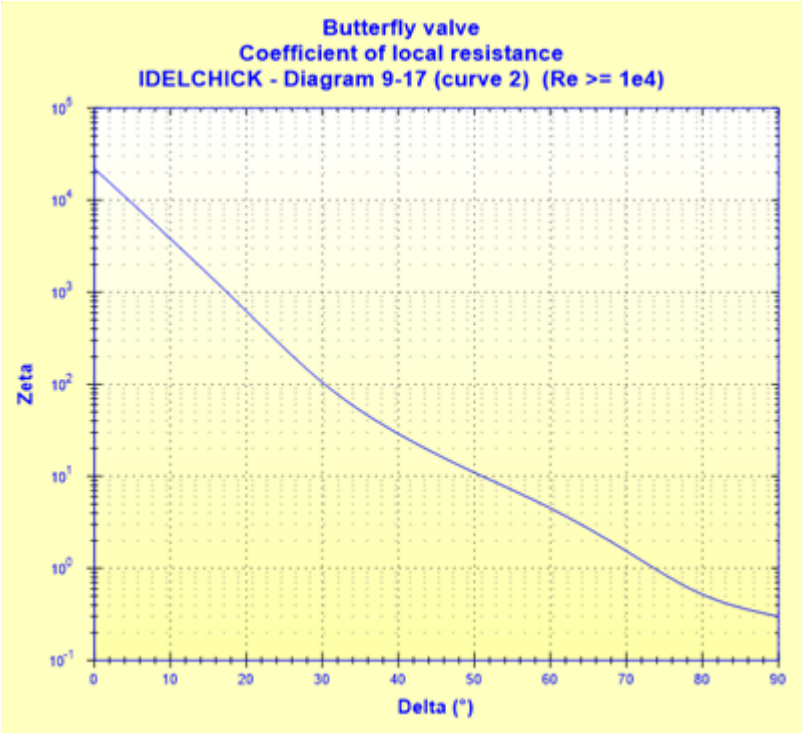
Reynolds number:

$$\mathrm{Re} = \frac{w \cdot D}{\nu}$$

Local resistance coefficient:

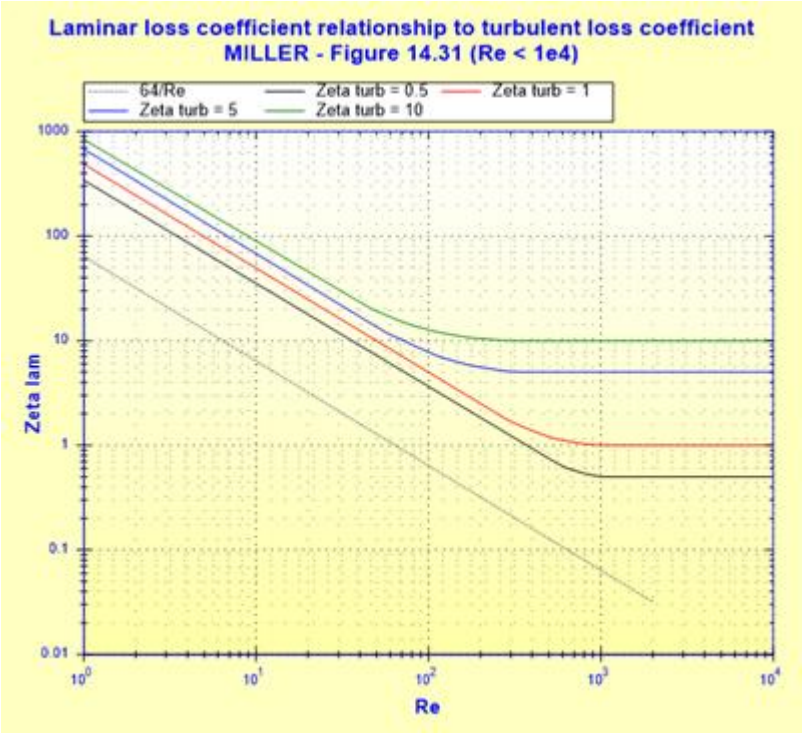
- Re ≥ 10^4 (turbulent flow)

$$\zeta_{turb} = f(\delta)$$ ([1] diagram 9-16 curve 2)



- Re < 10^4 (laminar flow)

$$\zeta_{lam} = f(\zeta_{turb}, \mathrm{Re})$$ ([2] figure 14.31)



Reynolds Number Correction ($Re < 10^4$):

$$C_{Re} = \frac{\zeta_{lam}}{\zeta_{turb}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$\zeta = \zeta_{turb}$$

- laminar flow ($Re < 10^4$):

$$\zeta = \zeta_{lam}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{w^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
F	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w	Mean velocity (m/s)
Re	Reynolds number ()
δ	Opening angle (°)
ζ_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
ζ_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
ζ	Pressure loss coefficient (based on the mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

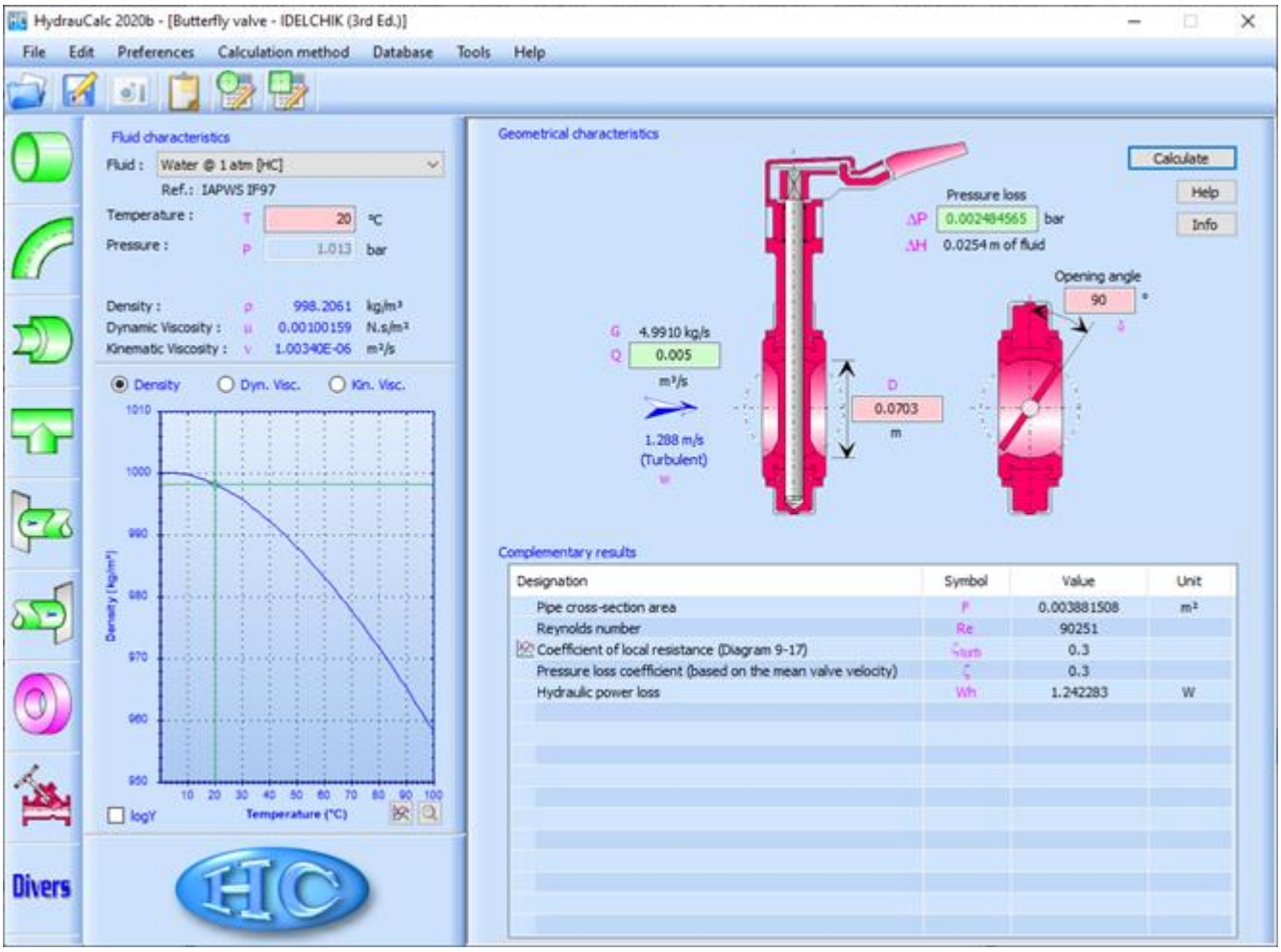
Validity range:

- any flow regime: laminar and turbulent

note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "ζ_{lam}" is estimated

---

Example of application:



References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

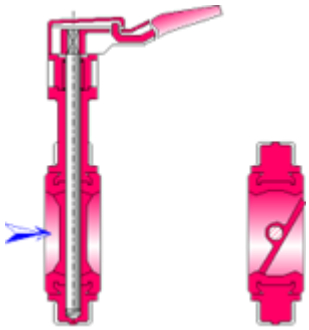
[2] Internal Flow System, Second Edition, D.S. Miller

2.10.2.2 MILLER type A

Butterfly valve

(MILLER)

Type A



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a butterfly valve installed in a straight pipe.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

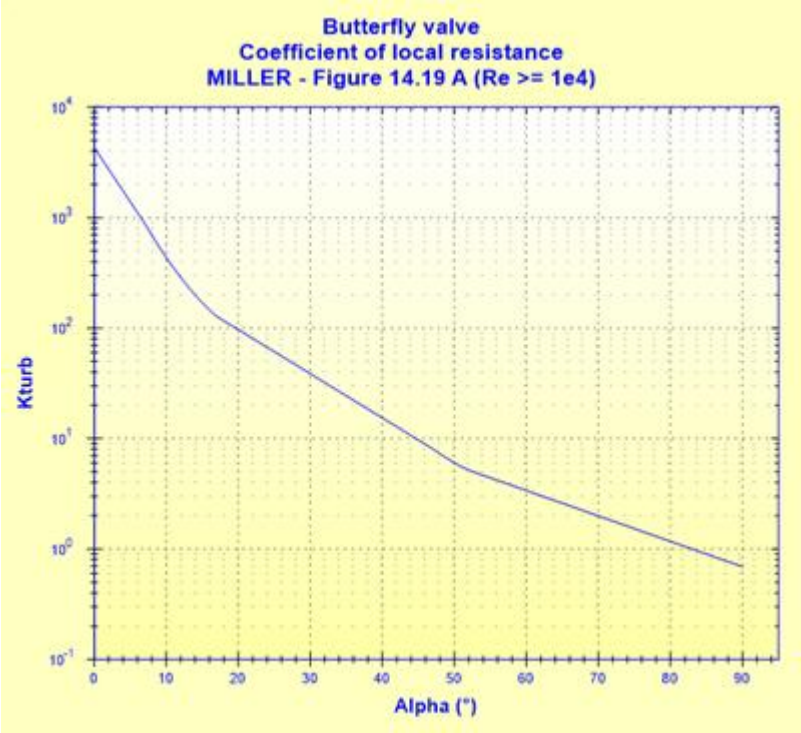
Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Local resistance coefficient:

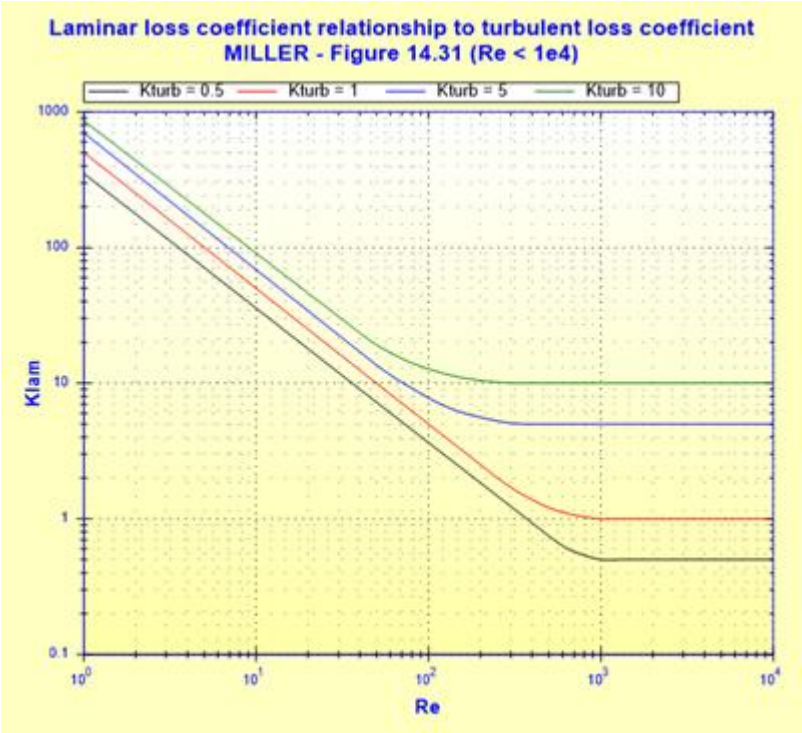
- Re ≥ 10^4 (turbulent flow)

$$K_{turb} = f(\alpha)$$ ([1] figure 14.19 A)



- Re < 10^4 (laminar flow)

$$K_{lam} = f(K_{turb}, \mathrm{Re})$$ ([1] figure 14.31)



Reynolds Number Correction ($Re < 10^4$):

$$C_{Re} = \frac{K_{lam}}{K_{turb}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$K = K_{turb}$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
Re	Reynolds number ()
α	Opening angle (°)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

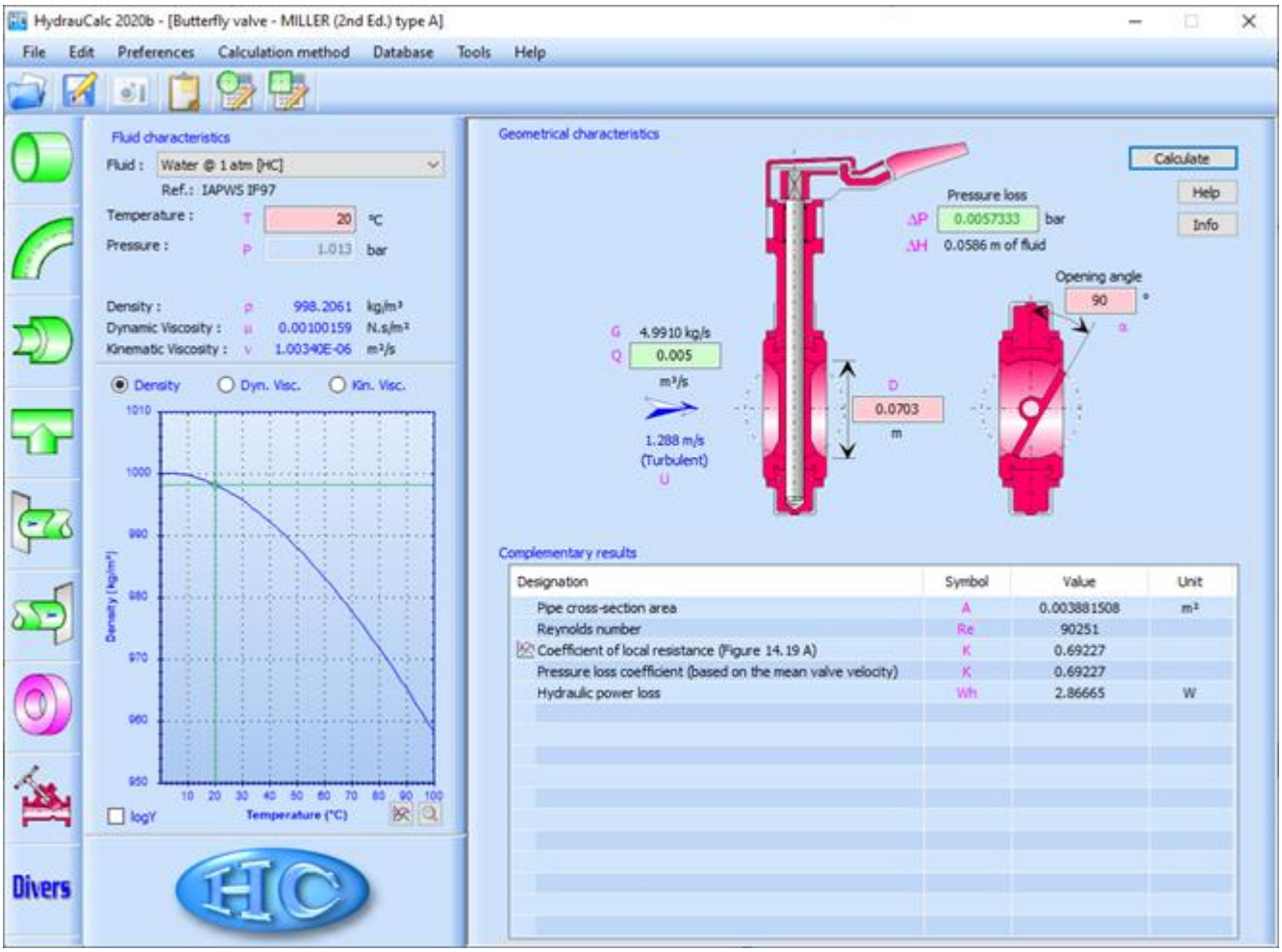
Validity range:

- any flow regime: laminar and turbulent

note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

---

Example of application:



References:

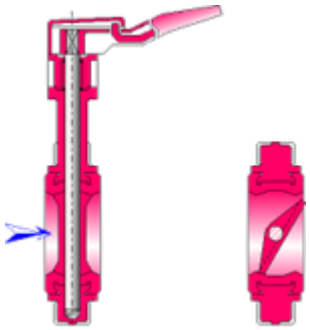
[1] Internal Flow System, Second Edition, D.S. Miller

2.10.2.3 MILLER type B

Butterfly valve

(MILLER)

Type B



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a butterfly valve installed in a straight pipe.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

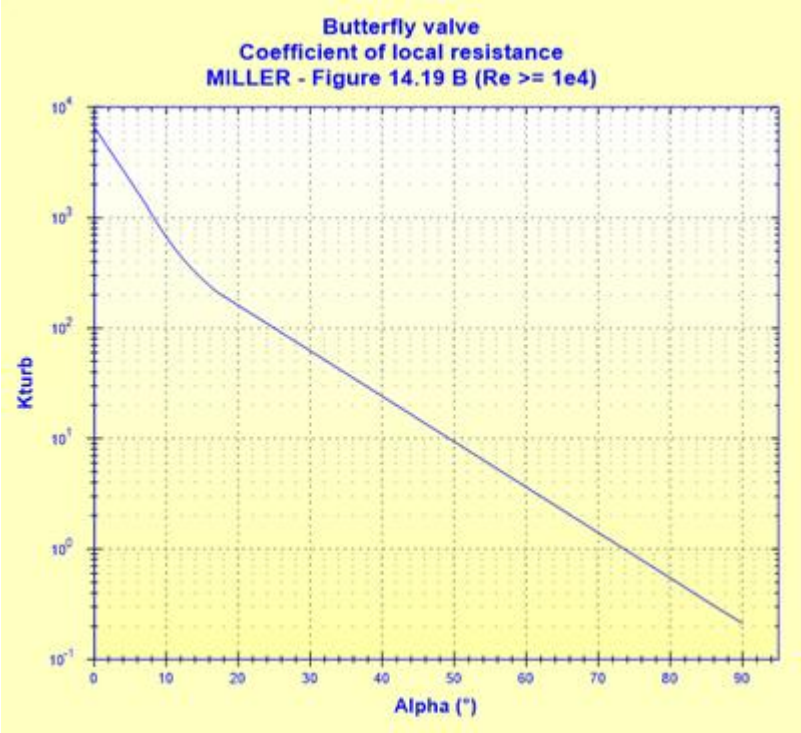
Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Local resistance coefficient:

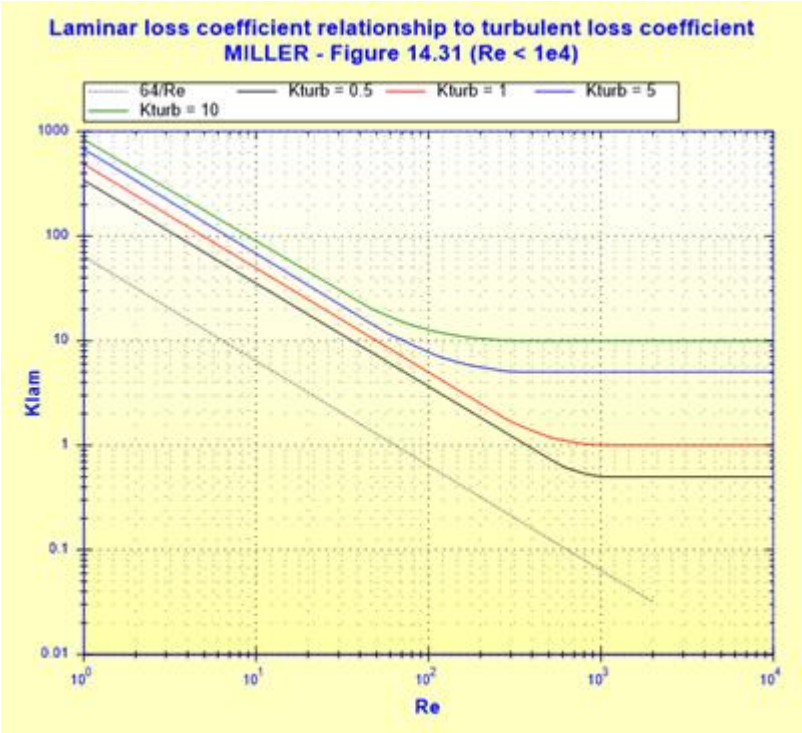
- Re ≥ 10^4 (turbulent flow)

$$K_{turb} = f(\alpha)$$ ([1] figure 14.19 B)



- Re < 10^4 (laminar flow)

$$K_{lam} = f(K_{turb}, \mathrm{Re})$$ ([1] figure 14.31)



Reynolds Number Correction ($Re < 10^4$):

$$C_{Re} = \frac{K_{lam}}{K_{turb}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$K = K_{turb}$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
Re	Reynolds number ()
α	Opening angle (°)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

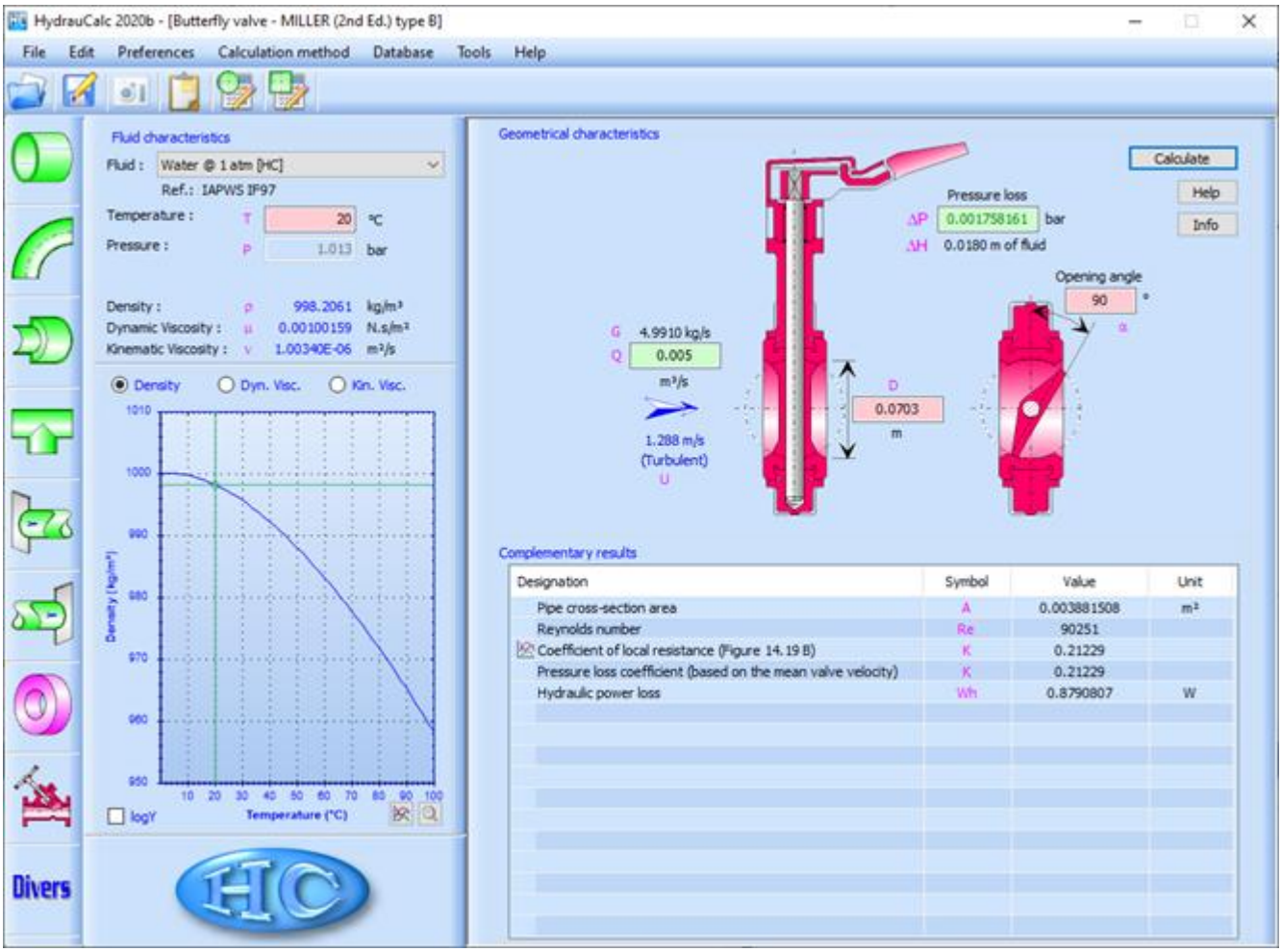
Validity range:

- any flow regime: laminar and turbulent

note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

---

Example of application:



References:

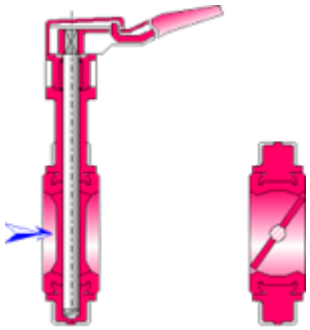
[1] Internal Flow System, Second Edition, D.S. Miller

2.10.2.4 MILLER type C

Butterfly valve

(MILLER)

Type C



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a butterfly valve installed in a straight pipe.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

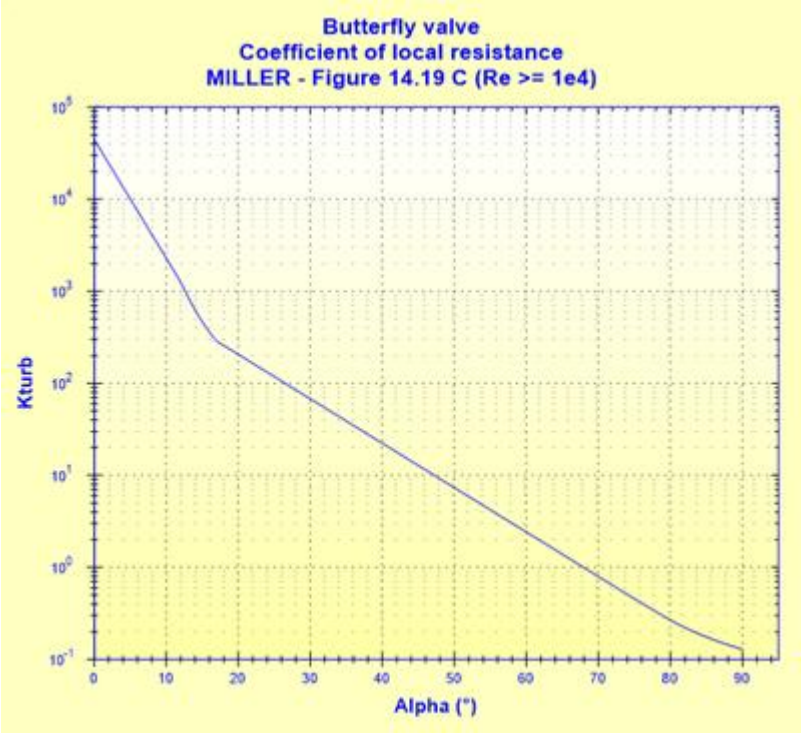
Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Local resistance coefficient:

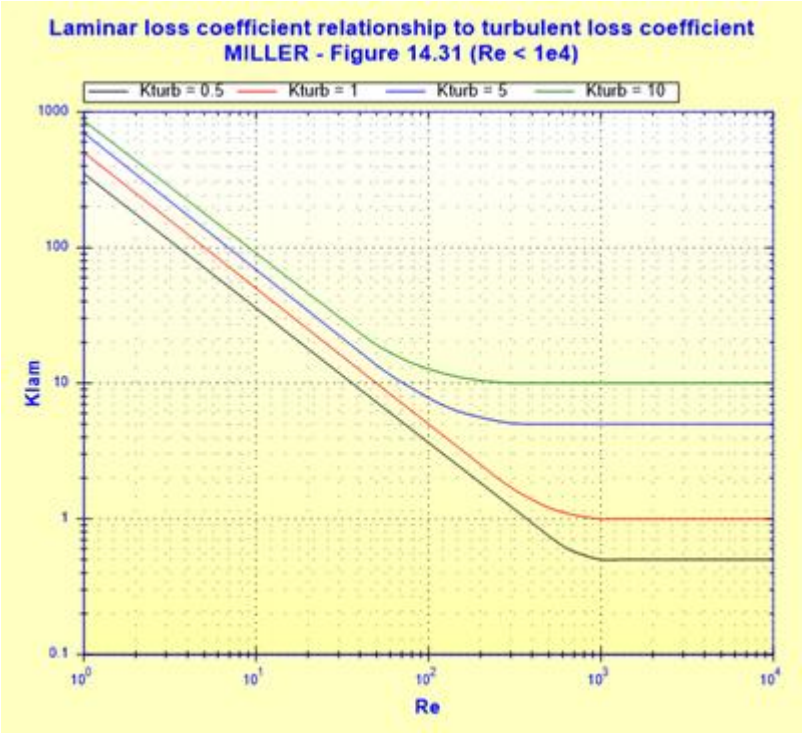
- Re ≥ 10^4 (turbulent flow)

$$K_{turb} = f(\alpha)$$ ([1] figure 14.19 C)



- Re < 10^4 (laminar flow)

$$K_{lam} = f(K_{turb}, \mathrm{Re})$$ ([1] figure 14.31)



Reynolds Number Correction ($Re < 10^4$):

$$C_{Re} = \frac{K_{lam}}{K_{turb}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$K = K_{turb}$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
Re	Reynolds number ()
α	Opening angle (°)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

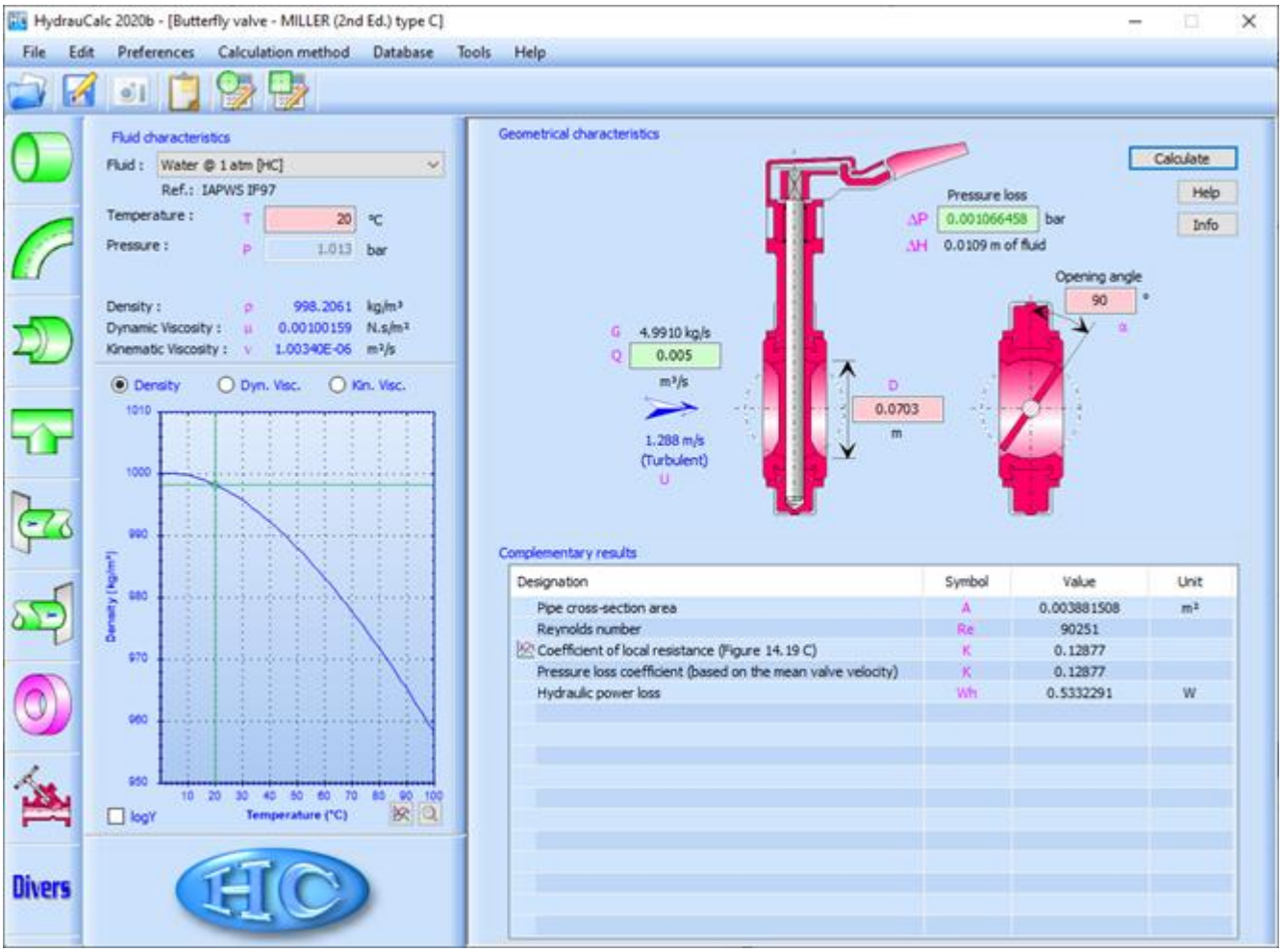
Validity range:

- any flow regime: laminar and turbulent

note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

---

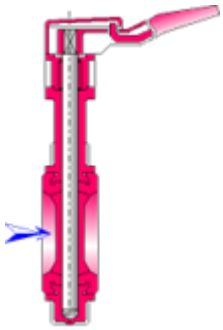
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.10.2.5 Manufacturer



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a butterfly valve installed in a straight pipe.

The valve characteristics are defined by valves manufacturer. The pressure drop of the valves is characterized by a flow coefficient "Kv", "Cv" or "Av" at full opening, and a law of flow coefficient evolution according the valve opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

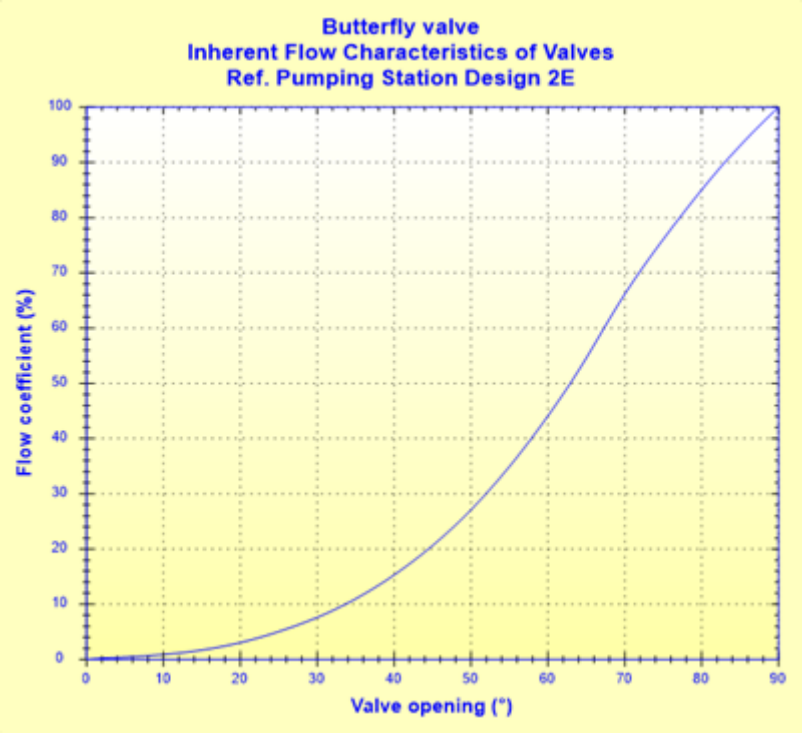
Evolution of the flow coefficients according to the opening of the valve:

$$Kv = Kvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Cv = Cvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Av = Avs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

Example of flow coefficient vs valve opening:



$F_{low}C_{oef}(V_{alve}O_{pening})$ ([1] Figure 5-2)

Local resistance coefficient (Pa):

- $Re \geq 10^4$ (turbulent flow)

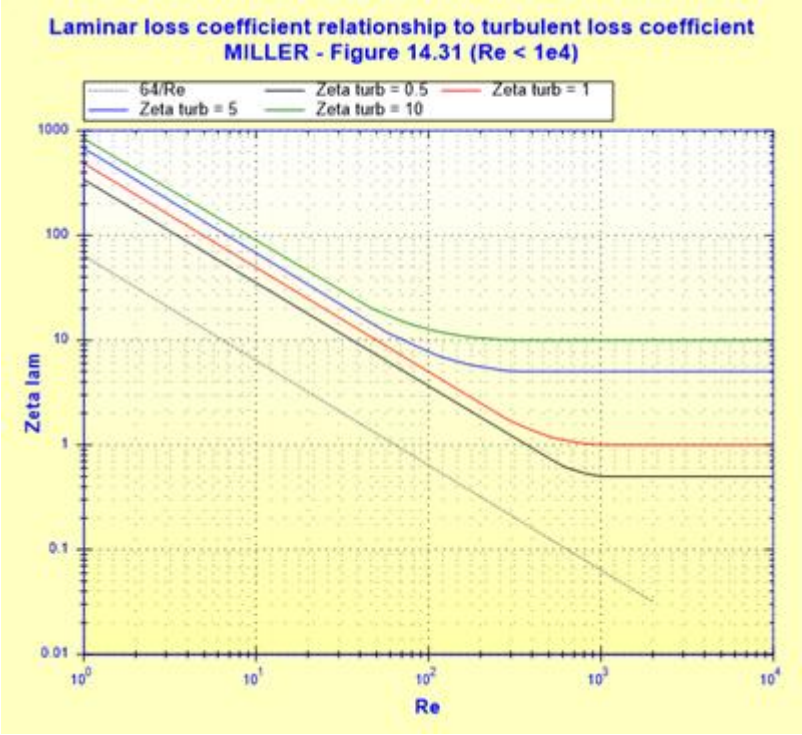
$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv / 36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv / 41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

■ Re < 10^4 (laminar flow)

$$K_{lam} = f(K_{turb}, \mathrm{Re})$$ ([2] figure 14.31)



Reynolds Number Correction (Re < 10^4):

$$C_{\mathrm{Re}} = \frac{K_{lam}}{K_{turb}}$$

Corrected flow coefficient in laminar flow (Re < 10^4):

$$Kv_c = \frac{Kv}{\sqrt{C_{Re}}}$$

$$Cv_c = \frac{Cv}{\sqrt{C_{Re}}}$$

$$Av_c = \frac{Av}{\sqrt{C_{Re}}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$K = K_{turb}$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
Re	Reynolds number ()

α	Opening angle (°)
Kvs	Fully open flow coefficient (m^3/h)
Cvs	Fully open flow coefficient (USG/min)
Avs	Fully open flow coefficient (m^2)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
Kv_c	Corrected flow coefficient in laminar flow (m^3/h)
Cv_c	Corrected flow coefficient in laminar flow (USG/min)
Av_c	Corrected flow coefficient in laminar flow (m^2)
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

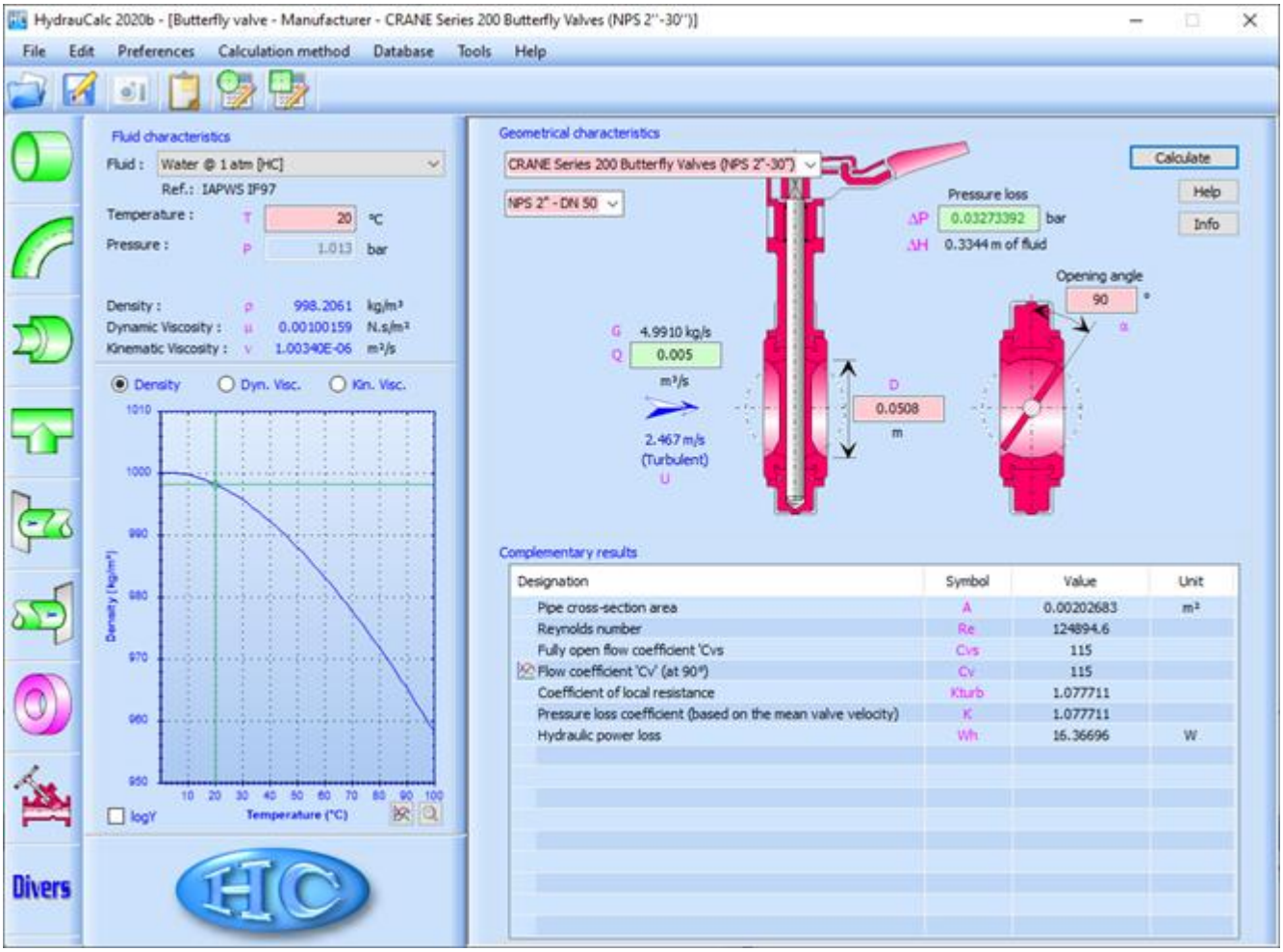
Validity range:

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

---

Example of application:



References:

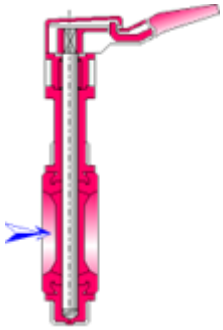
[1] Pumping Station Design, Second Edition, Garr M. Jones

[2] Internal Flow System, Second Edition, D.S. Miller

2.10.2.6 User

Butterfly valve

(User defined by a flow coefficient)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a butterfly valve installed in a straight pipe.

The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening, and a law of flow coefficient evolution according the valve opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

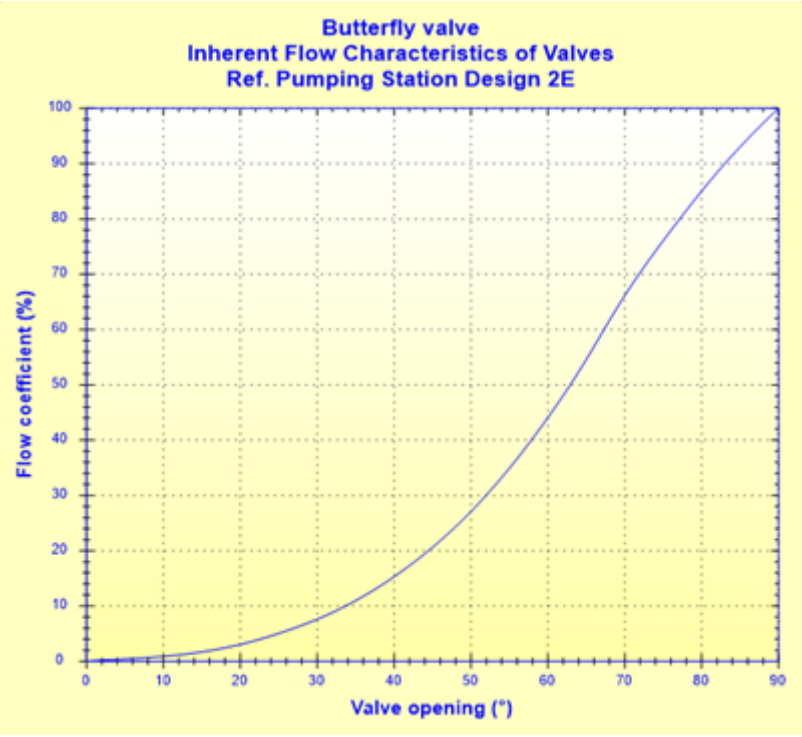
$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Evolution of the flow coefficients according to the opening of the valve:

$$Kv = Kvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Cv = Cvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Av = Avs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$



$F_{low}C_{oef}(V_{alve}O_{pening})$ ([1] Figure 5-2)

Local resistance coefficient (Pa):

- Re ≥ 10^4 (turbulent flow)

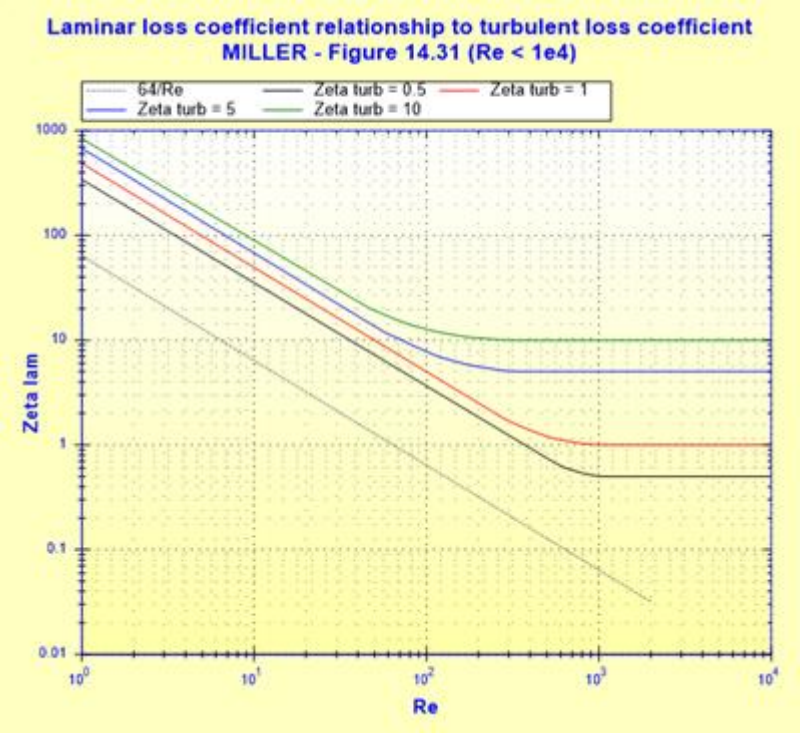
$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv / 36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv / 41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

■ $Re < 10^4$ (laminar flow)

$K_{lam} = f(K_{turb}, Re)$ ([2] figure 14.31)



Reynolds Number Correction ($Re < 10^4$):

$$C_{Re} = \frac{K_{lam}}{K_{turb}}$$

Corrected flow coefficient in laminar flow ($Re < 10^4$):

$$Kv_c = \frac{Kv}{\sqrt{C_{Re}}}$$

$$Cv_c = \frac{Cv}{\sqrt{C_{Re}}}$$

$$Av_c = \frac{Av}{\sqrt{C_{Re}}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$K = K_{turb}$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
Re	Reynolds number ()

α	Opening angle (°)
Kvs	Fully open flow coefficient (m^3/h)
Cvs	Fully open flow coefficient (USG/min)
Avs	Fully open flow coefficient (m^2)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
Kv_c	Corrected flow coefficient in laminar flow (m^3/h)
Cv_c	Corrected flow coefficient in laminar flow (USG/min)
Av_c	Corrected flow coefficient in laminar flow (m^2)
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

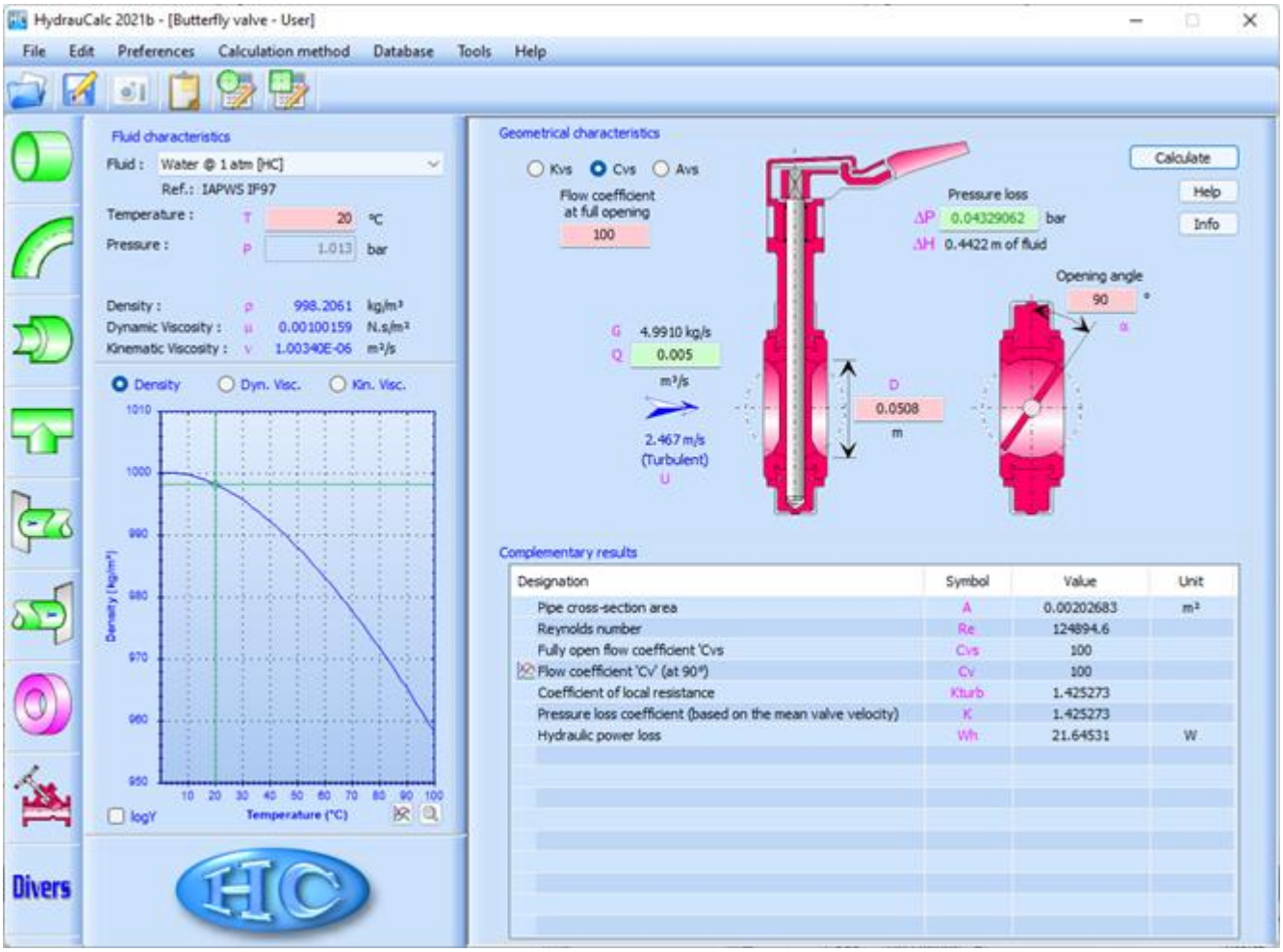
Validity range:

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

---

Example of application:

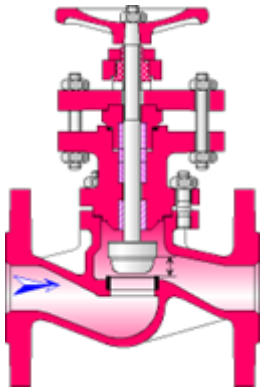


References:

[1] Pumping Station Design, Second Edition, Garr M. Jones

[2] Internal Flow System, Second Edition, D.S. Miller

2.10.3 Globe valve

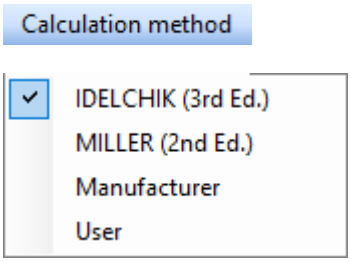


For the calculation of the pressure loss coefficient of Globe valves, the user can choose from one of the methods described in the following two reference documents:

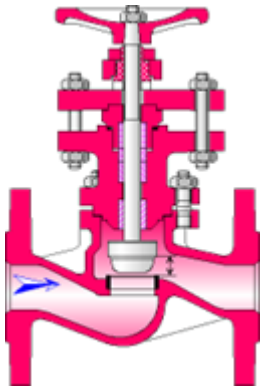
- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

It can also select a valve from a list of valves offered by manufacturers or define its own valve.

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.10.3.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a Globe valve installed in a straight pipe.

Model formulation:

Cross-sectional area (m^2):

$$F = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$w = \frac{Q}{F}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

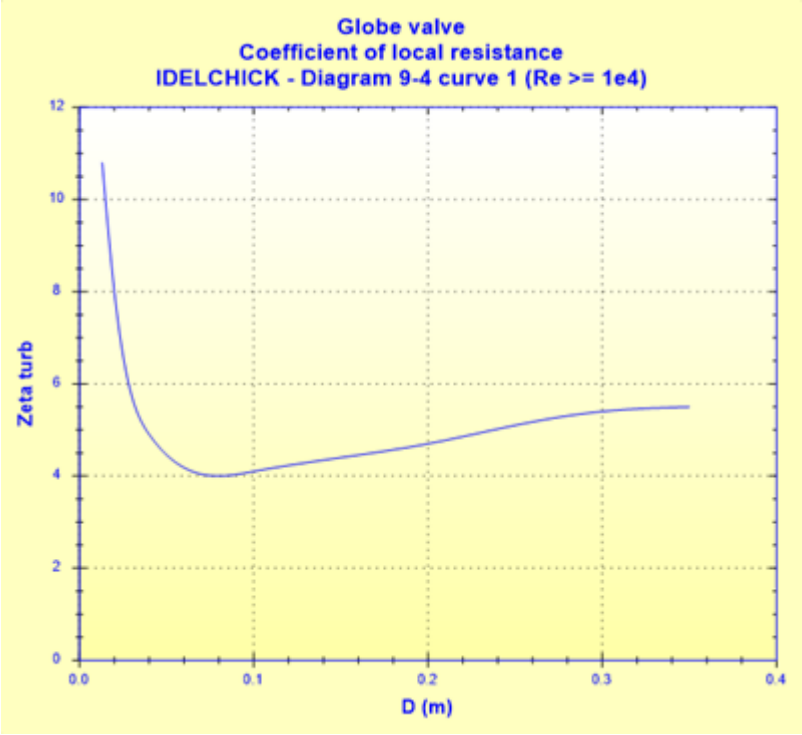
Reynolds number:

$$Re = \frac{W \cdot D}{\nu}$$

Local resistance coefficient:

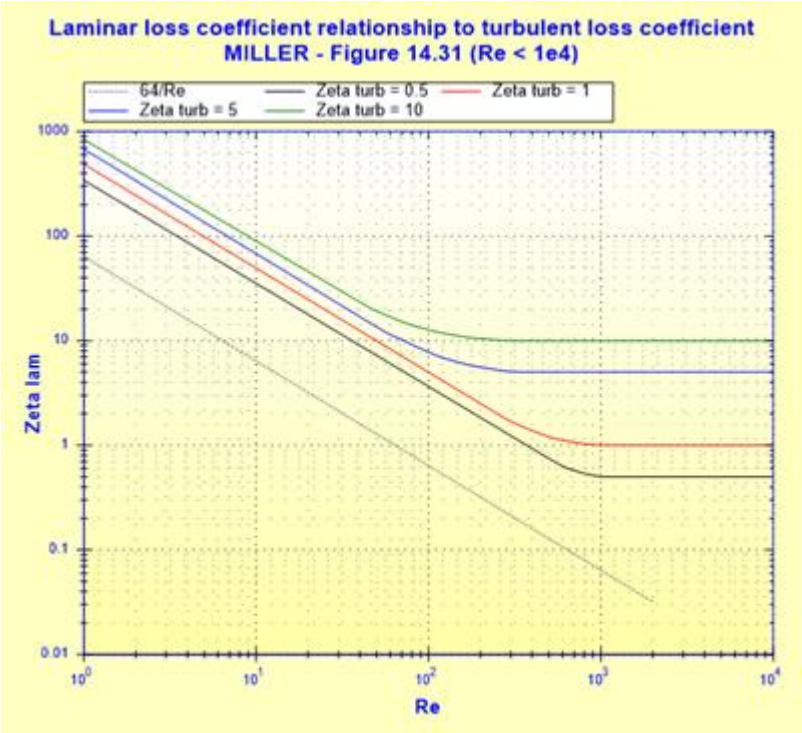
- Re ≥ 10^4 (turbulent flow)

$$\zeta_{turb} = f(D)$$ ([1] diagram 9-2)



- Re < 10^4 (laminar flow)

$$\zeta_{lam} = f(\zeta_{turb}, Re)$$ ([2] figure 14.31)



Reynolds Number Correction ($Re < 10^4$):

$$C_{Re} = \frac{\zeta_{lam}}{\zeta_{turb}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$\zeta = \zeta_{turb}$$

- laminar flow ($Re < 10^4$):

$$\zeta = \zeta_{lam}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{w^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
F	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w	Mean velocity (m/s)
Re	Reynolds number ()
ζ_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
ζ_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
ζ	Pressure loss coefficient (based on the mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

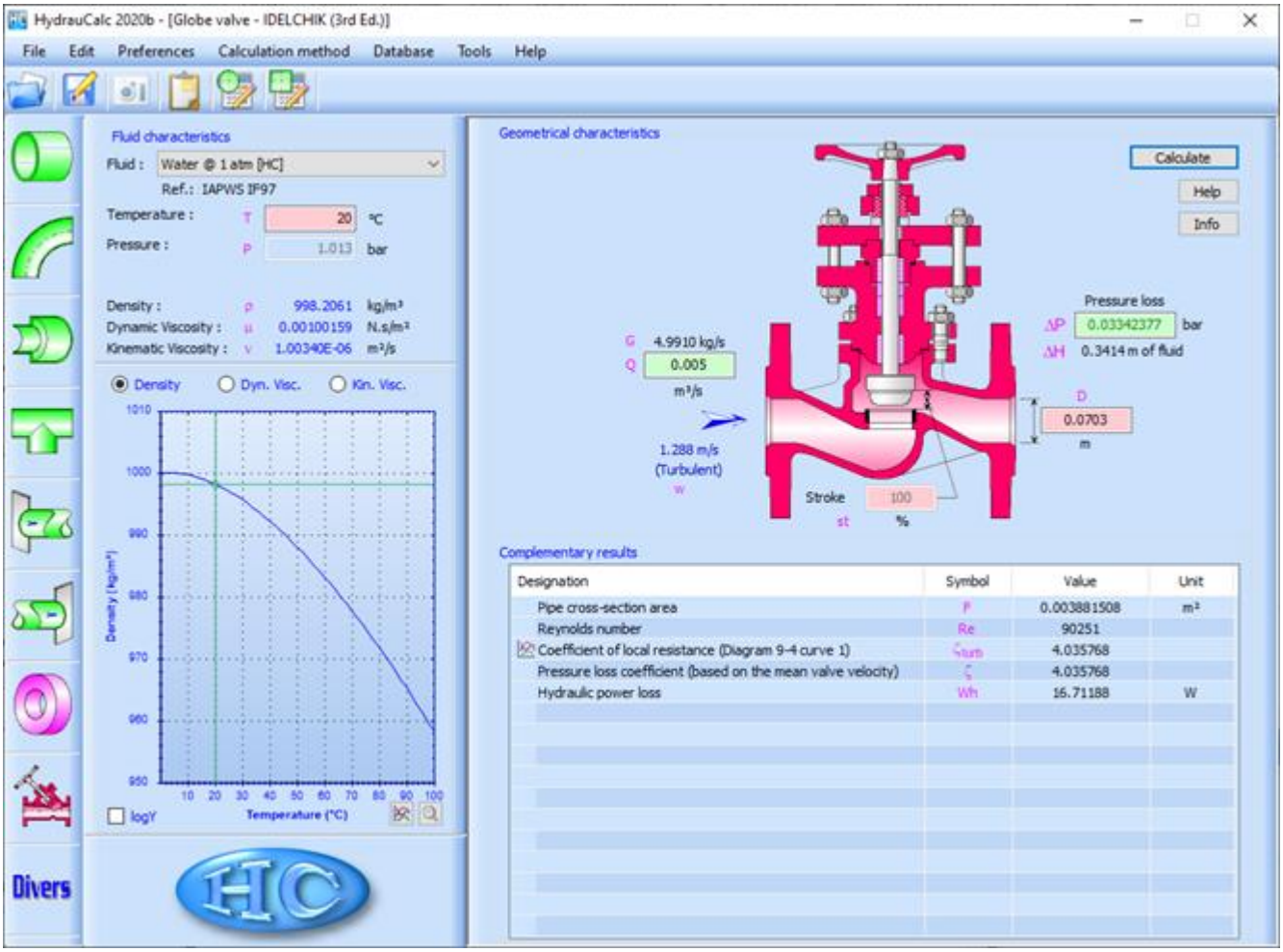
- diameter D between 0.013 m and 0.35 m
- full opening of the valve

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "ζ_{lam}" is estimated

---

Example of application:

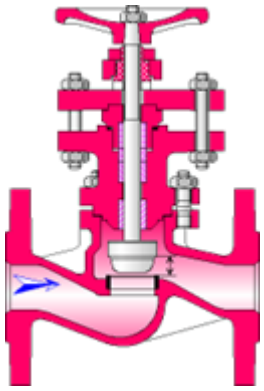


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

[2] Internal Flow System, Second Edition, D.S. Miller

2.10.3.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a globe valve installed in a straight pipe.

Model formulation:

Cross-sectional area at valve inlet (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

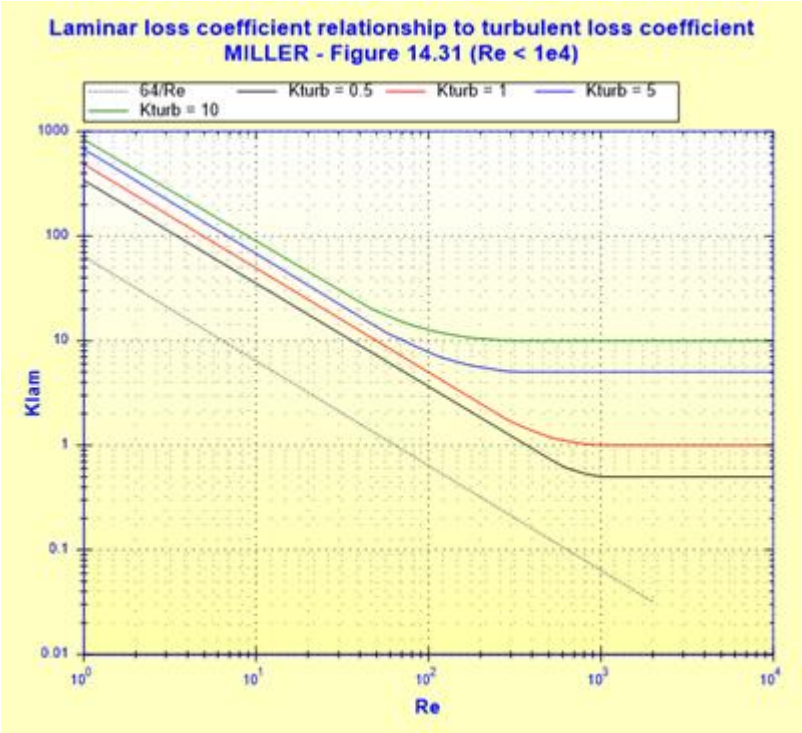
Local resistance coefficient:

- Re ≥ 10^4 (turbulent flow)

$$K_{turb} = f(\alpha)$$ ([1] figure 14.24)

- Re < 10^4 (laminar flow)

$$K_{lam} = f(K_{turb}, \mathrm{Re})$$ ([1] figure 14.31)



Reynolds Number Correction ($Re < 10^4$):

$$C_{Re} = \frac{K_{lam}}{K_{turb}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$K = K_{turb}$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
Re	Reynolds number ()
st	Opening stroke of the valve (%)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

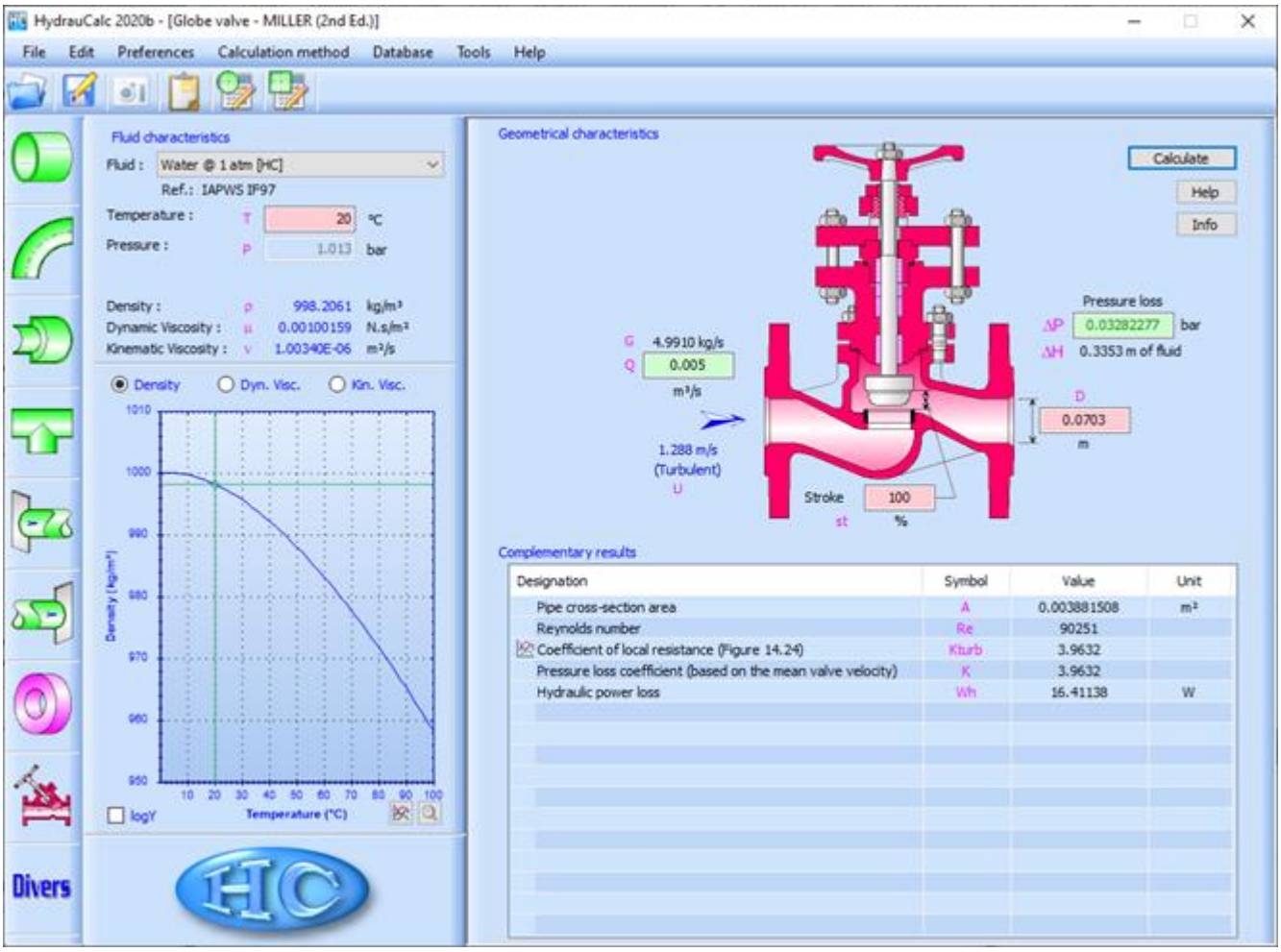
Validity range:

- any flow regime: laminar and turbulent

note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

---

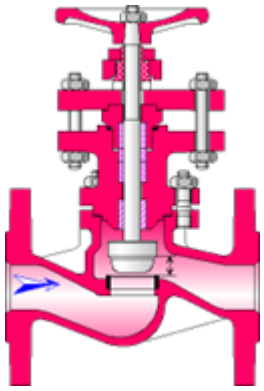
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.10.3.3 Manufacturer



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a globe valve installed in a straight pipe.

The valve characteristics are defined by valves manufacturers. The pressure drop of the valve is characterized by a flow coefficient "Kv", "Cv" or "Av" at full opening, and a law of flow coefficient evolution according the valve opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Evolution of the flow coefficients according to the opening of the valve:

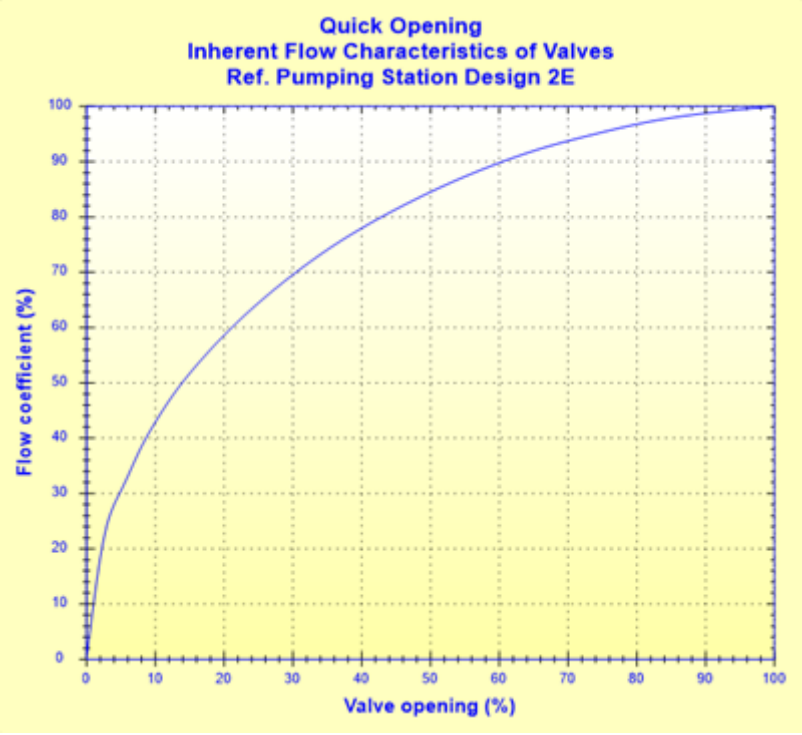
$$Kv = Kvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Cv = Cvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Av = Avs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

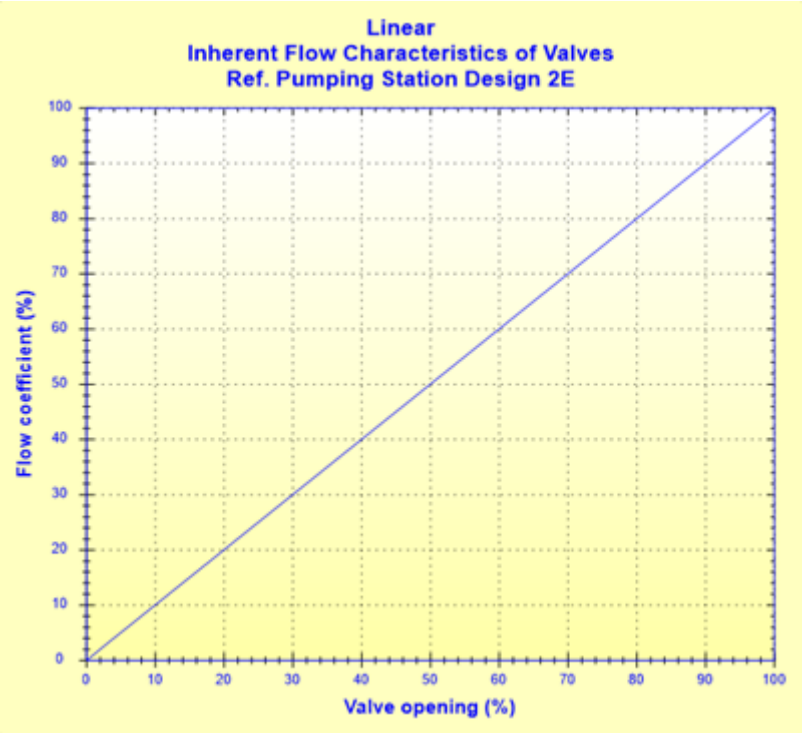
Inherent Flow Characteristics of Valves:

■ Quick Opening:



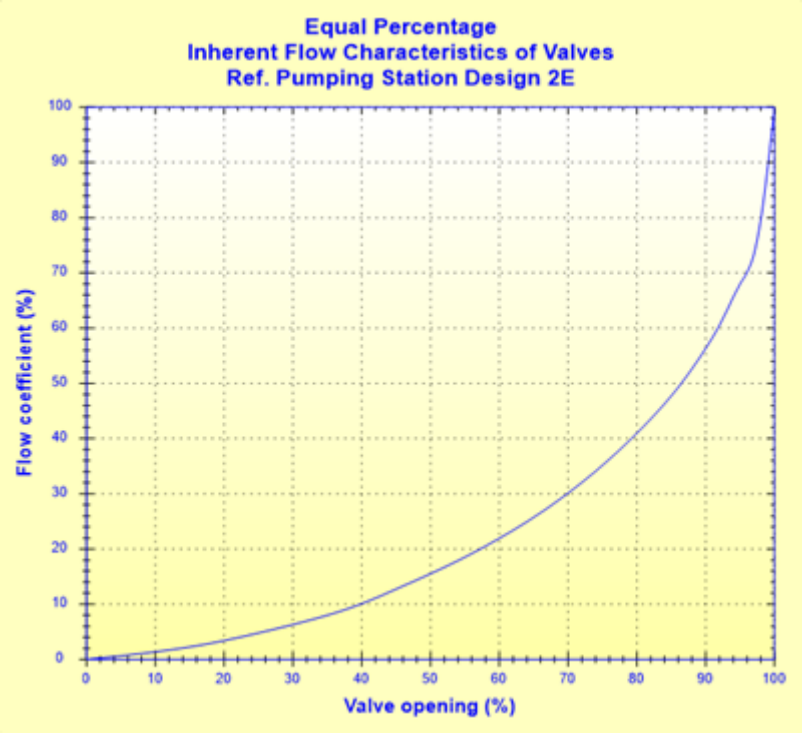
$F_{low}C_{oef}(V_{alve}O_{pening})$ ([1] Figure 3)

■ Linear:



$FlowCoef(ValveOpening)$ ([1] Figure 3)

■ Equal Percentage:



$FlowCoef(ValveOpening)$ ([1] Figure 3)

Local resistance coefficient (Pa):

■ Re ≥ 10^4 (turbulent flow)

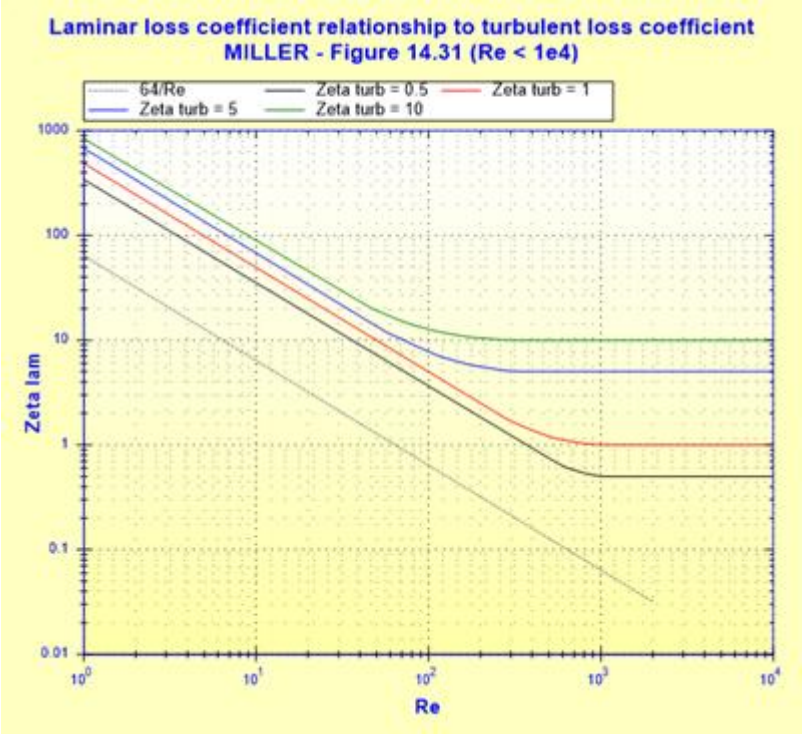
$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv / 36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv / 41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

■ Re < 10^4 (laminar flow)

$$K_{lam} = f(K_{turb}, \mathrm{Re})$$ ([2] figure 14.31)



Reynolds Number Correction (Re < 10^4):

$$C_{\mathrm{Re}} = \frac{K_{lam}}{K_{turb}}$$

Corrected flow coefficient in laminar flow (Re < 10^4):

$$Kv_c = \frac{Kv}{\sqrt{C_{Re}}}$$

$$Cv_c = \frac{Cv}{\sqrt{C_{Re}}}$$

$$Av_c = \frac{Av}{\sqrt{C_{Re}}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$K = K_{turb}$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
Re	Reynolds number ()

st	Opening stroke of the valve (%)
Kvs	Fully open flow coefficient (m^3/h)
Cvs	Fully open flow coefficient (USG/min)
Avs	Fully open flow coefficient (m^2)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
Kv_c	Corrected flow coefficient in laminar flow (m^3/h)
Cv_c	Corrected flow coefficient in laminar flow (USG/min)
Av_c	Corrected flow coefficient in laminar flow (m^2)
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

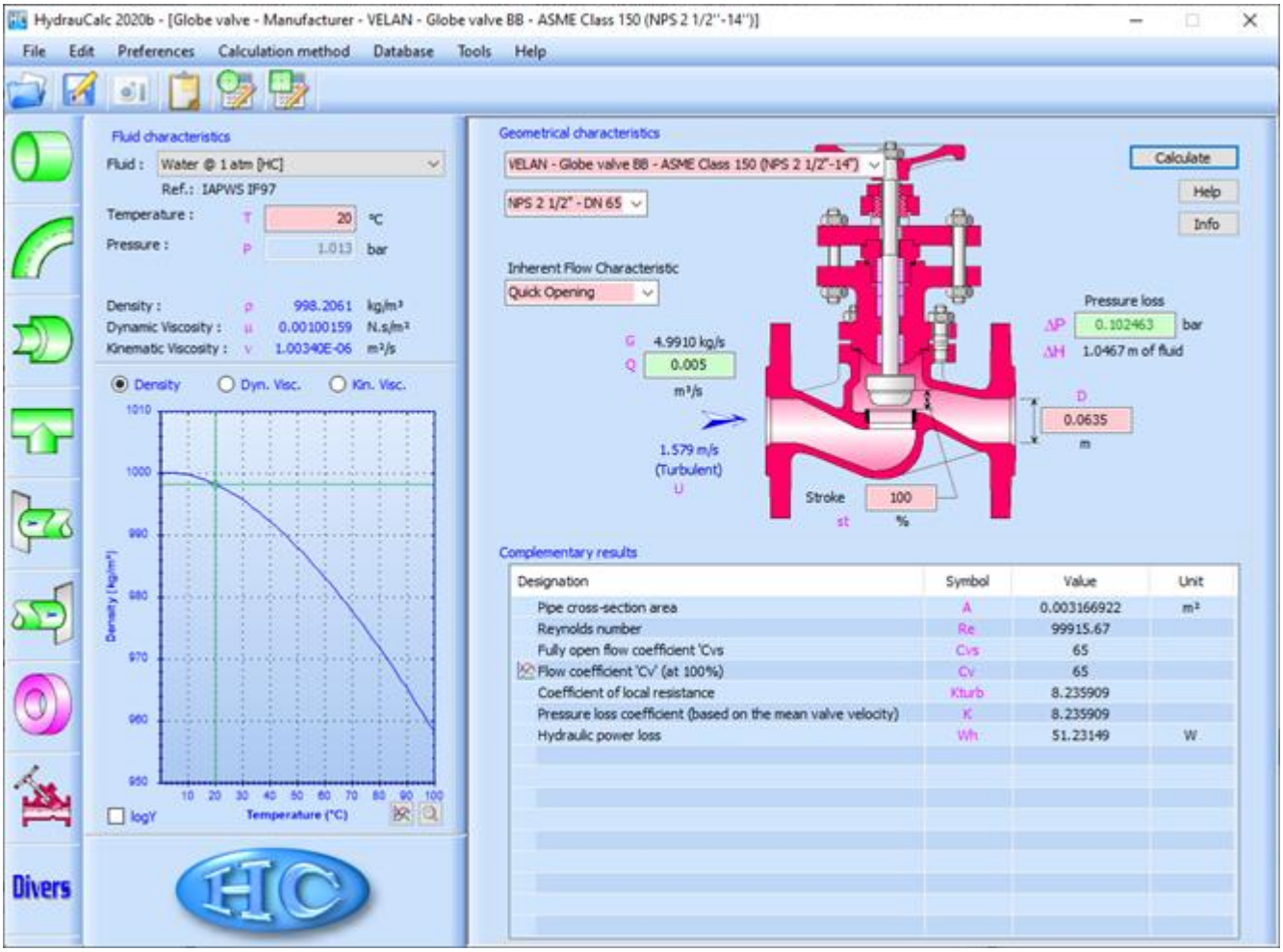
Validity range:

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

---

Example of application:



References:

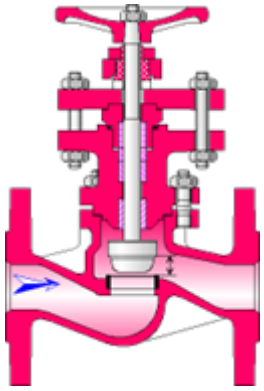
[1] PTC 6th Pipeline Technology Conference 2011

[2] Internal Flow System, Second Edition, D.S. Miller

2.10.3.4 User

Globe valve

(User defined by a flow coefficient)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a globe valve installed in a straight pipe.

The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening, and a law of flow coefficient evolution according the valve opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Evolution of the flow coefficients according to the opening of the valve:

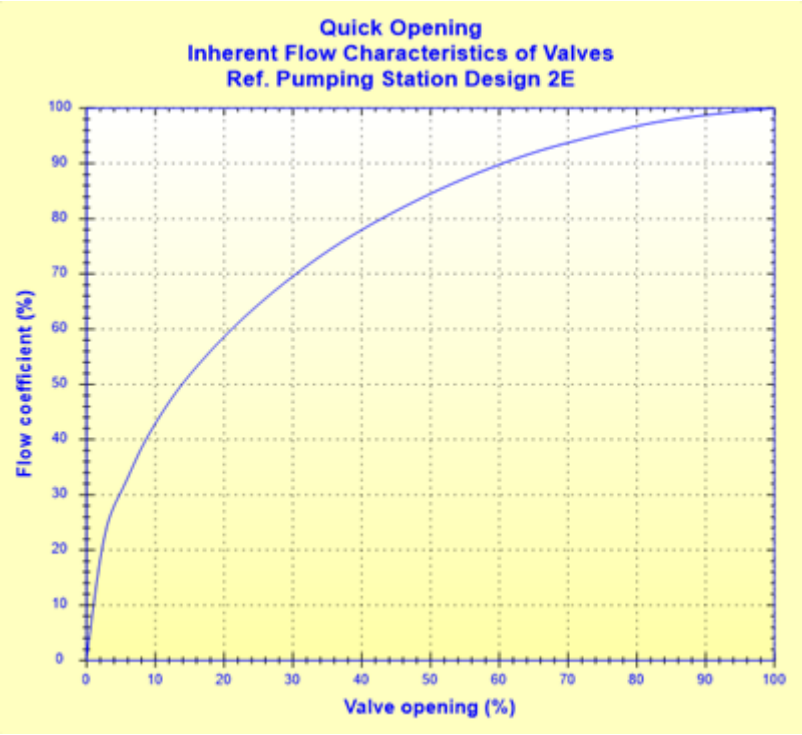
$$Kv = Kvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Cv = Cvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Av = Avs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

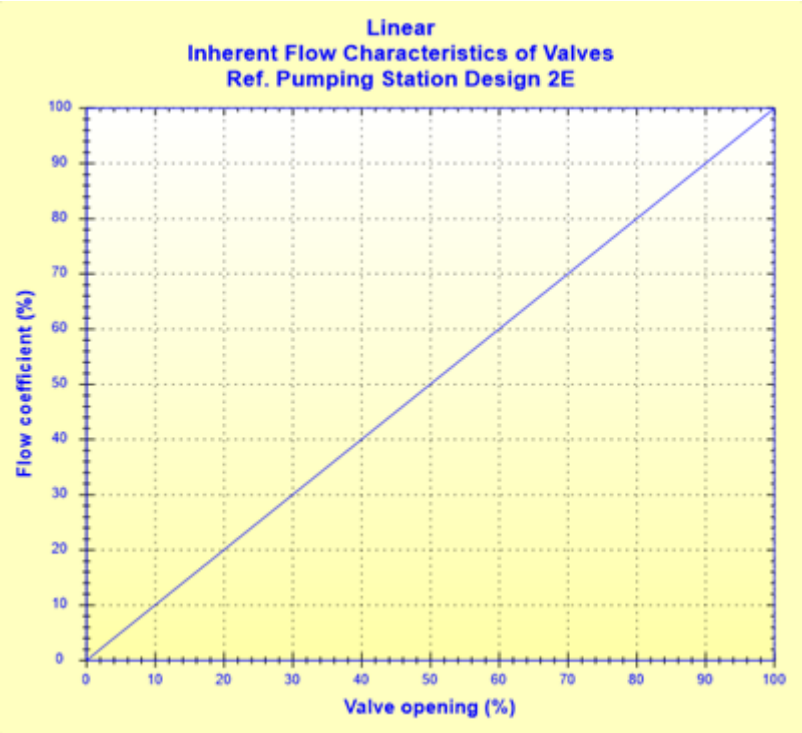
Inherent Flow Characteristics of Valves:

■ Quick Opening:



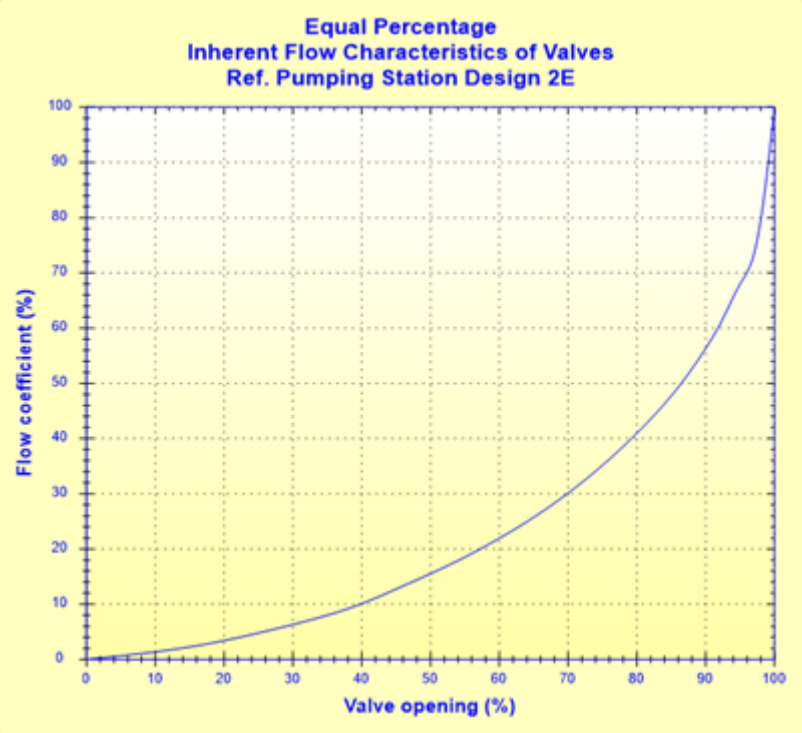
$F_{low}C_{oef}(V_{alve}O_{pening})$ ([1] Figure 3)

■ Linear:



$FlowCoef(ValveOpening)$ ([1] Figure 3)

■ Equal Percentage:



$FlowCoef(ValveOpening)$ ([1] Figure 3)

Local resistance coefficient (Pa):

■ Re ≥ 10^4 (turbulent flow)

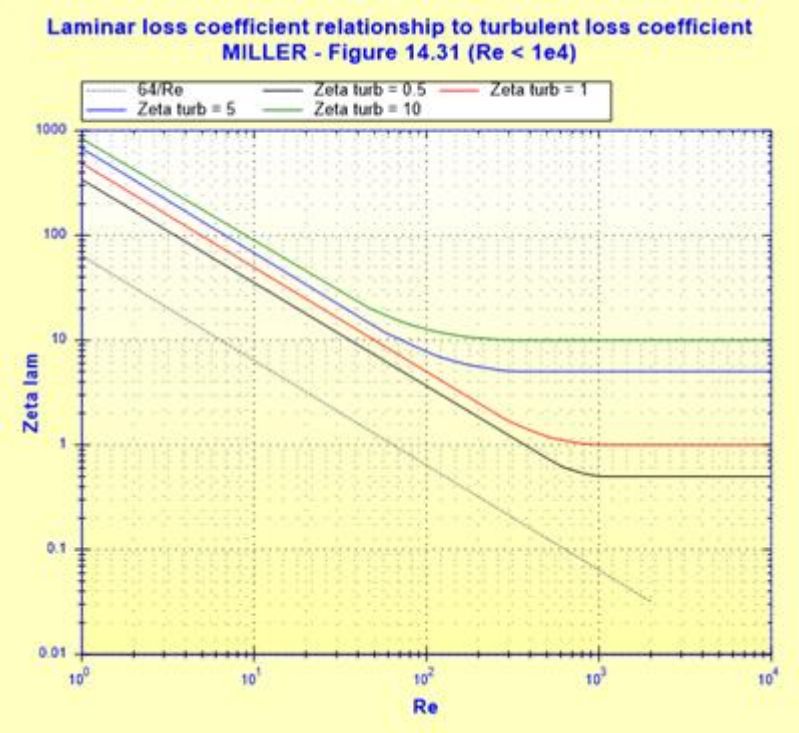
$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv / 36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv / 41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

■ $Re < 10^4$ (laminar flow)

$K_{lam} = f(K_{turb}, Re)$ ([2] figure 14.31)



Reynolds Number Correction ($Re < 10^4$):

$$C_{Re} = \frac{K_{lam}}{K_{turb}}$$

Corrected flow coefficient in laminar flow ($Re < 10^4$):

$$Kv_c = \frac{Kv}{\sqrt{C_{Re}}}$$

$$Cv_c = \frac{Cv}{\sqrt{C_{Re}}}$$

$$Av_c = \frac{Av}{\sqrt{C_{Re}}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$K = K_{turb}$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
Re	Reynolds number ()

st	Opening stroke of the valve (%)
Kvs	Fully open flow coefficient (m^3/h)
Cvs	Fully open flow coefficient (USG/min)
Avs	Fully open flow coefficient (m^2)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
Kv_c	Corrected flow coefficient in laminar flow (m^3/h)
Cv_c	Corrected flow coefficient in laminar flow (USG/min)
Av_c	Corrected flow coefficient in laminar flow (m^2)
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

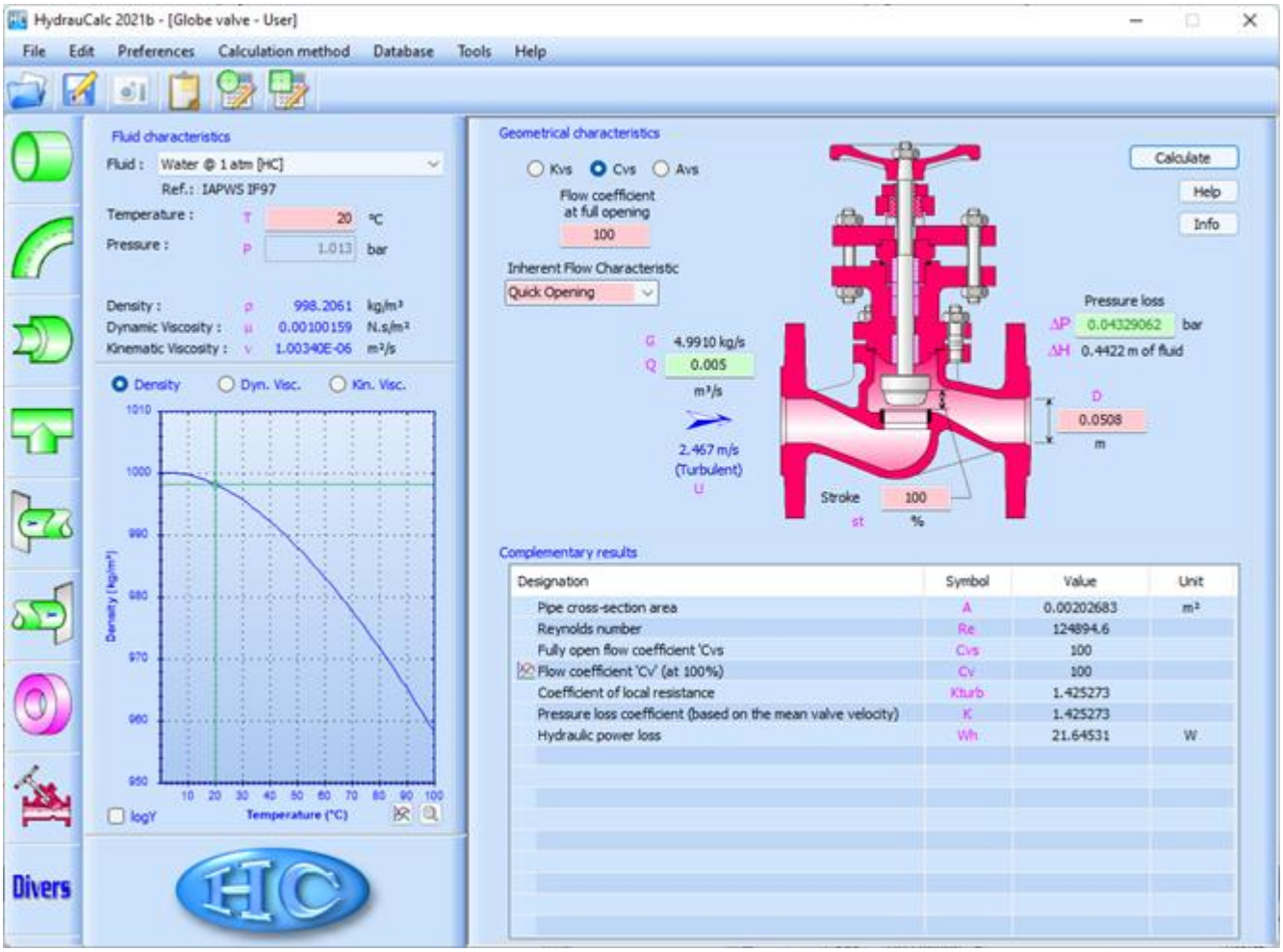
Validity range:

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

---

Example of application:

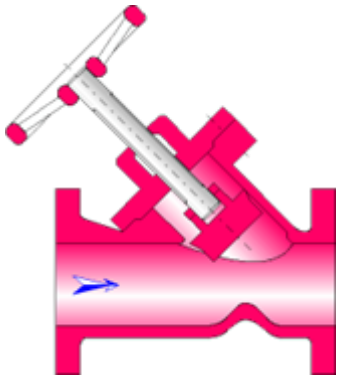


References:

[1] PTC 6th Pipeline Technology Conference 2011

[2] Internal Flow System, Second Edition, D.S. Miller

2.10.4 Y globe valve

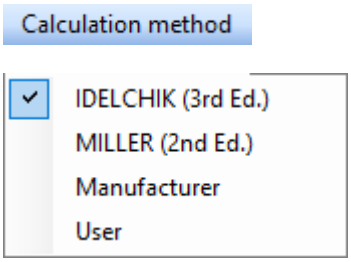


For the calculation of the pressure loss coefficient of Y Globe valves, the user can choose from one of the methods described in the following two reference documents:

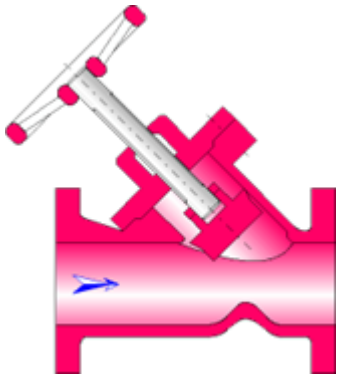
- Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik
- Internal Flow System, 2nd Edition, D.S. Miller

It can also select a valve from a list of valves offered by manufacturers or define its own valve.

The calculation method is selected using the "Calculation method" menu. The default option is "IDELCHIK (3rd Ed.)"



2.10.4.1 IDELCHIK



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a Y Globe valve installed in a straight pipe.

Model formulation:

Cross-sectional area (m^2):

$$F = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$w = \frac{Q}{F}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

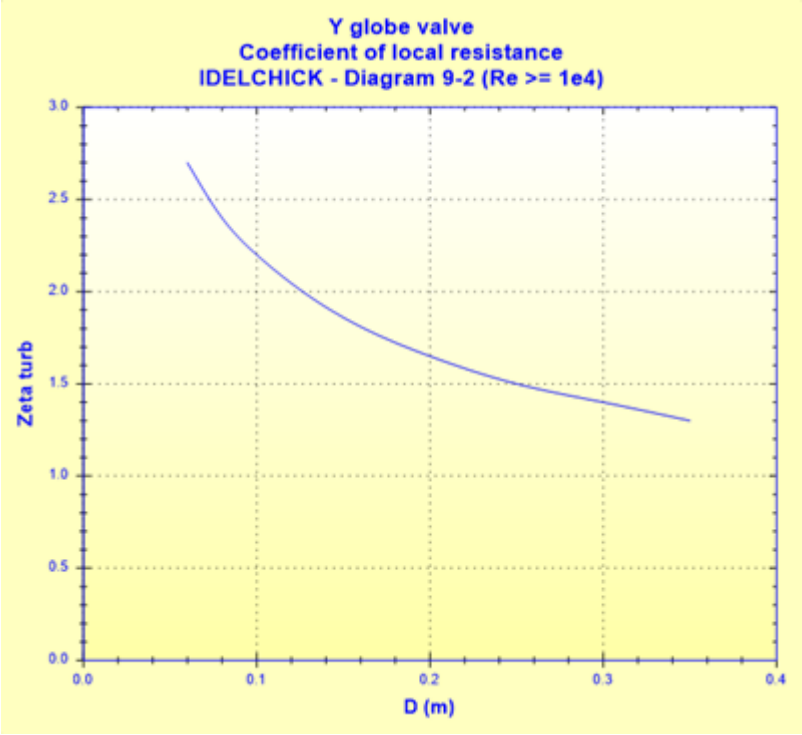
Reynolds number:

$$Re = \frac{W \cdot D}{\nu}$$

Local resistance coefficient:

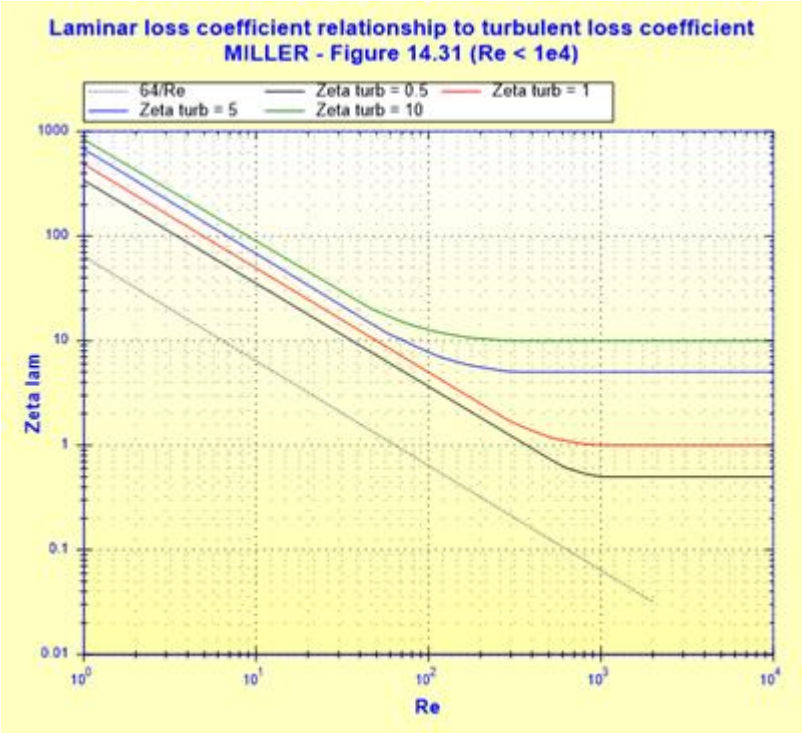
- Re ≥ 10^4 (turbulent flow)

$$\zeta_{turb} = f(D)$$ ([1] diagram 9-2)



- Re < 10^4 (laminar flow)

$$\zeta_{lam} = f(\zeta_{turb}, Re)$$ ([2] figure 14.31)



Reynolds Number Correction ($Re < 10^4$):

$$C_{Re} = \frac{\zeta_{lam}}{\zeta_{turb}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$\zeta = \zeta_{turb}$$

- laminar flow ($Re < 10^4$):

$$\zeta = \zeta_{lam}$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot W^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = \zeta \cdot \frac{w^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
F	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
w	Mean velocity (m/s)
Re	Reynolds number ()
ζ_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
ζ_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
ζ	Pressure loss coefficient (based on the mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

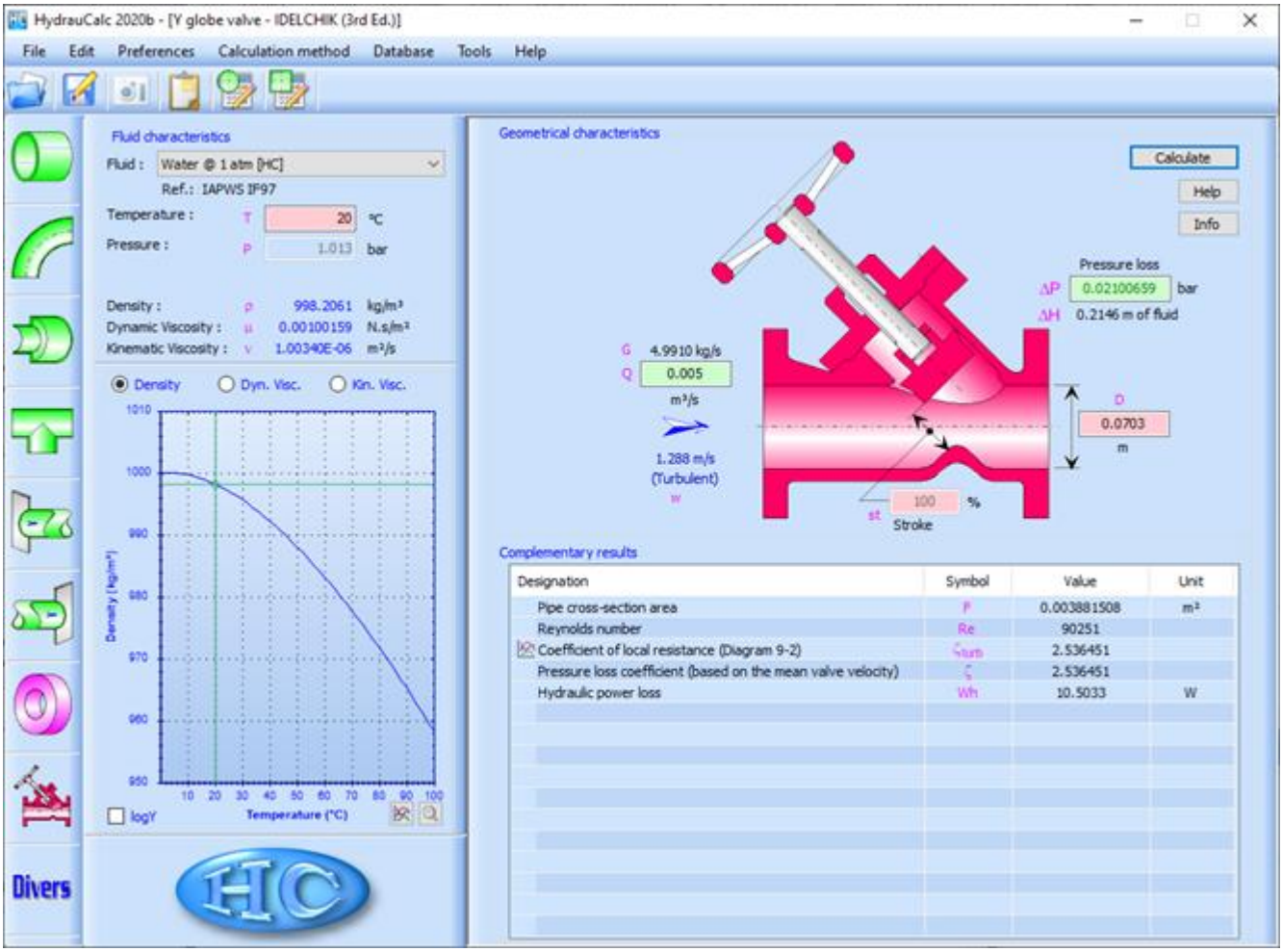
- diameter D between 0.06 m and 0.35 m
- full opening of the valve

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "ζ_{lam}" is estimated

---

Example of application:

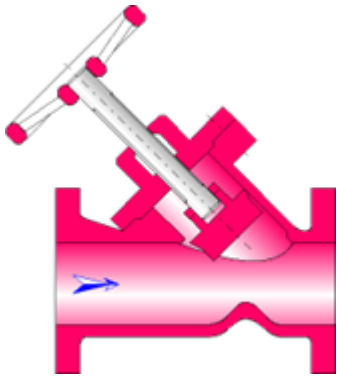


References:

[1] Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik

[2] Internal Flow System, Second Edition, D.S. Miller

2.10.4.2 MILLER



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a Y Globe valve installed in a straight pipe.

Model formulation:

Cross-sectional area at valve inlet (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

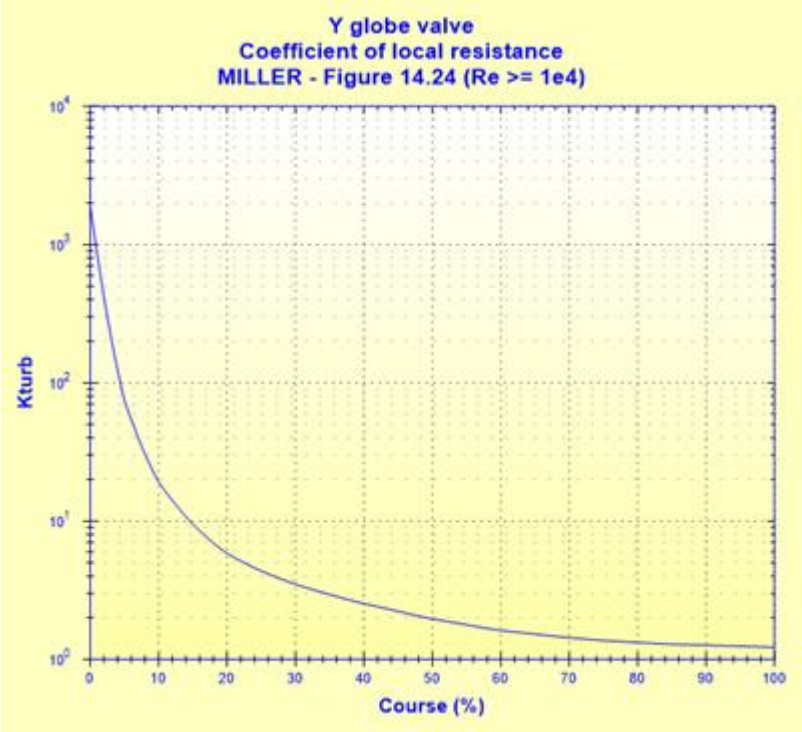
Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

Local resistance coefficient:

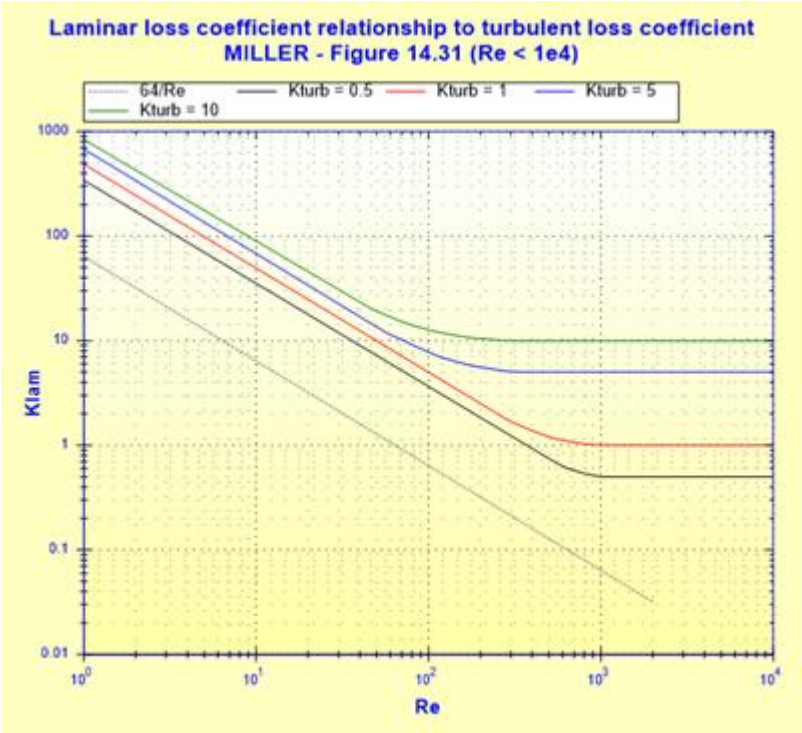
- Re ≥ 10^4 (turbulent flow)

$$K_{turb} = f(\alpha)$$ ([1] figure 14.24)



- Re < 10^4 (laminar flow)

$$K_{lam} = f(K_{turb}, Re)$$ ([1] figure 14.31)



Reynolds Number Correction ($Re < 10^4$):

$$C_{Re} = \frac{K_{lam}}{K_{turb}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$K = K_{turb}$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
Re	Reynolds number ()
st	Opening stroke of the valve (%)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

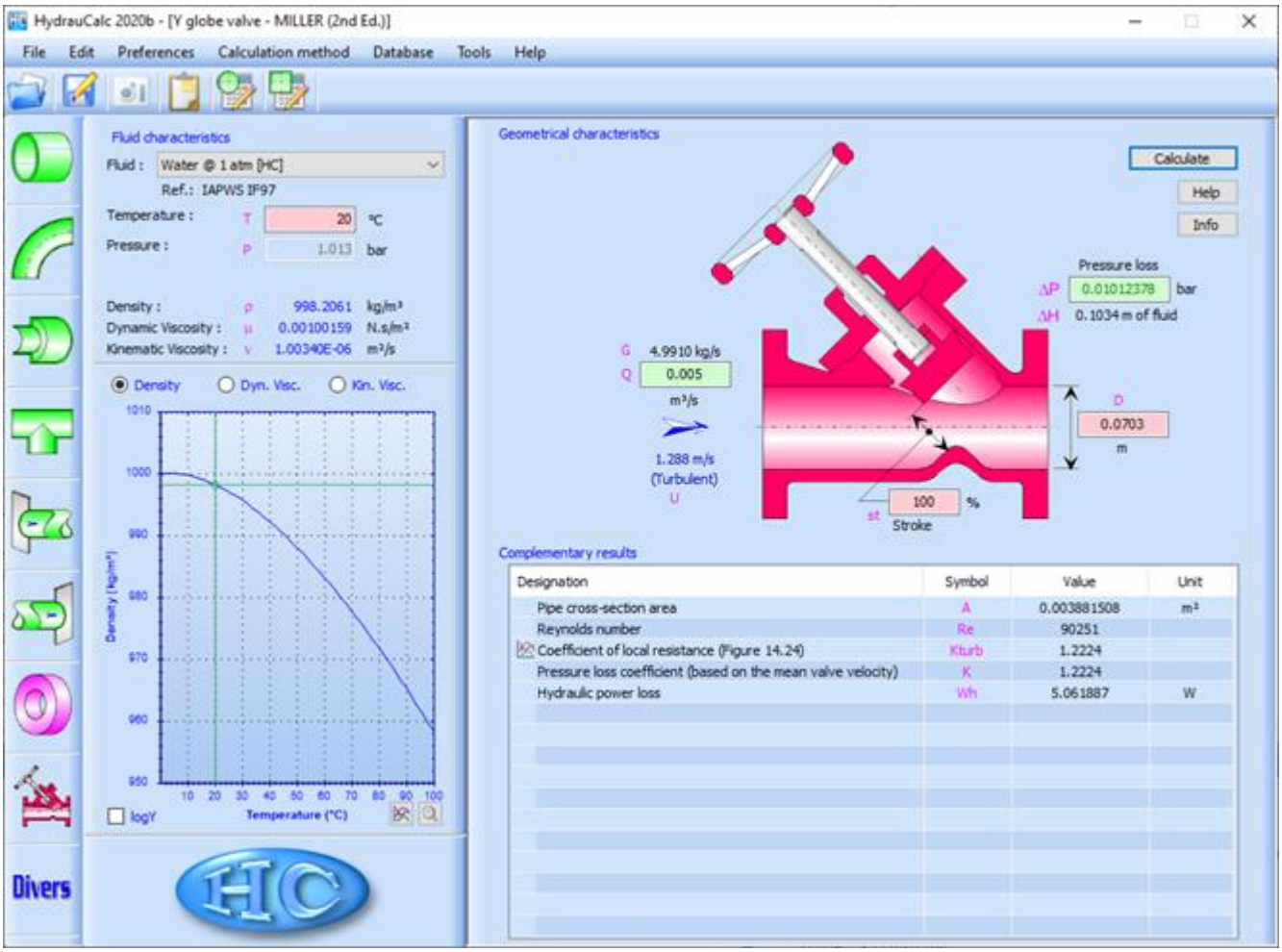
Validity range:

- any flow regime: laminar and turbulent

note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

---

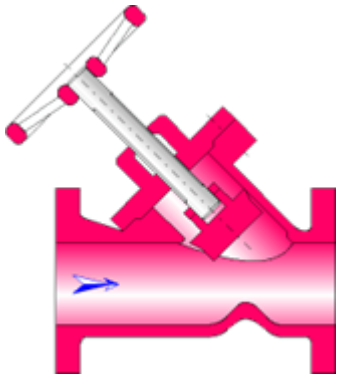
Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

2.10.4.3 Manufacturer



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a Y Globe valve installed in a straight pipe.

The valve characteristics are defined by valves manufacturers. The pressure drop of the valve is characterized by a flow coefficient "Kv", "Cv" or "Av" at full opening, and a law of flow coefficient evolution according the valve opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

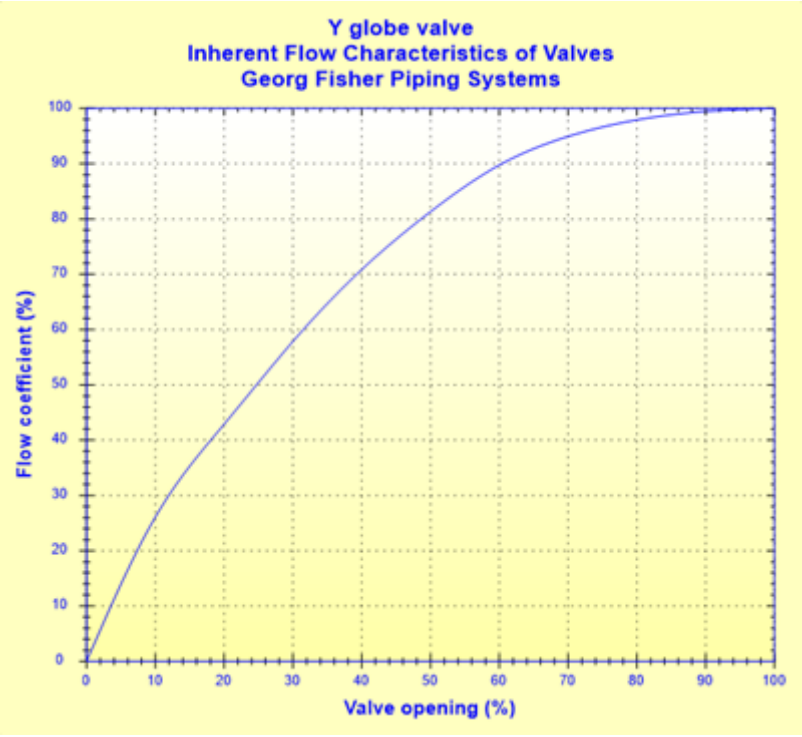
$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Evolution of the flow coefficients according to the opening of the valve:

$$Kv = Kvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Cv = Cvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Av = Avs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$



$F_{low}C_{oef}(V_{alve}O_{pening})$ ([1] Page 10.147)

Local resistance coefficient (Pa):

- Re ≥ 10^4 (turbulent flow)

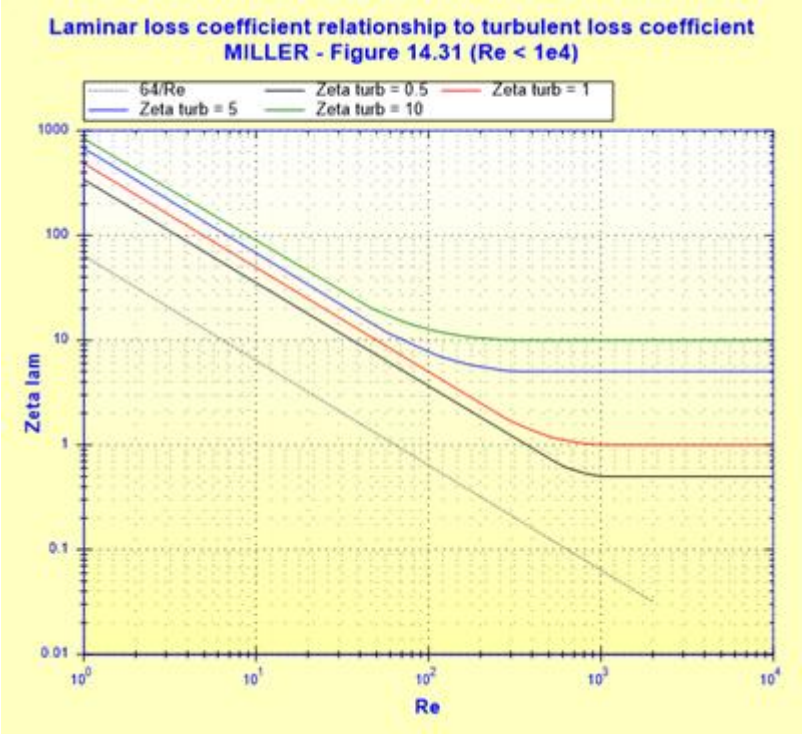
$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv / 36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv / 41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

■ Re < 10^4 (laminar flow)

$K_{lam} = f(K_{turb}, \mathrm{Re})$ ([2] figure 14.31)



Reynolds Number Correction (Re < 10^4):

$$C_{\mathrm{Re}} = \frac{K_{lam}}{K_{turb}}$$

Corrected flow coefficient in laminar flow (Re < 10^4):

$$Kv_c = \frac{Kv}{\sqrt{C_{Re}}}$$

$$Cv_c = \frac{Cv}{\sqrt{C_{Re}}}$$

$$Av_c = \frac{Av}{\sqrt{C_{Re}}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$K = K_{turb}$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
Re	Reynolds number ()

st	Opening stroke of the valve (%)
Kvs	Fully open flow coefficient (m^3/h)
Cvs	Fully open flow coefficient (USG/min)
Avs	Fully open flow coefficient (m^2)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
Kv_c	Corrected flow coefficient in laminar flow (m^3/h)
Cv_c	Corrected flow coefficient in laminar flow (USG/min)
Av_c	Corrected flow coefficient in laminar flow (m^2)
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

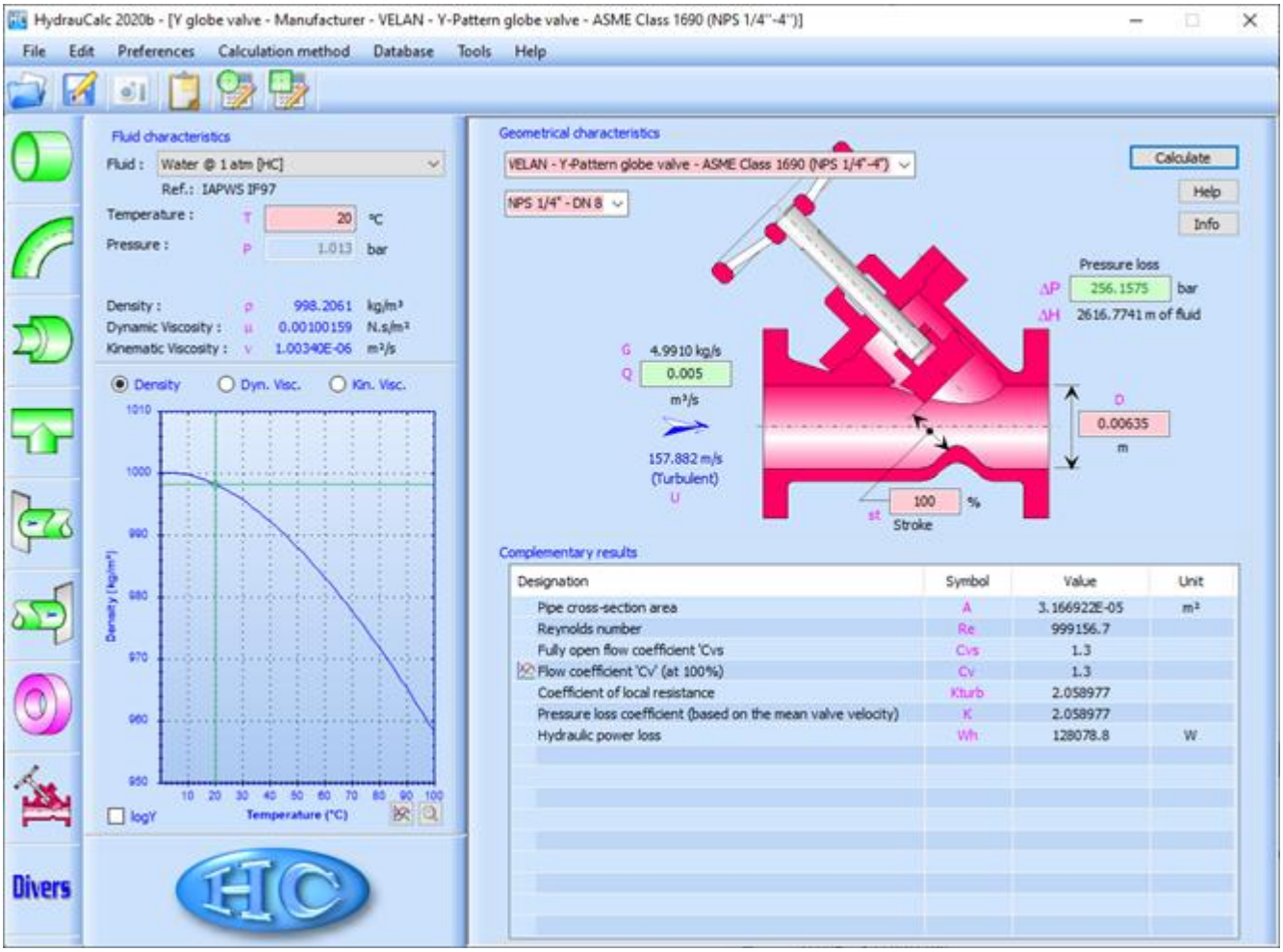
Validity range:

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

---

Example of application:



References:

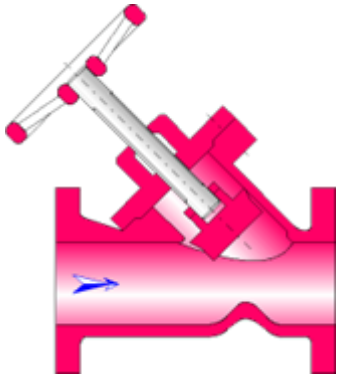
[1] Georg Fisher Piping Systems, Technical Data for Y-Globe Valves

[2] Internal Flow System, Second Edition, D.S. Miller

2.10.4.4 User

Y Globe valve

(User defined by a flow coefficient)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a Y Globe valve installed in a straight pipe.

The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening, and a law of flow coefficient evolution according the valve opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

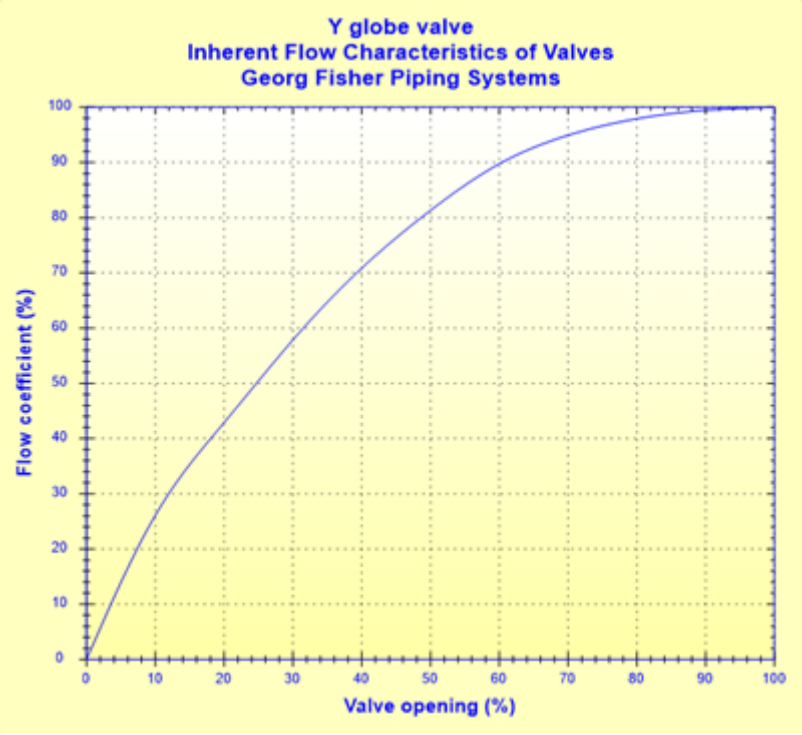
$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Evolution of the flow coefficients according to the opening of the valve:

$$Kv = Kvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Cv = Cvs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$

$$Av = Avs \cdot F_{low}C_{oef}\left(V_{alve}O_{pening}\right)/100$$



$F_{low}C_{oef}(V_{alve}O_{pening})$ ([1] Page 10.147)

Local resistance coefficient (Pa):

- Re ≥ 10^4 (turbulent flow)

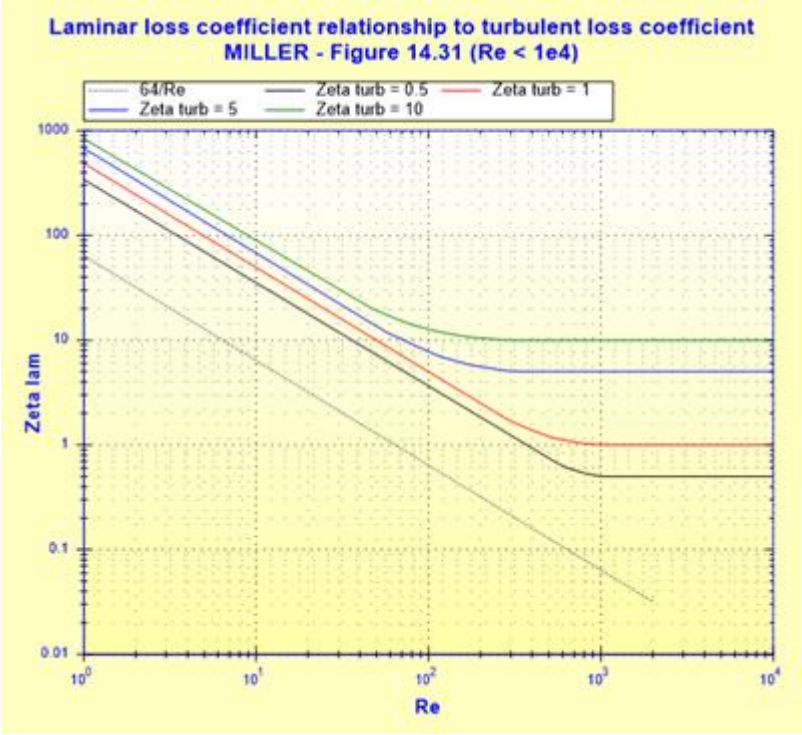
$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv / 36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv / 41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

■ Re < 10^4 (laminar flow)

$$K_{lam} = f(K_{turb}, \mathrm{Re})$$ ([2] figure 14.31)



Reynolds Number Correction (Re < 10^4):

$$C_{\mathrm{Re}} = \frac{K_{lam}}{K_{turb}}$$

Corrected flow coefficient in laminar flow (Re < 10^4):

$$Kv_c = \frac{Kv}{\sqrt{C_{Re}}}$$

$$Cv_c = \frac{Cv}{\sqrt{C_{Re}}}$$

$$Av_c = \frac{Av}{\sqrt{C_{Re}}}$$

Total pressure loss coefficient (based on mean velocity):

- turbulent flow ($Re \geq 10^4$):

$$K = K_{turb}$$

- laminar flow ($Re < 10^4$):

$$K = K_{lam}$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
U	Mean velocity (m/s)
Re	Reynolds number ()

st	Opening stroke of the valve (%)
Kvs	Fully open flow coefficient (m^3/h)
Cvs	Fully open flow coefficient (USG/min)
Avs	Fully open flow coefficient (m^2)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
C_{Re}	Reynolds number correction for $Re < 10^4$ ()
Kv_c	Corrected flow coefficient in laminar flow (m^3/h)
Cv_c	Corrected flow coefficient in laminar flow (USG/min)
Av_c	Corrected flow coefficient in laminar flow (m^2)
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

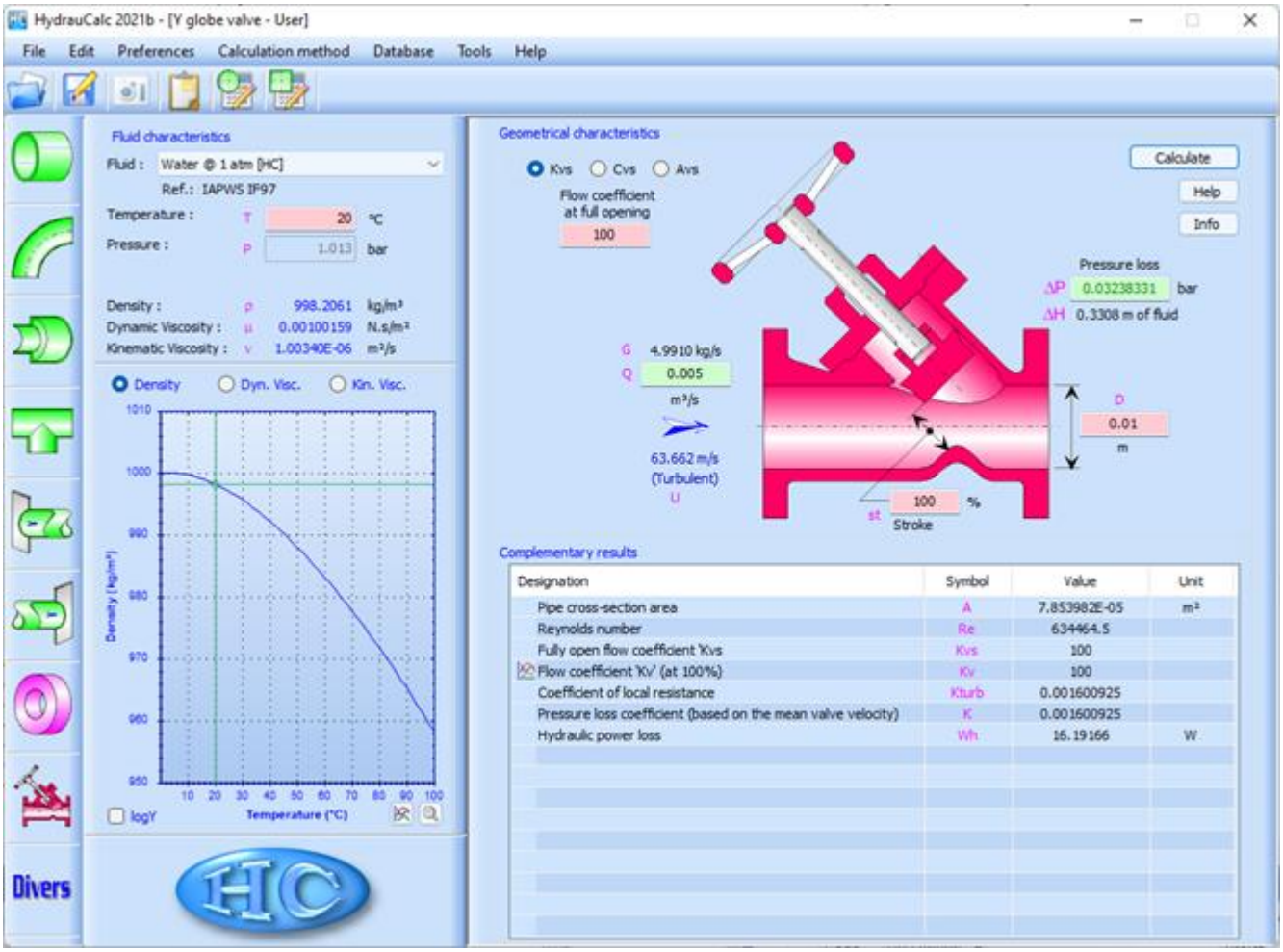
Validity range:

- any flow regime: laminar and turbulent

  note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient "K_{lam}" is estimated

---

Example of application:



References:

[1] Georg Fisher Piping Systems, Technical Data for Y-Globe Valves

[2] Internal Flow System, Second Edition, D.S. Miller

2.11 Check valves

This subsection regroups the set of check valves that can be modeled and calculated. The types of check valves available are:

- Swing Check Valve

- Dual Plate Check Valve

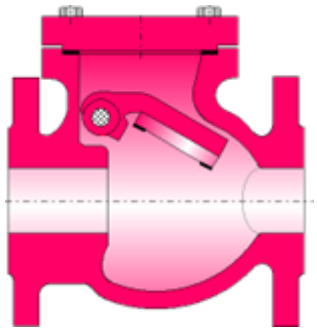
- Axial Check Valve

- Membrane Check Valve

- Ball Check Valve

- Foot Check Valve

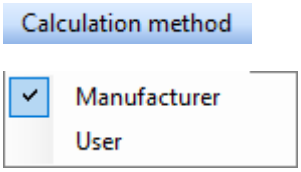
2.11.1 Swing check valve



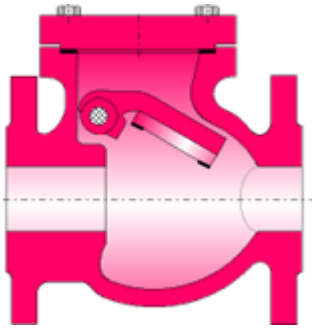
For the calculation of the pressure loss coefficient of swing check valves, the user can:

- choose from a list of swing check valves offered by manufacturers,
- define your own swing check valve.

The calculation method is selected using the "Calculation method" menu. The default option is "Manufacturer"



2.11.1.1 Manufacturer



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a swing check valve installed in a straight pipe.

The swing check valve characteristics are defined by valves manufacturers. The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening. The model also takes into account the partial opening of the valve, the opening is partial when the pressure at the inlet of the valve is between the pressure at the begin of opening and the minimum pressure for full opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

- check valve at full opening:

Local resistance coefficient:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kvs / 36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cvs / 41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Avs^2}$$

Total pressure loss coefficient (based on mean velocity):

$$K = K_{turb}$$

Total pressure loss (Pa):

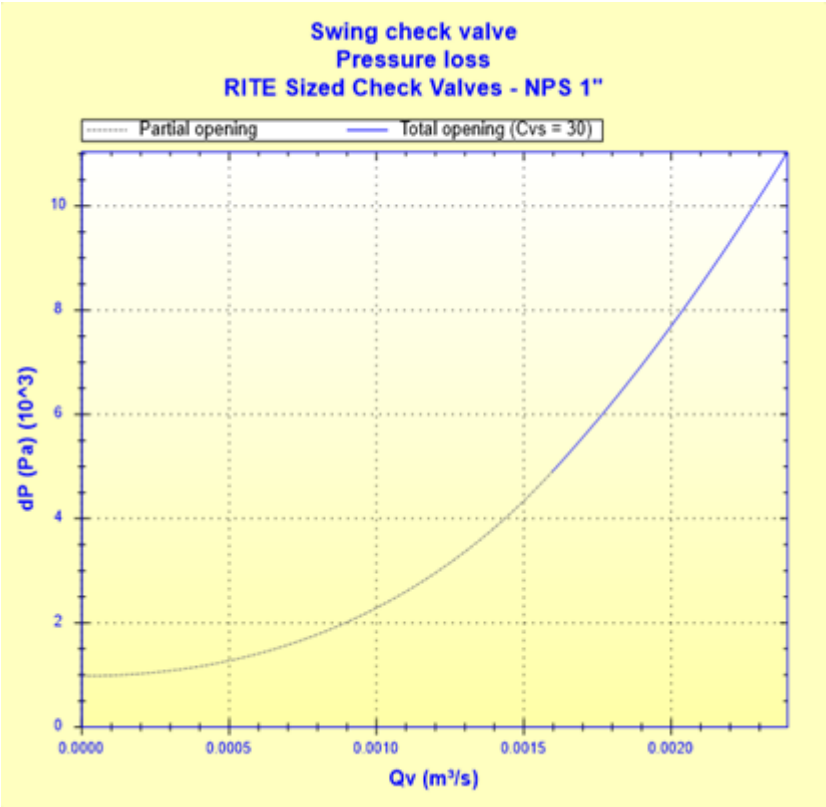
$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

- check valve at partial opening:

The pressure drop at partial opening is estimated by curvilinear interpolation between the pressure at the begin of opening "Pbo" and the minimum pressure for full opening "Pto".

$$\Delta P = f(Qv, Pbo, Pto)$$

The figure below shows an example of the pressure drop of a check valve with partial opening.



Flow coefficient:

$$Kv = 36023 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Cv = 41650 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Av = Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

Total pressure loss coefficient (based on mean velocity):

$$K = \frac{2 \cdot \Delta P}{\rho \cdot U^2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number ()
Kvs	Full opening flow coefficient (m^3/h)
Cvs	Full opening flow coefficient (USG/min)
Avs	Full opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
Pbo	Pressure at the begin of opening (Pa)
Pto	Minimum pressure for full opening (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- flow regime: turbulent

  note: for laminar flow regime ($Re < 10^4$) and for operation in partial opening, the pressure loss coefficient "K" is estimated

---

Example of application:

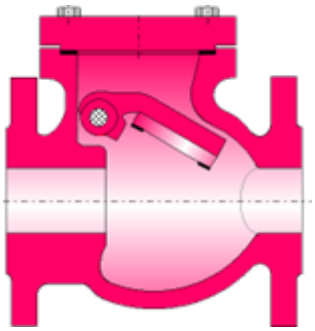
References:

Manufacturers

2.11.1.2 User

Swing Check Valve

(User defined)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a swing check valve installed in a straight pipe.

The swing check valve characteristics are defined by the user. The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening. The model also takes into account the partial opening of the valve, the opening is partial when the pressure at the inlet of the valve is between the pressure at the begin of opening and the minimum pressure for full opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

- check valve at full opening:

Local resistance coefficient:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kvs / 36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cvs / 41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Avs^2}$$

Total pressure loss coefficient (based on mean velocity):

$$K = K_{turb}$$

Total pressure loss (Pa):

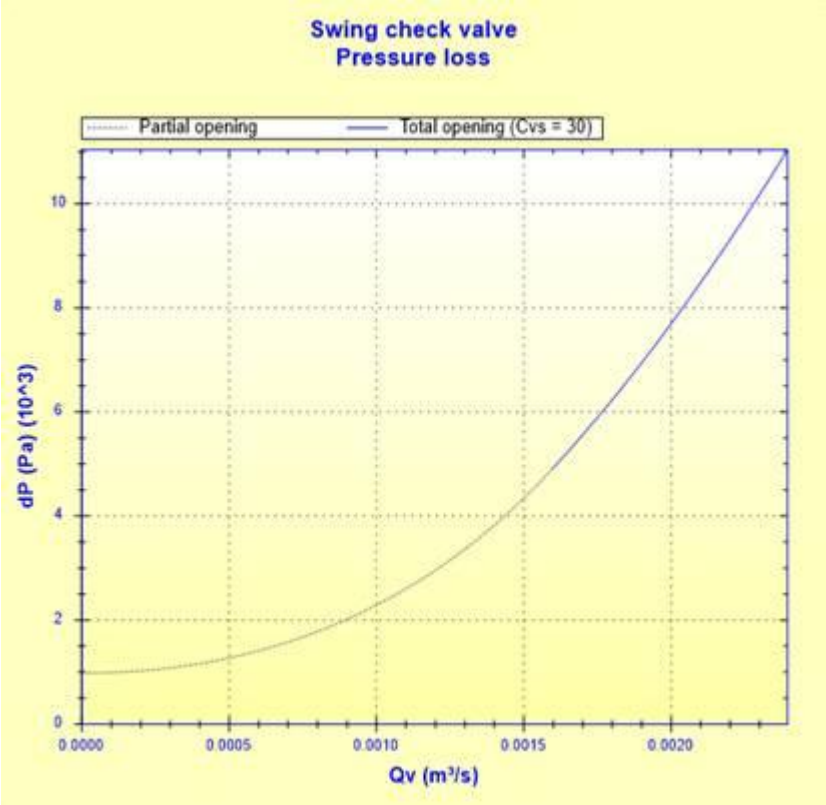
$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

- check valve at partial opening:

The pressure drop at partial opening is estimated by curvilinear interpolation between the pressure at the begin of opening "Pbo" and the minimum pressure for full opening "Pto".

$$\Delta P = f(Qv, Pbo, Pto)$$

The figure below shows an example of the pressure drop of a check valve with partial opening.



Flow coefficient:

$$Kv = 36023 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Cv = 41650 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Av = Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

Total pressure loss coefficient (based on mean velocity):

$$K = \frac{2 \cdot \Delta P}{\rho \cdot U^2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number ()
Kvs	Full opening flow coefficient (m^3/h)
Cvs	Full opening flow coefficient (USG/min)
Avs	Full opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
Pbo	Pressure at the begin of opening (Pa)
Pto	Minimum pressure for full opening (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

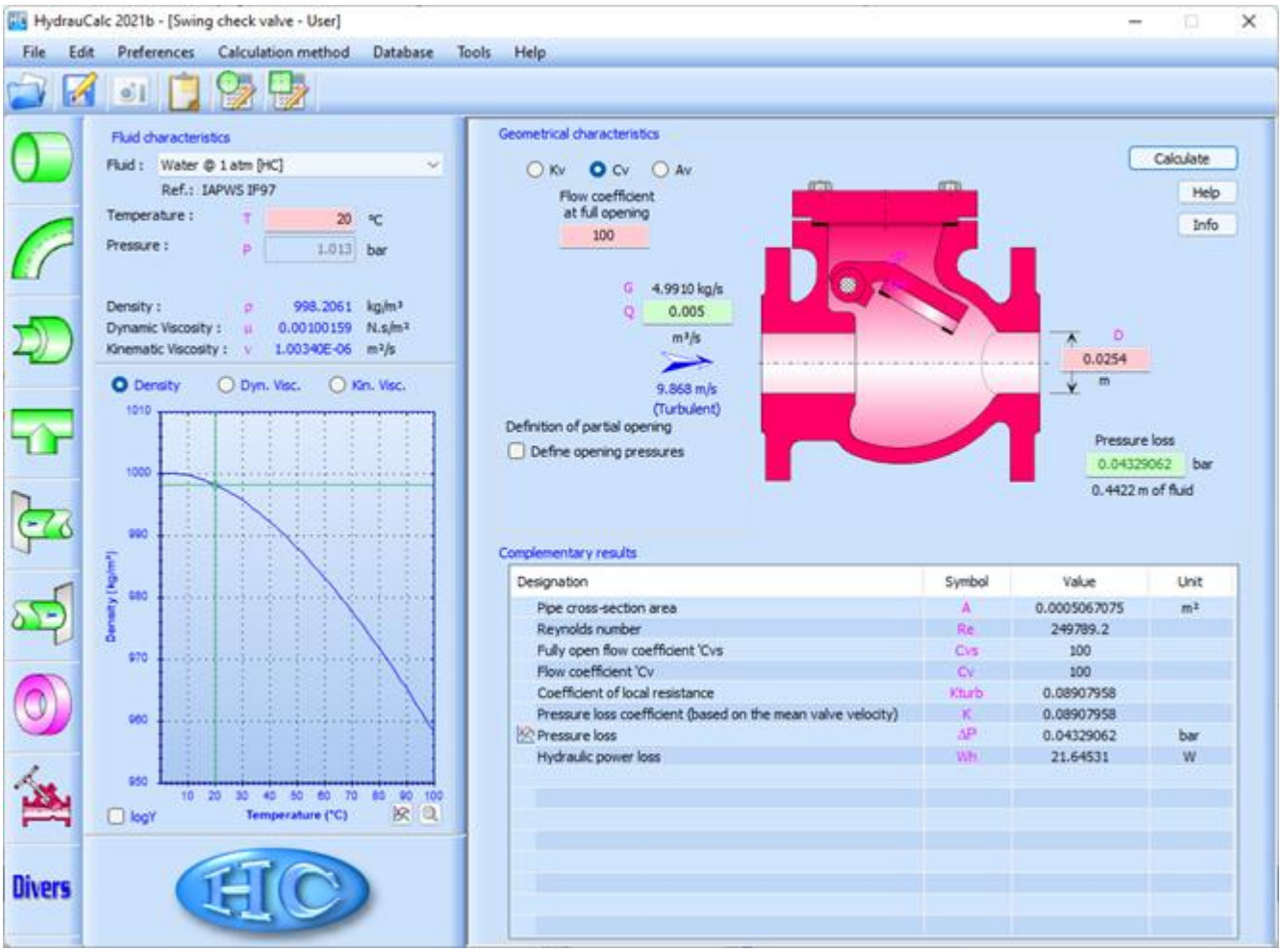
Validity range:

- flow regime: turbulent

  note: for laminar flow regime ($Re < 10^4$) and for operation in partial opening, the pressure loss coefficient "K" is estimated

---

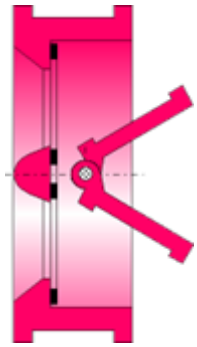
Example of application:



References:

Manufacturers

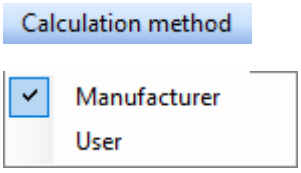
2.11.2 Dual plate check valve



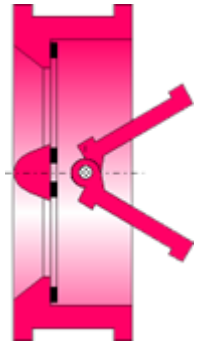
For the calculation of the pressure loss coefficient of dual plate check valves, the user can:

- choose from a list of dual plate check valves offered by manufacturers,
- define your own dual plate check valve.

The calculation method is selected using the "Calculation method" menu. The default option is "Manufacturer"



2.11.2.1 Manufacturer



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a dual plate check valve installed in a straight pipe.

The swing check valve characteristics are defined by valves manufacturers. The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening. The model also takes into account the partial opening of the valve, the opening is partial when the pressure at the inlet of the valve is between the pressure at the begin of opening and the minimum pressure for full opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

- check valve at full opening:

Local resistance coefficient:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kvs / 36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cvs / 41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Avs^2}$$

Total pressure loss coefficient (based on mean velocity):

$$K = K_{turb}$$

Total pressure loss (Pa):

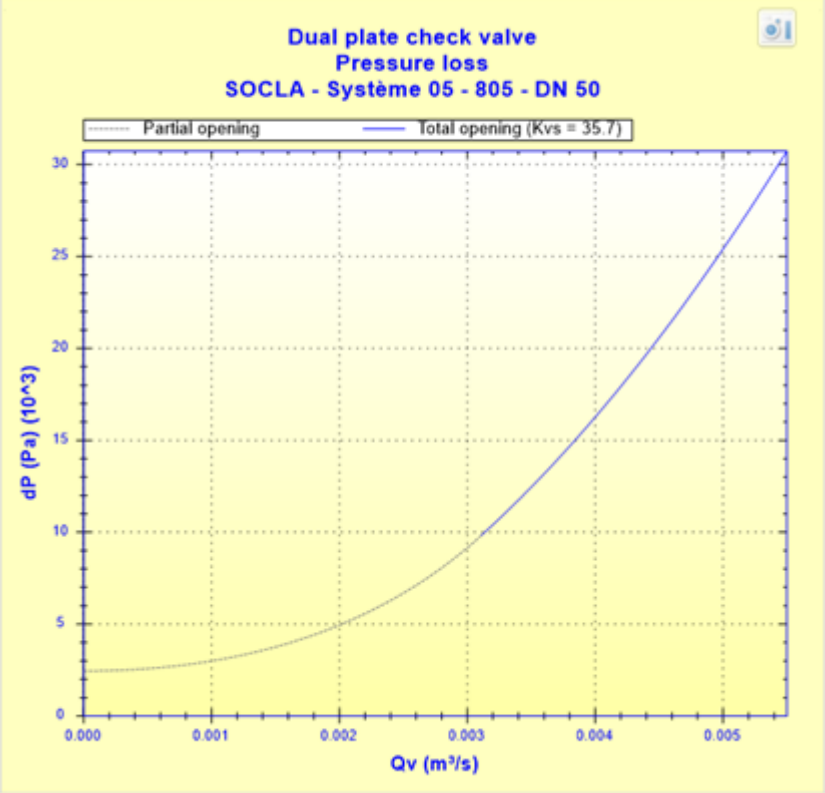
$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

- check valve at partial opening:

The pressure drop at partial opening is estimated by curvilinear interpolation between the pressure at the begin of opening "Pbo" and the minimum pressure for full opening "Pto".

$$\Delta P = f(Qv, Pbo, Pto)$$

The figure below shows an example of the pressure drop of a check valve with partial opening.



Flow coefficient:

$$Kv = 36023 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Cv = 41650 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Av = Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

Total pressure loss coefficient (based on mean velocity):

$$K = \frac{2 \cdot \Delta P}{\rho \cdot U^2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number ()
Kvs	Full opening flow coefficient (m^3/h)
Cvs	Full opening flow coefficient (USG/min)
Avs	Full opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
Pbo	Pressure at the begin of opening (Pa)
Pto	Minimum pressure for full opening (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- flow regime: turbulent

  note: for laminar flow regime ($Re < 10^4$) and for operation in partial opening, the pressure loss coefficient "K" is estimated

---

Example of application:

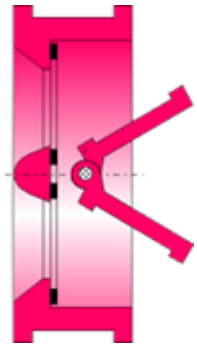
References:

Manufacturers

2.11.2.2 User

Dual Plate Check Valve

(User defined)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a dual plate check valve installed in a straight pipe.

The swing check valve characteristics are defined by the user. The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening. The model also takes into account the partial opening of the valve, the opening is partial when the pressure at the inlet of the valve is between the pressure at the begin of opening and the minimum pressure for full opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

- check valve at full opening:

Local resistance coefficient:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kvs / 36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cvs / 41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Avs^2}$$

Total pressure loss coefficient (based on mean velocity):

$$K = K_{turb}$$

Total pressure loss (Pa):

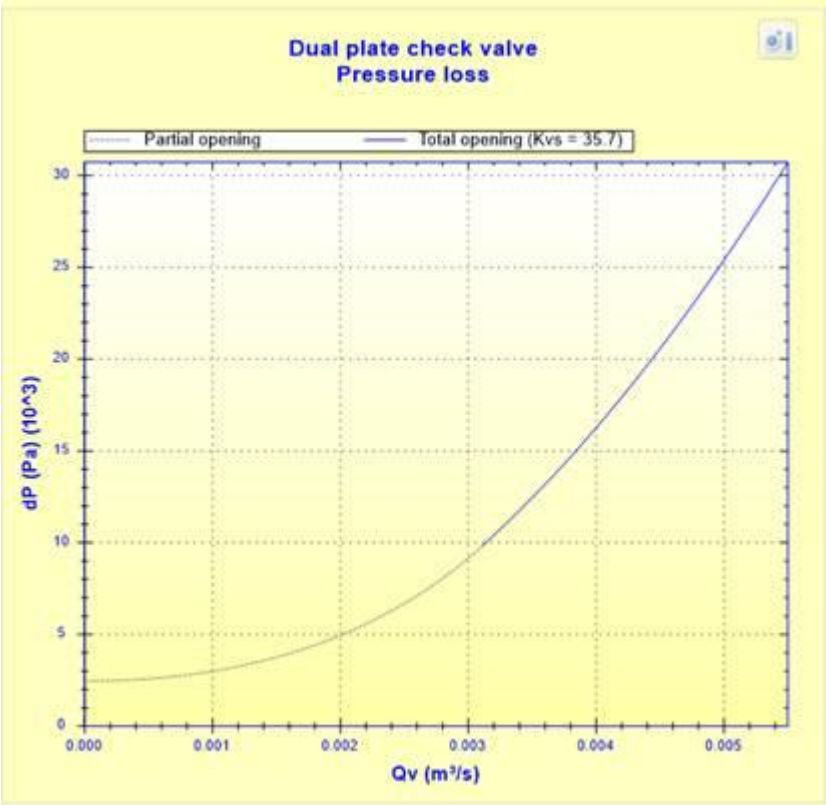
$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

- check valve at partial opening:

The pressure drop at partial opening is estimated by curvilinear interpolation between the pressure at the begin of opening "Pbo" and the minimum pressure for full opening "Pto".

$$\Delta P = f(Qv, Pbo, Pto)$$

The figure below shows an example of the pressure drop of a check valve with partial opening.



Flow coefficient:

$$Kv = 36023 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Cv = 41650 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Av = Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

Total pressure loss coefficient (based on mean velocity):

$$K = \frac{2 \cdot \Delta P}{\rho \cdot U^2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number ()
Kvs	Full opening flow coefficient (m^3/h)
Cvs	Full opening flow coefficient (USG/min)
Avs	Full opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
Pbo	Pressure at the begin of opening (Pa)
Pto	Minimum pressure for full opening (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

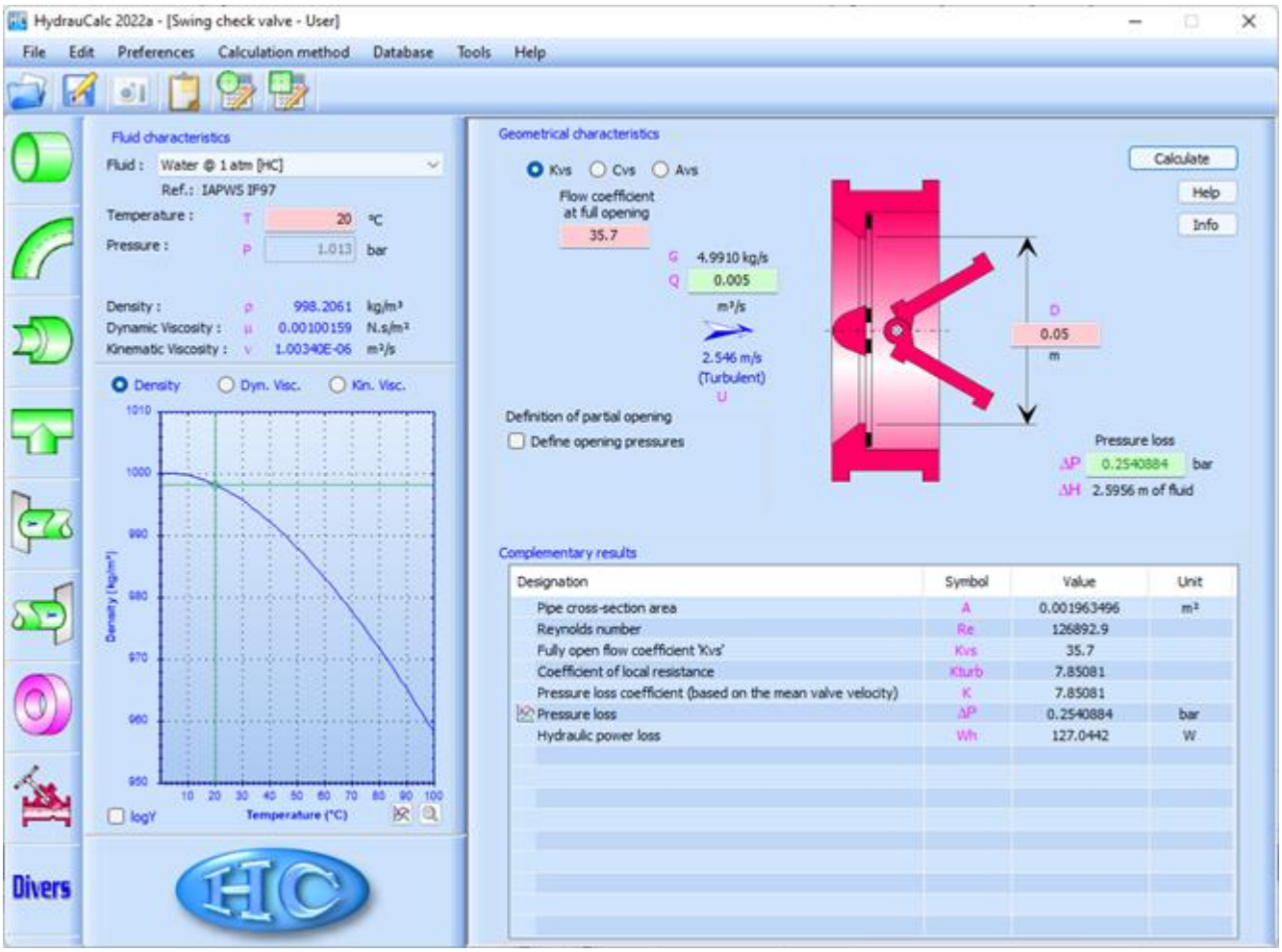
Validity range:

- flow regime: turbulent

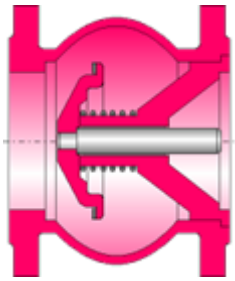
  note: for laminar flow regime ($Re < 10^4$) and for operation in partial opening, the pressure loss coefficient "K" is estimated

---

Example of application:



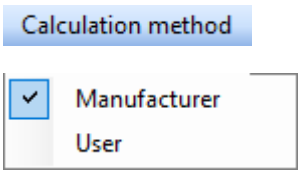
2.11.3 Axial check valve



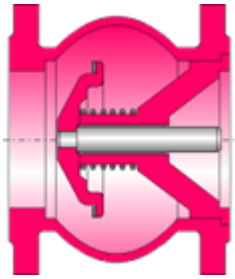
For the calculation of the pressure loss coefficient of axial check valves, the user can:

- choose from a list of axial check valves offered by manufacturers,
- define your own axial check valve.

The calculation method is selected using the "Calculation method" menu. The default option is "Manufacturer"



2.11.3.1 Manufacturer



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in an axial check valve installed in a straight pipe.

The swing check valve characteristics are defined by valves manufacturers. The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening. The model also takes into account the partial opening of the valve, the opening is partial when the pressure at the inlet of the valve is between the pressure at the begin of opening and the minimum pressure for full opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

- check valve at full opening:

Local resistance coefficient:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kvs / 36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cvs / 41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Avs^2}$$

Total pressure loss coefficient (based on mean velocity):

$$K = K_{turb}$$

Total pressure loss (Pa):

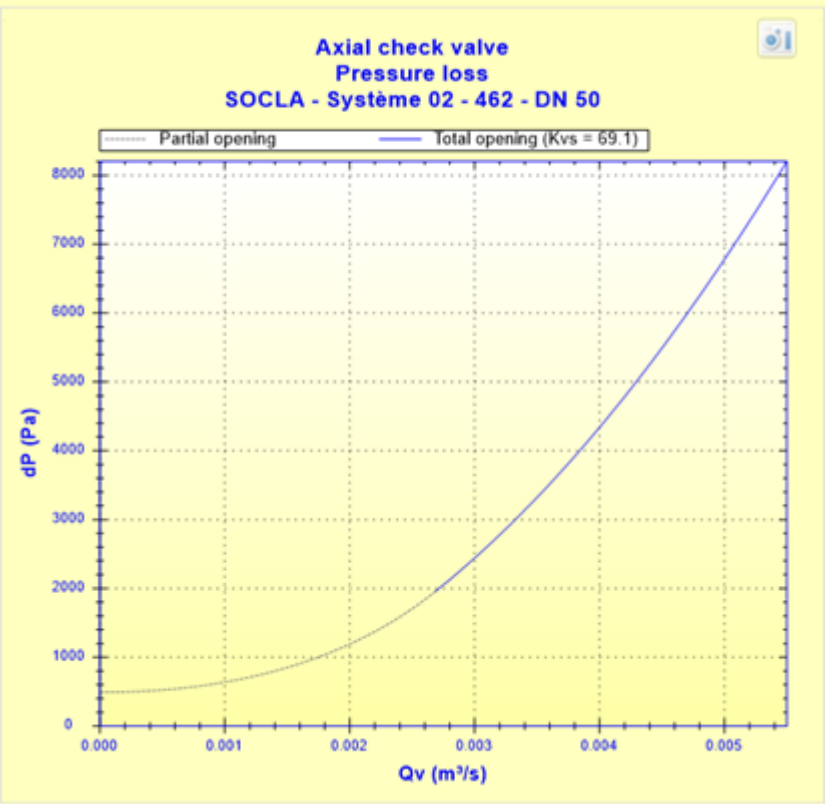
$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

- check valve at partial opening:

The pressure drop at partial opening is estimated by curvilinear interpolation between the pressure at the begin of opening "Pbo" and the minimum pressure for full opening "Pto".

$$\Delta P = f(Qv, Pbo, Pto)$$

The figure below shows an example of the pressure drop of a check valve with partial opening.



Flow coefficient:

$$Kv = 36023 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Cv = 41650 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Av = Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

Total pressure loss coefficient (based on mean velocity):

$$K = \frac{2 \cdot \Delta P}{\rho \cdot U^2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number ()
Kvs	Full opening flow coefficient (m^3/h)
Cvs	Full opening flow coefficient (USG/min)
Avs	Full opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
Pbo	Pressure at the begin of opening (Pa)
Pto	Minimum pressure for full opening (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

Validity range:

- flow regime: turbulent

  note: for laminar flow regime ($Re < 10^4$) and for operation in partial opening, the pressure loss coefficient "K" is estimated

---

Example of application:

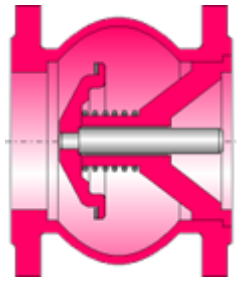
References:

Manufacturers

2.11.3.2 User

Swing Check Valve

(User defined)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in an axial check valve installed in a straight pipe.

The swing check valve characteristics are defined by the user. The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening. The model also takes into account the partial opening of the valve, the opening is partial when the pressure at the inlet of the valve is between the pressure at the begin of opening and the minimum pressure for full opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

- check valve at full opening:

Local resistance coefficient:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kvs / 36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cvs / 41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Avs^2}$$

Total pressure loss coefficient (based on mean velocity):

$$K = K_{turb}$$

Total pressure loss (Pa):

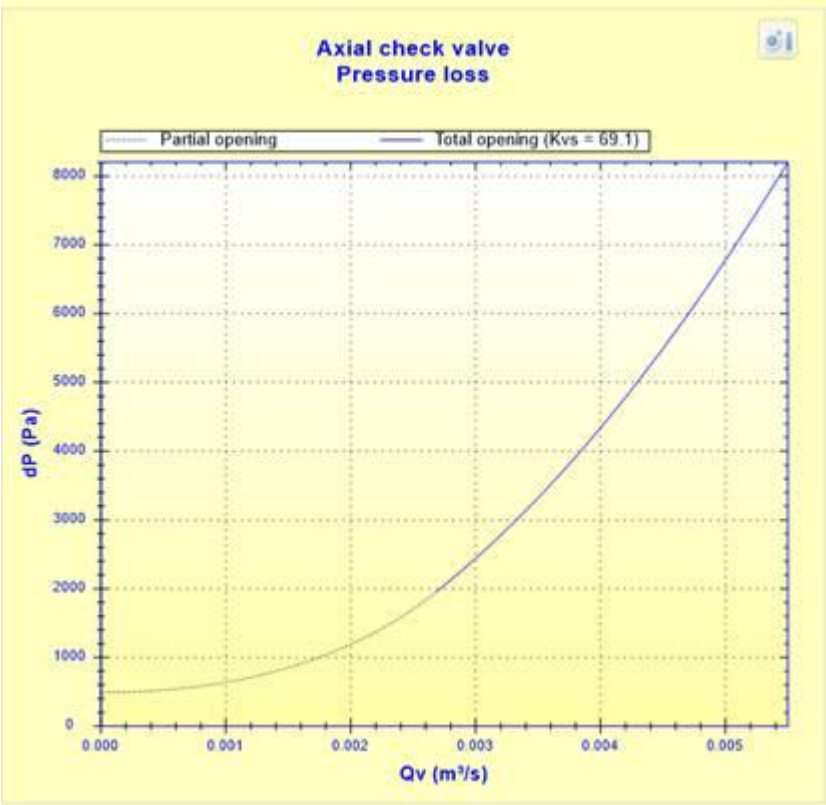
$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

- check valve at partial opening:

The pressure drop at partial opening is estimated by curvilinear interpolation between the pressure at the begin of opening "Pbo" and the minimum pressure for full opening "Pto".

$$\Delta P = f(Qv, Pbo, Pto)$$

The figure below shows an example of the pressure drop of a check valve with partial opening.



Flow coefficient:

$$Kv = 36023 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Cv = 41650 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Av = Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

Total pressure loss coefficient (based on mean velocity):

$$K = \frac{2 \cdot \Delta P}{\rho \cdot U^2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number ()
Kvs	Full opening flow coefficient (m^3/h)
Cvs	Full opening flow coefficient (USG/min)
Avs	Full opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
Pbo	Pressure at the begin of opening (Pa)
Pto	Minimum pressure for full opening (Pa)

ΔH Total head loss of fluid (m)

Wh Hydraulic power loss (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

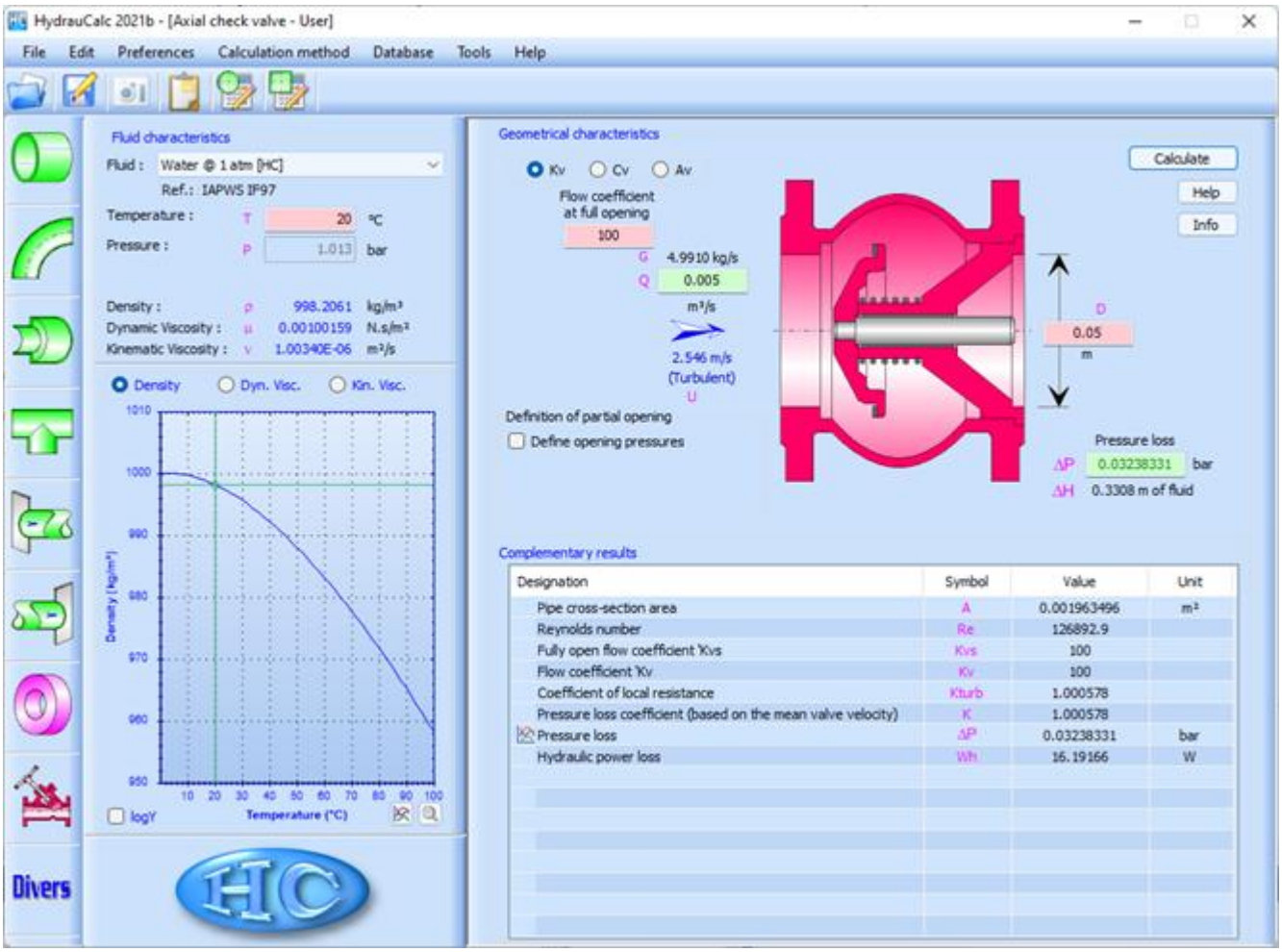
Validity range:

- flow regime: turbulent

  note: for laminar flow regime ($Re < 10^4$) and for operation in partial opening, the pressure loss coefficient "K" is estimated

---

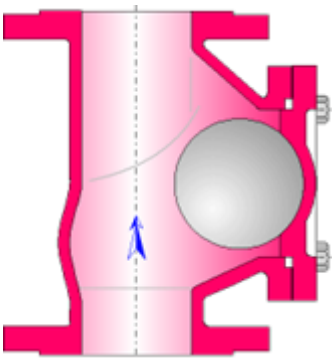
Example of application:



References :

Manufacturers

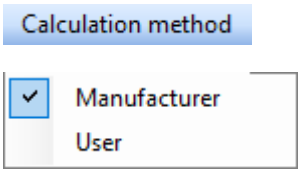
2.11.4 Ball check valve



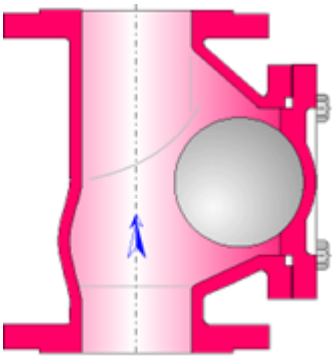
For the calculation of the pressure loss coefficient of ball check valves, the user can:

- choose from a list of ball check valves offered by manufacturers,
- define your own ball check valve.

The calculation method is selected using the "Calculation method" menu. The default option is "Manufacturer"



2.11.4.1 Manufacturer



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a ball check valve connected to a straight pipe.

The ball check valve characteristics are defined by valves manufacturers. The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening. The model also takes into account the partial opening of the valve, the opening is partial when the pressure at the inlet of the valve is between the pressure at the begin of opening and the minimum pressure for full opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

- check valve at full opening:

Local resistance coefficient:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kvs/36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cvs/41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Avs^2}$$

Total pressure loss coefficient (based on mean velocity):

$$K = K_{turb}$$

Total pressure loss (Pa):

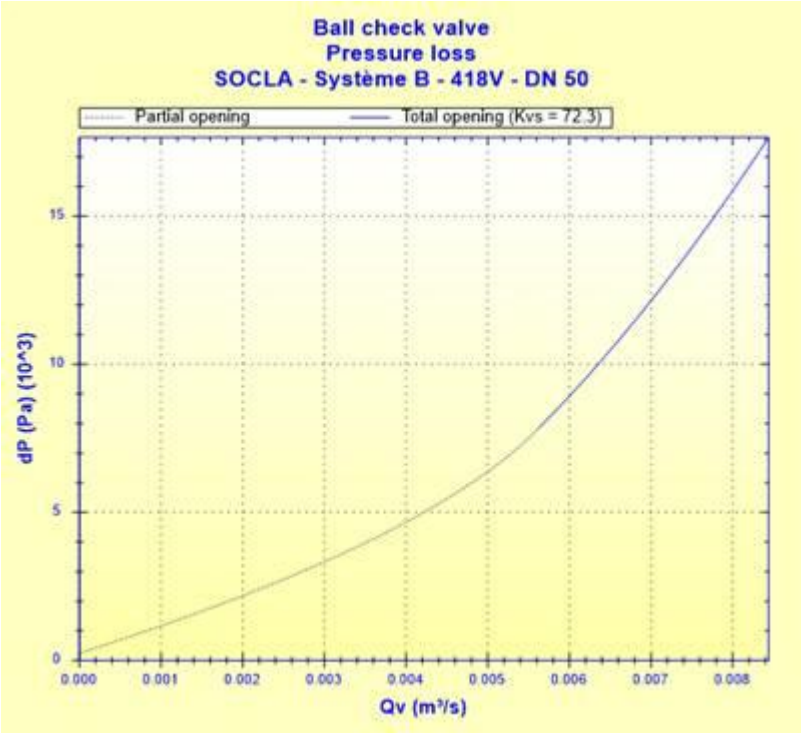
$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

- check valve at partial opening:

The pressure drop at partial opening is estimated by curvilinear interpolation between the pressure at the begin of opening "Pbo" and the minimum pressure for full opening "Pto".

$$\Delta P = f(Qv, Pbo, Pto)$$

The figure below shows an example of the pressure drop of a check valve with partial opening.



Flow coefficient:

$$Kv = 36023 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Cv = 41650 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Av = Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

Total pressure loss coefficient (based on mean velocity):

$$K = \frac{2 \cdot \Delta P}{\rho \cdot U^2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number ()
Kvs	Full opening flow coefficient (m^3/h)
Cvs	Full opening flow coefficient (USG/min)
Avs	Full opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
Pbo	Pressure at the begin of opening (Pa)
Pto	Minimum pressure for full opening (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

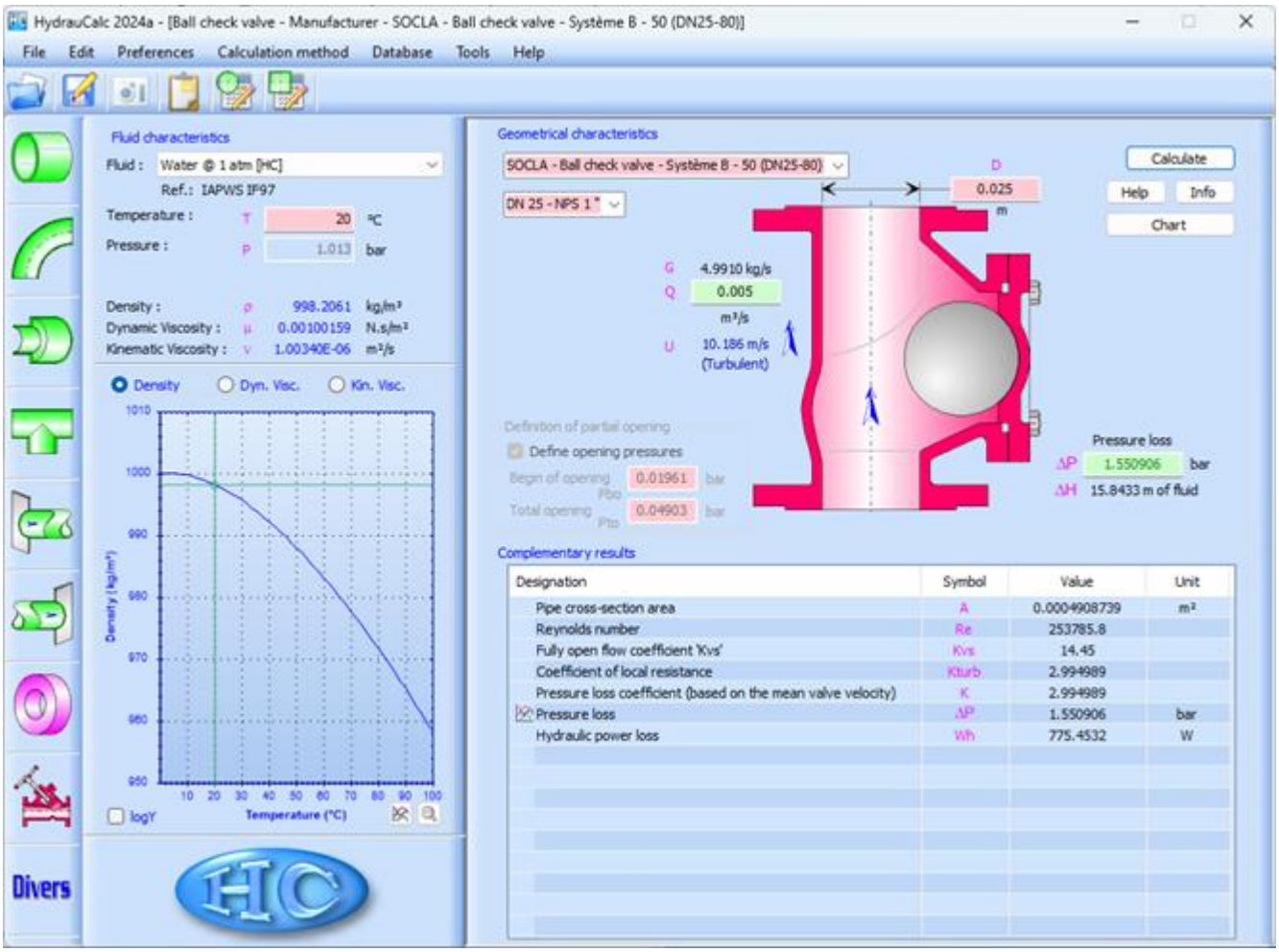
Validity range:

- flow regime: turbulent

  note: for operation in partial opening, the pressure loss coefficient "K" is estimated

---

Example of application:



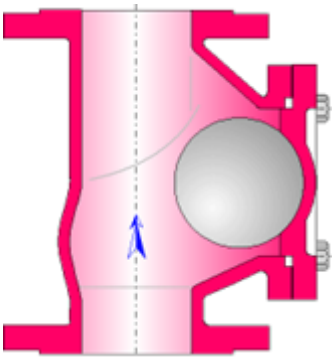
References:

Manufacturers

2.11.4.2 User

Ball Check Valve

(User defined)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a ball check valve connected to a straight pipe.

The ball check valve characteristics are defined by the user. The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening. The model also takes into account the partial opening of the valve, the opening is partial when the pressure at the inlet of the valve is between the pressure at the begin of opening and the minimum pressure for full opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

- check valve at full opening:

Local resistance coefficient:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kvs/36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cvs/41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Avs^2}$$

Total pressure loss coefficient (based on mean velocity):

$$K = K_{turb}$$

Total pressure loss (Pa):

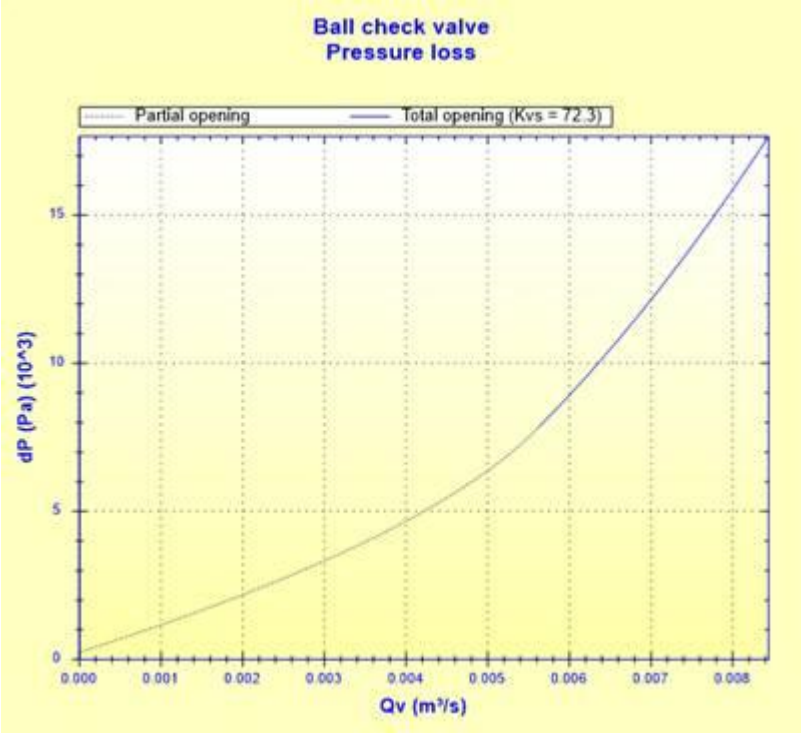
$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

- check valve at partial opening:

The pressure drop at partial opening is estimated by curvilinear interpolation between the pressure at the begin of opening "Pbo" and the minimum pressure for full opening "Pto".

$$\Delta P = f(Qv, Pbo, Pto)$$

The figure below shows an example of the pressure drop of a check valve with partial opening.



Flow coefficient:

$$Kv = 36023 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Cv = 41650 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Av = Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

Total pressure loss coefficient (based on mean velocity):

$$K = \frac{2 \cdot \Delta P}{\rho \cdot U^2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number ()
Kvs	Full opening flow coefficient (m^3/h)
Cvs	Full opening flow coefficient (USG/min)
Avs	Full opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
Pbo	Pressure at the begin of opening (Pa)
Pto	Minimum pressure for full opening (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

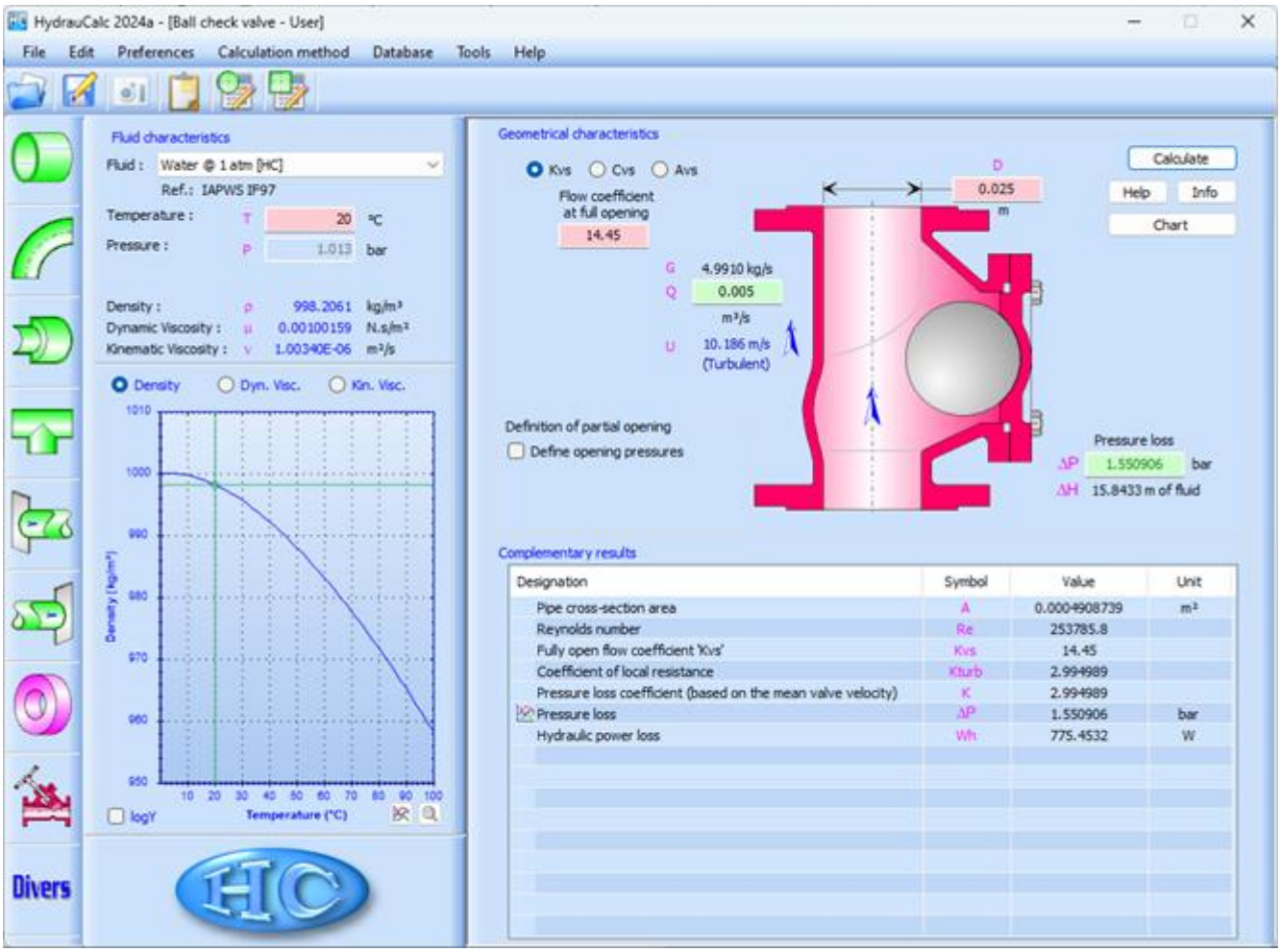
Validity range:

- flow regime: turbulent

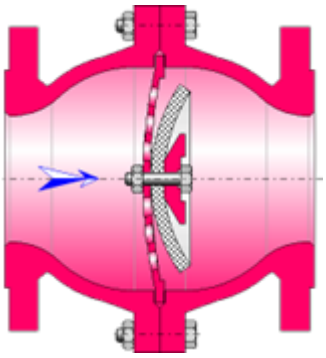
  note: for operation in partial opening, the pressure loss coefficient "K" is estimated

---

Example of application:



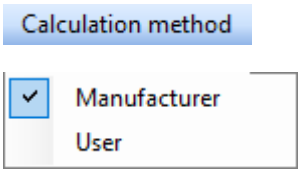
2.11.5 Membrane check valve



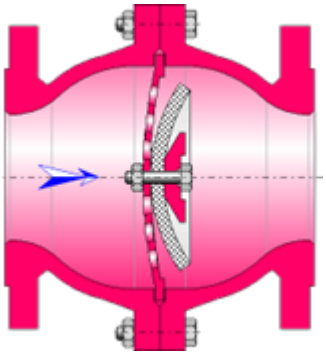
For the calculation of the pressure loss coefficient of membrane check valves, the user can:

- choose from a list of membrane check valves offered by manufacturers,
- define your own membrane check valve.

The calculation method is selected using the "Calculation method" menu. The default option is "Manufacturer"



2.11.5.1 Manufacturer



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a membrane check valve connected to a straight pipe.

The membrane check valve characteristics are defined by valves manufacturers. The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening. The model also takes into account the partial opening of the valve, the opening is partial when the pressure at the inlet of the valve is between the pressure at the begin of opening and the minimum pressure for full opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

- check valve at full opening:

Local resistance coefficient:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kvs/36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cvs/41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Avs^2}$$

Total pressure loss coefficient (based on mean velocity):

$$K = K_{turb}$$

Total pressure loss (Pa):

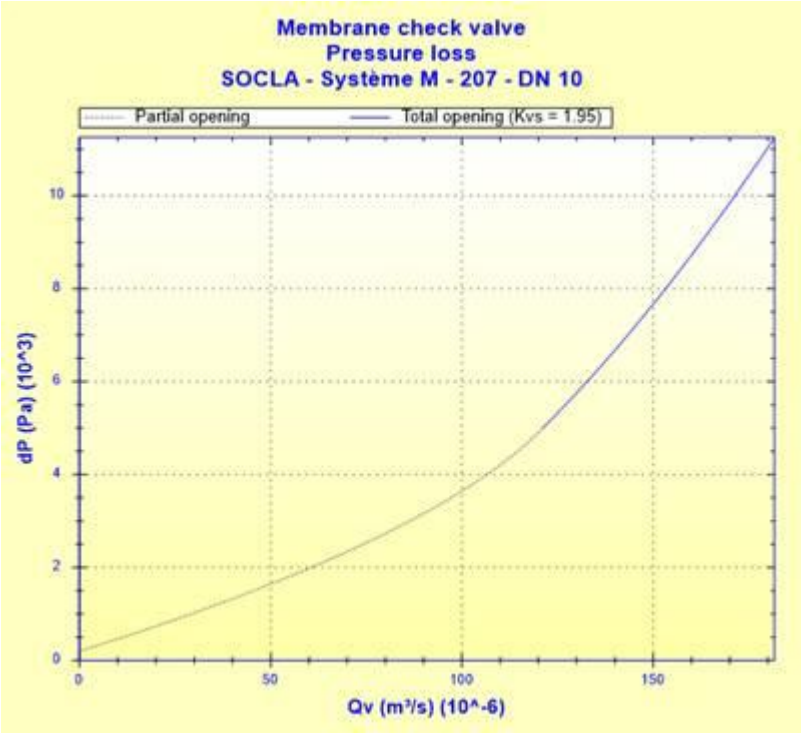
$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

- check valve at partial opening:

The pressure drop at partial opening is estimated by curvilinear interpolation between the pressure at the begin of opening "Pbo" and the minimum pressure for full opening "Pto".

$$\Delta P = f(Qv, Pbo, Pto)$$

The figure below shows an example of the pressure drop of a check valve with partial opening.



Flow coefficient:

$$Kv = 36023 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Cv = 41650 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Av = Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

Total pressure loss coefficient (based on mean velocity):

$$K = \frac{2 \cdot \Delta P}{\rho \cdot U^2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number ()
α	Opening angle (°)
Kvs	Full opening flow coefficient (m^3/h)
Cvs	Full opening flow coefficient (USG/min)
Avs	Full opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
Pbo	Pressure at the begin of opening (Pa)
Pto	Minimum pressure for full opening (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

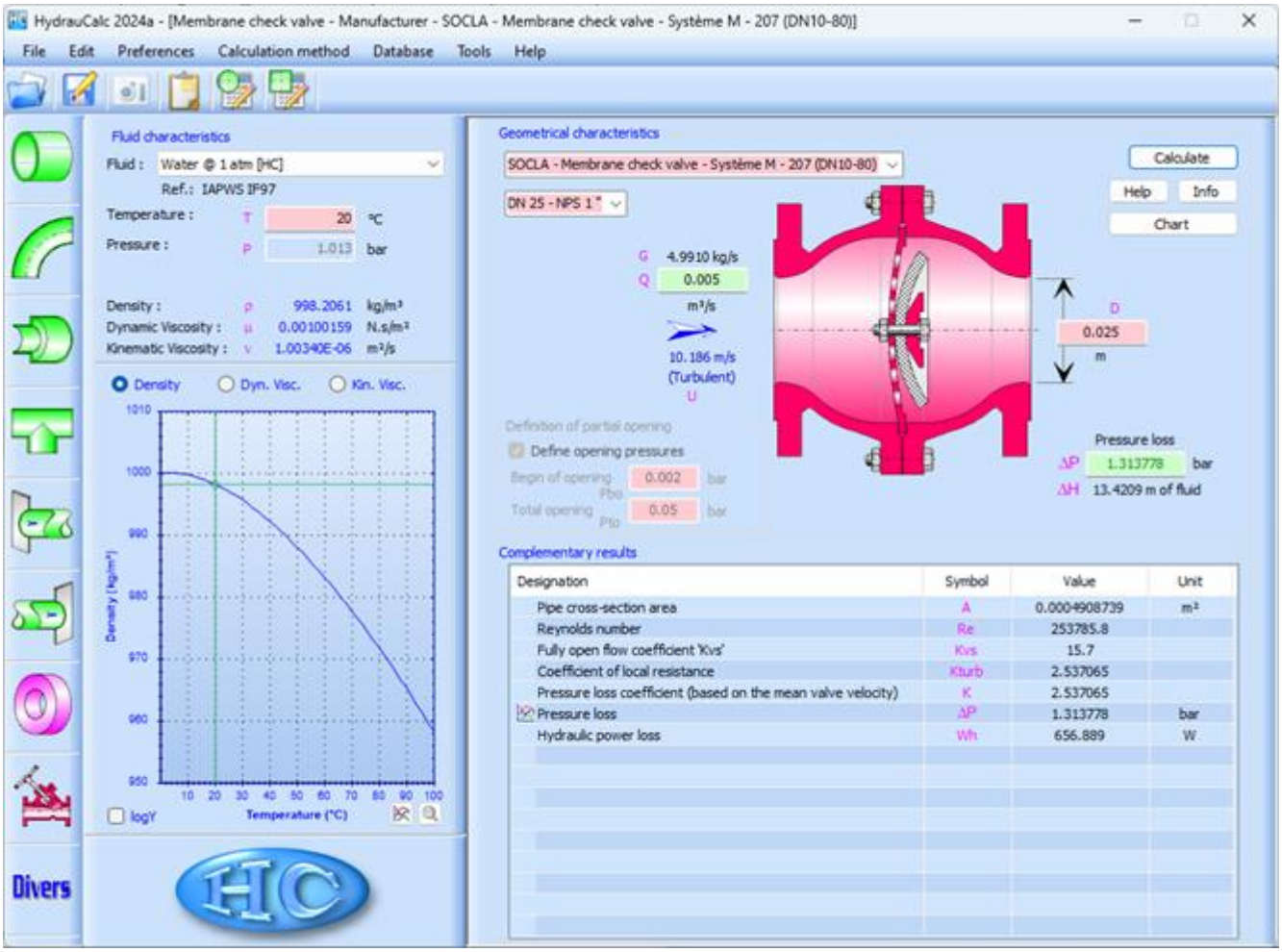
Validity range:

- flow regime: turbulent

  note: for operation in partial opening, the pressure loss coefficient "K" is estimated

---

Example of application:



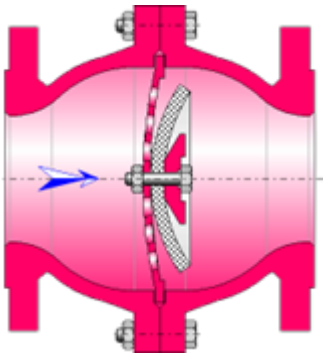
References:

Manufacturers

2.11.5.2 User

Membrane Check Valve

(User defined)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a membrane check valve connected to a straight pipe.

The membrane check valve characteristics are defined by the user. The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening. The model also takes into account the partial opening of the valve, the opening is partial when the pressure at the inlet of the valve is between the pressure at the begin of opening and the minimum pressure for full opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

- check valve at full opening:

Local resistance coefficient:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kvs/36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cvs/41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Avs^2}$$

Total pressure loss coefficient (based on mean velocity):

$$K = K_{turb}$$

Total pressure loss (Pa):

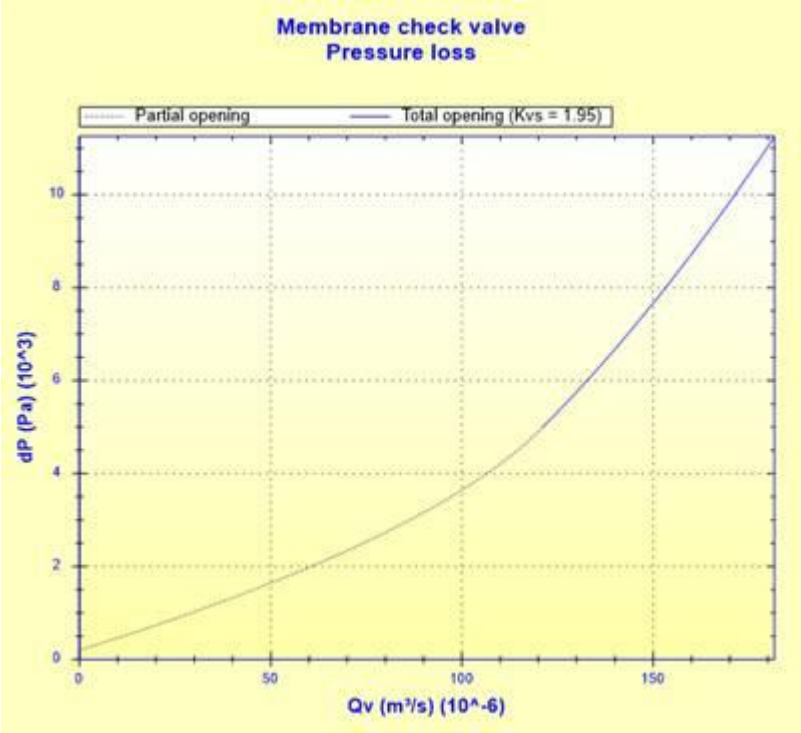
$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

- check valve at partial opening:

The pressure drop at partial opening is estimated by curvilinear interpolation between the pressure at the begin of opening "Pbo" and the minimum pressure for full opening "Pto".

$$\Delta P = f(Qv, Pbo, Pto)$$

The figure below shows an example of the pressure drop of a check valve with partial opening.



Flow coefficient:

$$Kv = 36023 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Cv = 41650 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Av = Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

Total pressure loss coefficient (based on mean velocity):

$$K = \frac{2 \cdot \Delta P}{\rho \cdot U^2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number ()
Kvs	Full opening flow coefficient (m^3/h)
Cvs	Full opening flow coefficient (USG/min)
Avs	Full opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
Pbo	Pressure at the begin of opening (Pa)
Pto	Minimum pressure for full opening (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

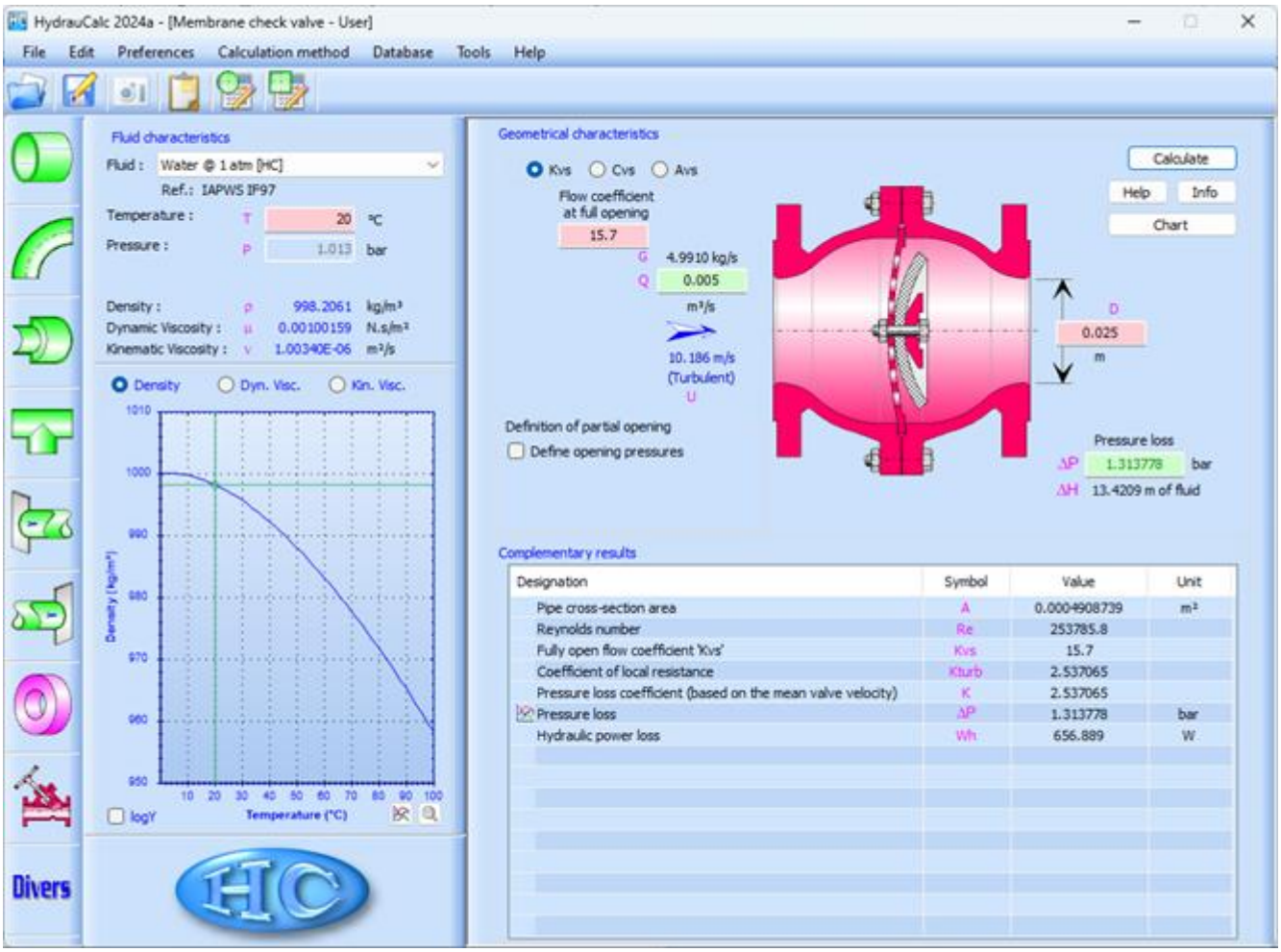
Validity range:

- flow regime: turbulent

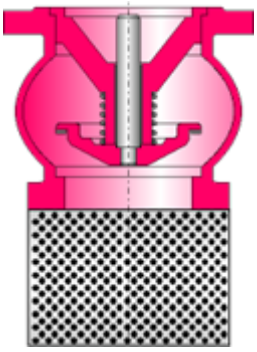
  note: for operation in partial opening, the pressure loss coefficient "K" is estimated

---

Example of application:



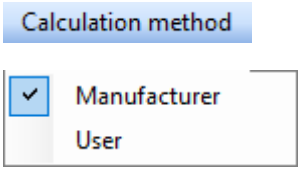
2.11.6 Foot check valve



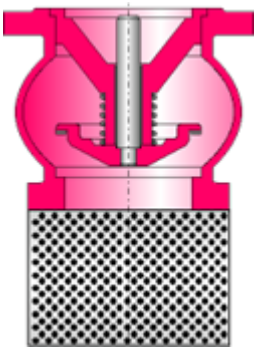
For the calculation of the pressure loss coefficient of foot check valves, the user can:

- choose from a list of foot check valves offered by manufacturers,
- define your own foot check valve.

The calculation method is selected using the "Calculation method" menu. The default option is "Manufacturer"



2.11.6.1 Manufacturer



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a foot check valve connected to a straight pipe.

The foot check valve characteristics are defined by valves manufacturers. The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening. The model also takes into account the partial opening of the valve, the opening is partial when the pressure at the inlet of the valve is between the pressure at the begin of opening and the minimum pressure for full opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

- check valve at full opening:

Local resistance coefficient:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kvs/36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cvs/41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Avs^2}$$

Total pressure loss coefficient (based on mean velocity):

$$K = K_{turb}$$

Total pressure loss (Pa):

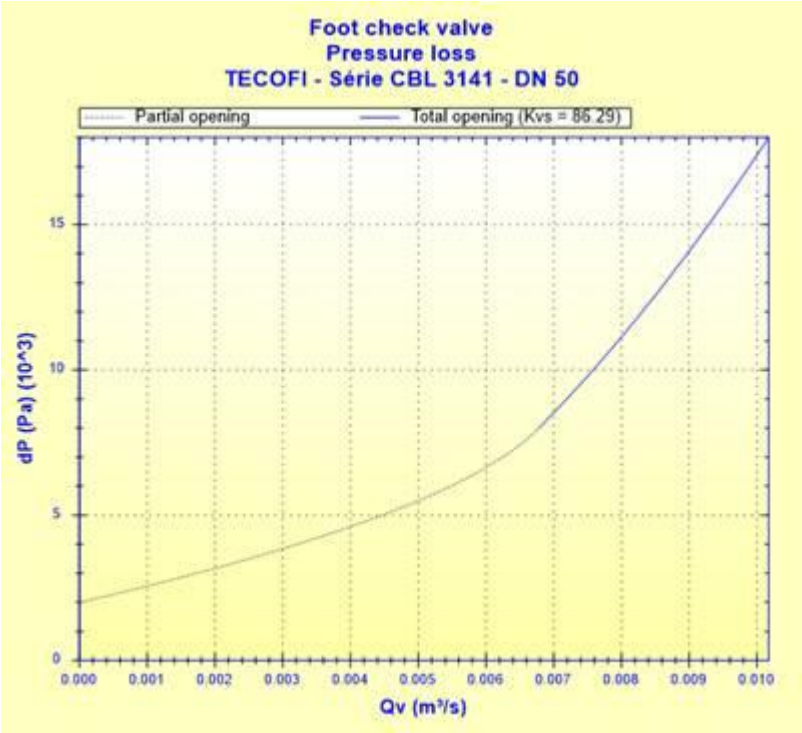
$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

- check valve at partial opening:

The pressure drop at partial opening is estimated by curvilinear interpolation between the pressure at the begin of opening "Pbo" and the minimum pressure for full opening "Pto".

$$\Delta P = f(Qv, Pbo, Pto)$$

The figure below shows an example of the pressure drop of a check valve with partial opening.



Flow coefficient:

$$Kv = 36023 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Cv = 41650 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Av = Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

Total pressure loss coefficient (based on mean velocity):

$$K = \frac{2 \cdot \Delta P}{\rho \cdot U^2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number ()
Kvs	Full opening flow coefficient (m^3/h)
Cvs	Full opening flow coefficient (USG/min)
Avs	Full opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
Pbo	Pressure at the begin of opening (Pa)
Pto	Minimum pressure for full opening (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)

ν Fluid kinematic viscosity (m^2/s)

g Gravitational acceleration (m/s^2)

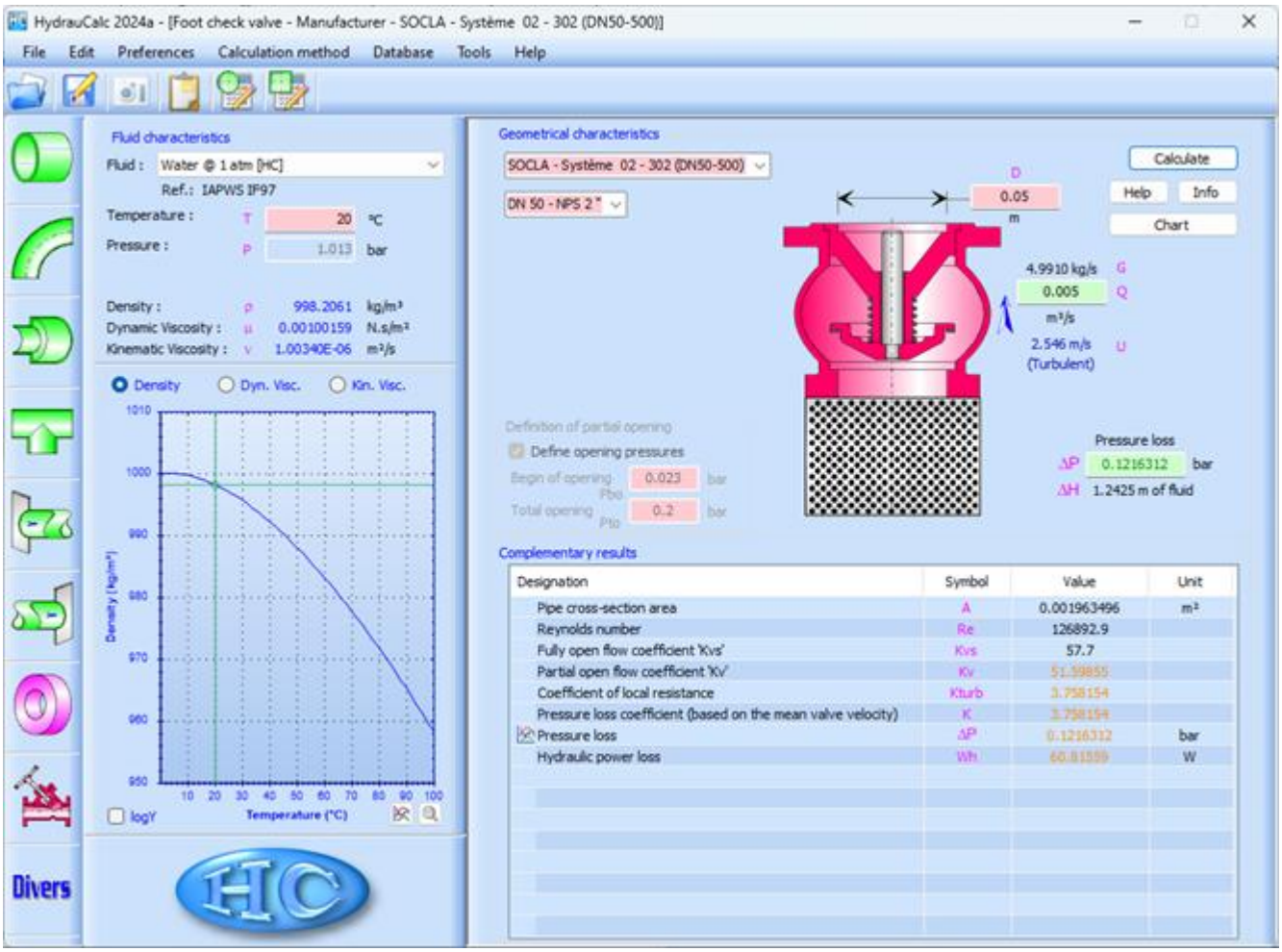
Validity range:

- flow regime: turbulent

  note: for operation in partial opening, the pressure loss coefficient "K" is estimated

---

Example of application:



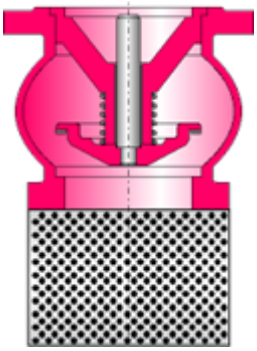
References:

Manufacturers

2.11.6.2 User

Foot Check Valve

(User defined)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a foot check valve connected to a straight pipe.

The foot check valve characteristics are defined by the user. The pressure drop of the valve is characterized by a flow coefficient "Kvs", "Cvs" or "Avs" at full opening. The model also takes into account the partial opening of the valve, the opening is partial when the pressure at the inlet of the valve is between the pressure at the begin of opening and the minimum pressure for full opening.

Model formulation:

Cross-sectional area (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

- check valve at full opening:

Local resistance coefficient:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kvs/36023\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{\left(Cvs/41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Avs^2}$$

Total pressure loss coefficient (based on mean velocity):

$$K = K_{turb}$$

Total pressure loss (Pa):

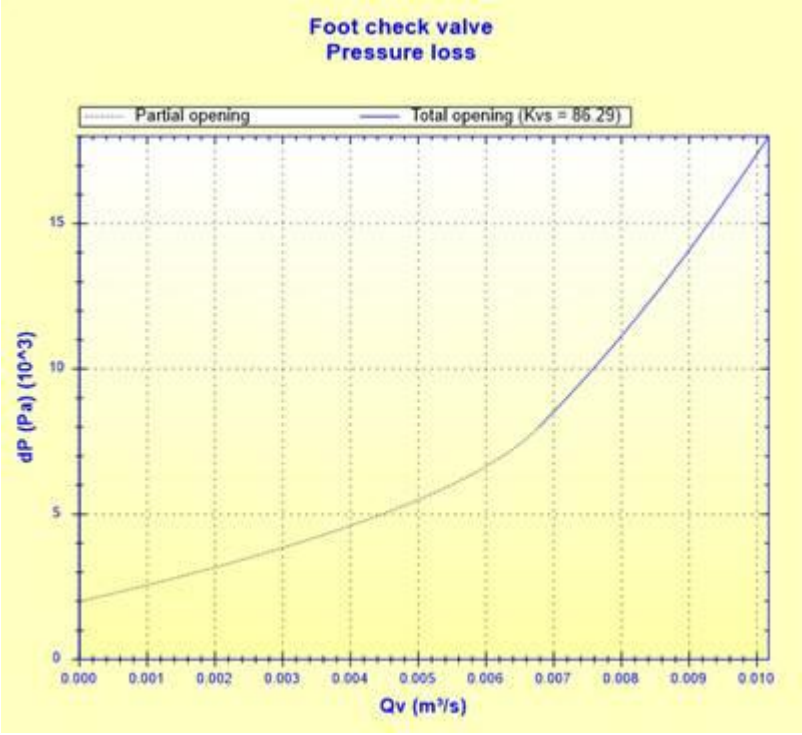
$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

- check valve at partial opening:

The pressure drop at partial opening is estimated by curvilinear interpolation between the pressure at the begin of opening "Pbo" and the minimum pressure for full opening "Pto".

$$\Delta P = f(Qv, Pbo, Pto)$$

The figure below shows an example of the pressure drop of a check valve with partial opening.



Flow coefficient:

$$Kv = 36023 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Cv = 41650 \cdot Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

$$Av = Q \cdot \sqrt{\frac{\rho}{\Delta P}}$$

Total pressure loss coefficient (based on mean velocity):

$$K = \frac{2 \cdot \Delta P}{\rho \cdot U^2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter (m)
A	Cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number ()
Kvs	Full opening flow coefficient (m^3/h)
Cvs	Full opening flow coefficient (USG/min)
Avs	Full opening flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
Kv	Partial opening flow coefficient (m^3/h)
Cv	Partial opening flow coefficient (USG/min)
Av	Partial opening flow coefficient (m^2)
Pbo	Pressure at the begin of opening (Pa)
Pto	Minimum pressure for full opening (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)

ρ Fluid density (kg/m³)

ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

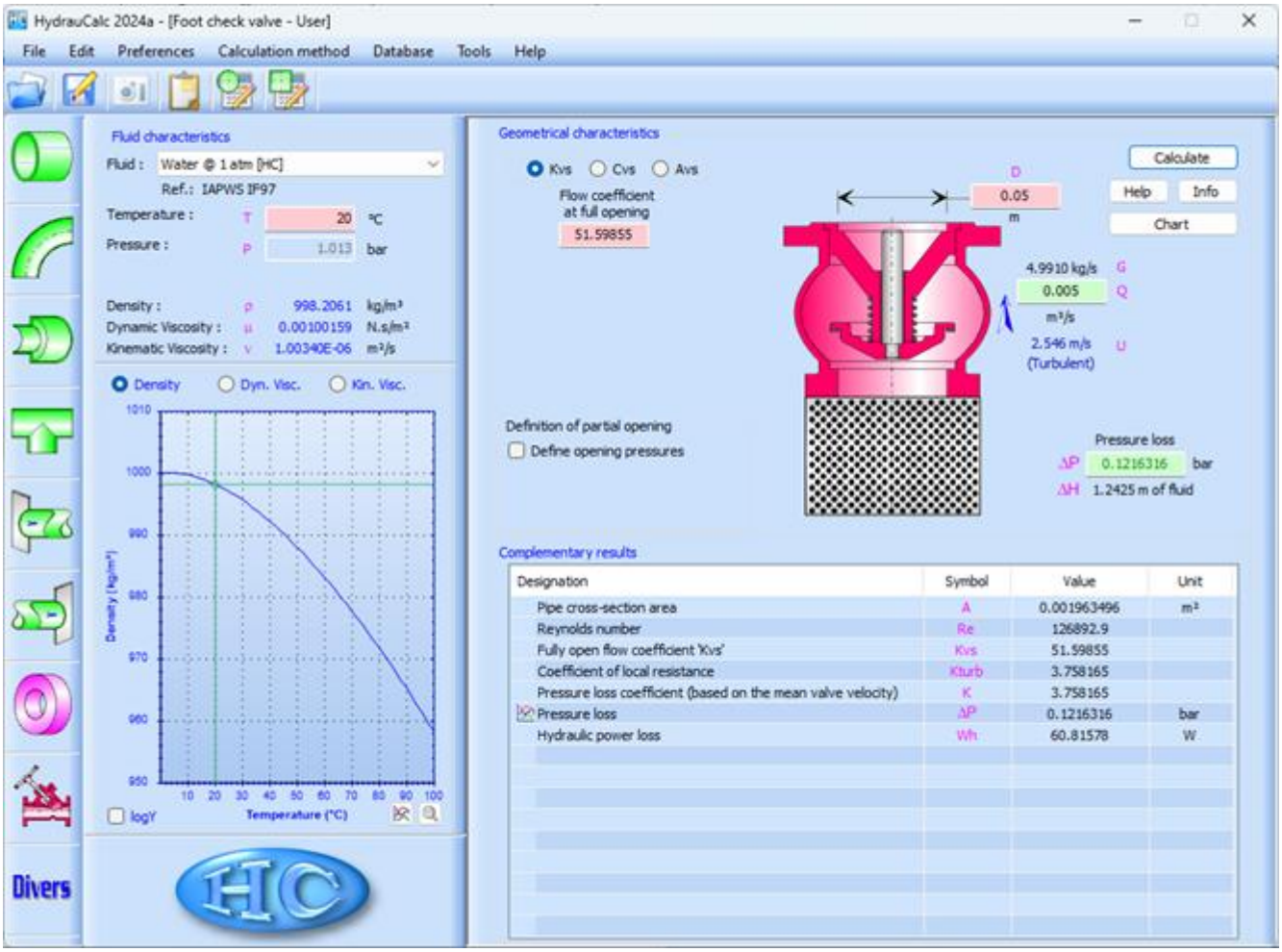
Validity range:

- flow regime: turbulent

  note: for operation in partial opening, the pressure loss coefficient "K" is estimated

---

Example of application:



Reference :

Manufacturers

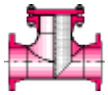
2.12 Strainers

This subsection regroups the set of strainers that can be modeled and calculated. The types of strainers available are:

- Basket strainer - Circular Cross-Section

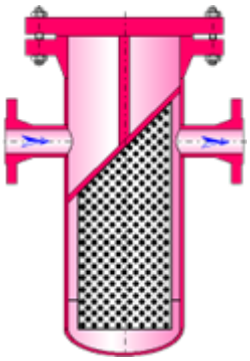
- Y strainer - Circular Cross-Section

- T strainer - Circular Cross-Section



- 90° Elbow Strainer - Circular Cross-Section

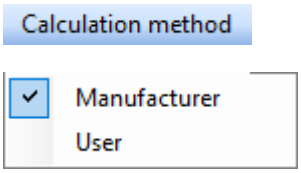
2.12.1 Basket strainer



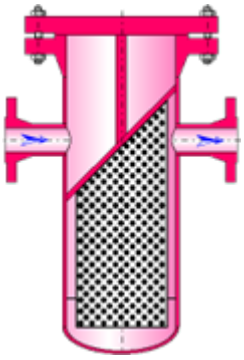
For the calculation of the pressure loss coefficient of basket strainer, the user can:

- choose from a list of basket strainer offered by manufacturers,
- define your own basket strainer.

The calculation method is selected using the "Calculation method" menu. The default option is "Manufacturer"



2.12.1.1 Manufacturer



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a basket strainer.

The basket strainer specifications are defined by strainers manufacturers. The pressure drop of the basket strainer is characterized by a flow coefficient "Kv", "Cv" or "Av". A calculation option allows to take into account the influence of the viscosity of the fluid in the case of viscous fluid.

Model formulation:

Cross-sectional area of the pipe (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Average flow velocity in the pipe (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in the pipe:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Local resistance coefficient for turbulent flow:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv / 36023\right)^2}$$

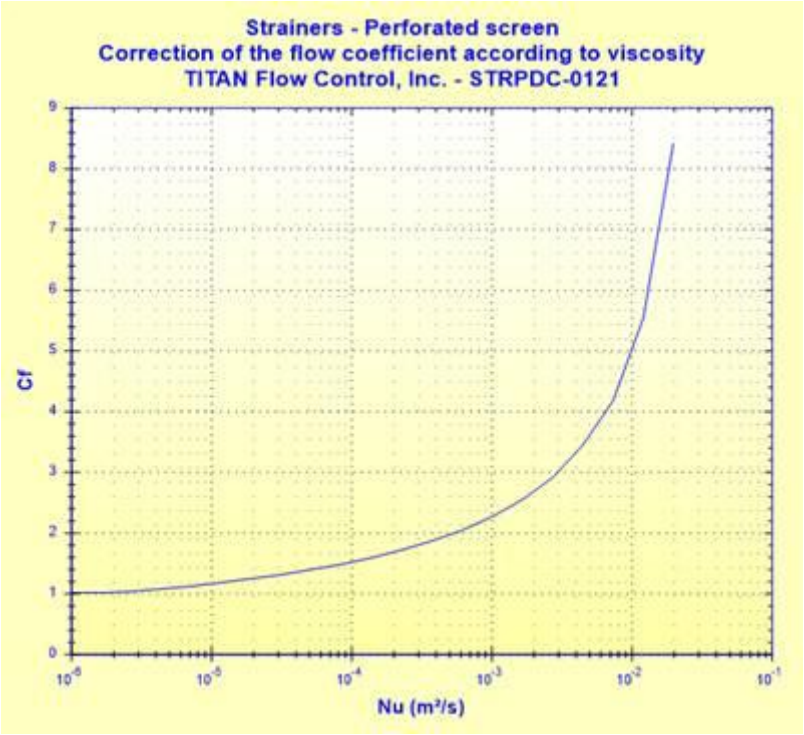
$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv / 41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

Correction factor according to viscosity (optional):

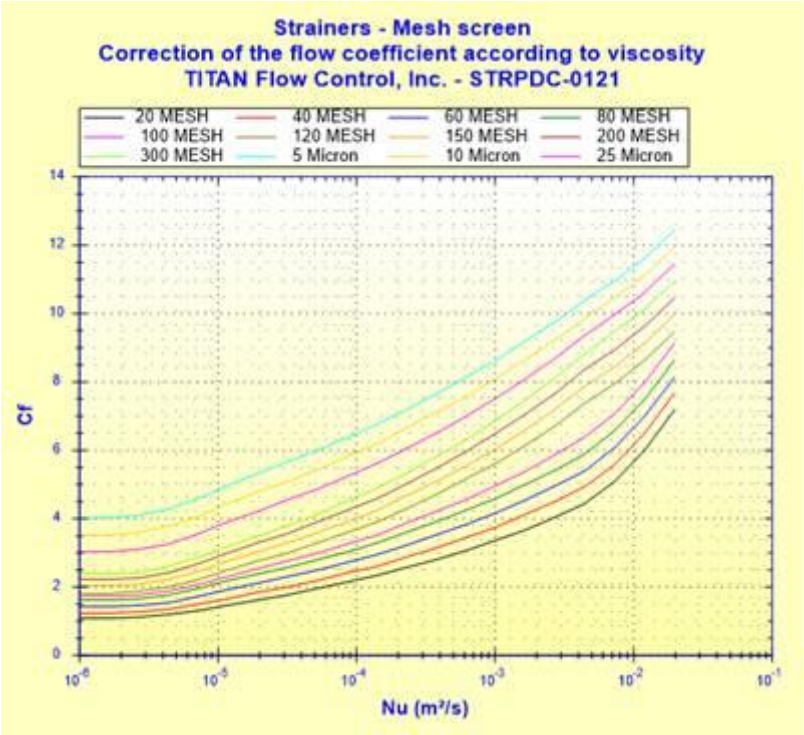
- Perforated screen

  $Cf = f(\nu)$ ([1])



■ Mesh screen

$$Cf = f(\nu, Mesh \text{ or Micron data})$$ ([1])



If this option is not activated, the factor Cf is equal to unity.

Total pressure loss coefficient (based on mean velocity in the pipe):

$$K = K_{turb} \cdot Cf$$ ([1])

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Corrected flow coefficient (in case of taking into account viscous fluid):

$$Kvc = \frac{Kv}{\sqrt{Cf}}$$

$$Cvc = \frac{Cv}{\sqrt{Cf}}$$

$$Avc = \frac{Av}{\sqrt{Cf}}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

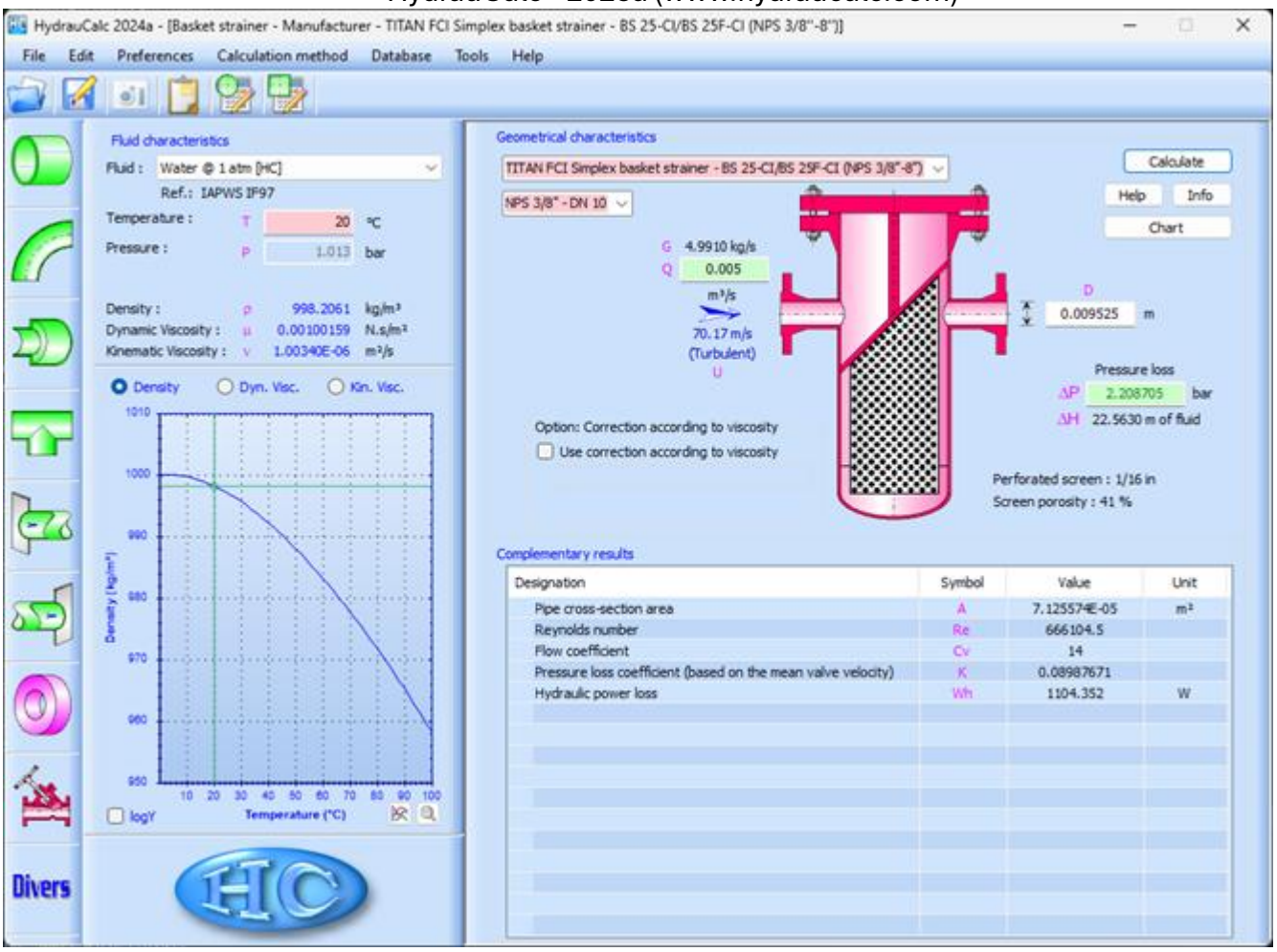
D	Internal diameter of the pipe (m)
A	Cross-sectional area of the pipe (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity in the pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in the pipe ()
Kv	Basic flow coefficient (m^3/h)
Cv	Basic flow coefficient (USG/min)

Av	Basic flow coefficient (m^2)
Cf	Correction factor according to viscosity ()
Kvc	Corrected flow coefficient (m^3/h)
Cvc	Corrected flow coefficient (USG/min)
Avc	Corrected flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- flow regime: turbulent and viscous fluid
- manufacturers specifications are given for clean filters

Example of application:



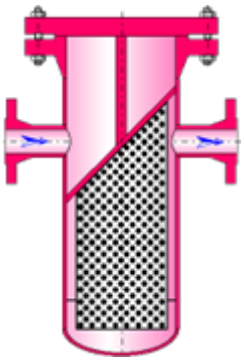
References:

[1] TITAN Flow Control, Inc. - STRPDC-0121

2.12.1.2 User

Basket strainer

(User defined)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a basket strainer.

The basket strainer specifications are defined by the user. The pressure drop of the basket strainer is characterized by a flow coefficient "Kv", "Cv" or "Av". A calculation option allows to take into account the influence of the viscosity of the fluid in the case of viscous fluid.

Model formulation:

Cross-sectional area of the pipe (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Average flow velocity in the pipe (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in the pipe:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Local resistance coefficient for turbulent flow:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv/36023\right)^2}$$

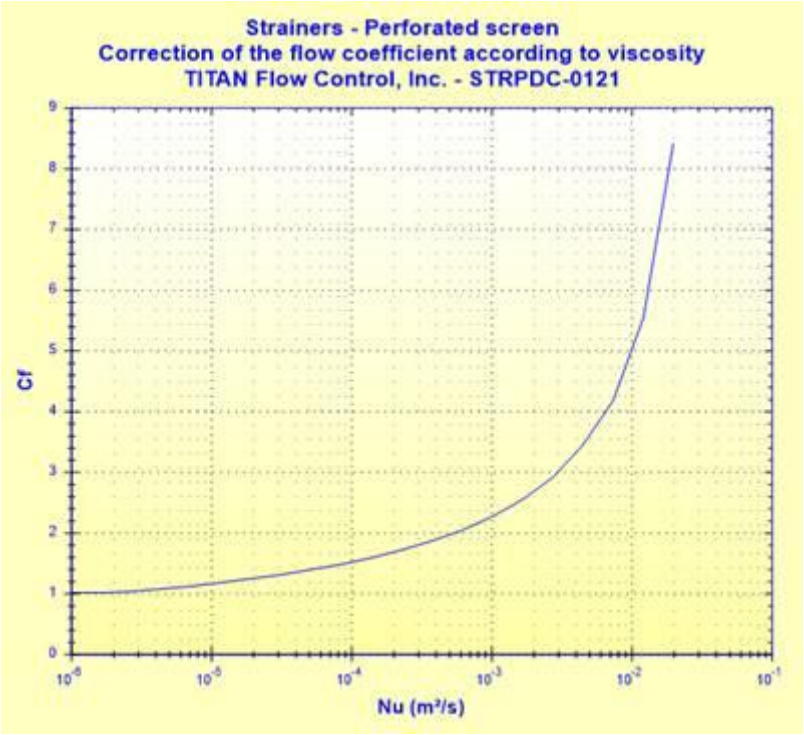
$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv/41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

Correction factor according to viscosity (optional):

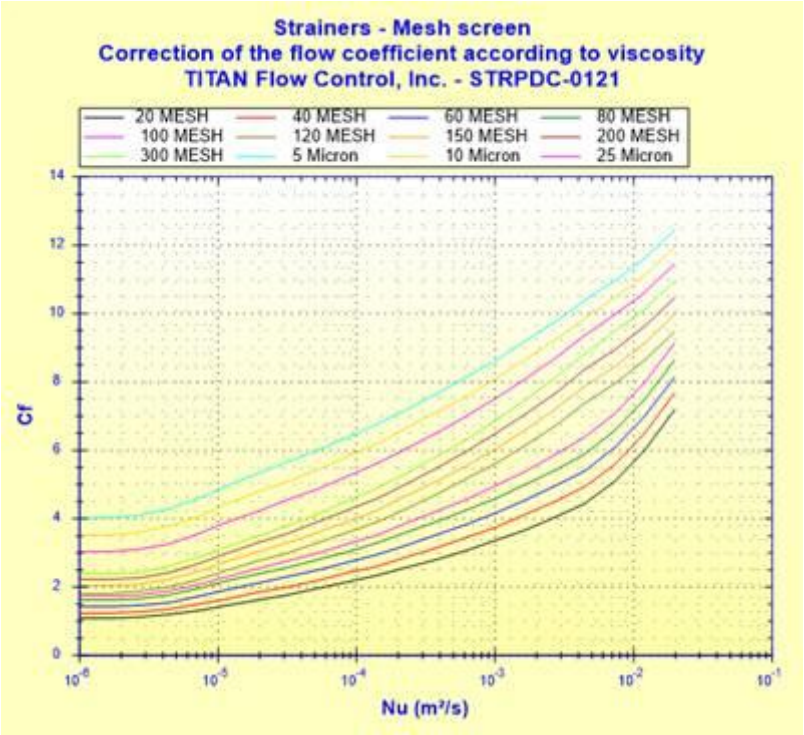
- Perforated screen

$$Cf = f(\nu)$$ ([1])



- Mesh screen

$$Cf = f(\nu, Mesh \text{ or Micron data})$$ ([1])



If this option is not activated, the factor Cf is equal to unity.

Total pressure loss coefficient (based on mean velocity in the pipe):

$$K = K_{turb} \cdot Cf$$ ([1])

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Corrected flow coefficient in case of taking into account viscous fluid):

$$Kvc = \frac{Kv}{\sqrt{Cf}}$$

$$Cvc = \frac{Cv}{\sqrt{Cf}}$$

$$Avc = \frac{Av}{\sqrt{Cf}}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

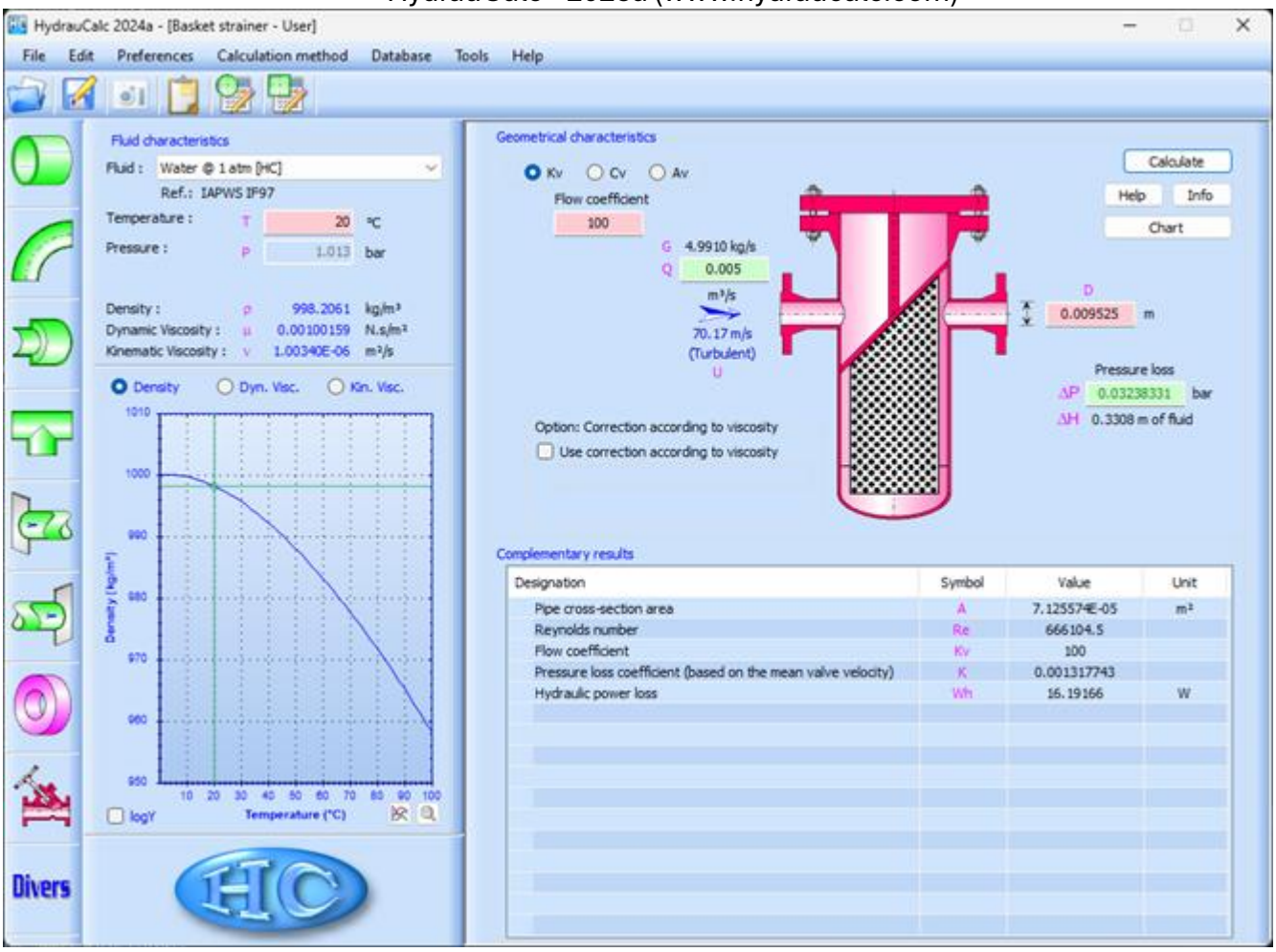
D	Internal diameter of the pipe (m)
A	Cross-sectional area of the pipe (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity in the pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in the pipe ()
Kv	Basic flow coefficient (m^3/h)
Cv	Basic flow coefficient (USG/min)

Av	Basic flow coefficient (m^2)
Cf	Correction factor according to viscosity ()
Kvc	Corrected flow coefficient (m^3/h)
Cvc	Corrected flow coefficient (USG/min)
Avc	Corrected flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- flow regime: turbulent and viscous fluid

Example of application:

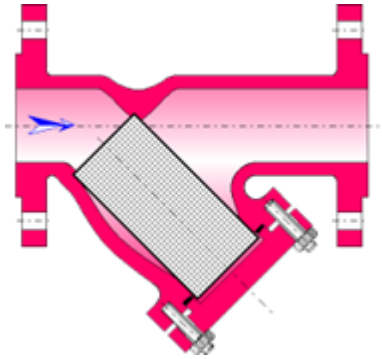


References:

[1] TITAN Flow Control, Inc. - STRPDC-0121

2.12.2 Y strainer

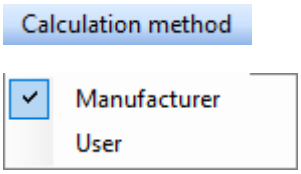
Y-Stainer



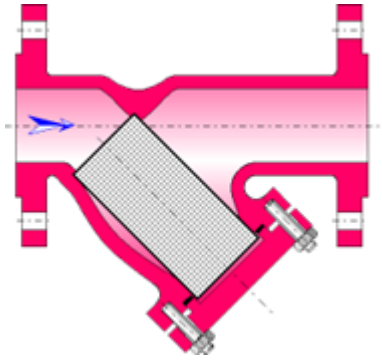
For the calculation of the pressure loss coefficient of Y-Stainer, the user can:

- choose from a list of Y-Stainer offered by manufacturers,
- define your own Y-Stainer.

The calculation method is selected using the "Calculation method" menu. The default option is "Manufacturer"



2.12.2.1 Manufacturer



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a Y strainer.

The Y strainer specifications are defined by strainers manufacturers. The pressure drop of the Y strainer is characterized by a flow coefficient "Kv", "Cv" or "Av". A calculation option allows to take into account the influence of the viscosity of the fluid in the case of viscous fluid.

Model formulation:

Cross-sectional area of the pipe (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Average flow velocity in the pipe (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in the pipe:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Local resistance coefficient for turbulent flow:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv/36023\right)^2}$$

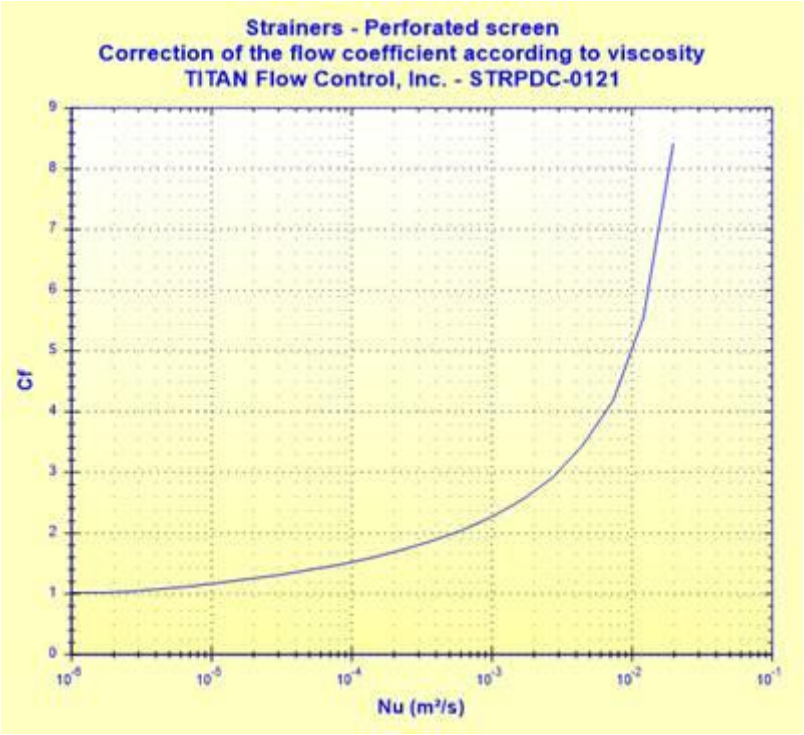
$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv/41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

Correction factor according to viscosity (optional):

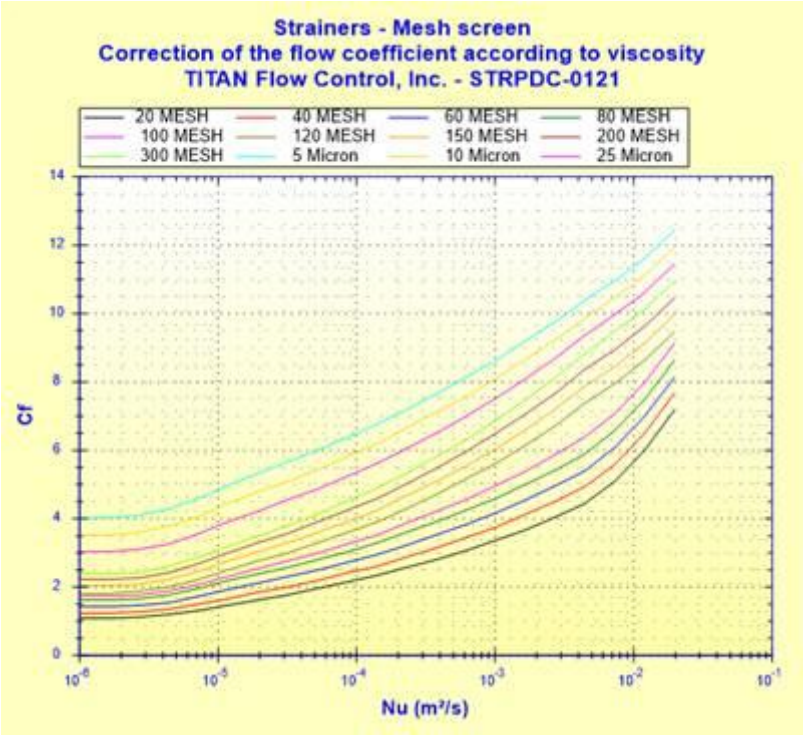
- Perforated screen

  $Cf = f(\nu)$ ([1])



■ Mesh screen

$$Cf = f(\nu, Mesh \text{ or Micron data})$$ ([1])



If this option is not activated, the factor Cf is equal to unity.

Total pressure loss coefficient (based on mean velocity in the pipe):

$$K = K_{turb} \cdot Cf$$ ([1])

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Corrected flow coefficient (in case of taking into account viscous fluid):

$$Kvc = \frac{Kv}{\sqrt{Cf}}$$

$$Cvc = \frac{Cv}{\sqrt{Cf}}$$

$$Avc = \frac{Av}{\sqrt{Cf}}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

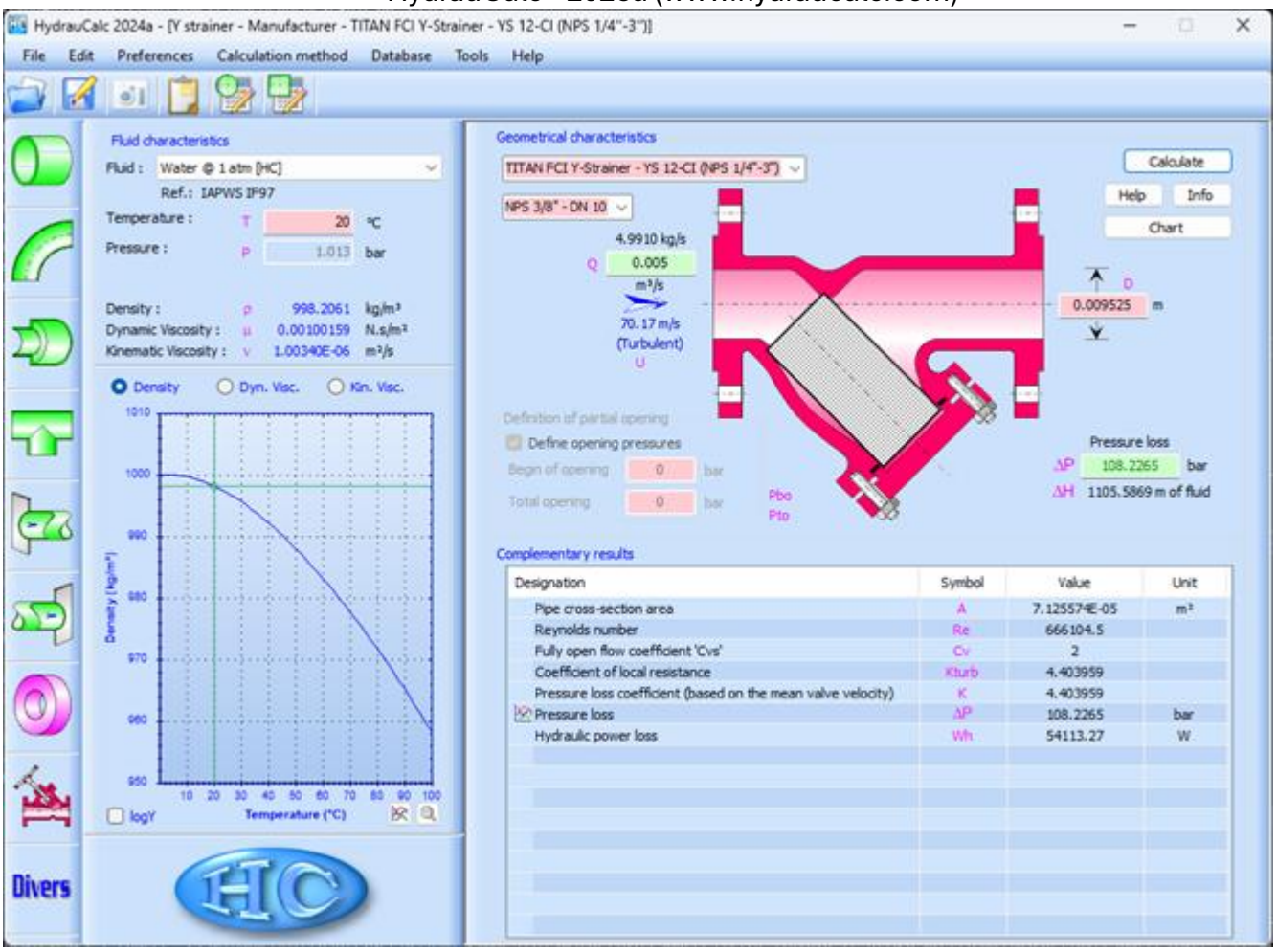
D	Internal diameter of the pipe (m)
A	Cross-sectional area of the pipe (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity in the pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in the pipe ()
Kv	Basic flow coefficient (m^3/h)
Cv	Basic flow coefficient (USG/min)

Av	Basic flow coefficient (m^2)
Cf	Correction factor according to viscosity ()
Kvc	Corrected flow coefficient (m^3/h)
Cvc	Corrected flow coefficient (USG/min)
Avc	Corrected flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- flow regime: turbulent and viscous fluid
- manufacturers specifications are given for clean filters

Example of application:



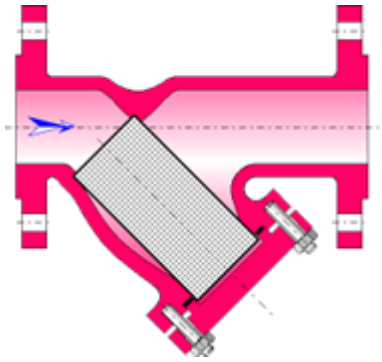
References:

[1] TITAN Flow Control, Inc. - STRPDC-0121

2.12.2.2 User

Y strainer

(User defined)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in an Y strainer.

The Y strainer specifications are defined by the user. The pressure drop of the Y strainer is characterized by a flow coefficient "Kv", "Cv" or "Av". A calculation option allows to take into account the influence of the viscosity of the fluid in the case of viscous fluid.

Model formulation:

Cross-sectional area of the pipe (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Average flow velocity in the pipe (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in the pipe:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Local resistance coefficient for turbulent flow:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv/36023\right)^2}$$

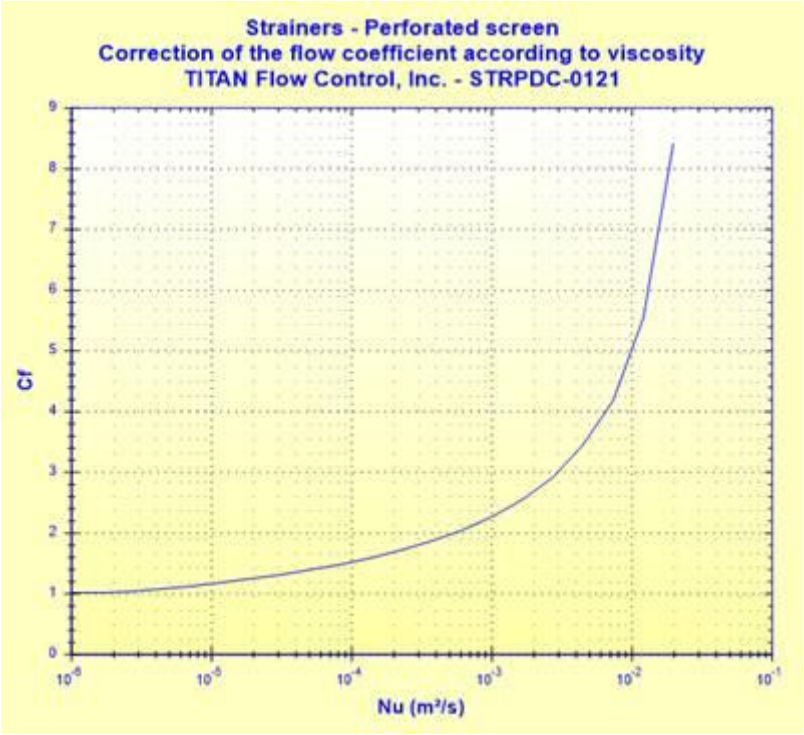
$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv/41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

Correction factor according to viscosity (optional):

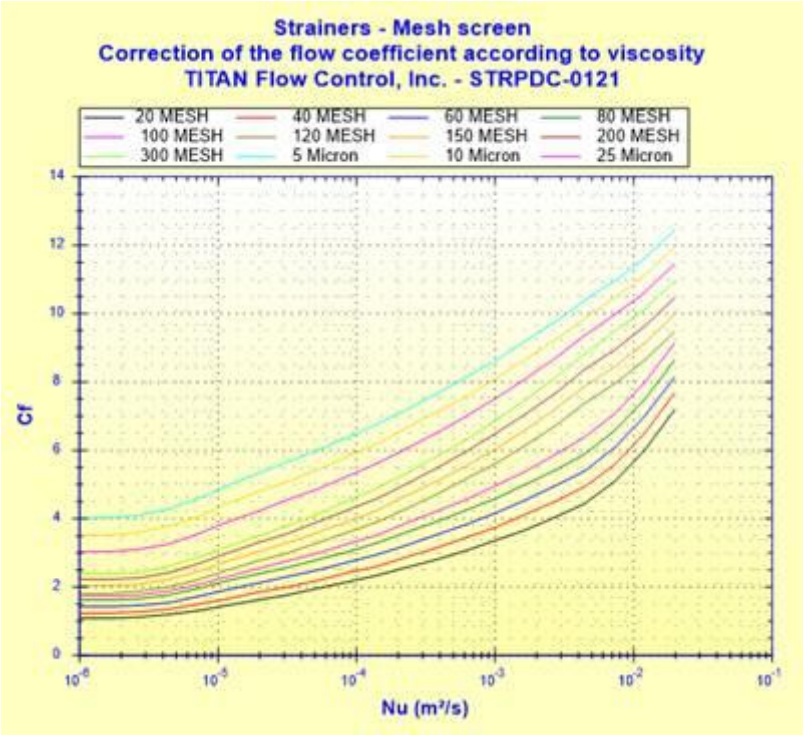
- Perforated screen

$$Cf = f(\nu)$$ ([1])



- Mesh screen

$$Cf = f(\nu, Mesh \text{ or Micron data})$$ ([1])



If this option is not activated, the factor Cf is equal to unity.

Total pressure loss coefficient (based on mean velocity in the pipe):

$$K = K_{turb} \cdot Cf$$ ([1])

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Corrected flow coefficient in case of taking into account viscous fluid):

$$Kvc = \frac{Kv}{\sqrt{Cf}}$$

$$Cvc = \frac{Cv}{\sqrt{Cf}}$$

$$Avc = \frac{Av}{\sqrt{Cf}}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

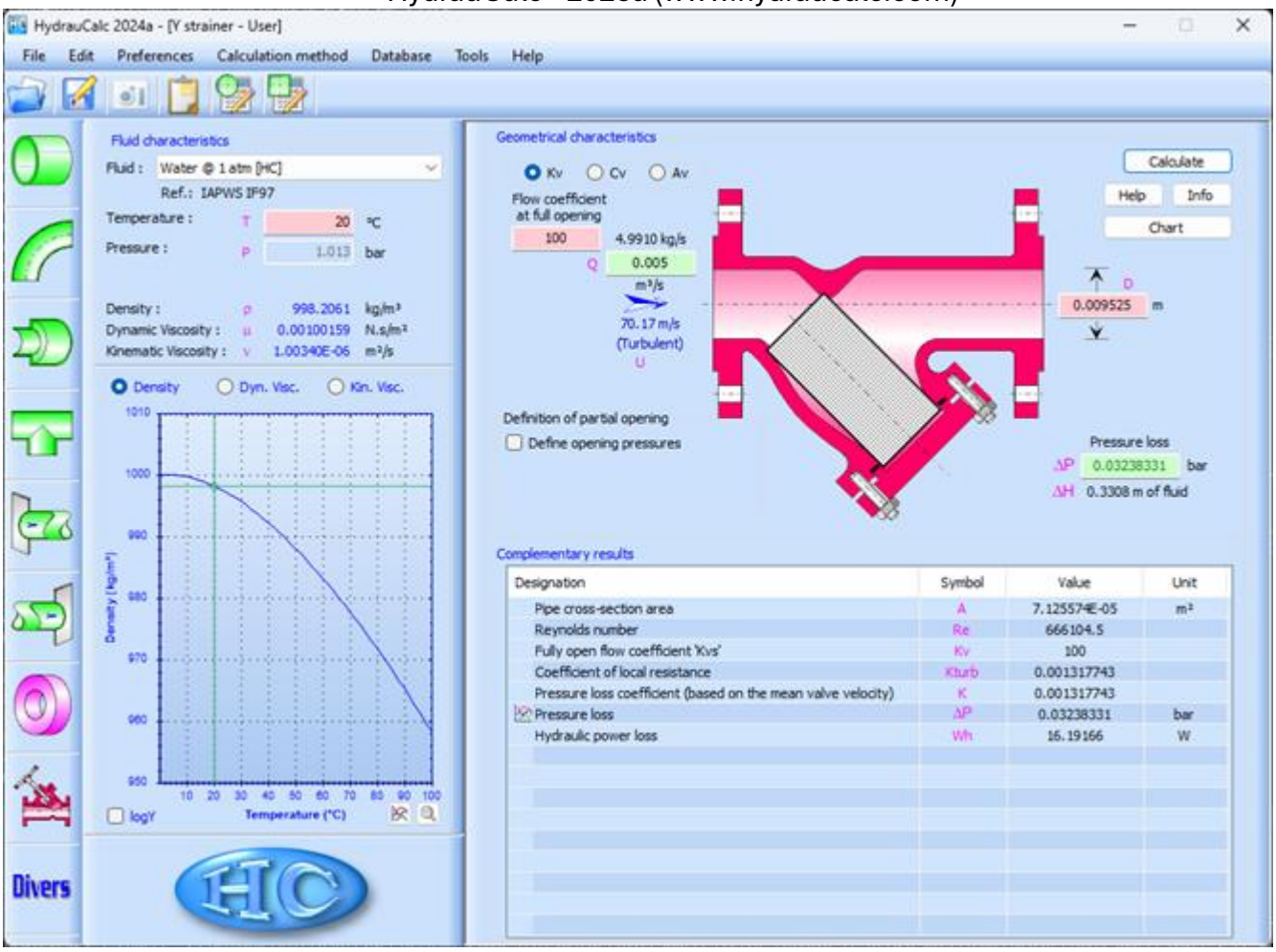
D	Internal diameter of the pipe (m)
A	Cross-sectional area of the pipe (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity in the pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in the pipe ()
Kv	Basic flow coefficient (m^3/h)
Cv	Basic flow coefficient (USG/min)

Av	Basic flow coefficient (m^2)
Cf	Correction factor according to viscosity ()
Kvc	Corrected flow coefficient (m^3/h)
Cvc	Corrected flow coefficient (USG/min)
Avc	Corrected flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- flow regime: turbulent and viscous fluid

Example of application:

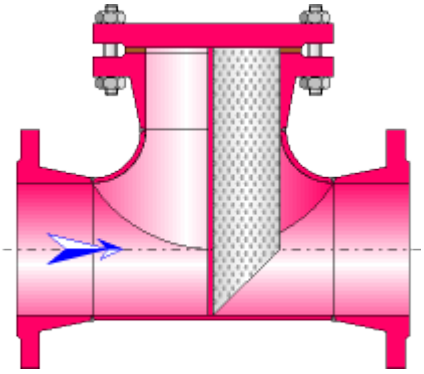


References:

[1] TITAN Flow Control, Inc. - STRPDC-0121

2.12.3 T strainer

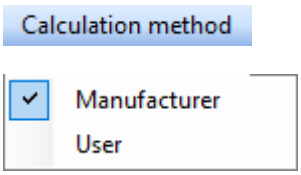
T-Stainer



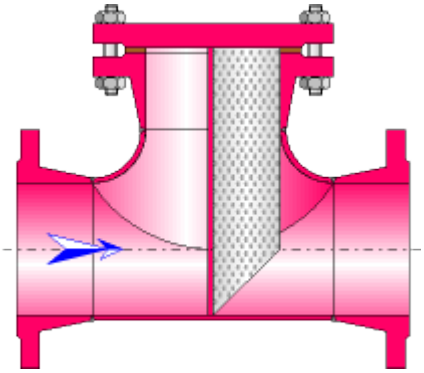
For the calculation of the pressure loss coefficient of T-Stainer, the user can:

- choose from a list of T-Stainer offered by manufacturers,
- define your own T-Stainer.

The calculation method is selected using the "Calculation method" menu. The default option is "Manufacturer"



2.12.3.1 Manufacturer



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a T strainer.

The T strainer specifications are defined by strainers manufacturers. The pressure drop of the T strainer is characterized by a flow coefficient "Kv", "Cv" or "Av". A calculation option allows to take into account the influence of the viscosity of the fluid in the case of viscous fluid.

Model formulation:

Cross-sectional area of the pipe (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Average flow velocity in the pipe (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in the pipe:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Local resistance coefficient for turbulent flow:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv/36023\right)^2}$$

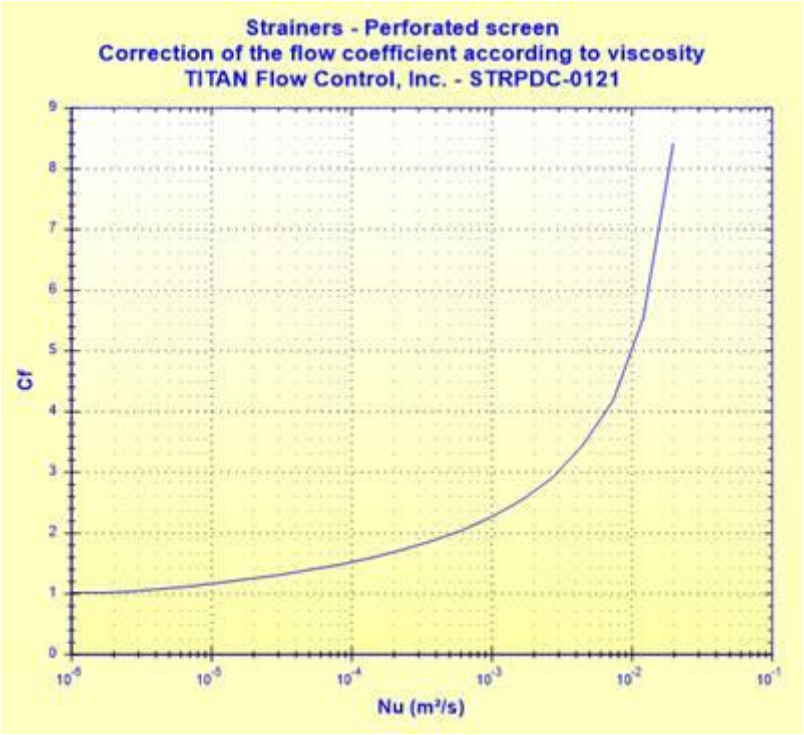
$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv/41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

Correction factor according to viscosity (optional):

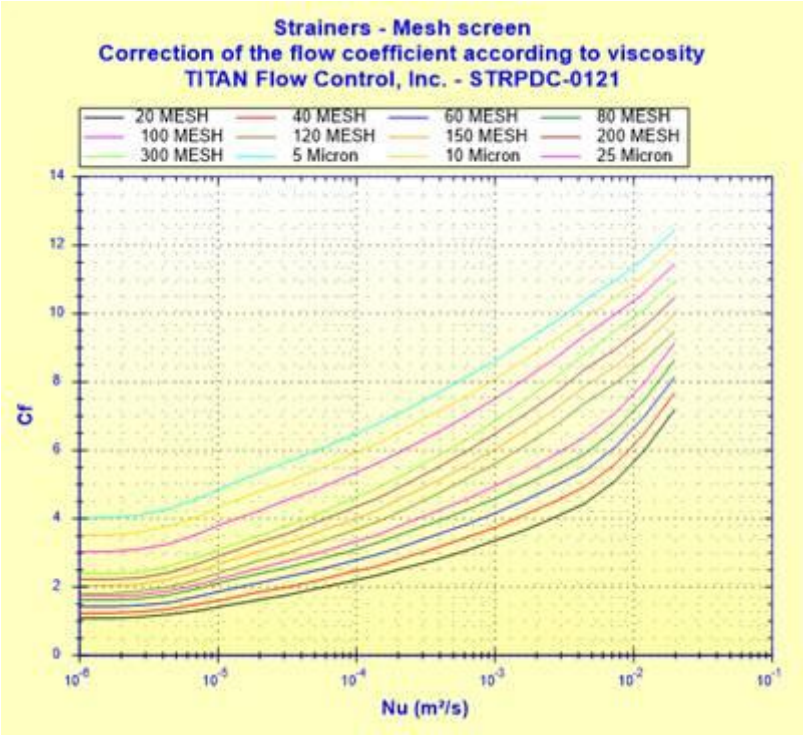
- Perforated screen

  $Cf = f(\nu)$ ([1])



- Mesh screen

$$Cf = f(\nu, Mesh \text{ or Micron data})$$ ([1])



If this option is not activated, the factor Cf is equal to unity.

Total pressure loss coefficient (based on mean velocity in the pipe):

$$K = K_{turb} \cdot Cf$$ ([1])

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Corrected flow coefficient (in case of taking into account viscous fluid):

$$Kvc = \frac{Kv}{\sqrt{Cf}}$$

$$Cvc = \frac{Cv}{\sqrt{Cf}}$$

$$Avc = \frac{Av}{\sqrt{Cf}}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

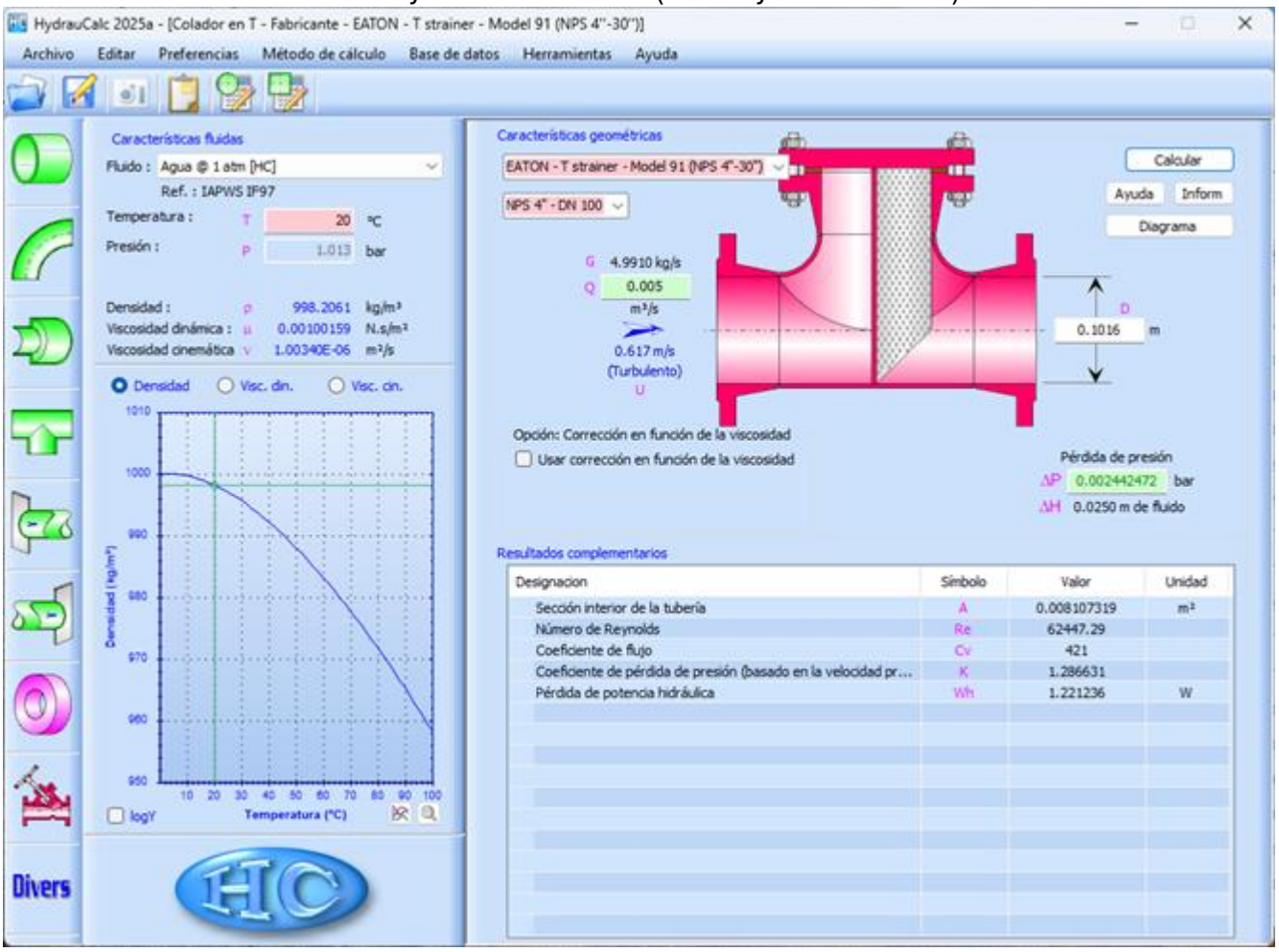
D	Internal diameter of the pipe (m)
A	Cross-sectional area of the pipe (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity in the pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in the pipe ()
Kv	Basic flow coefficient (m^3/h)
Cv	Basic flow coefficient (USG/min)

Av	Basic flow coefficient (m^2)
Cf	Correction factor according to viscosity ()
Kvc	Corrected flow coefficient (m^3/h)
Cvc	Corrected flow coefficient (USG/min)
Avc	Corrected flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- flow regime: turbulent and viscous fluid
- manufacturers specifications are given for clean filters

Example of application:



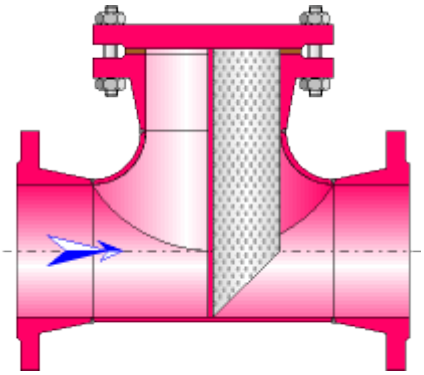
References:

[1] TITAN Flow Control, Inc. - STRPDC-0121

2.12.3.2 User

T strainer

(User defined)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in an T strainer.

The T strainer specifications are defined by the user. The pressure drop of the T strainer is characterized by a flow coefficient "Kv", "Cv" or "Av". A calculation option allows to take into account the influence of the viscosity of the fluid in the case of viscous fluid.

Model formulation:

Cross-sectional area of the pipe (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Average flow velocity in the pipe (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in the pipe:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Local resistance coefficient for turbulent flow:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv/36023\right)^2}$$

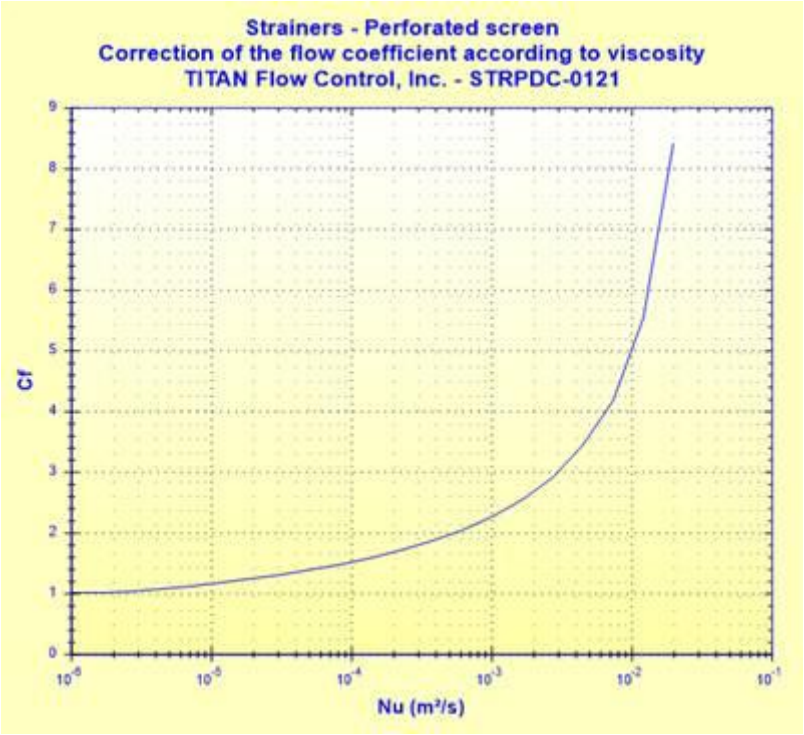
$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv/41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

Correction factor according to viscosity (optional):

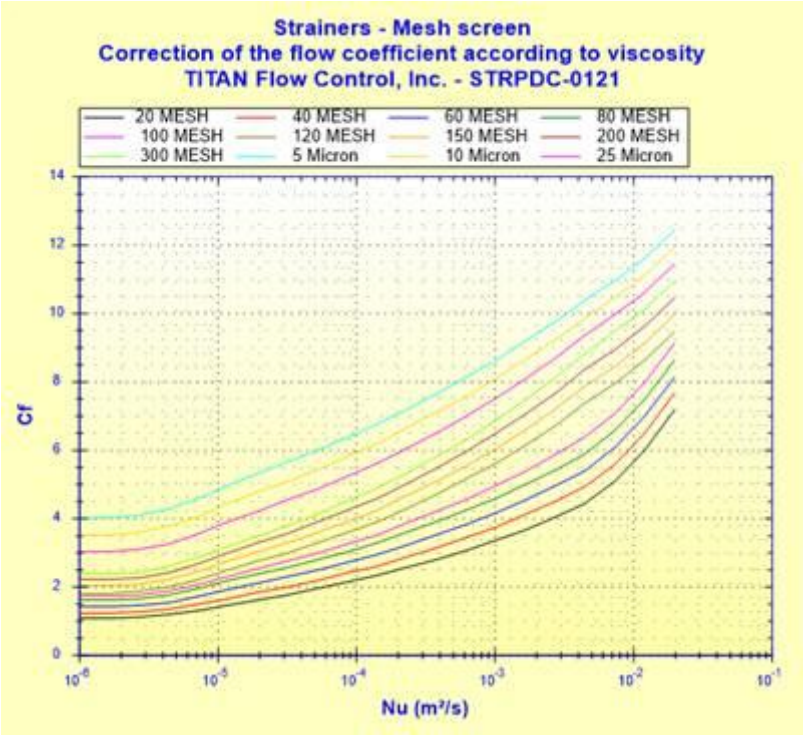
- Perforated screen

$$Cf = f(\nu)$$ ([1])



■ Mesh screen

$Cf = f(\nu, Mesh \text{ or Micron data})$ ([1])



If this option is not activated, the factor Cf is equal to unity.

Total pressure loss coefficient (based on mean velocity in the pipe):

$$K = K_{turb} \cdot Cf$$ ([1])

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Corrected flow coefficient in case of taking into account viscous fluid):

$$Kvc = \frac{Kv}{\sqrt{Cf}}$$

$$Cvc = \frac{Cv}{\sqrt{Cf}}$$

$$Avc = \frac{Av}{\sqrt{Cf}}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

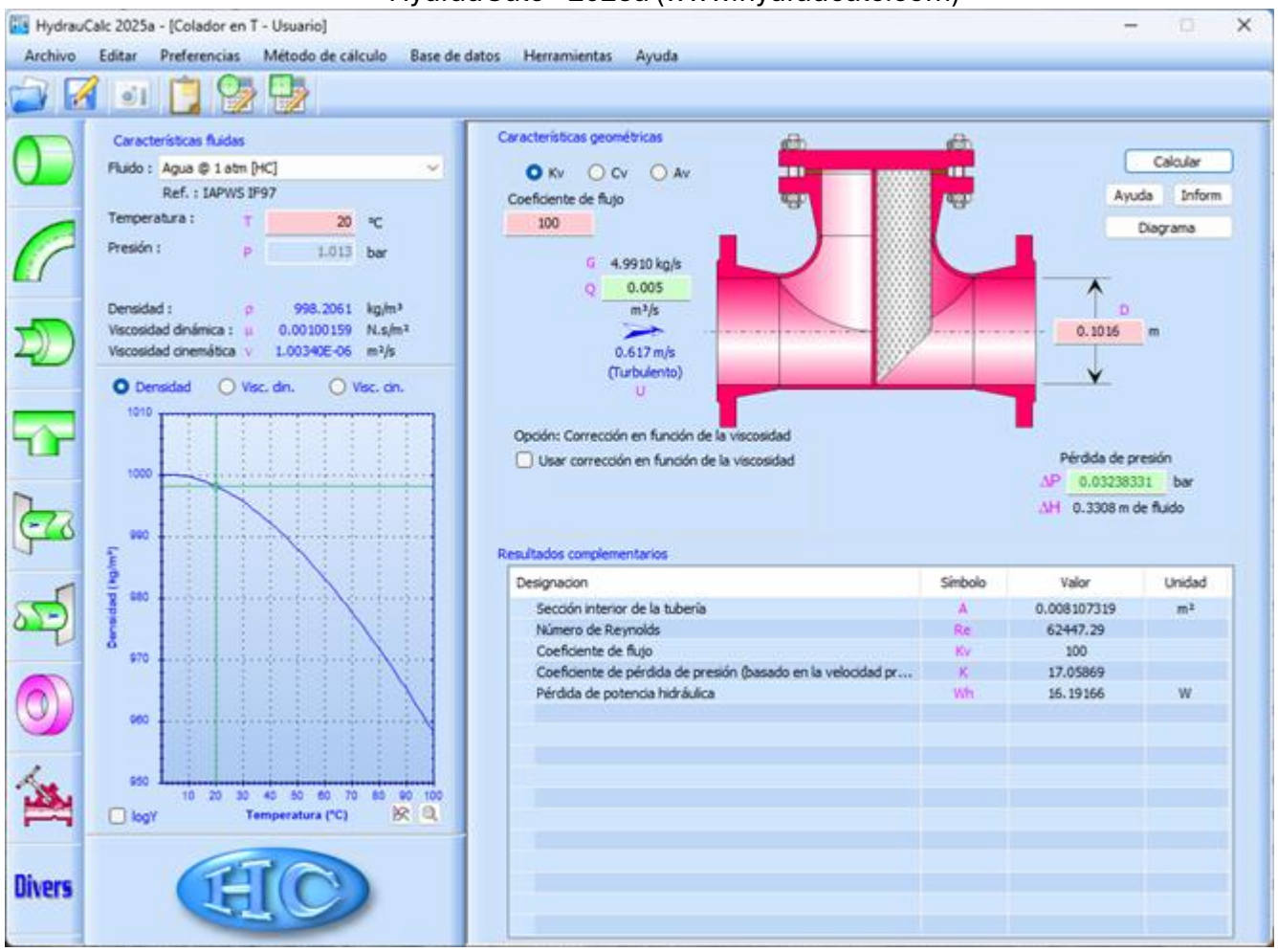
D	Internal diameter of the pipe (m)
A	Cross-sectional area of the pipe (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity in the pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in the pipe ()
Kv	Basic flow coefficient (m^3/h)
Cv	Basic flow coefficient (USG/min)

Av	Basic flow coefficient (m^2)
Cf	Correction factor according to viscosity ()
Kvc	Corrected flow coefficient (m^3/h)
Cvc	Corrected flow coefficient (USG/min)
Avc	Corrected flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- flow regime: turbulent and viscous fluid

Example of application:

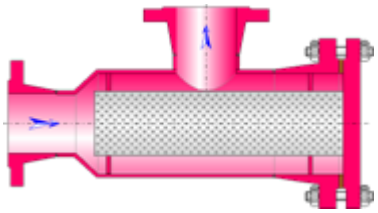


References:

[1] TITAN Flow Control, Inc. - STRPDC-0121

2.12.4 90° Elbow strainer

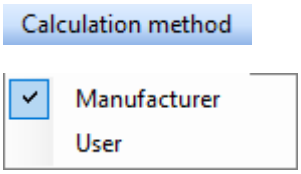
90° Elbow -Stainer



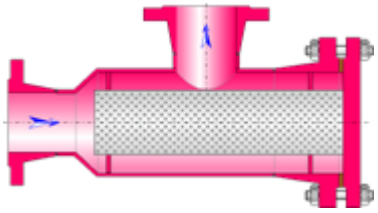
For the calculation of the pressure loss coefficient of 90° elbow -Stainer, the user can:

- choose from a list of 90° elbow -Stainer offered by manufacturers,
- define your own 90° elbow -Stainer.

The calculation method is selected using the "Calculation method" menu. The default option is "Manufacturer"



2.12.4.1 Manufacturer



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a 90° elbow strainer.

The 90° elbow strainer specifications are defined by strainers manufacturers. The pressure drop of the 90° elbow strainer is characterized by a flow coefficient "Kv", "Cv" or "Av". A calculation option allows to take into account the influence of the viscosity of the fluid in the case of viscous fluid.

Model formulation:

Cross-sectional area of the pipe (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Average flow velocity in the pipe (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in the pipe:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Local resistance coefficient for turbulent flow:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv/36023\right)^2}$$

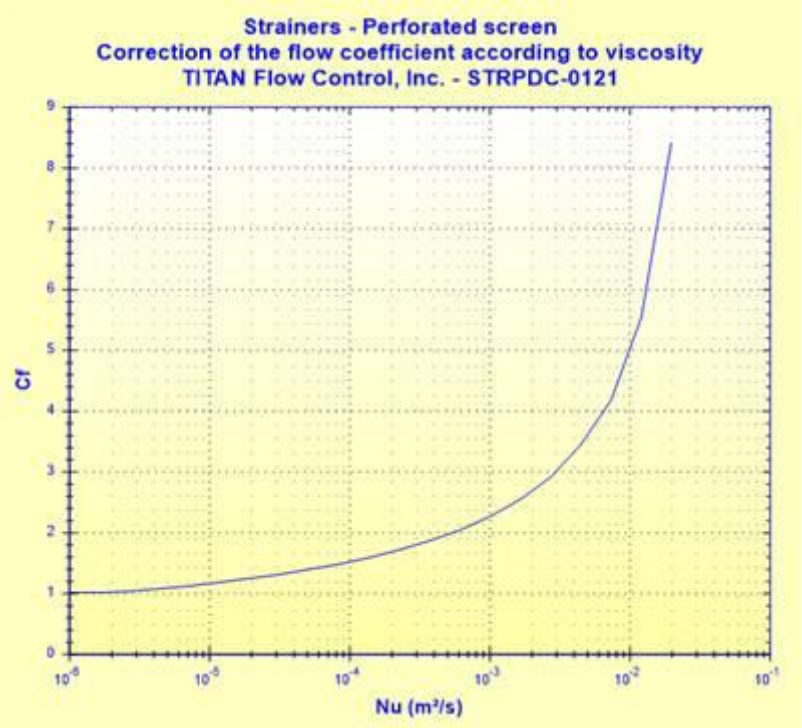
$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv/41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

Correction factor according to viscosity (optional):

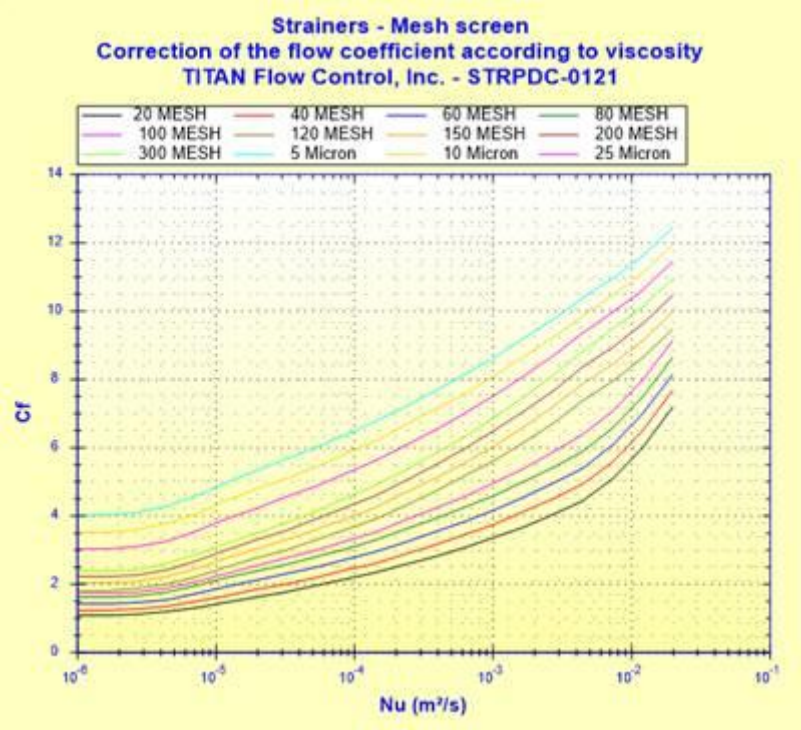
- Perforated screen

$$Cf = f(\nu)$$ ([1])



■ Mesh screen

$$Cf = f(\nu, Mesh \text{ or Micron data})$$ ([1])



If this option is not activated, the factor Cf is equal to unity.

Total pressure loss coefficient (based on mean velocity in the pipe):

$$K = K_{turb} \cdot Cf$$ ([1])

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Corrected flow coefficient (in case of taking into account viscous fluid):

$$Kvc = \frac{Kv}{\sqrt{Cf}}$$

$$Cvc = \frac{Cv}{\sqrt{Cf}}$$

$$Avc = \frac{Av}{\sqrt{Cf}}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Internal diameter of the pipe (m)
A	Cross-sectional area of the pipe (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity in the pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in the pipe ()
Kv	Basic flow coefficient (m^3/h)
Cv	Basic flow coefficient (USG/min)
Av	Basic flow coefficient (m^2)
Cf	Correction factor according to viscosity ()
Kvc	Corrected flow coefficient (m^3/h)
Cvc	Corrected flow coefficient (USG/min)
Avc	Corrected flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)

ρ Fluid density (kg/m³)

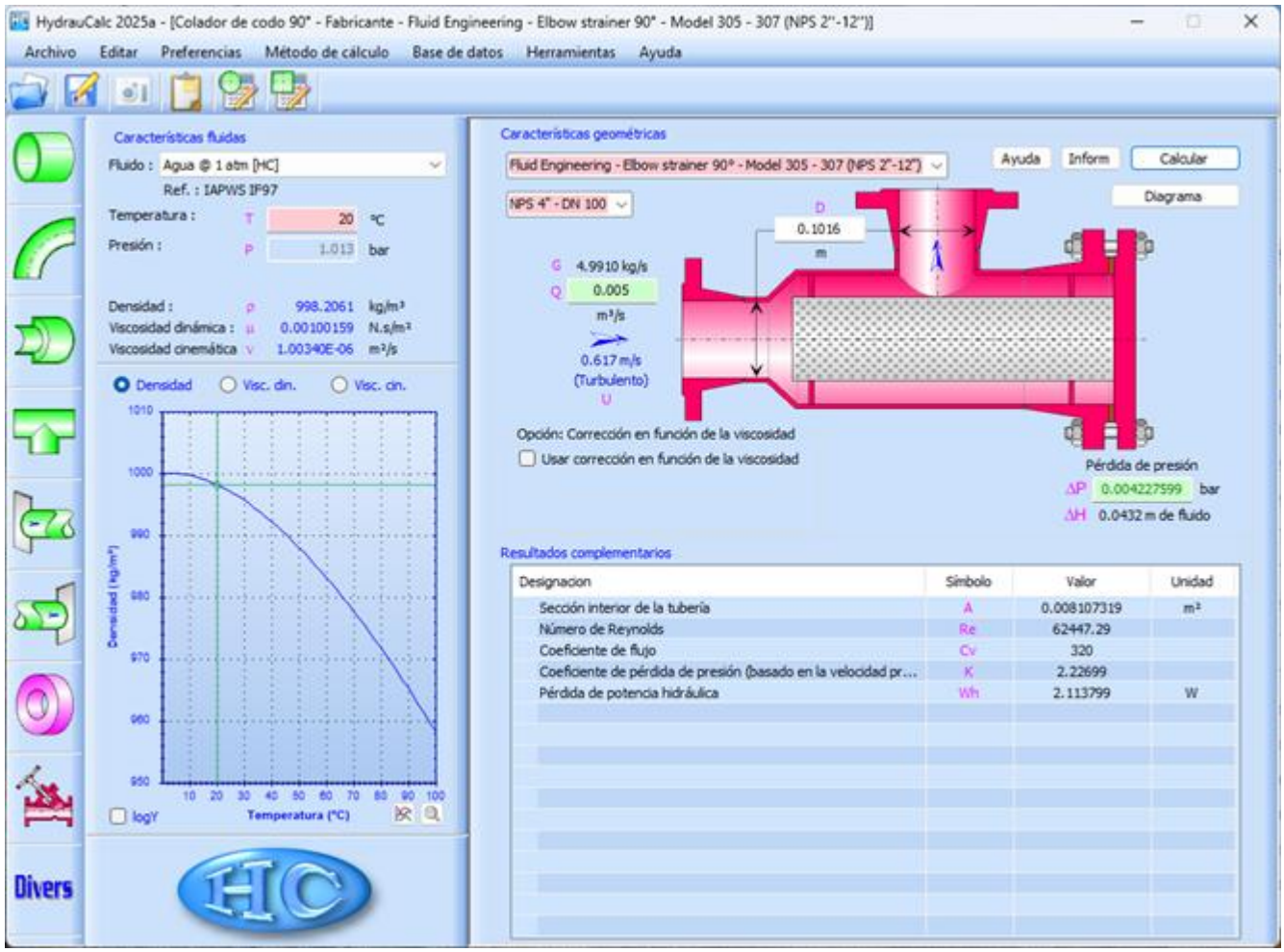
ν Fluid kinematic viscosity (m²/s)

g Gravitational acceleration (m/s²)

Validity range:

- flow regime: turbulent and viscous fluid
- manufacturers specifications are given for clean filters

Example of application:



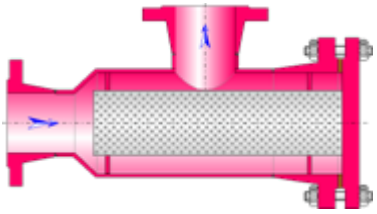
References:

[1] TITAN Flow Control, Inc. - STRPDC-0121

2.12.4.2 User

90° Elbow Strainer

(User defined)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in an 90° elbow strainer.

The 90° elbow strainer specifications are defined by the user. The pressure drop of the 90° elbow strainer is characterized by a flow coefficient "Kv", "Cv" or "Av". A calculation option allows to take into account the influence of the viscosity of the fluid in the case of viscous fluid.

Model formulation:

Cross-sectional area of the pipe (m^2):

$$A = \pi \cdot \frac{D^2}{4}$$

Average flow velocity in the pipe (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Reynolds number in the pipe:

$$\mathrm{Re} = \frac{U \cdot D}{\nu}$$

Local resistance coefficient for turbulent flow:

$$K_{turb} = \frac{2 \cdot A^2}{\left(Kv/36023\right)^2}$$

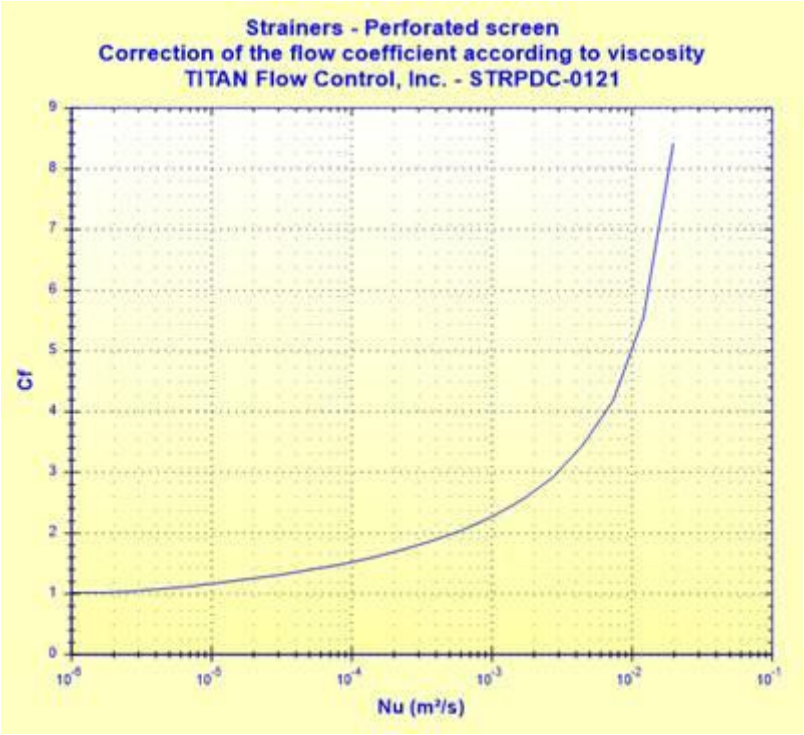
$$K_{turb} = \frac{2 \cdot A^2}{\left(Cv/41650\right)^2}$$

$$K_{turb} = \frac{2 \cdot A^2}{Av^2}$$

Correction factor according to viscosity (optional):

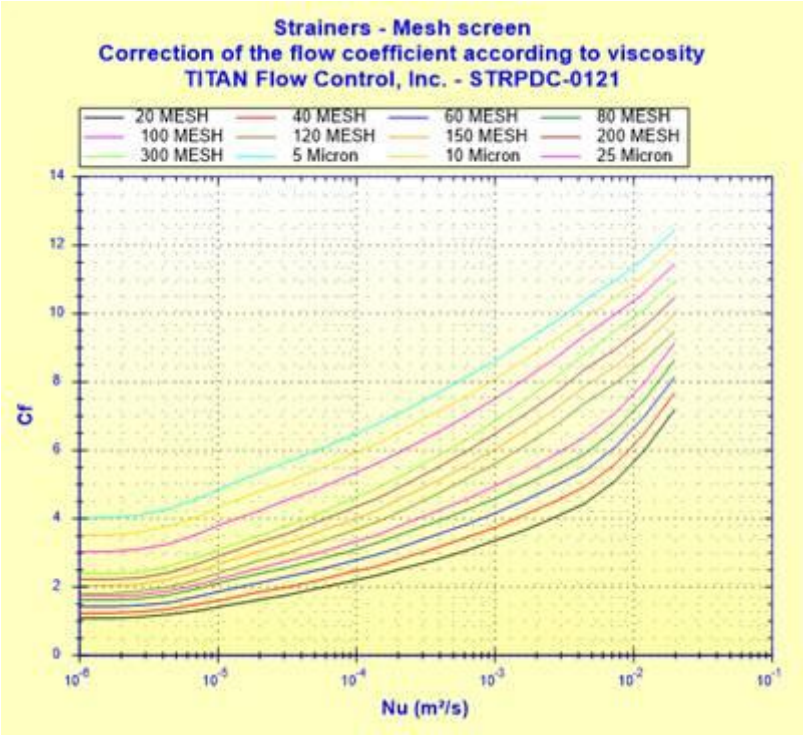
- Perforated screen

  $Cf = f(\nu)$ ([1])



■ Mesh screen

$Cf = f(\nu, Mesh \text{ or Micron data})$ ([1])



If this option is not activated, the factor Cf is equal to unity.

Total pressure loss coefficient (based on mean velocity in the pipe):

$$K = K_{turb} \cdot Cf$$ ([1])

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

Corrected flow coefficient in case of taking into account viscous fluid):

$$Kvc = \frac{Kv}{\sqrt{Cf}}$$

$$Cvc = \frac{Cv}{\sqrt{Cf}}$$

$$Avc = \frac{Av}{\sqrt{Cf}}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

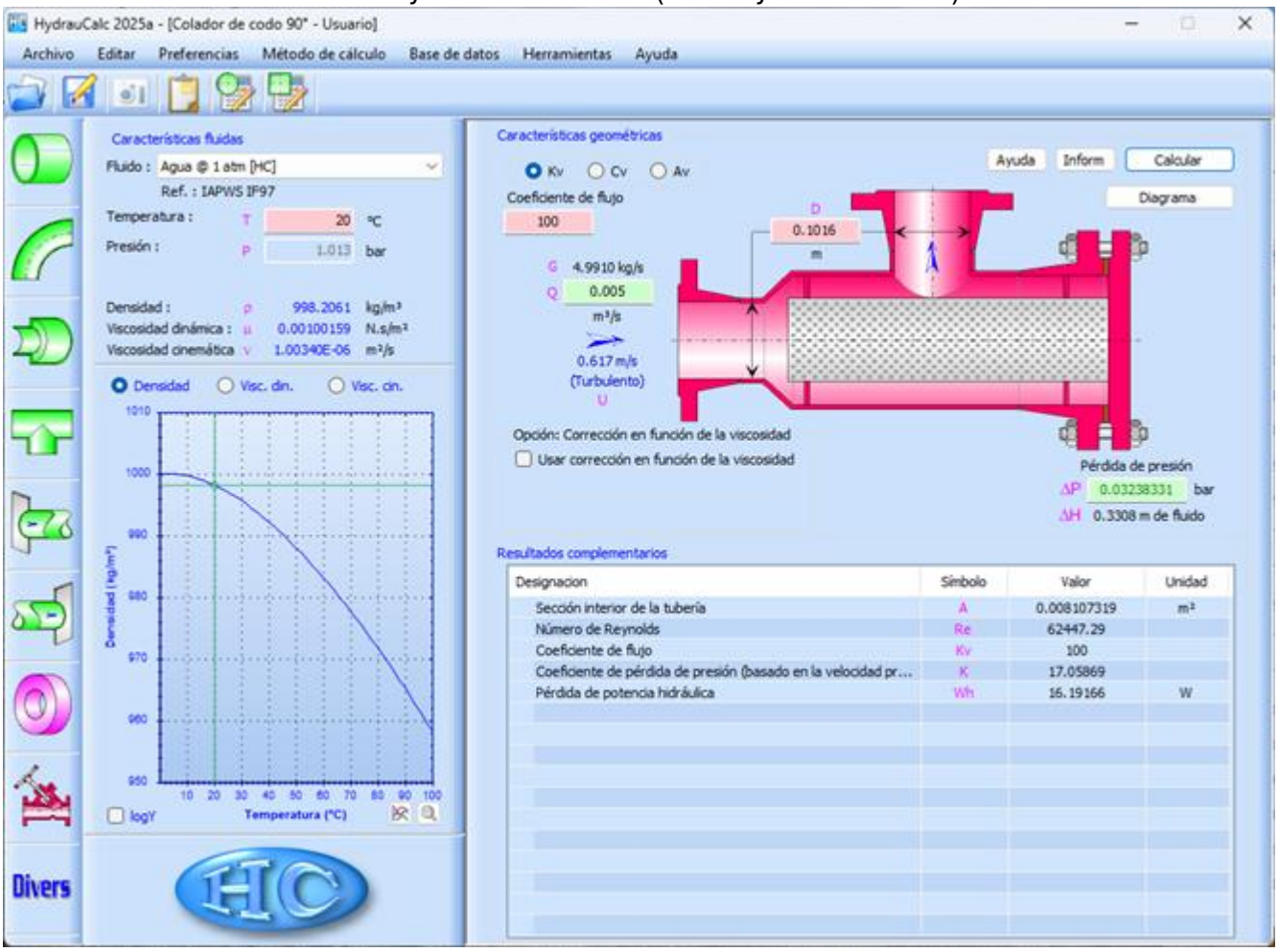
D	Internal diameter of the pipe (m)
A	Cross-sectional area of the pipe (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity in the pipe (m/s)
G	Mass flow rate (kg/s)
Re	Reynolds number in the pipe ()
Kv	Basic flow coefficient (m^3/h)
Cv	Basic flow coefficient (USG/min)

Av	Basic flow coefficient (m^2)
Cf	Correction factor according to viscosity ()
Kvc	Corrected flow coefficient (m^3/h)
Cvc	Corrected flow coefficient (USG/min)
Avc	Corrected flow coefficient (m^2)
K_{turb}	Local resistance coefficient for $Re \geq 10^4$ ()
K	Total pressure loss coefficient (based on mean velocity) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- flow regime: turbulent and viscous fluid

Example of application:



References:

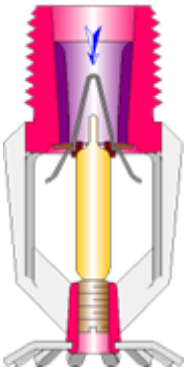
[1] TITAN Flow Control, Inc. - STRPDC-0121

2.13 Sprinklers

This subsection presents the type of sprinkler that can be modeled and calculated.:

- Fire sprinkler

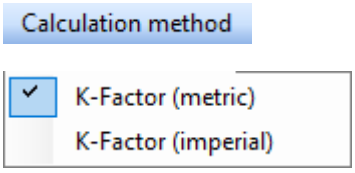
2.13.1 Fire sprinkler



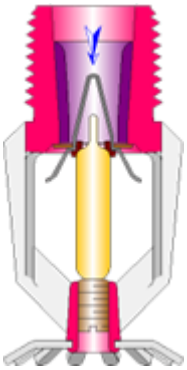
The calculation method used to calculate the pressure loss of a fire sprinkler is described in the following reference document:

- NFPA 13 Standard for the Installation of Sprinkler Systems 2022 Edition

Two calculation methods are proposed. The calculation method is selected using the "Calculation method" menu. The default option is " K-Factor (metric)".



2.13.1.1 K-Factor (metric)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a fire sprinkler defined in a metric unit system.

Model formulation:

Entrance cross-sectional area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity in entrance (m/s):

$$V = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

$$Re = \frac{V \cdot d}{\nu}$$

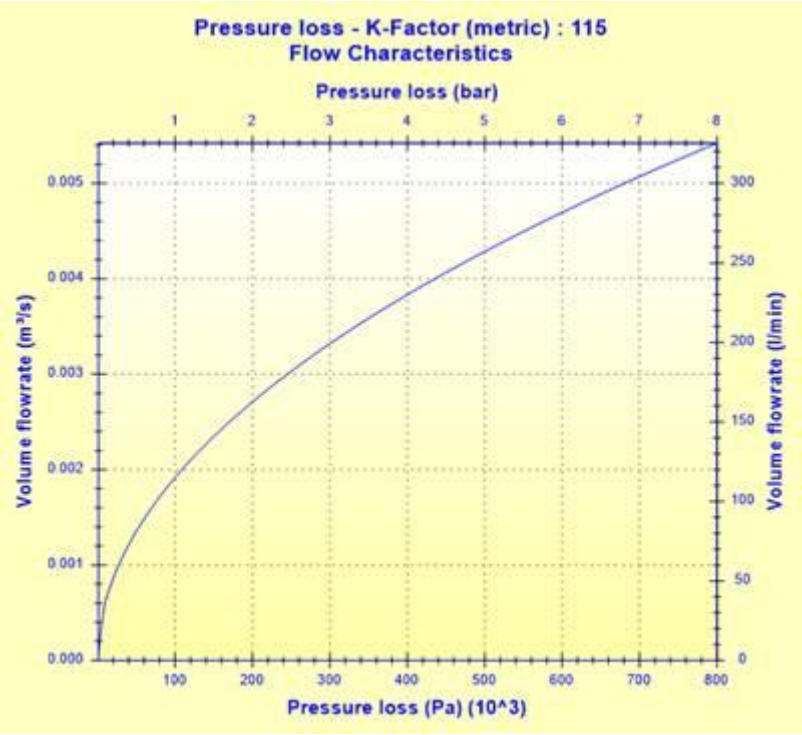
Pressure loss (metric units):

$$\Delta P\ [bar] = \frac{Q\ [l/min]}{K_f\ [metric]^2}$$

Pressure loss (S.I. units):

$$\Delta P\ [Pa] = \frac{Q\ [m^3/s] \,/\, 60000}{K_f\ [metric]^2} \cdot 100000$$

Example of the evolution of pressure loss as a function of volume flow:



with K-Factor metric = 115

Value of nominal K-Factors:

Nominal K-Factor gpm/(psi)$^{1/2}$	Nominal K-Factor l/min/(bar)$^{1/2}$	K-Factor Range gpm/(psi)$^{1/2}$	K-Factor Range l/min/(bar)$^{1/2}$
1.4	20	1.3-1.5	19-22
1.9	27	1.8-2.0	26-29
2.8	40	2.6-2.9	38-42
4.2	60	4.0-4.4	57-63
5.6	80	5.3-5.8	76-84
8.0	115	7.4-8.2	107-118
11.2	160	10.7-11.7	159-166
14.0	200	13.5-14.5	195-209
16.8	240	16.0-17.6	231-254
19.6	280	18.6-20.6	272-301
22.4	320	21.3-23.5	311-343
25.2	360	23.9-26.5	349-387
28.0	400	26.6-29.4	389-430
33.6	480	31.9-35.3	456-504

([1] Table 7.2.2.1 Sprinkler Discharge Characteristics Identification)

Nominal orifice size :

Nominal K-Factor		Nominal Orifice Size	
gpm/(psi)$^{1/2}$	l/min/(bar)$^{1/2}$	in	mm
1.4	20	1/4"	6.4
1.9	27	5/16"	8
2.8	40	3/8"	9.5
4.2	60	7/16"	11
5.6	80	1/2"	12.7
8.0	115	17/32"	13.5
11.2	160	5/8"	15.9
14.0	200	3/4"	19
16.8	240	-	-
19.6	280	-	-
22.4	320	-	-
25.2	360	-	-
28.0	400	-	-
33.6	480	-	-

([1] Table A.7.2.2.1 Nominal Sprinkler Orifice Sizes)

Pressure loss coefficient (based on mean velocity in pipe):

$$K = \frac{2 \cdot \Delta P}{\rho_m \cdot V^2}$$

Head loss of fluid:

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss:

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

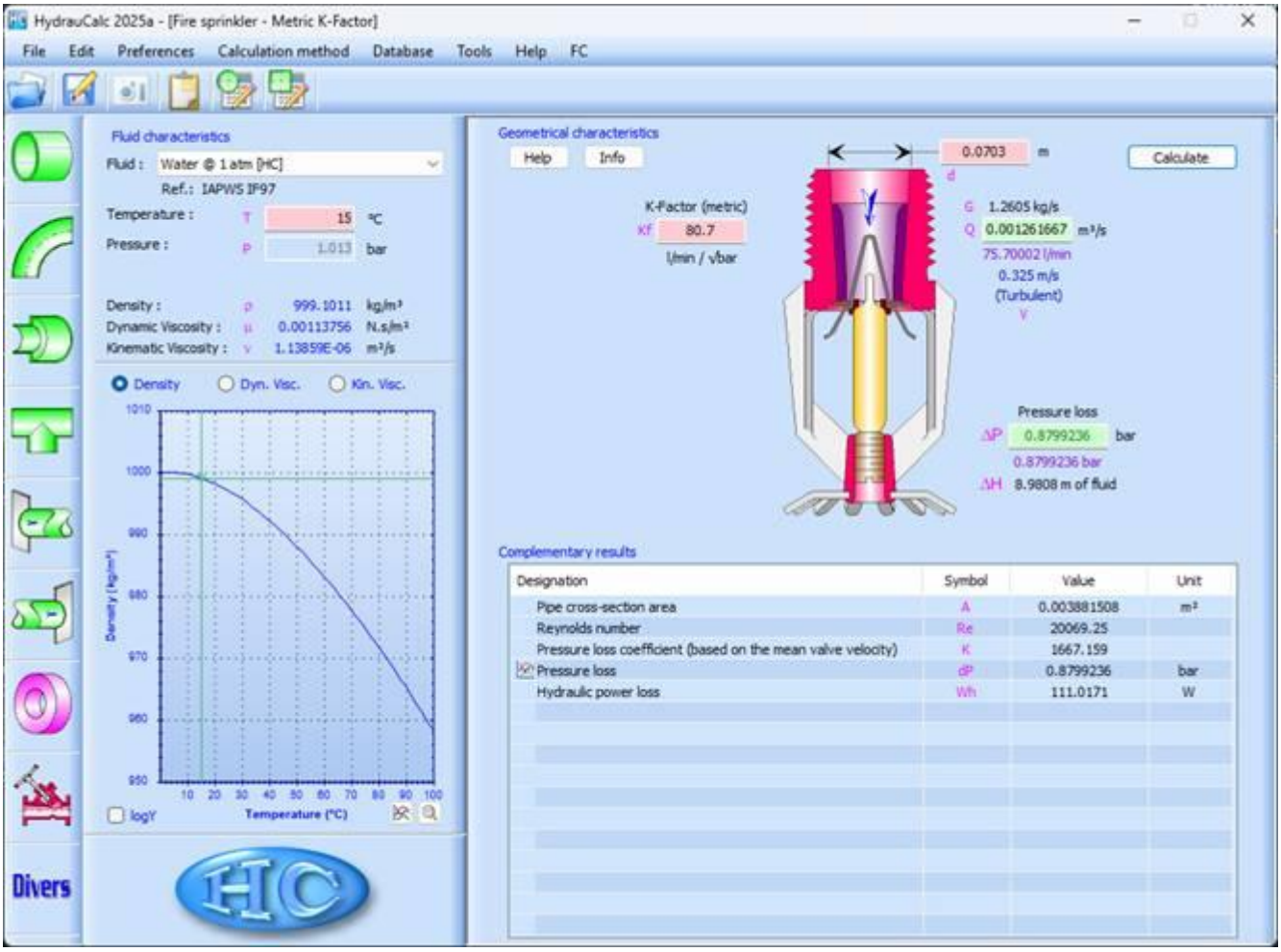
d	Entrance diameter (m)
A	Entrance cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V	Mean velocity in entrance (m/s)
Re	Reynolds number in entrance ()
K_f	Sprinkler K-factor (l/min / √bar)
K	Pressure loss coefficient (based on mean velocity in entrance) ()
ΔP	Pressure loss (Pa)
ΔH	Head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in the entrance of the sprinkler ($Re \geq 10^4$)
- valid only for fresh water close to 15 ° C with a kinematic viscosity of approximately $1.13 \cdot 10^{-6}$ m²/s

---

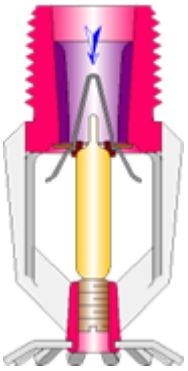
Example of application:



References:

[1] NFPA 13 Standard for the Installation of Sprinkler Systems 2022 Edition

2.13.1.2 K-Factor (imperial)



Model description:

This model of component calculates the minor head loss (pressure drop) generated by the flow in a fire sprinkler defined in an imperial unit system.

Model formulation:

Entrance cross-sectional area (m^2):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity in entrance (m/s):

$$V = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Reynolds number in pipe:

$$\mathrm{Re} = \frac{V \cdot d}{\nu}$$

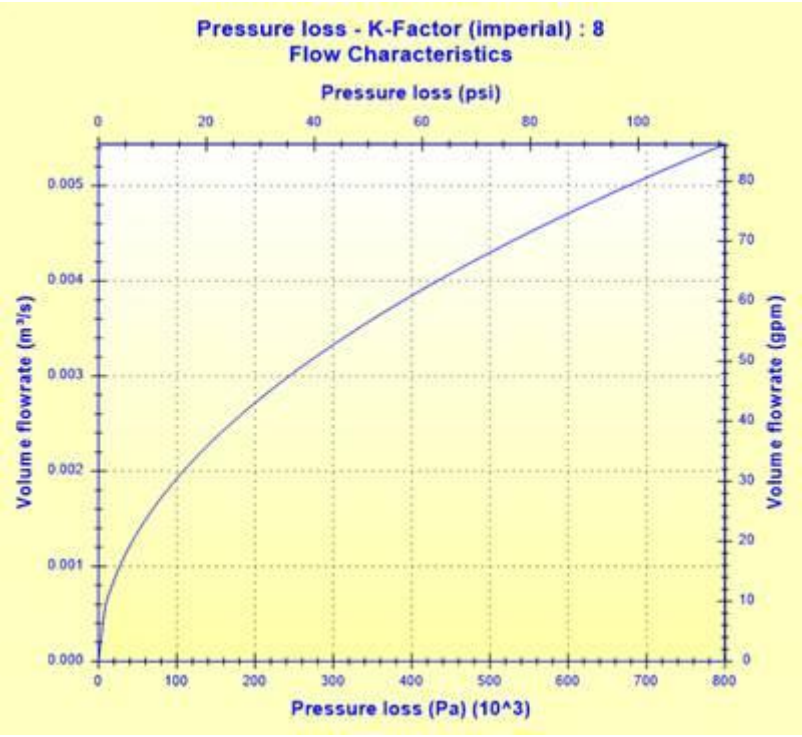
Pressure loss (imperial units):

$$\Delta P\ [psi] = \frac{Q\ [gpm\ US]}{K_f\ [\mathrm{imperial}]^2}$$

Pressure loss (S.I. units):

$$\Delta P\ [Pa] = \frac{Q\ [m^3/s] \Big/ 15850}{K_f\ [\mathrm{imperial}]^2} \cdot 6894.7$$

Example of the evolution of pressure loss as a function of volume flow:



with K-Factor imperial = 8

Value of nominal K-Factors:

Nominal K-Factor gpm/(psi)$^{1/2}$	Nominal K-Factor l/min/(bar)$^{1/2}$	K-Factor Range gpm/(psi)$^{1/2}$	K-Factor Range l/min/(bar)$^{1/2}$
1.4	20	1.3-1.5	19-22
1.9	27	1.8-2.0	26-29
2.8	40	2.6-2.9	38-42
4.2	60	4.0-4.4	57-63
5.6	80	5.3-5.8	76-84
8.0	115	7.4-8.2	107-118
11.2	160	10.7-11.7	159-166
14.0	200	13.5-14.5	195-209
16.8	240	16.0-17.6	231-254
19.6	280	18.6-20.6	272-301
22.4	320	21.3-23.5	311-343
25.2	360	23.9-26.5	349-387
28.0	400	26.6-29.4	389-430
33.6	480	31.9-35.3	456-504

([1] Table 7.2.2.1 Sprinkler Discharge Characteristics Identification)

Nominal orifice size :

Nominal K-Factor		Nominal Orifice Size	
gpm/(psi)$^{1/2}$	l/min/(bar)$^{1/2}$	in	mm
1.4	20	1/4"	6.4
1.9	27	5/16"	8
2.8	40	3/8"	9.5
4.2	60	7/16"	11
5.6	80	1/2"	12.7
8.0	115	17/32"	13.5
11.2	160	5/8"	15.9
14.0	200	3/4"	19
16.8	240	-	-
19.6	280	-	-
22.4	320	-	-
25.2	360	-	-
28.0	400	-	-
33.6	480	-	-

([1] Table A.7.2.2.1 Nominal Sprinkler Orifice Sizes)

Pressure loss coefficient (based on mean velocity in pipe):

$$K = \frac{2 \cdot \Delta P}{\rho_m \cdot V^2}$$

Head loss of fluid:

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss:

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

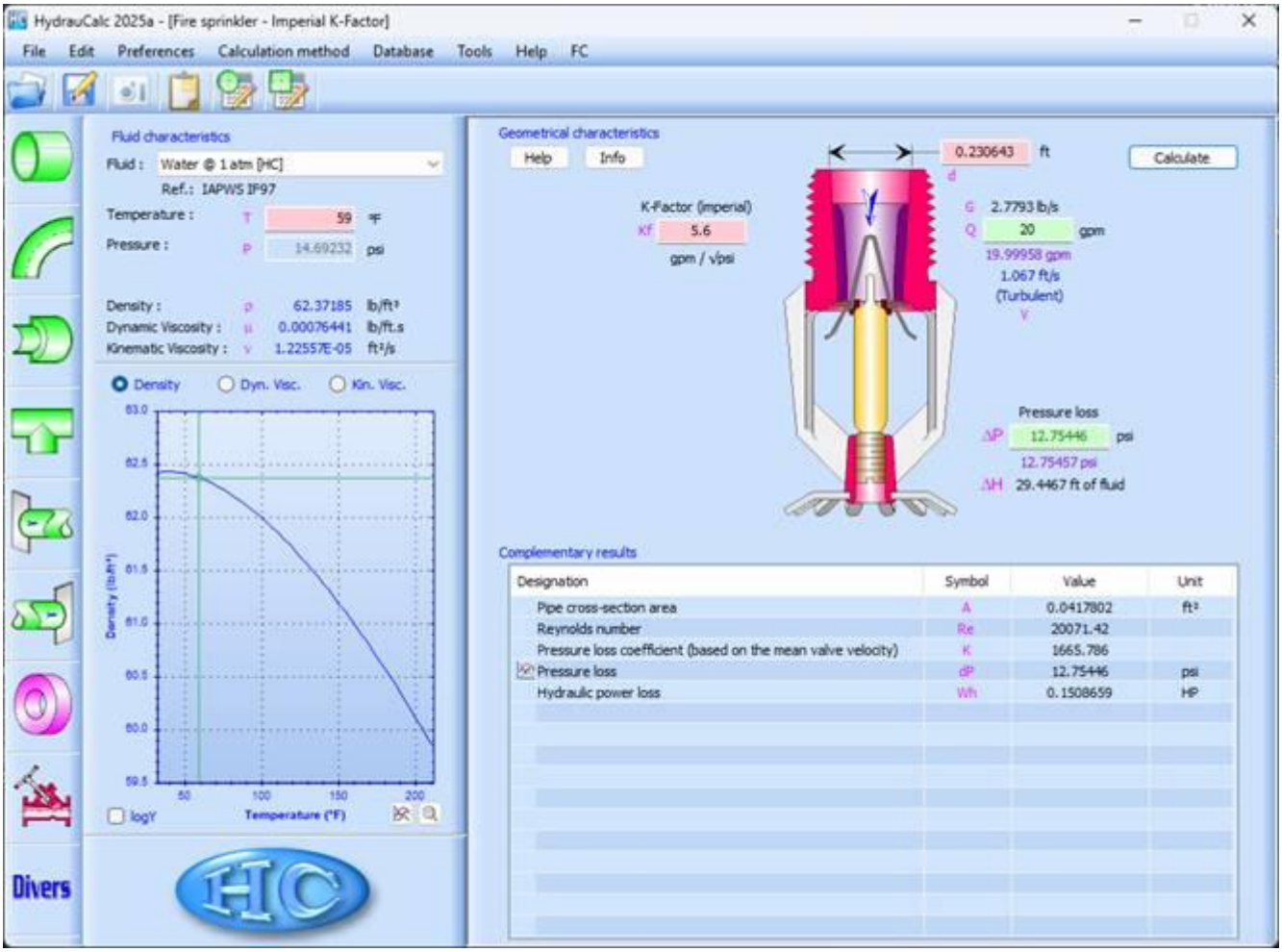
d	Entrance diameter (m)
A	Entrance cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
V	Mean velocity in entrance (m/s)
Re	Reynolds number in entrance ()
K_f	K-factor (gpm US / √psi)
K	Pressure loss coefficient (based on mean velocity in entrance) ()
ΔP	Pressure loss (Pa)
ΔH	Head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime in the entrance of the sprinkler ($Re \geq 10^4$)
- valid only for fresh water close to 15 ° C with a kinematic viscosity of approximately $1.13 \cdot 10^{-6}$ m²/s

---

Example of application:



References:

[1] NFPA 13 Standard for the Installation of Sprinkler Systems 2022 Edition

2.14 General formulas

This subsection regroups two models of formulas relating to the calculation of pressure drops for incompressible fluids. The two types of General formulas available are:

- General Formulas - Circular Cross-Section

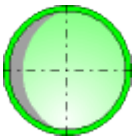
- General Formulas - Rectangular Cross-Section

2.14.1 General Formulas - Circular cross-section

General Head Drop Formulations

for Steady State and Incompressible Fluid

Circular Cross-Section



Model description:

This component model brings together the main formulas relating to the calculation of pressure drops for incompressible fluids. These formulas apply to pipes of circular section and for stabilized flows.

Model formulation:

Cross-section area (m^2):

$$S = \pi \cdot \frac{d^2}{4}$$

Mean velocity (m/s):

$$V = \frac{Qv}{S}$$

Mass flow rate (kg/s):

$$Qm = Qv \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{V \cdot d}{\nu}$$

Flow coefficient Av (m^2):

$$Av = Qv \cdot \sqrt{\frac{\rho}{\Delta P}}$$

or:

$$Av = S \cdot \sqrt{\frac{2}{\zeta}}$$

Flow coefficient Cv (gal/min US):

$$Cv = 41650 \cdot Av$$

or:

$$Cv = Qv_{[gpm\ US]} \cdot \sqrt{\frac{G_{[-]}}{\Delta P_{[psi]}}}$$

where:

Qv Volume flow rate (gal/min US)

ΔP Pressure loss (psi)

G Specific gravity of fluid (1 for water at 60°F)

Flow coefficient Kv (m^3/h):

$$Kv = 36023 \cdot Av$$

or:

$$Kv = Qv_{[m^3/h]} \cdot \sqrt{\frac{G_{[-]}}{\Delta P_{[bar]}}}$$

where:

Qv Volume flow rate (m^3/h)

ΔP Pressure loss (bar)

G Specific gravity of fluid (1 for water at 15°C)

Pressure loss coefficient ():

$$\zeta = \lambda \cdot \frac{L}{d}$$

Pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot V^2}{2}$$

Head loss of fluid (m):

$$\Delta h = \zeta \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Qv$$

Symbols, Definitions, SI Units:

d Pipe internal diameter (m)

S Cross-sectional area (m^2)

Qv Volume flow rate (m^3/s)

Qm Mass flow rate (kg/s)

V Mean velocity (m/s)

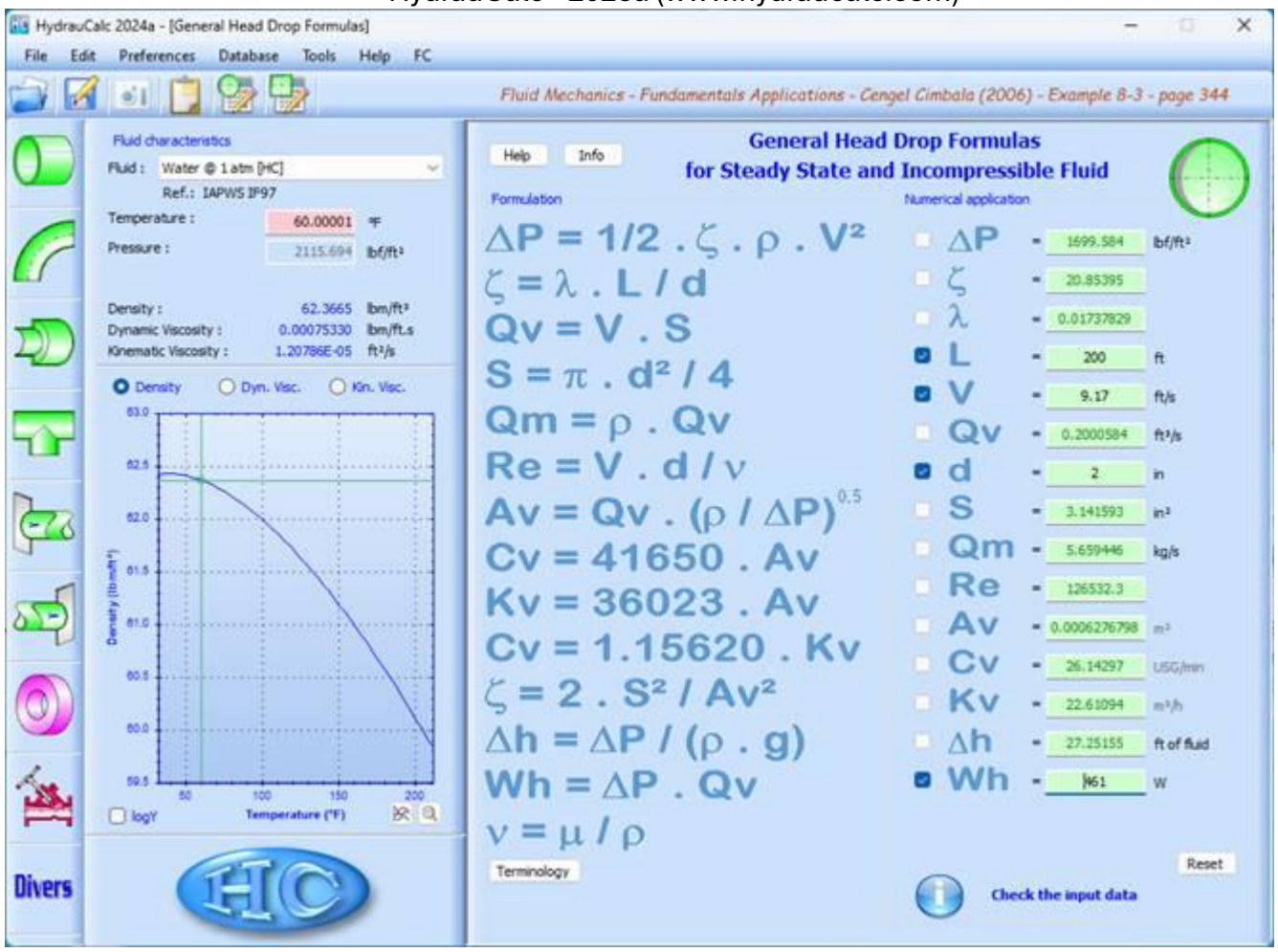
Re Reynolds number ()

Av	Flow coefficient (m^2)
Cv	Flow coefficient (USG/min)
Kv	Flow coefficient (m^3/h)
ζ	Pressure loss coefficient ()
λ	Friction coefficient ()
L	Straight length (m)
ΔP	Pressure loss (Pa)
Δh	Head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- Equations for the flow coefficients Av, Cv and Kv are valid only for turbulent flows.

Example of input data and results:

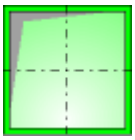

HydrauCalc 2024a - [General Head Drop Formulas]
File Edit Preferences Database Tools Help FC
Fluid Mechanics - Fundamentals Applications - Cengel Cimbala (2006) - Example 8-3 - page 344
Fluid characteristics
Fluid : Water @ 1 atm [HC]
Ref.: IAPWS IF97
Temperature : 60.00001 °F
Pressure : 2115.694 lbf/ft²
Density : 62.3665 lbm/ft³
Dynamic Viscosity : 0.00075330 lbm/ft.s
Kinematic Viscosity : 1.20786E-05 ft²/s
Density Dyn. Visc. Kin. Visc.
logY
Temperature (°F)
Divers
Help Info
General Head Drop Formulas
for Steady State and Incompressible Fluid
Formulation
Numerical application
ΔP = 1/2 . ζ . ρ . V²
ζ = λ . L / d
Qv = V . S
S = π . d² / 4
Qm = ρ . Qv
Re = V . d / ν
Av = Qv . (ρ / ΔP)^0.5
Cv = 41650 . Av
Kv = 36023 . Av
Cv = 1.15620 . Kv
ζ = 2 . S² / Av²
Δh = ΔP / (ρ . g)
Wh = ΔP . Qv
ν = μ / ρ
ΔP - 1699.584 lbf/ft²
ζ - 20.85395
λ - 0.01737829
L - 200 ft
V - 9.17 ft/s
Qv - 0.2000584 ft³/s
d - 2 in
S - 3.141593 in²
Qm - 5.659446 kg/s
Re - 126532.3
Av - 0.0006276798 m²
Cv - 26.14297 USG/min
Kv - 22.61094 m³/h
Δh - 27.25155 ft of fluid
Wh - 961 W
Terminology
Reset
Check the input data

2.14.2 General Formulas - Rectangular cross-section

General Head Drop Formulations

for Steady State and Incompressible Fluid

Rectangular Cross-Section



Model description:

This component model brings together the main formulas relating to the calculation of pressure drops for incompressible fluids. These formulas apply to pipes of rectangular section and for stabilized flows.

Model formulation:

Cross-section area (m^2):

$$S = a \cdot b$$

Cross-section perimeter (m):

$$P = 2 \cdot (a + b)$$

Hydraulic diameter (m):

$$d_h = \frac{4 \cdot S}{P}$$

Mean velocity (m/s):

$$V = \frac{Qv}{S}$$

Mass flow rate (kg/s):

$$Qm = Qv \cdot \rho$$

Reynolds number:

$$\mathrm{Re} = \frac{V \cdot d_h}{\nu}$$

Flow coefficient Av (m^2):

$$Av = Qv \cdot \sqrt{\frac{\rho}{\Delta P}}$$

or:

$$Av = S \cdot \sqrt{\frac{2}{\zeta}}$$

Flow coefficient Cv (gal/min US):

$$Cv = 41650 \cdot Av$$

or:

$$Cv = Qv_{[gpm\ US]} \cdot \sqrt{\frac{G_{[-]}}{\Delta P_{[psi]}}}$$

where:

Qv Volume flow rate (gal/min US)

ΔP Pressure loss (psi)

G Specific gravity of fluid (1 for water at 60°F)

Flow coefficient Kv (m^3/h):

$$Kv = 36023 \cdot Av$$

or:

$$Kv = Qv_{[m^3/h]} \cdot \sqrt{\frac{G_{[-]}}{\Delta P_{[bar]}}}$$

where:

Qv Volume flow rate (m^3/h)

ΔP Pressure loss (bar)

G Specific gravity of fluid (1 for water at 15°C)

Pressure loss coefficient ():

$$\zeta = \lambda \cdot \frac{L}{d_h}$$

Pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot V^2}{2}$$

Head loss of fluid (m):

$$\Delta h = \zeta \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Qv$$

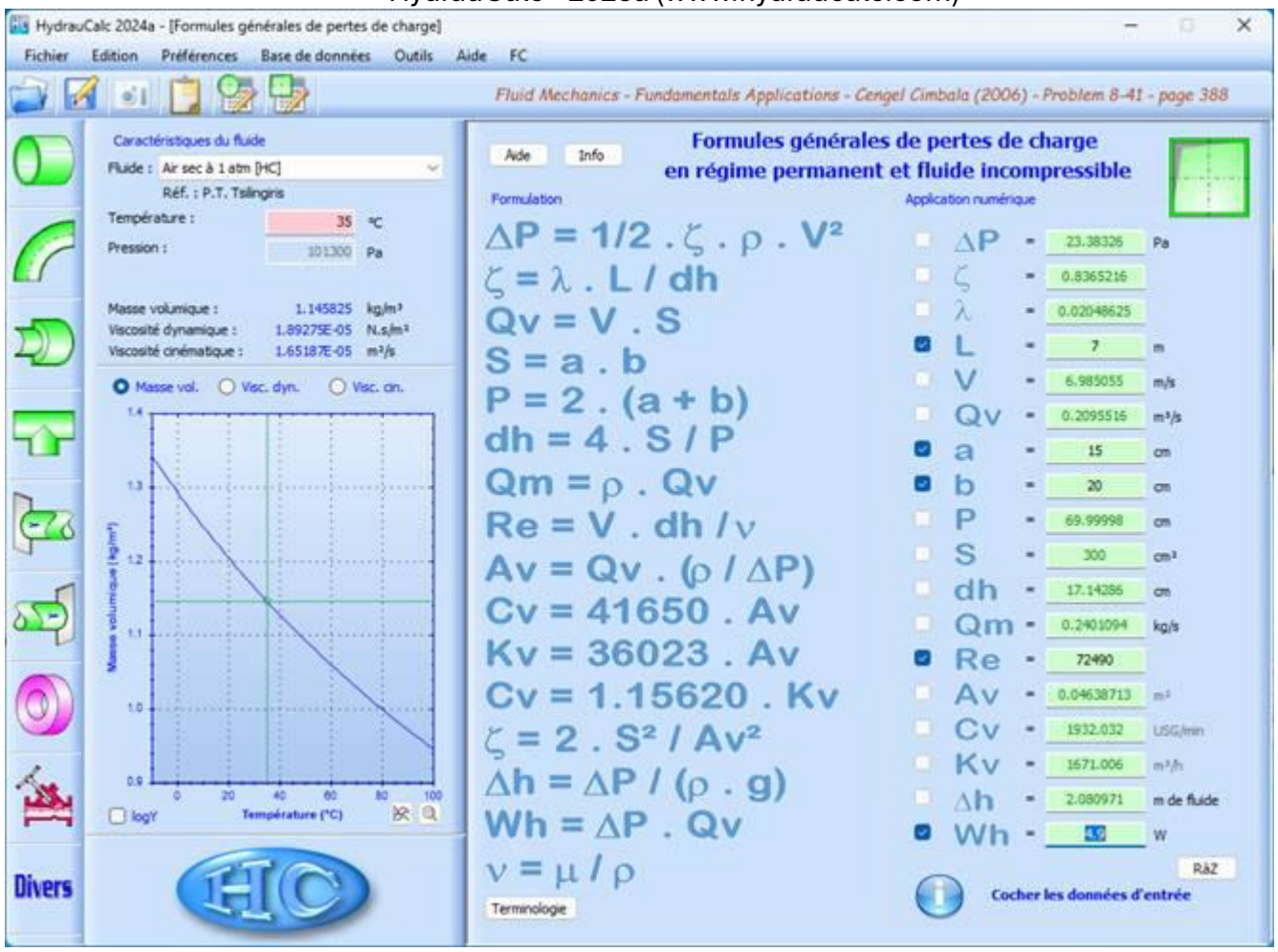
Symbols, Definitions, SI Units:

a	Rectangular cross-section width (m)
b	Rectangular cross-section height (m)
d_h	Pipe hydraulic diameter (m)
S	Cross-sectional perimeter (m)
S	Cross-sectional area (m^2)
Qv	Volume flow rate (m^3/s)
Qm	Mass flow rate (kg/s)
V	Mean velocity (m/s)
Re	Reynolds number ()
Av	Flow coefficient (m^2)
Cv	Flow coefficient (USG/min)
Kv	Flow coefficient (m^3/h)
ζ	Pressure loss coefficient ()
λ	Friction factor ()
L	Straight length (m)
ΔP	Pressure loss (Pa)
Δh	Head loss of fluid (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- Equations for the flow coefficients Av, Cv and Kv are valid only for turbulent flows.

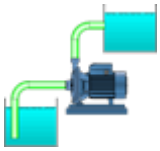
Example of input data and results:


HydrauCalc 2024a - [Formules générales de pertes de charge]
Fichier Edition Préférences Base de données Outils Aide FC
Fluid Mechanics - Fundamentals Applications - Cengel Cimbala (2006) - Problem 8-41 - page 388
Caractéristiques du fluide
Fluide : Air sec à 1 atm [HC]
Réf. : P.T. Tsilingiris
Température : 35 °C
Pression : 101300 Pa
Masse volumique : 1.145825 kg/m³
Viscosité dynamique : 1.89275E-05 N.s/m²
Viscosité cinématique : 1.65187E-05 m²/s
Masse vol. Visc. dyn. Visc. cin.
Masse volumique (kg/m³)
Température (°C)
logY
Divers
Aide Info
Formules générales de pertes de charge
en régime permanent et fluide incompressible
Formulation
Application numérique
ΔP = 1/2 . ζ . ρ . V²
ζ = λ . L / dh
Qv = V . S
S = a . b
P = 2 . (a + b)
dh = 4 . S / P
Qm = ρ . Qv
Re = V . dh / ν
Av = Qv . (ρ / ΔP)
Cv = 41650 . Av
Kv = 36023 . Av
Cv = 1.15620 . Kv
ζ = 2 . S² / Av²
Δh = ΔP / (ρ . g)
Wh = ΔP . Qv
ν = μ / ρ
ΔP = 23.38326 Pa
ζ = 0.8365216
λ = 0.02048625
L = 7 m
V = 6.985055 m/s
Qv = 0.2095516 m³/s
a = 15 cm
b = 20 cm
P = 69.99998 cm
S = 300 cm²
dh = 17.14286 cm
Qm = 0.2401094 kg/s
Re = 72490
Av = 0.04638713 m²
Cv = 1932.032 USG/min
Kv = 1671.006 m³/h
Δh = 2.080971 m de fluide
Wh = 4.9 W
RAZ
Terminologie
Cocher les données d'entrée

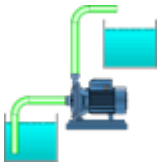
2.15 Pump quick design

This sub-section groups together all the pumping configurations that can be modeled and calculated. The types of configurations available are:

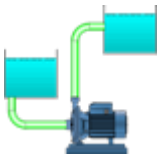
- Suction lift operation - Tank with pipe ending below the fluid level (Configuration 1)



- Suction lift operation - Free flow from the pipe ending above the water level (Configuration 2)

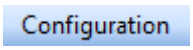


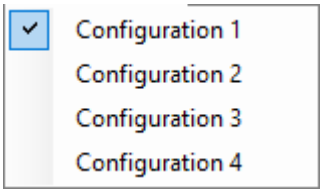
- Suction head operation - Tank with pipe ending below the fluid level (Configuration 3)



- Suction head operation - Free flow from the pipe ending above the water level (Configuration 4)

The selection of the pumping configuration is made using the "Configuration" menu. The default option is "Configuration 1"





The calculation of pump characteristics is based on the following document:

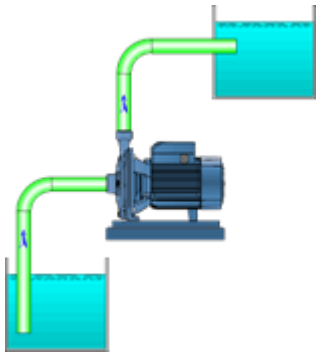
- KSB - Selecting Centrifugal Pumps – 4th Edition (2005)

2.15.1 Configuration 1

Pump Design

Suction lift operation

(Tank with pipe ending below the fluid level)



Model description:

This component model calculates the Total Dynamic Height (TDH) of a pump installed in a hydraulic installation. There is also an option to calculate the Net Positive Suction Head available (NPSHa) of the installation.

In this model,

- the pump is operating in suction mode (the level of the suction tank is located below the suction flange of the pump),
- the pump delivers into a tank whose pipe outlet is located below the fluid level of this tank and whose level is located above the pump discharge flange.

Model formulation:

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Cross-sectional area (m^2):

- Suction piping:

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

- Discharge piping:

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity (m/s):

- Surface of the suction tank:

$$v_0 \approx 0$$

- Suction piping:

$$v_1 = \frac{Q}{A_1}$$

- Discharge piping:

$$v_2 = \frac{Q}{A_2}$$

- Surface of the discharge tank:

$$v_3 \approx 0$$

Reynolds number:

- Suction piping:

$$Re_1 = \frac{v_1 \cdot D_1}{\nu}$$

- Discharge piping:

$$Re_2 = \frac{v_2 \cdot D_2}{\nu}$$

Darcy friction factor:

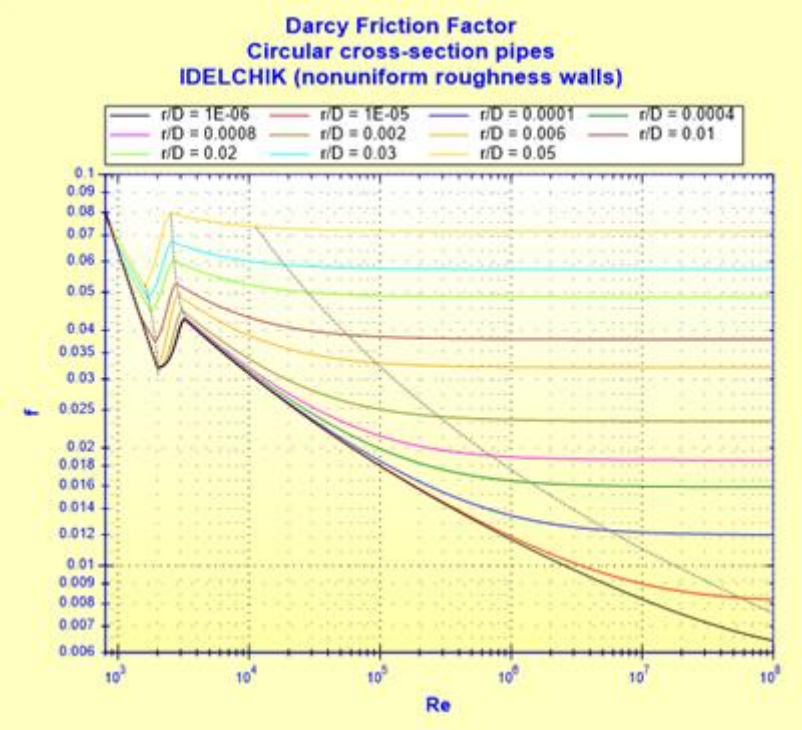
- Suction piping:

$$f_1 = f\left(\mathrm{Re}_1, \frac{r_1}{D_1}\right)$$

- Discharge piping:

$$f_2 = f\left(\mathrm{Re}_2, \frac{r_2}{D_2}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



Coefficient of major pressure losses (friction in pipes):

- Suction piping:

$$Kf_1 = f_1 \cdot \frac{L_1}{D_1}$$

- Discharge piping:

$$Kf_2 = f_2 \cdot \frac{L_2}{D_2}$$

Total pressure loss coefficient:

- Suction piping:

$$K_1 = Kf_1 + Ks_1$$

- Discharge piping:

$$K_2 = Kf_2 + Ks_1$$

Total pressure loss (Pa):

- Suction piping:

$$dP_{01} = K_1 \cdot \frac{\rho \cdot V_1^2}{2}$$

- Discharge piping:

$$dP_{23} = K_2 \cdot \frac{\rho \cdot V_2^2}{2}$$

Total head loss (m):

- Suction piping:

$$dH_{01} = K_1 \cdot \frac{V_1^2}{2 \cdot g}$$

- Discharge piping:

$$dH_{23} = K_2 \cdot \frac{V_2^2}{2 \cdot g}$$

Total gage pressure at the suction flange (Pa):

$$P_1 = P_0 + \frac{V_0^2 \cdot \rho}{2} - (dH_{01} + H_0) \cdot \rho \cdot g$$

Total gage pressure at the discharge flange (Pa):

$$P_2 = P_3 + \frac{V_3^2 \cdot \rho}{2} + (dH_{23} + H_3) \cdot \rho \cdot g$$

Bernoulli's equation:

$$P_i + \frac{1}{2} \cdot \rho \cdot V_i^2 + \rho \cdot g \cdot z_i = P_o + \frac{1}{2} \cdot \rho \cdot V_o^2 + \rho \cdot g \cdot z_o$$

(Perfect fluid, incompressible, steady state flow)

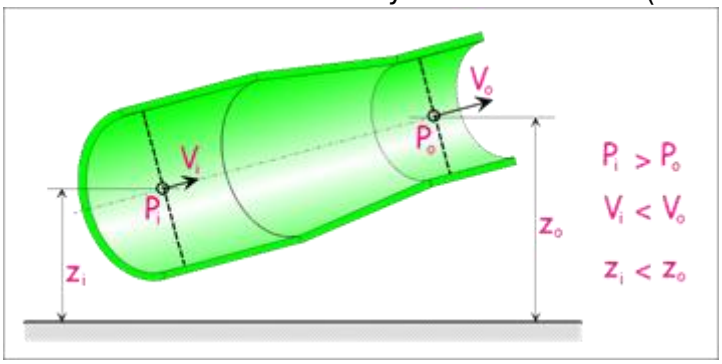


Illustration of Bernoulli's theorem

Pump Total Dynamic Head (application of the extended Bernoulli equation for a real fluid):

$$TDH = (H_0 + H_3) + \left(\frac{P_3 - P_0}{\rho \cdot g}\right) + \left(\frac{v_3^2 - v_0^2}{2 \cdot g}\right) + (dH_{01} + dH_{23})$$

([1] equation 5)

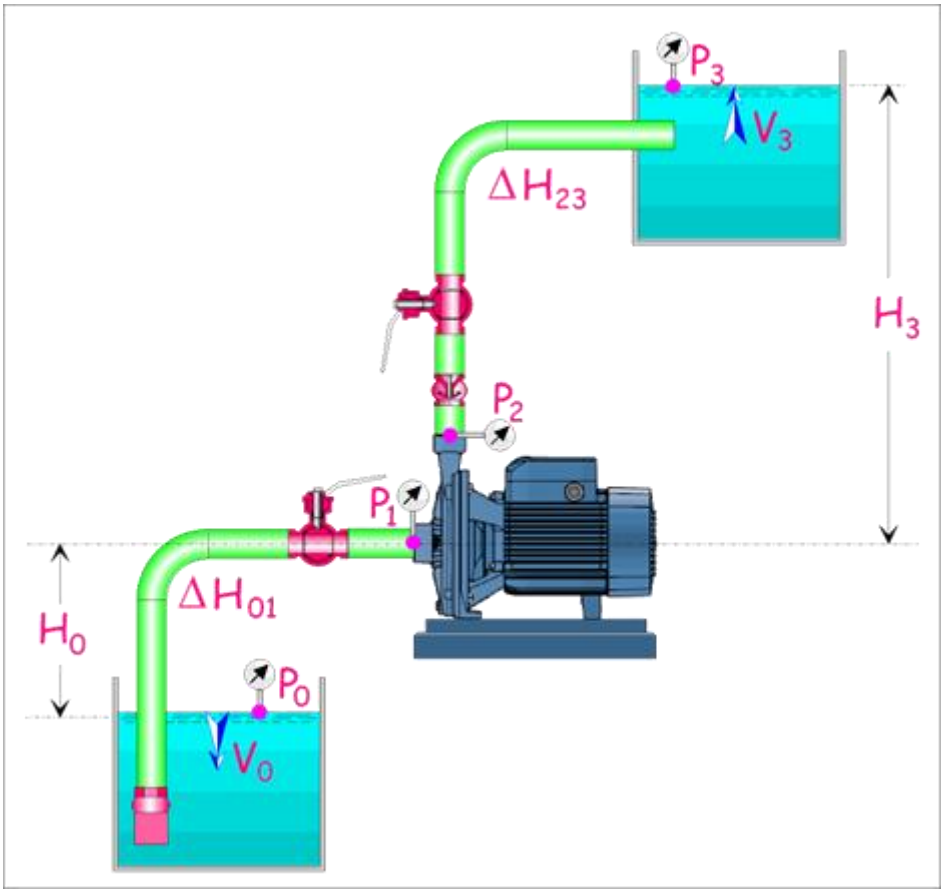


Illustration of the system

where:

$H_0 + H_3$ Total static head, this is the difference in height between the liquid level on the inlet and discharge sides (geodetic head).

$$\frac{P_3 - P_0}{\rho \cdot g}$$

Static pressure head, this is the pressure head difference between the inlet and outlet tank.
In the case of open boxes at atmospheric pressure, the pressures P_0 and P_3 are equal and the static pressure head is zero.

$$\frac{v_3^2 - v_0^2}{2 \cdot g}$$

Dynamic head, this is the dynamic height due to the vertical speed difference in the two tanks.
In general, the liquid surface flow velocities v_0 and v_3 of tanks are very low and the dynamic head is considered to be zero (negligible).

$$dH_{01} + dH_{23}$$

Pressure loss head, this is the sum of all the head losses of the installation, suction and discharge piping.
(= resistance to flow in the pipes, valves, strainer, piping inlet and outlet, etc.).

NPSH Available of the system:

$$NPSH_a = P_1 - P_{vap}$$

By applying the extended Bernoulli equation for a real fluid, between the tank level and the pump suction flange, we obtain the following equation:

$$NPSH_a = \frac{P_0 + P_{atm} - P_{vap}}{\rho \cdot g} + \frac{v_0^2}{2 \cdot g} - dH_{01} - H_0$$

([1] equation 29)

where (as for the TDH):

$$\frac{P_0 + P_{atm} - P_{vap}}{\rho \cdot g}$$

Static pressure head.

$$\frac{v_0^2}{2 \cdot g}$$

Dynamic head.

$$dH_{01}$$

Pressure loss head.

$$H_0$$

Total static head.

Hydraulic power supplied to the fluid by the pump (W):

$$Wh = TDH \cdot \rho \cdot g \cdot Q$$

Input mechanical power taken by the pump (W):

$$Wm = \frac{Wh}{\eta p}$$

Note: Pumping media which are more viscous than water will require a higher input power.

Electric power absorbed by the electric motor (W):

$$We = \frac{Wm}{\eta m}$$

Symbols, Definitions, SI Units:

Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
D_1	Suction piping diameter (m)
D_2	Discharge piping diameter (m)
A_1	Suction piping cross-sectional area (m^2)
A_2	Discharge piping cross-sectional area (m^2)
v_0	Flow velocity of the liquid surface of the suction tank (m/s)
v_1	Mean velocity in suction piping (m/s)
v_2	Mean velocity in discharge piping (m/s)
v_3	Flow velocity of the liquid surface of the discharge tank (m/s)
Re_1	Reynolds number in suction piping ()
Re_2	Reynolds number in discharge piping ()
r_1	Suction piping absolute roughness (m)
r_2	Discharge piping absolute roughness (m)
f_1	Darcy friction factor of the suction piping ()
f_2	Darcy friction factor of the discharge piping ()
L_1	Length of the suction pipe (m)
L_2	Length of the discharge pipe (m)

Kf_1 Coefficient of friction resistance of the suction piping ()

Kf_2 Coefficient of friction resistance of the discharge piping ()

Ks_1 Resistance coefficient of the singularities of the suction piping ()

Ks_2 Resistance coefficient of the singularities of the discharge piping ()

K_1 Total pressure loss coefficient of the suction piping ()

K_2 Total pressure loss coefficient of the discharge piping ()

dP_{01} Total pressure loss of the suction piping (Pa)

dP_{23} Total pressure loss of the discharge piping (Pa)

dH_{01} Total head loss of the suction piping (Pa)

dH_{23} Total head loss of the discharge piping (Pa)

P_0 Relative pressure on the surface of the suction tank(Pa)

P_1 Total relative pressure at the suction flange (Pa)

P_2 Total relative pressure at the discharge flange (Pa)

P_3 Relative pressure on the surface of the discharge tank (Pa)

H_1 Height difference between the fluid level of the suction tank and the suction flange (m)

H_3 Height difference between the suction flange and the fluid level of the discharge tank (m)

TDH Pump Total Dynamic Head (m)

P_{atm} Atmospheric pressure (Pa)

P_{vap} Vapour pressure of liquid at suction flange temperature (Pa)

$NPSH_a$ Net Positive Suction Head available of the system (m)

Wh Hydraulic power supplied to the fluid by the pump (W)

ηp Pump efficiency ()

Wm Input mechanical power taken by the pump (W)

ηm Electrical motor efficiency ()

We Electric power absorbed by the electric motor (W)

ρ Fluid density (kg/m³)

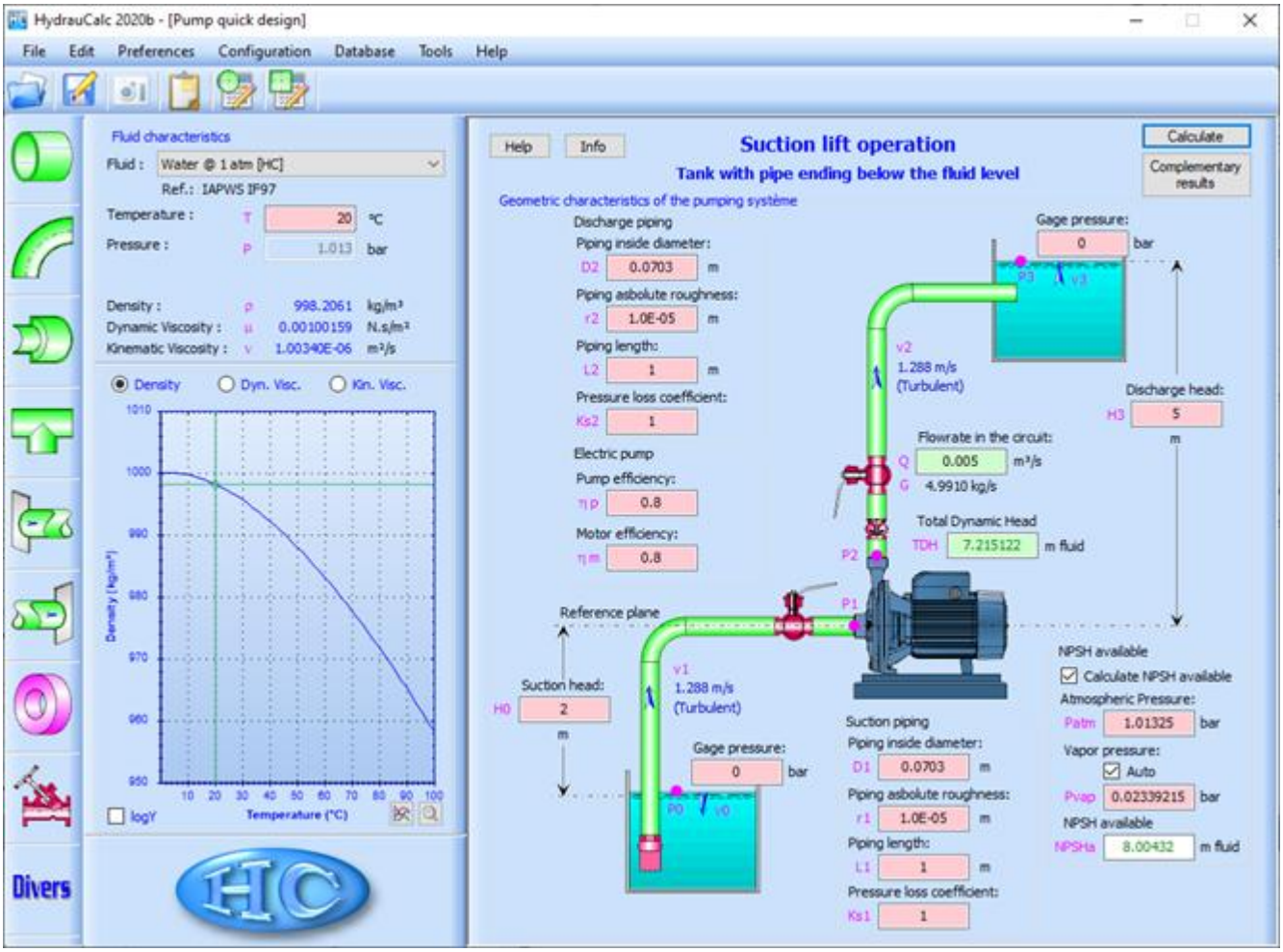
ν Fluid kinematic viscosity (m²/s)

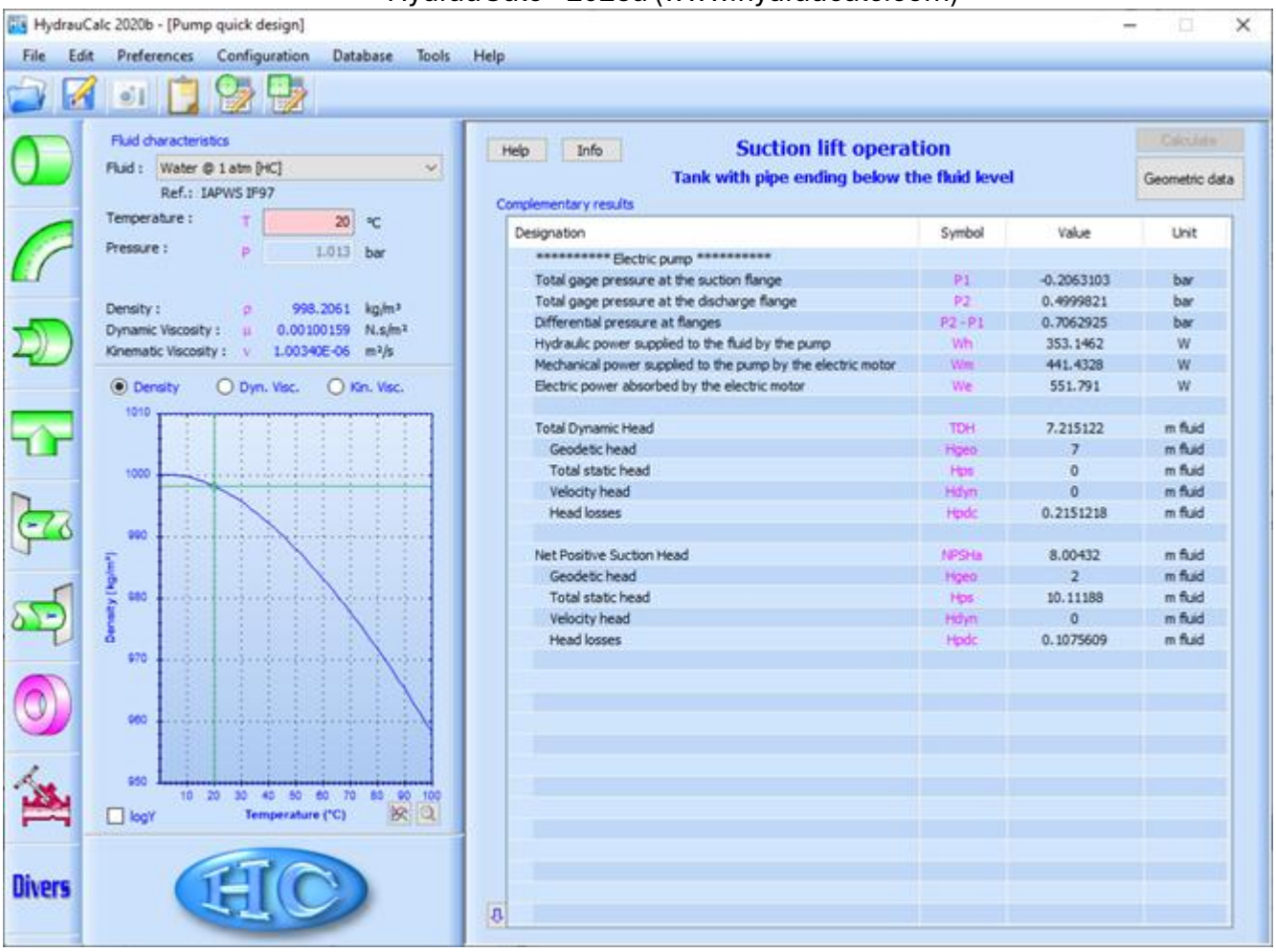
g Gravitational acceleration (9.80665 m/s²)

Validity range:

- turbulent flow regime

Example of application:





References:

[1] KSB - Selecting Centrifugal Pumps – 4th Edition (2005)

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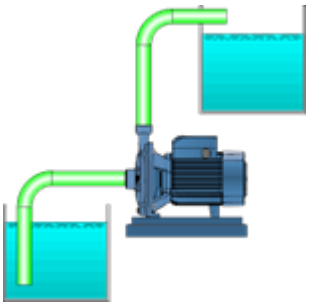
2.15.2 Configuration 2

Pump Design

Suction lift operation

(Free flow from the pipe ending above the fluid level)



Model description:

This component model calculates the Total Dynamic Height (TDH) of a pump installed in a hydraulic installation. There is also an option to calculate the Net Positive Suction Head available (NPSHa) of the installation.

In this model,

- the pump is operating in suction mode (the level of the suction tank is located below the suction flange of the pump),
- the pump delivers into a tank whose pipe outlet is located above the fluid level of this tank and whose level is located above the pump discharge flange.

Model formulation:

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Cross-sectional area (m^2):

- Suction piping:

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

- Discharge piping:

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity (m/s):

- Surface of the suction tank:

$$v_0 \approx 0$$

- Suction piping:

$$v_1 = \frac{Q}{A_1}$$

- Discharge piping:

$$v_2 = \frac{Q}{A_2}$$

- Outlet of the discharge pipe:

$$v_3 = v_2$$

Reynolds number:

- Suction piping:

$$Re_1 = \frac{v_1 \cdot D_1}{\nu}$$

- Discharge piping:

$$Re_2 = \frac{v_2 \cdot D_2}{\nu}$$

Darcy friction factor:

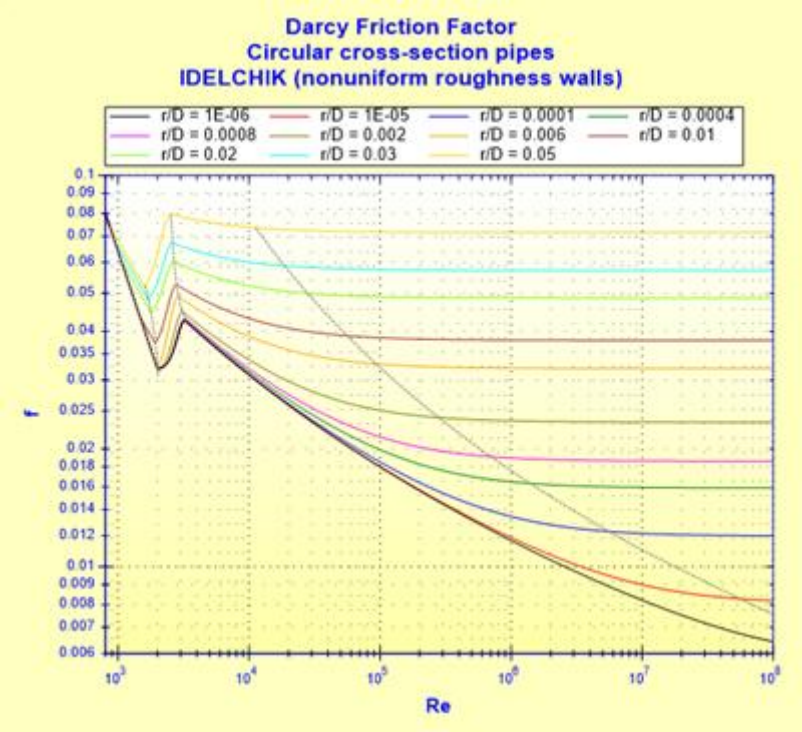
- Suction piping:

$$f_1 = f\left(Re_1, \frac{r_1}{D_1}\right)$$

- Discharge piping:

$$f_2 = f\left(\mathrm{Re}_2, \frac{r_2}{D_2}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



Coefficient of major pressure losses (friction in pipes):

- Suction piping:

$$Kf_1 = f_1 \cdot \frac{L_1}{D_1}$$

- Discharge piping:

$$Kf_2 = f_2 \cdot \frac{L_2}{D_2}$$

Total pressure loss coefficient:

- Suction piping:

$$K_1 = Kf_1 + Ks_1$$

- Discharge piping:

$$K_2 = Kf_2 + Ks_1$$

Total pressure loss (Pa):

- Suction piping:

$$dP_{01} = K_1 \cdot \frac{\rho \cdot V_1^2}{2}$$

- Discharge piping:

$$dP_{23} = K_2 \cdot \frac{\rho \cdot V_2^2}{2}$$

Total head loss (m):

- Suction piping:

$$dH_{01} = K_1 \cdot \frac{V_1^2}{2 \cdot g}$$

- Discharge piping:

$$dH_{23} = K_2 \cdot \frac{V_2^2}{2 \cdot g}$$

Total gage pressure at the suction flange (Pa):

$$P_1 = P_0 + \frac{V_0^2 \cdot \rho}{2} - (dH_{01} + H_0) \cdot \rho \cdot g$$

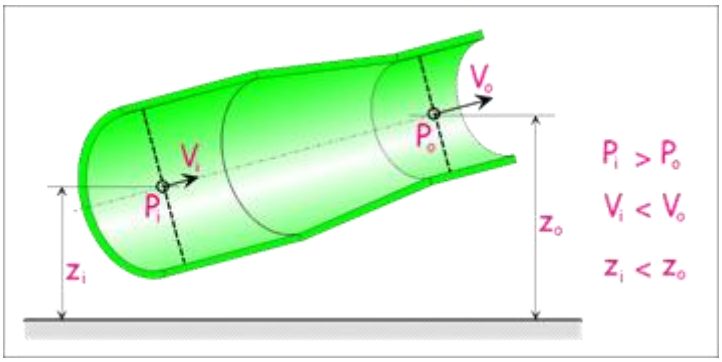
Total gage pressure at the discharge flange (Pa):

$$P_2 = P_3 + \frac{V_3^2 \cdot \rho}{2} + (dH_{23} + H_3) \cdot \rho \cdot g$$

Bernoulli's equation:

$$P_i + \frac{1}{2} \cdot \rho \cdot V_i^2 + \rho \cdot g \cdot z_i = P_o + \frac{1}{2} \cdot \rho \cdot V_o^2 + \rho \cdot g \cdot z_o$$

(Perfect fluid, incompressible, steady state flow)



Pump Total Dynamic Head (application of the extended Bernoulli equation for a real fluid):

$$TDH = (H_0 + H_3) + \left(\frac{P_3 - P_0}{\rho \cdot g}\right) + \left(\frac{v_3^2 - v_0^2}{2 \cdot g}\right) + (dH_{01} + dH_{23})$$

([1] equation 5)

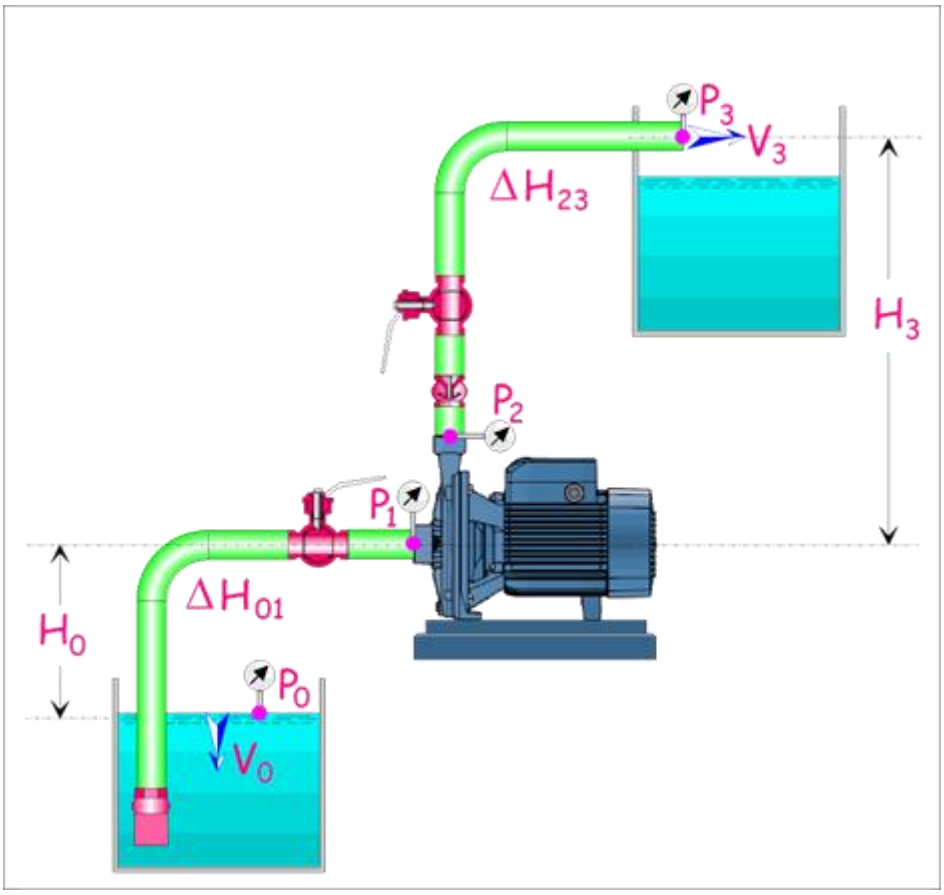


Illustration of the system

where:

$H_0 + H_3$

Total static head, this is the difference in height between the liquid level in the suction tank and the center of the exit plane (geodetic head).

$\frac{P_3 - P_0}{\rho \cdot g}$

Static pressure head, this is the pressure head difference between the inlet and outlet tank.
In the case of open boxes at atmospheric pressure, the pressures P_0 and P_3 are equal and the static pressure head is zero.

$\frac{v_3^2 - v_0^2}{2 \cdot g}$

Dynamic head, this is the dynamic height due to the vertical speed difference in the two tanks.

In general, the liquid surface flow velocities v_0 and v_3 of tanks are very low and the dynamic head is considered to be zero (negligible).

$dH_{01} + dH_{23}$ Pressure loss head, this is the sum of all the head losses of the installation, suction and discharge piping.
(= resistance to flow in the pipes, valves, strainer, piping inlet and outlet, etc.).

NPSH Available of the system:

$$NPSH_a = P_1 - P_{vap}$$

By applying the extended Bernoulli equation for a real fluid, between the tank level and the pump suction flange, we obtain the following equation:

$$NPSH_a = \frac{P_0 + P_{atm} - P_{vap}}{\rho \cdot g} + \frac{v_0^2}{2 \cdot g} - dH_{01} - H_0$$ ([1] equation 29)

where (as for the TDH):

$\frac{P_0 + P_{atm} - P_{vap}}{\rho \cdot g}$ Static pressure head.

$\frac{v_0^2}{2 \cdot g}$ Dynamic head.

dH_{01} Pressure loss head.

H_0 Total static head.

Hydraulic power supplied to the fluid by the pump (W):

$$Wh = TDH \cdot \rho \cdot g \cdot Q$$

Input mechanical power taken by the pump (W):

$$Wm = \frac{Wh}{\eta p}$$

Note: Pumping media which are more viscous than water will require a higher input power.

Electric power absorbed by the electric motor (W):

$$We = \frac{Wm}{\eta m}$$

Symbols, Definitions, SI Units:

Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
D_1	Suction piping diameter (m)
D_2	Discharge piping diameter (m)
A_1	Suction piping cross-sectional area (m^2)
A_2	Discharge piping cross-sectional area (m^2)
v_0	Flow velocity of the liquid surface of the suction tank (m/s)
v_1	Mean velocity in suction piping (m/s)
v_2	Mean velocity in discharge piping (m/s)
v_3	Flow velocity at the outlet of the discharge pipe (m/s)
Re_1	Reynolds number in suction piping ()
Re_2	Reynolds number in discharge piping ()
r_1	Suction piping absolute roughness (m)
r_2	Discharge piping absolute roughness (m)
f_1	Darcy friction factor of the suction piping ()
f_2	Darcy friction factor of the discharge piping ()
L_1	Length of the suction pipe (m)
L_2	Length of the discharge pipe (m)
Kf_1	Coefficient of friction resistance of the suction piping ()
Kf_2	Coefficient of friction resistance of the discharge piping ()
Ks_1	Resistance coefficient of the singularities of the suction piping ()
Ks_2	Resistance coefficient of the singularities of the discharge piping ()
K_1	Total pressure loss coefficient of the suction piping ()
K_2	Total pressure loss coefficient of the discharge piping ()

dP_{01} Total pressure loss of the suction piping (Pa)

dP_{23} Total pressure loss of the discharge piping (Pa)

dH_{01} Total head loss of the suction piping (Pa)

dH_{23} Total head loss of the discharge piping (Pa)

P_0 Relative pressure on the surface of the suction tank (Pa)

P_1 Total relative pressure at the suction flange (Pa)

P_2 Total relative pressure at the discharge flange (Pa)

P_3 Relative pressure on the surface of the discharge tank (Pa)

H_1 Height difference between the fluid level of the suction tank and the suction flange (m)

H_3 Height difference between the suction flange and the center of the exit plane (m)

TDH Pump Total Dynamic Head (m)

P_{atm} Atmospheric pressure (Pa)

P_{vap} Vapour pressure of liquid at suction flange temperature (Pa)

$NPSH_a$ Net Positive Suction Head available of the system (m)

Wh Hydraulic power supplied to the fluid by the pump (W)

ηp Pump efficiency ()

Wm Input mechanical power taken by the pump (W)

ηm Electrical motor efficiency ()

We Electric power absorbed by the electric motor (W)

ρ Fluid density (kg/m^3)

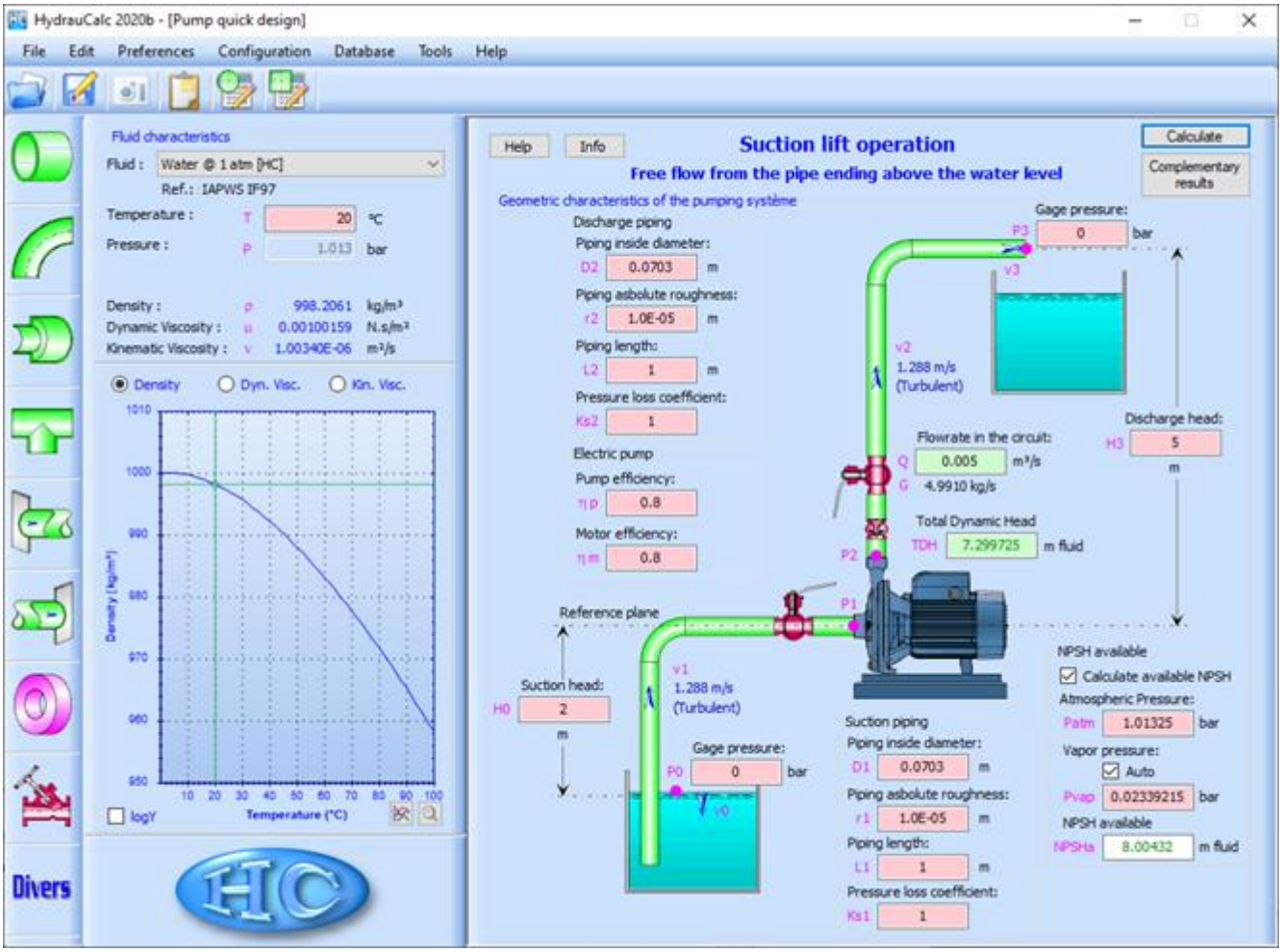
ν Fluid kinematic viscosity (m^2/s)

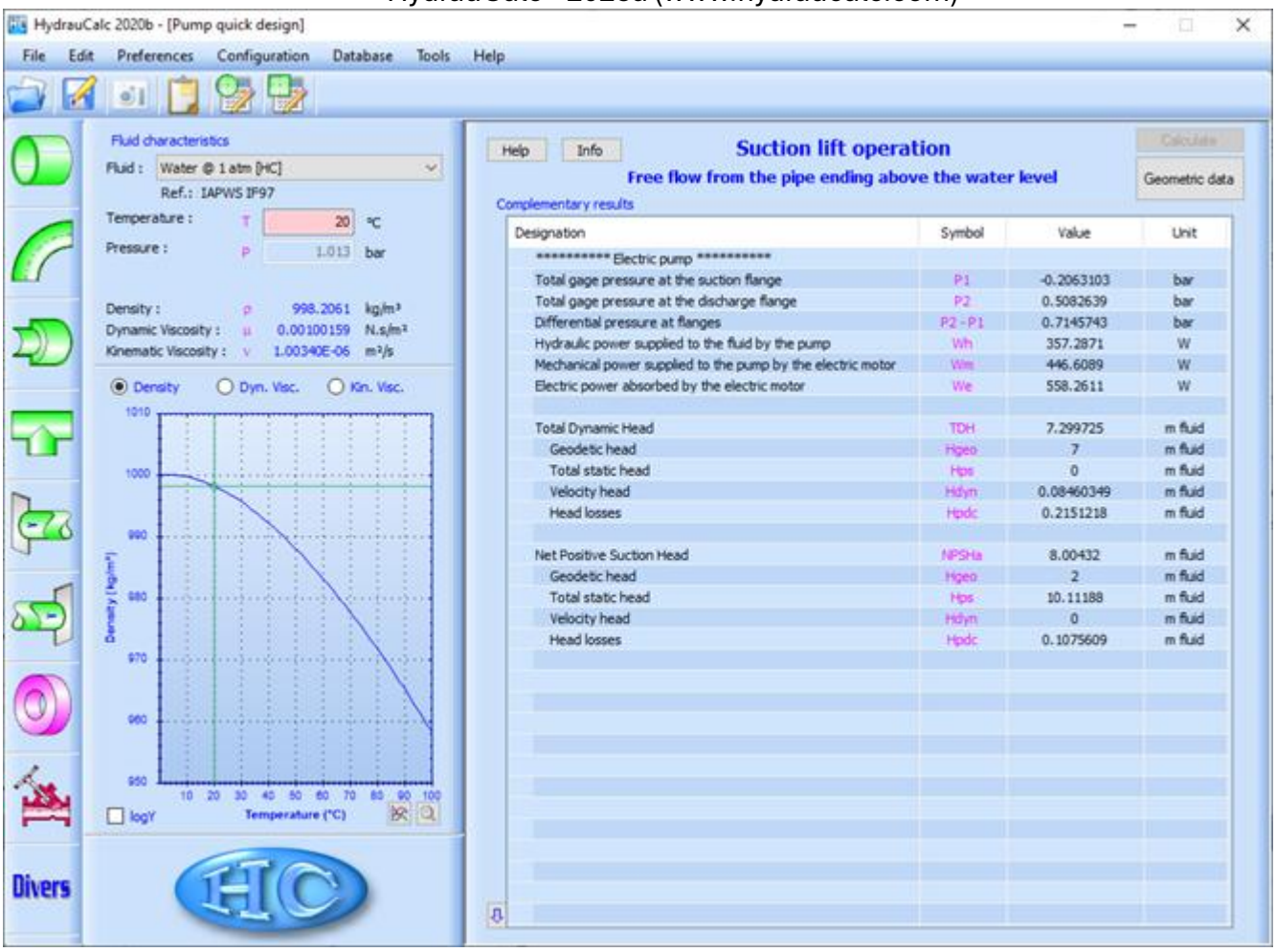
g Gravitational acceleration (9.80665 m/s^2)

Validity range:

- turbulent flow regime

Example of application:





References:

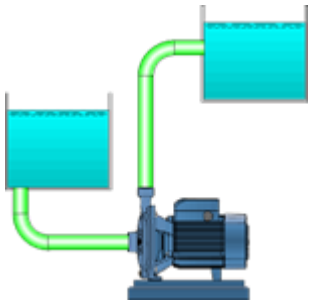
[1] KSB - Selecting Centrifugal Pumps – 4th Edition (2005)

2.15.3 Configuration 3

Pump Design

Suction head operation

(Tank with pipe ending below the fluid level)



Model description:

This component model calculates the Total Dynamic Height (TDH) of a pump installed in a hydraulic installation. There is also an option to calculate the Net Positive Suction Head available (NPSHa) of the installation.

In this model,

- the pump is operating in head mode (the level of the suction tank is located above the suction flange of the pump),
- the pump delivers into a tank whose pipe outlet is located below the fluid level of this tank and whose level is located above the pump discharge flange.

Model formulation:

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Cross-sectional area (m^2):

- Suction piping:

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

- Discharge piping:

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity (m/s):

- Surface of the suction tank:

$$v_0 \approx 0$$

- Suction piping:

$$v_1 = \frac{Q}{A_1}$$

- Discharge piping:

$$v_2 = \frac{Q}{A_2}$$

- Surface of the discharge tank:

$$v_3 \approx 0$$

Reynolds number:

- Suction piping:

$$Re_1 = \frac{v_1 \cdot D_1}{\nu}$$

- Discharge piping:

$$Re_2 = \frac{v_2 \cdot D_2}{\nu}$$

Darcy friction factor:

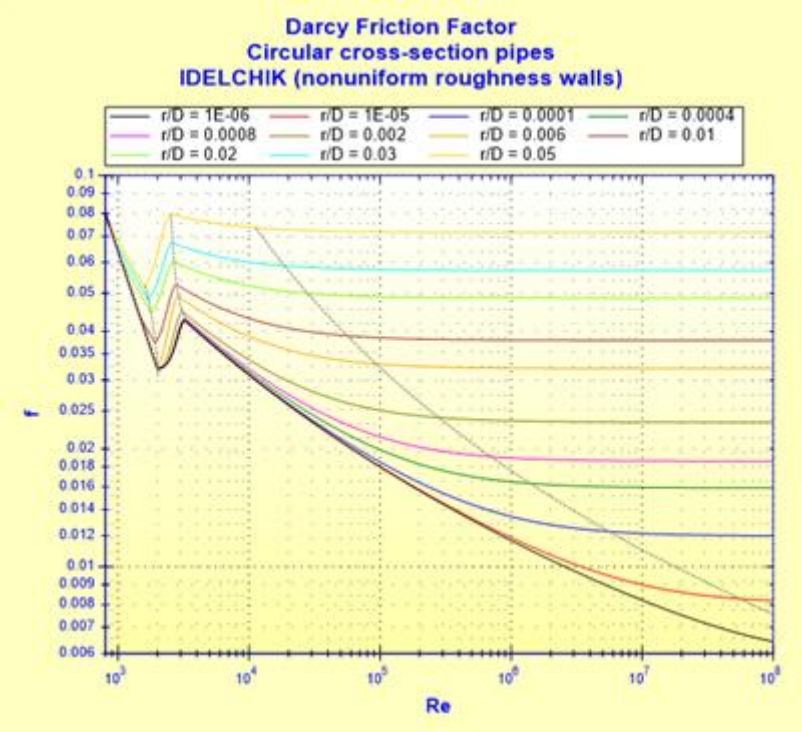
- Suction piping:

$$f_1 = f\left(Re_1, \frac{r_1}{D_1}\right)$$

- Discharge piping:

$$f_2 = f\left(\mathrm{Re}_2, \frac{r_2}{D_2}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



Coefficient of major pressure losses (friction in pipes):

- Suction piping:

$$Kf_1 = f_1 \cdot \frac{L_1}{D_1}$$

- Discharge piping:

$$Kf_2 = f_2 \cdot \frac{L_2}{D_2}$$

Total pressure loss coefficient:

- Suction piping:

$$K_1 = Kf_1 + Ks_1$$

- Discharge piping:

$$K_2 = Kf_2 + Ks_1$$

Total pressure loss (Pa):

- Suction piping:

$$dP_{01} = K_1 \cdot \frac{\rho \cdot V_1^2}{2}$$

- Discharge piping:

$$dP_{23} = K_2 \cdot \frac{\rho \cdot V_2^2}{2}$$

Total head loss (m):

- Suction piping:

$$dH_{01} = K_1 \cdot \frac{V_1^2}{2 \cdot g}$$

- Discharge piping:

$$dH_{23} = K_2 \cdot \frac{V_2^2}{2 \cdot g}$$

Total gage pressure at the suction flange (Pa):

$$P_1 = P_0 + \frac{V_0^2 \cdot \rho}{2} + (H_0 - dH_{01}) \cdot \rho \cdot g$$

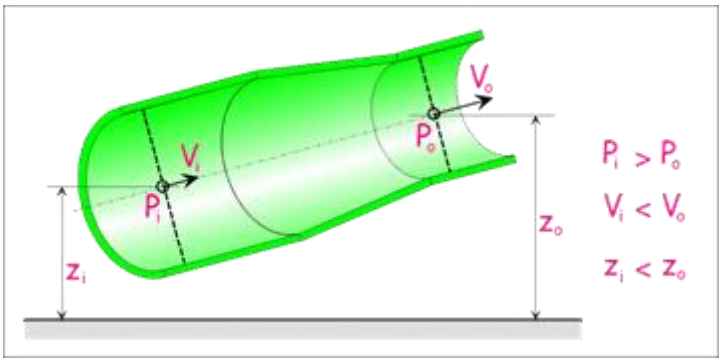
Total gage pressure at the discharge flange (Pa):

$$P_2 = P_3 + \frac{V_3^2 \cdot \rho}{2} + (dH_{23} + H_3) \cdot \rho \cdot g$$

Bernoulli's equation:

$$P_i + \frac{1}{2} \cdot \rho \cdot V_i^2 + \rho \cdot g \cdot z_i = P_o + \frac{1}{2} \cdot \rho \cdot V_o^2 + \rho \cdot g \cdot z_o$$

(Perfect fluid, incompressible, steady state flow)



Pump Total Dynamic Head (application of the extended Bernoulli equation for a real fluid):

$$TDH = (H_0 + H_3) + \left(\frac{P_3 - P_0}{\rho \cdot g}\right) + \left(\frac{v_3^2 - v_0^2}{2 \cdot g}\right) + (dH_{01} + dH_{23})$$

([1] equation 5)

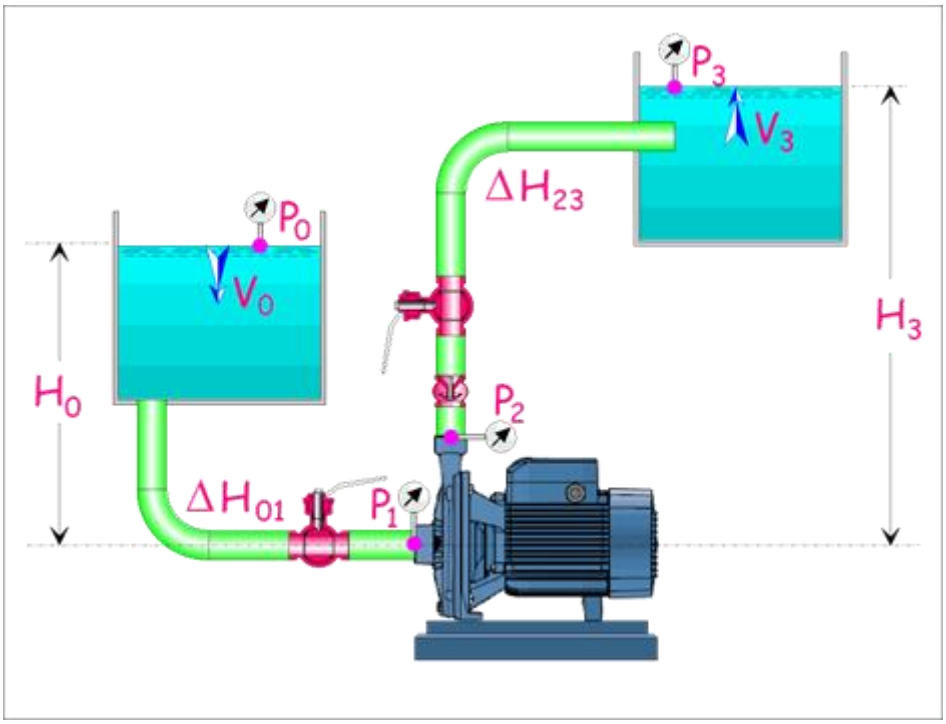


Illustration of the system

where:

$H_3 - H_0$ Total static head, this is the difference in height between the liquid level on the inlet and discharge sides (geodetic head).

$\frac{P_3 - P_0}{\rho \cdot g}$ Static pressure head, this is the pressure head difference between the inlet and outlet tank.
In the case of open boxes at atmospheric pressure, the pressures P_0 and P_3 are equal and the static pressure head is zero.

$\frac{v_3^2 - v_0^2}{2 \cdot g}$ Dynamic head, this is the dynamic height due to the vertical speed difference in the two tanks.
In general, the liquid surface flow velocities v_0 and v_3 of tanks are very low and the dynamic head is considered to be zero (negligible).

$dH_{01} + dH_{23}$ Pressure loss head, this is the sum of all the head losses of the installation, suction and discharge piping.
(= resistance to flow in the pipes, valves, strainer, piping inlet and outlet, etc.).

NPSH Available of the system:

$$NPSH_a = P_1 - P_{vap}$$

By applying the extended Bernoulli equation for a real fluid, between the tank level and the pump suction flange, we obtain the following equation:

$$NPSH_a = \frac{P_0 + P_{atm} - P_{vap}}{\rho \cdot g} + \frac{v_0^2}{2 \cdot g} - dH_{01} + H_0$$ ([1] equation 31)

where (as for the TDH):

$\frac{P_0 + P_{atm} - P_{vap}}{\rho \cdot g}$ Static pressure head.

$\frac{v_0^2}{2 \cdot g}$ Dynamic head.

dH_{01} Pressure loss head.

H_0 Total static head.

Hydraulic power supplied to the fluid by the pump (W):

$$Wh = TDH \cdot \rho \cdot g \cdot Q$$

Input mechanical power taken by the pump (W):

$$Wm = \frac{Wh}{\eta p}$$

Note: Pumping media which are more viscous than water will require a higher input power.

Electric power absorbed by the electric motor (W):

$$We = \frac{Wm}{\eta m}$$

Symbols, Definitions, SI Units:

Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
D_1	Suction piping diameter (m)
D_2	Discharge piping diameter (m)
A_1	Suction piping cross-sectional area (m^2)
A_2	Discharge piping cross-sectional area (m^2)
v_0	Flow velocity of the liquid surface of the suction tank (m/s)
v_1	Mean velocity in suction piping (m/s)
v_2	Mean velocity in discharge piping (m/s)
v_3	Flow velocity of the liquid surface of the discharge tank (m/s)
Re_1	Reynolds number in suction piping ()
Re_2	Reynolds number in discharge piping ()
r_1	Suction piping absolute roughness (m)
r_2	Discharge piping absolute roughness (m)
f_1	Darcy friction factor of the suction piping ()
f_2	Darcy friction factor of the discharge piping ()
L_1	Length of the suction pipe (m)
L_2	Length of the discharge pipe (m)
Kf_1	Coefficient of friction resistance of the suction piping ()
Kf_2	Coefficient of friction resistance of the discharge piping ()
Ks_1	Resistance coefficient of the singularities of the suction piping ()
Ks_2	Resistance coefficient of the singularities of the discharge piping ()
K_1	Total pressure loss coefficient of the suction piping ()
K_2	Total pressure loss coefficient of the discharge piping ()
dP_{01}	Total pressure loss of the suction piping (Pa)

dP_{23} Total pressure loss of the discharge piping (Pa)

dH_{01} Total head loss of the suction piping (Pa)

dH_{23} Total head loss of the discharge piping (Pa)

P_0 Relative pressure on the surface of the suction tank (Pa)

P_1 Total relative pressure at the suction flange (Pa)

P_2 Total relative pressure at the discharge flange (Pa)

P_3 Relative pressure on the surface of the discharge tank (Pa)

H_1 Height difference between the fluid level of the suction tank and the suction flange (m)

H_3 Height difference between the suction flange and the fluid level of the discharge tank (m)

TDH Pump Total Dynamic Head (m)

P_{atm} Atmospheric pressure (Pa)

P_{vap} Vapour pressure of liquid at suction flange temperature (Pa)

$NPSH_a$ Net Positive Suction Head available of the system (m)

Wh Hydraulic power supplied to the fluid by the pump (W)

ηp Pump efficiency ()

Wm Input mechanical power taken by the pump (W)

ηm Electrical motor efficiency ()

We Electric power absorbed by the electric motor (W)

ρ Fluid density (kg/m^3)

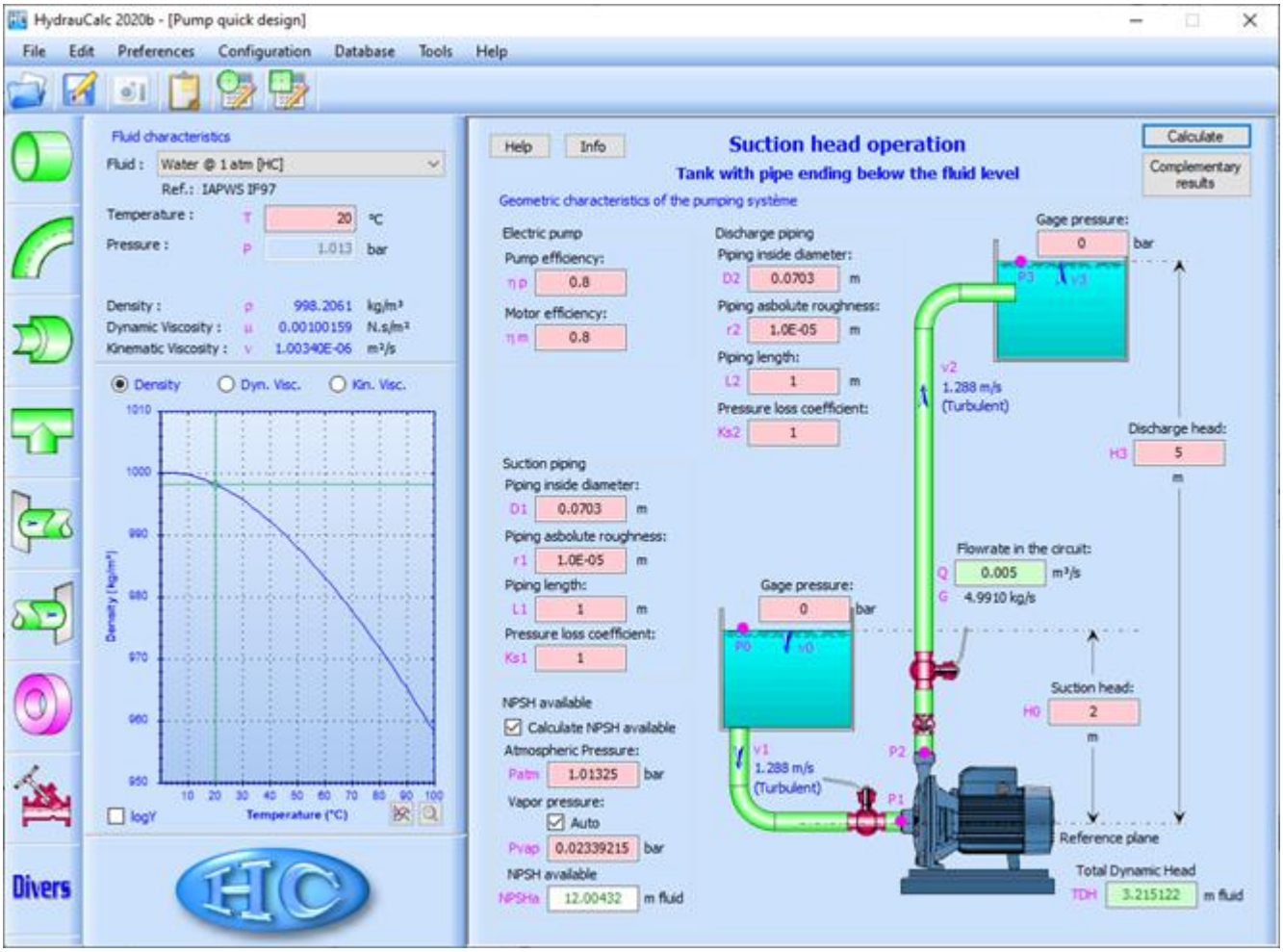
ν Fluid kinematic viscosity (m^2/s)

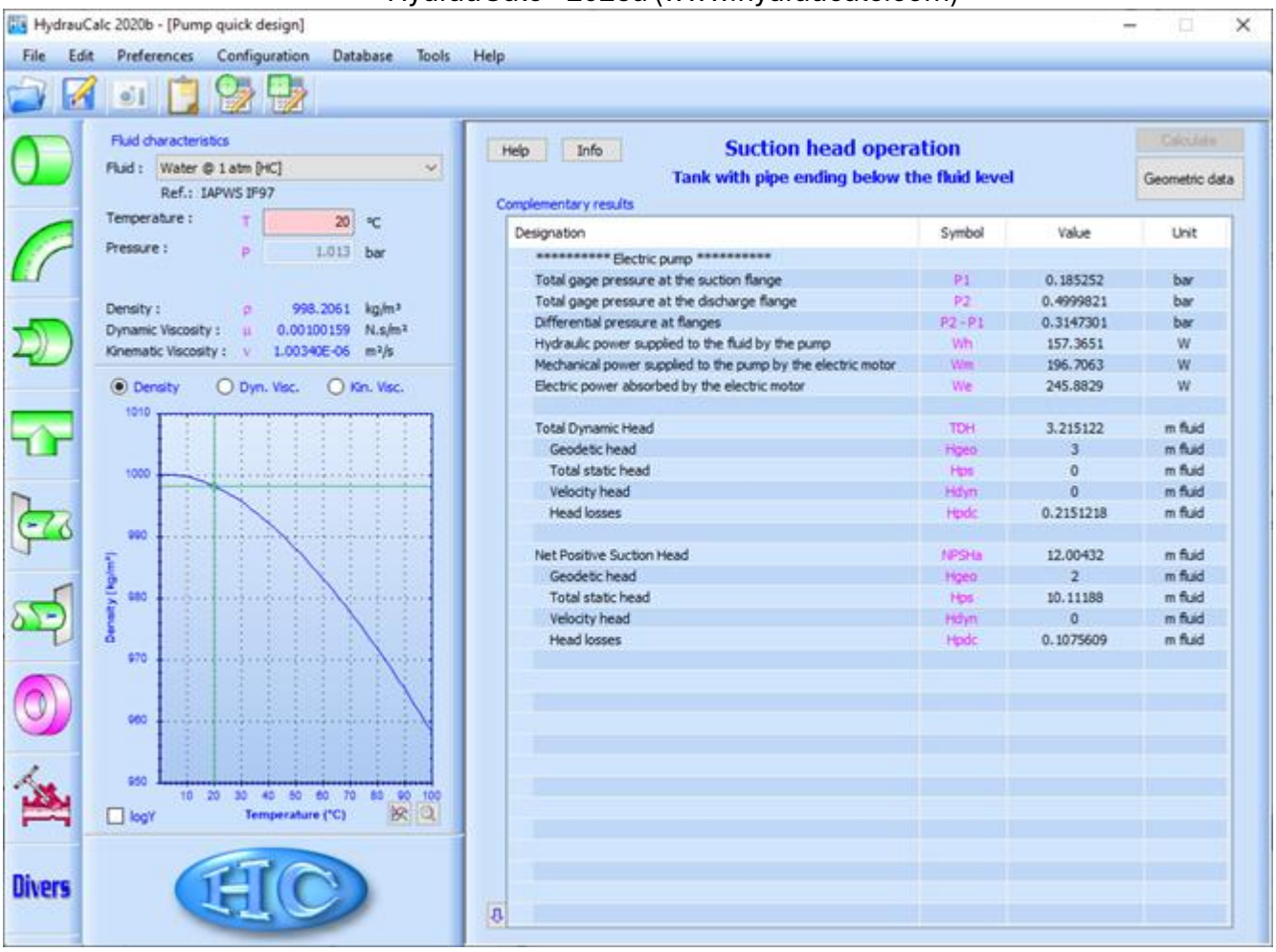
g Gravitational acceleration (9.80665 m/s^2)

Validity range:

- turbulent flow regime

Example of application:





References:

[1] KSB - Selecting Centrifugal Pumps – 4th Edition (2005)

HydrauCalc Edition: January 2021

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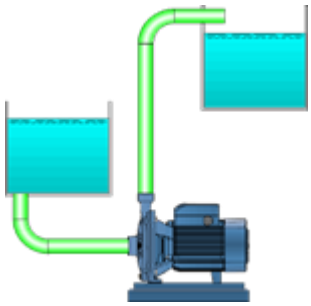
2.15.4 Configuration 4

Pump Design

Suction head operation

(Free flow from the pipe ending above the fluid level)



Model description:

This component model calculates the Total Dynamic Height (TDH) of a pump installed in a hydraulic installation. There is also an option to calculate the Net Positive Suction Head available (NPSHa) of the installation.

In this model,

- the pump is operating in head mode (the level of the suction tank is located above the suction flange of the pump),
- the pump delivers into a tank whose pipe outlet is located above the fluid level of this tank and whose level is located above the pump discharge flange.

Model formulation:

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Cross-sectional area (m^2):

- Suction piping:

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

- Discharge piping:

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity (m/s):

- Surface of the suction tank:

$$v_0 \approx 0$$

- Suction piping:

$$v_1 = \frac{Q}{A_1}$$

- Discharge piping:

$$v_2 = \frac{Q}{A_2}$$

- Outlet of the discharge pipe:

$$v_3 = v_2$$

Reynolds number:

- Suction piping:

$$Re_1 = \frac{v_1 \cdot D_1}{\nu}$$

- Discharge piping:

$$Re_2 = \frac{v_2 \cdot D_2}{\nu}$$

Darcy friction factor:

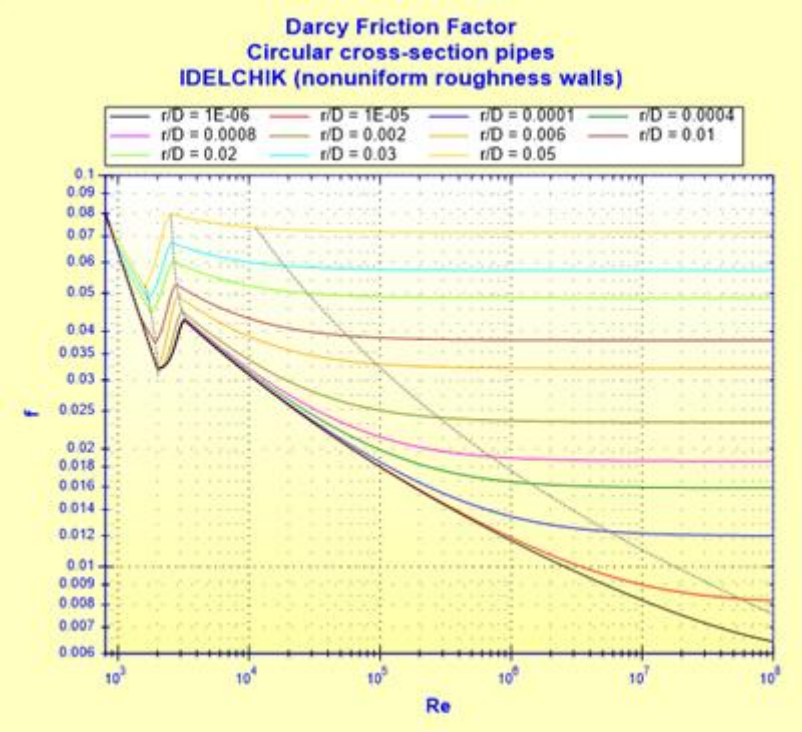
- Suction piping:

$$f_1 = f\left(Re_1, \frac{r_1}{D_1}\right)$$

- Discharge piping:

$$f_2 = f\left(\mathrm{Re}_2, \frac{r_2}{D_2}\right)$$

See Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



Coefficient of major pressure losses (friction in pipes):

- Suction piping:

$$Kf_1 = f_1 \cdot \frac{L_1}{D_1}$$

- Discharge piping:

$$Kf_2 = f_2 \cdot \frac{L_2}{D_2}$$

Total pressure loss coefficient:

- Suction piping:

$$K_1 = Kf_1 + Ks_1$$

- Discharge piping:

$$K_2 = Kf_2 + Ks_1$$

Total pressure loss (Pa):

- Suction piping:

$$dP_{01} = K_1 \cdot \frac{\rho \cdot V_1^2}{2}$$

- Discharge piping:

$$dP_{23} = K_2 \cdot \frac{\rho \cdot V_2^2}{2}$$

Total head loss (m):

- Suction piping:

$$dH_{01} = K_1 \cdot \frac{V_1^2}{2 \cdot g}$$

- Discharge piping:

$$dH_{23} = K_2 \cdot \frac{V_2^2}{2 \cdot g}$$

Total gage pressure at the suction flange (Pa):

$$P_1 = P_0 + \frac{V_0^2 \cdot \rho}{2} + (H_0 - dH_{01}) \cdot \rho \cdot g$$

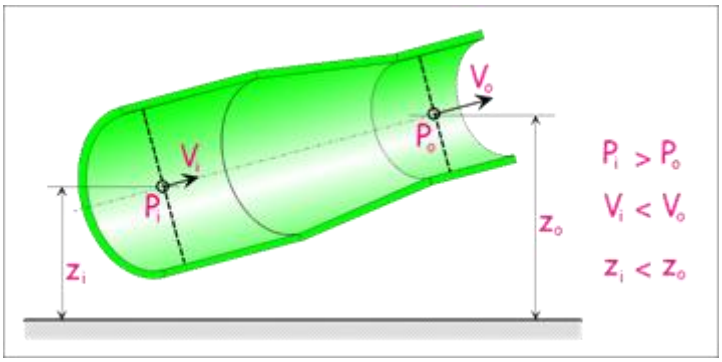
Total gage pressure at the discharge flange (Pa):

$$P_2 = P_3 + \frac{V_3^2 \cdot \rho}{2} + (dH_{23} + H_3) \cdot \rho \cdot g$$

Bernoulli's equation:

$$P_i + \frac{1}{2} \cdot \rho \cdot V_i^2 + \rho \cdot g \cdot z_i = P_o + \frac{1}{2} \cdot \rho \cdot V_o^2 + \rho \cdot g \cdot z_o$$

(Perfect fluid, incompressible, steady state flow)



Pump Total Dynamic Head (application of the extended Bernoulli equation for a real fluid):

$$TDH = (H_0 + H_3) + \left(\frac{P_3 - P_0}{\rho \cdot g}\right) + \left(\frac{v_3^2 - v_0^2}{2 \cdot g}\right) + (dH_{01} + dH_{23})$$

([1] equation 5)

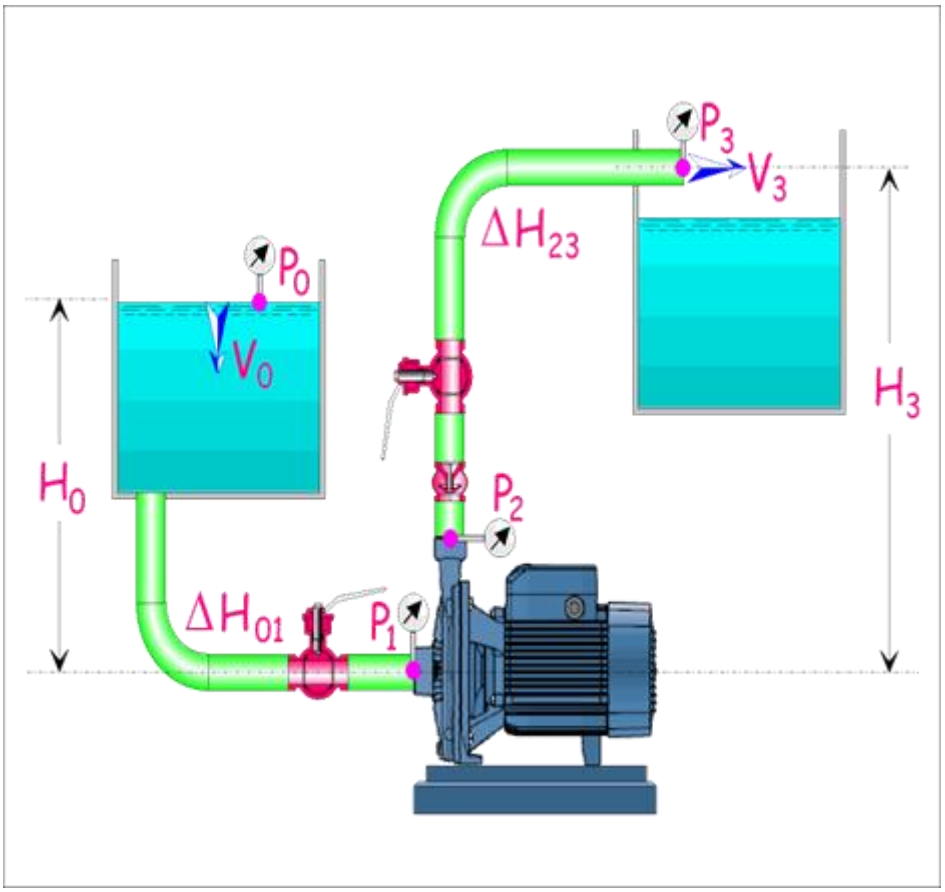


Illustration of the system

where:

$H_3 - H_0$

Total static head, this is the difference in height between the liquid level in the suction tank and the center of the exit plane (geodetic head).

$\frac{P_3 - P_0}{\rho \cdot g}$

Static pressure head, this is the pressure head difference between the inlet and outlet tank.
In the case of open boxes at atmospheric pressure, the pressures P_0 and P_3 are equal and the static pressure head is zero.

$\frac{v_3^2 - v_0^2}{2 \cdot g}$

Dynamic head, this is the dynamic height due to the vertical speed difference in the two tanks.

In general, the liquid surface flow velocities v_0 and v_3 of tanks are very low and the dynamic head is considered to be zero (negligible).

$dH_{01} + dH_{23}$ Pressure loss head, this is the sum of all the head losses of the installation, suction and discharge piping.
(= resistance to flow in the pipes, valves, strainer, piping inlet and outlet, etc.).

NPSH Available of the system:

$$NPSH_a = P_1 - P_{vap}$$

By applying the extended Bernoulli equation for a real fluid, between the tank level and the pump suction flange, we obtain the following equation:

$$NPSH_a = \frac{P_0 + P_{atm} - P_{vap}}{\rho \cdot g} + \frac{v_0^2}{2 \cdot g} - dH_{01} + H_0$$

([1] equation 31)

where (as for the TDH):

$\frac{P_0 + P_{atm} - P_{vap}}{\rho \cdot g}$ Static pressure head.

$\frac{v_0^2}{2 \cdot g}$ Dynamic head.

dH_{01} Pressure loss head.

H_0 Total static head.

Hydraulic power supplied to the fluid by the pump (W):

$$Wh = TDH \cdot \rho \cdot g \cdot Q$$

Input mechanical power taken by the pump (W):

$$Wm = \frac{Wh}{\eta p}$$

Note: Pumping media which are more viscous than water will require a higher input power.

Electric power absorbed by the electric motor (W):

$$We = \frac{Wm}{\eta m}$$

Symbols, Definitions, SI Units:

Q	Volume flow rate (m^3/s)
G	Mass flow rate (kg/s)
D_1	Suction piping diameter (m)
D_2	Discharge piping diameter (m)
A_1	Suction piping cross-sectional area (m^2)
A_2	Discharge piping cross-sectional area (m^2)
v_0	Flow velocity of the liquid surface of the suction tank (m/s)
v_1	Mean velocity in suction piping (m/s)
v_2	Mean velocity in discharge piping (m/s)
v_3	Flow velocity at the outlet of the discharge pipe (m/s)
Re_1	Reynolds number in suction piping ()
Re_2	Reynolds number in discharge piping ()
r_1	Suction piping absolute roughness (m)
r_2	Discharge piping absolute roughness (m)
f_1	Darcy friction factor of the suction piping ()
f_2	Darcy friction factor of the discharge piping ()
L_1	Length of the suction pipe (m)
L_2	Length of the discharge pipe (m)
Kf_1	Coefficient of friction resistance of the suction piping ()
Kf_2	Coefficient of friction resistance of the discharge piping ()
Ks_1	Resistance coefficient of the singularities of the suction piping ()
Ks_2	Resistance coefficient of the singularities of the discharge piping ()
K_1	Total pressure loss coefficient of the suction piping ()
K_2	Total pressure loss coefficient of the discharge piping ()

dP_{01} Total pressure loss of the suction piping (Pa)

dP_{23} Total pressure loss of the discharge piping (Pa)

dH_{01} Total head loss of the suction piping (Pa)

dH_{23} Total head loss of the discharge piping (Pa)

P_0 Relative pressure on the surface of the suction tank (Pa)

P_1 Total relative pressure at the suction flange (Pa)

P_2 Total relative pressure at the discharge flange (Pa)

P_3 Relative pressure on the surface of the discharge tank (Pa)

H_1 Height difference between the fluid level of the suction tank and the suction flange (m)

H_3 Height difference between the suction flange and the center of the exit plane (m)

TDH Pump Total Dynamic Head (m)

P_{atm} Atmospheric pressure (Pa)

P_{vap} Vapour pressure of liquid at suction flange temperature (Pa)

$NPSH_a$ Net Positive Suction Head available of the system (m)

Wh Hydraulic power supplied to the fluid by the pump (W)

ηp Pump efficiency ()

Wm Input mechanical power taken by the pump (W)

ηm Electrical motor efficiency ()

We Electric power absorbed by the electric motor (W)

ρ Fluid density (kg/m^3)

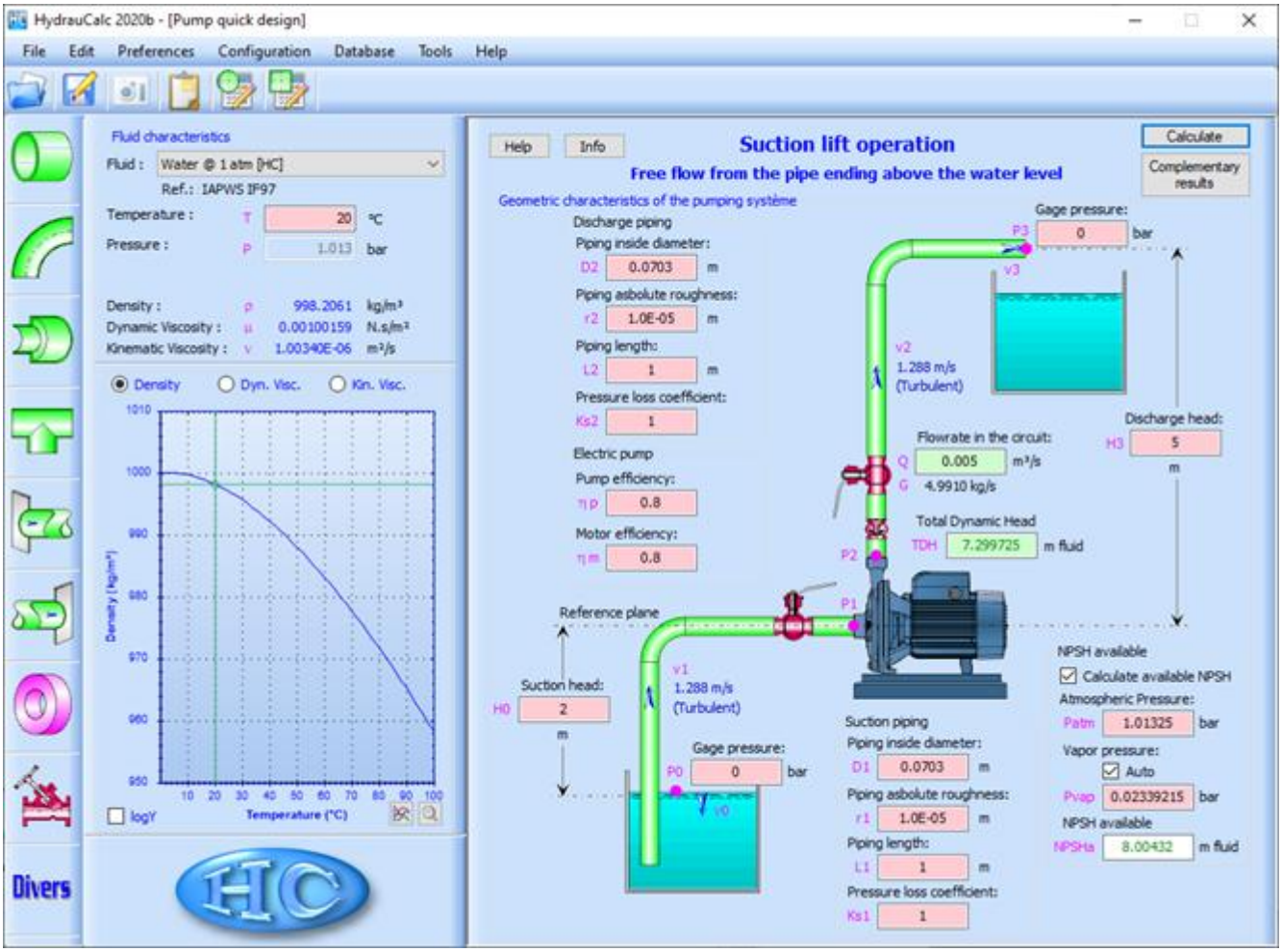
ν Fluid kinematic viscosity (m^2/s)

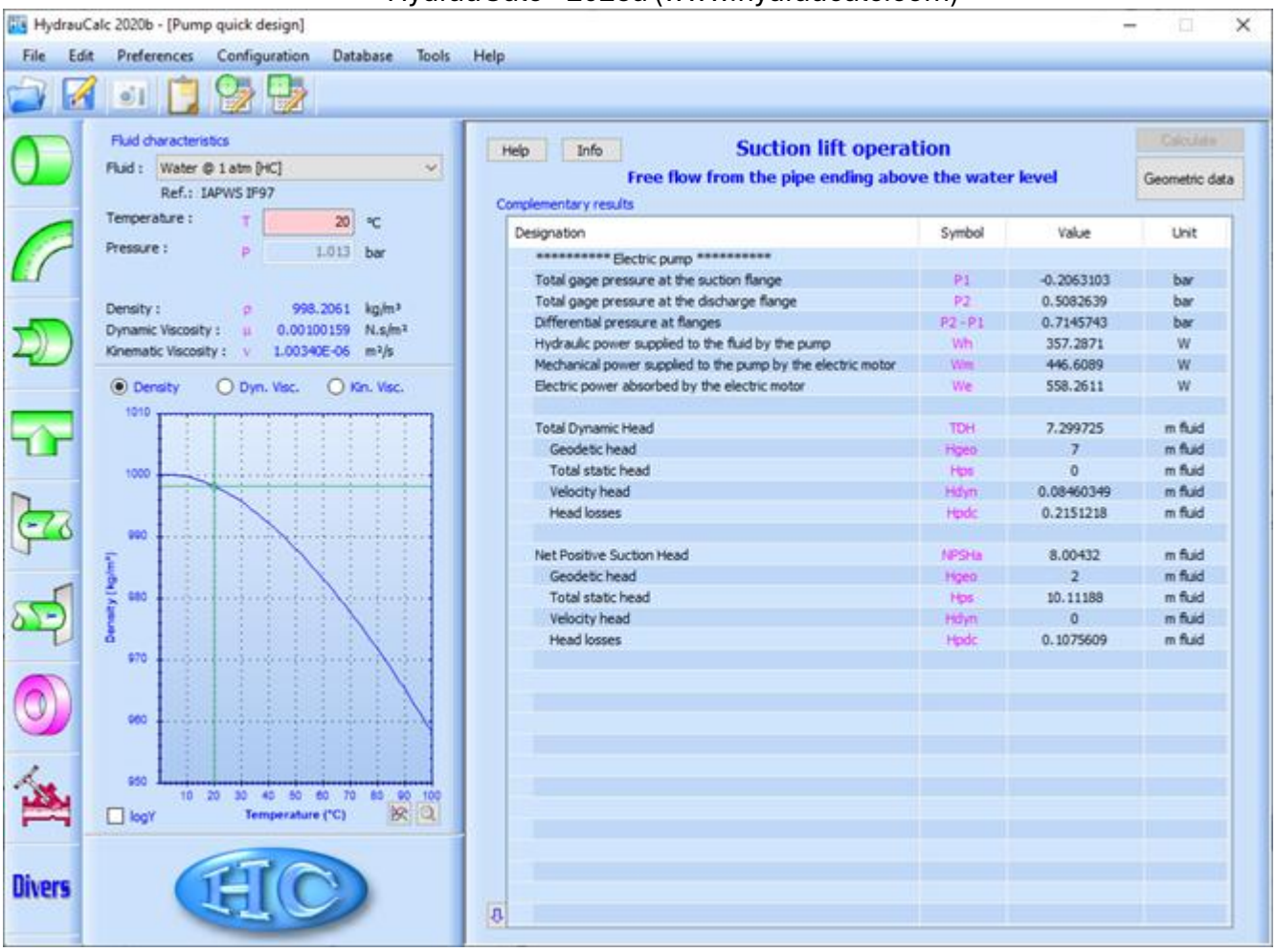
g Gravitational acceleration (9.80665 m/s^2)

Validity range:

- turbulent flow regime

Example of application:





References:

[1] KSB - Selecting Centrifugal Pumps – 4th Edition (2005)

HydrauCalc Edition: January 2021

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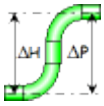
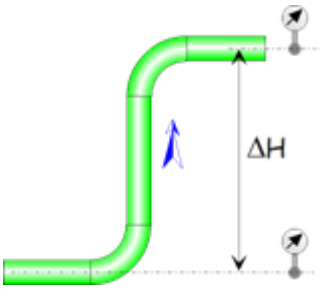
2.16 Pressures

This subsection presents the type of pressure that can be modeled and calculated.:

- Hydrostatic pressure



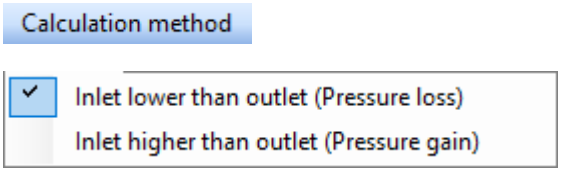
2.16.1 Hydrostatic pressure



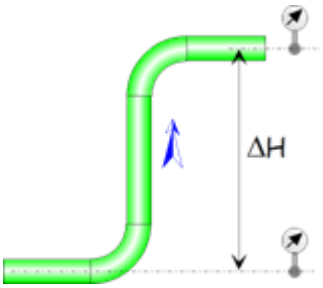
The calculation method used to calculate the pressure loss or gain due to a height difference between the inlet and outlet of a hydraulic circuit is described in the following reference document:

- VDI Heat Atlas - 2nd Ed. (2010)

Two different calculations are available. The calculation method is selected using the "Calculation Method" menu. The default option is "Inlet lower than outlet (Pressure Loss)".



2.16.1.1 Inlet lower than outlet (Pressure loss)



Model description:

The pressure variation due to a height difference between the inlet and outlet of a hydraulic circuit is governed by the principles of hydrostatic pressure. This pressure variation is caused by gravity and the height difference.

When the circuit inlet is lower than the outlet, the outlet pressure decreases, which is a pressure loss.

Model formulation:

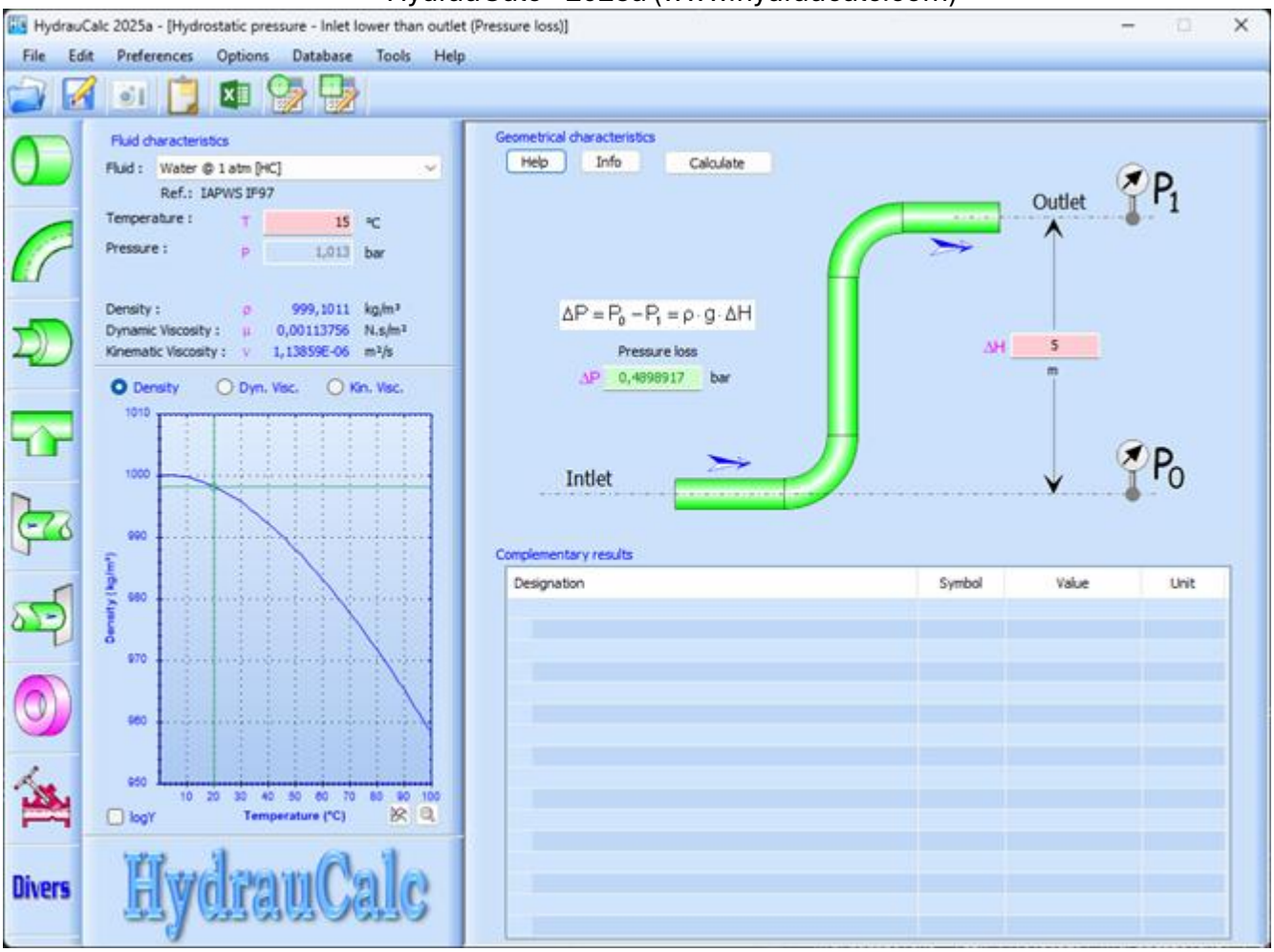
Hydrostatic pressure loss (Pa):

$$\Delta P = \rho \cdot g \cdot \Delta H$$

Symbols, Definitions, SI Units:

ΔP	Hydrostatic pressure gain (Pa)
ρ	Fluid density (kg/m³)
g	Gravitational acceleration (m/s²)
ΔH	Height difference (m)

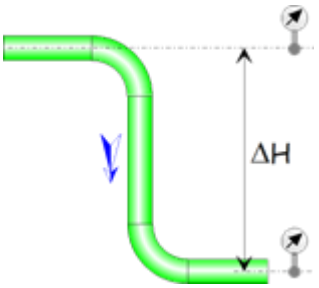
Example of application:



References:

[1] VDI Heat Atlas - 2nd Ed. (2010)

2.16.1.2 Inlet higher than outlet (Pressure gain)



Model description:

The pressure variation due to a height difference between the inlet and outlet of a hydraulic circuit is governed by the principles of hydrostatic pressure. This pressure variation is caused by gravity and the height difference.

When the circuit inlet is higher than the outlet, the outlet pressure increases, which is a pressure gain.

Model formulation:

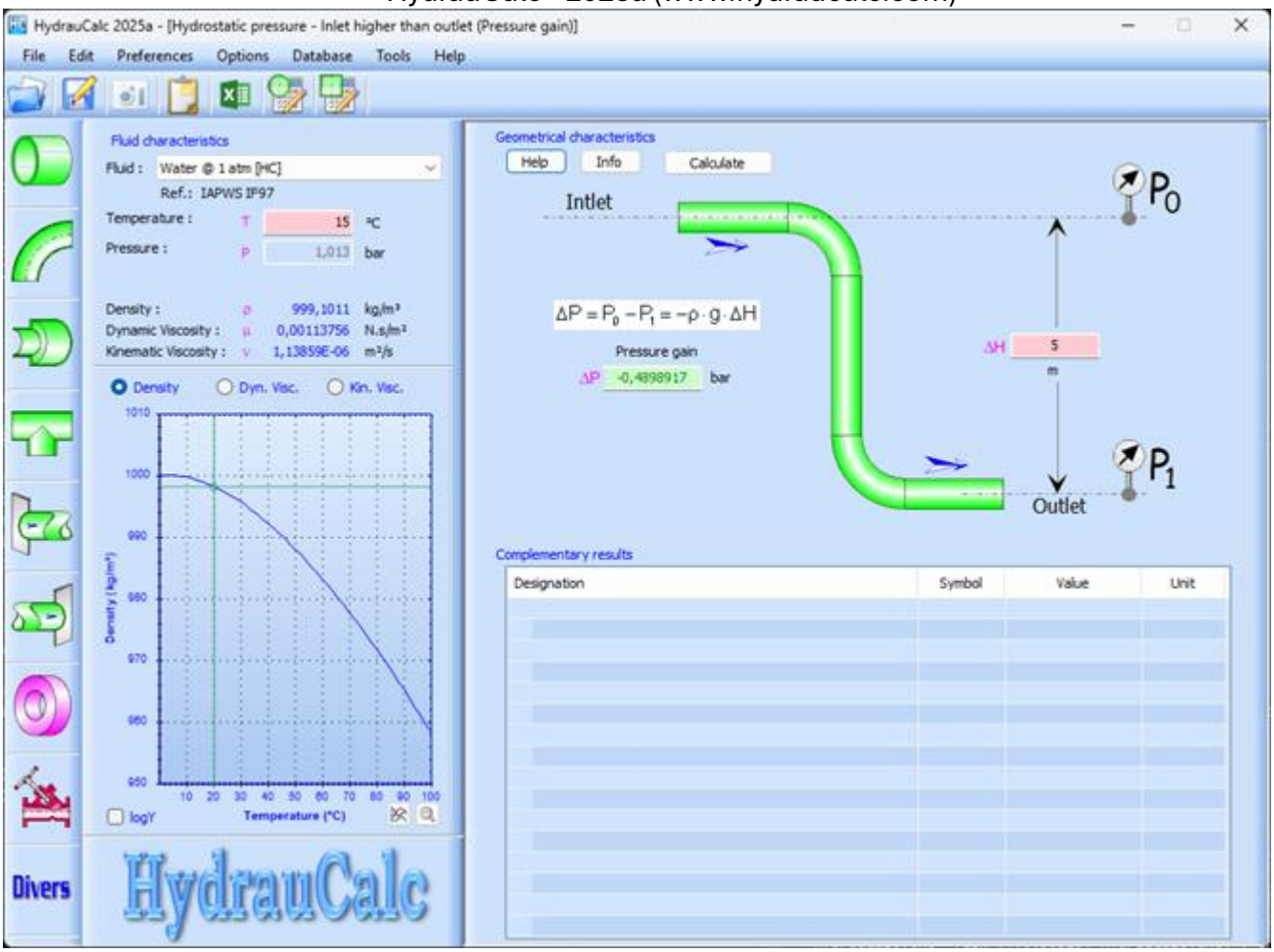
Hydrostatic pressure gain (Pa):

$$\Delta P = -\rho \cdot g \cdot \Delta H$$

Symbols, Definitions, SI Units:

ΔP	Hydrostatic pressure gain (Pa)
ρ	Fluid density (kg/m³)
g	Gravitational acceleration (m/s²)
ΔH	Height difference (m)

Example of application:



References:

[1] VDI Heat Atlas - 2nd Ed. (2010)