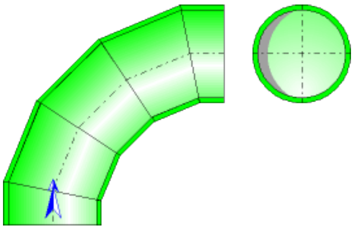
Composite Bend 90° (4 x 22.5°)
Circular Cross-Section
(IDELCHIK)



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 (m³):

$$V = F_0 \cdot l$$

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

- $R_0/D_0 > 0.55$

$\bar{\Delta}$		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	$\lambda_\Delta / \lambda_{sm}$	$1 + 10^3 \cdot \bar{\Delta}$
> 0.001	1.0	2.0	2.0

with:

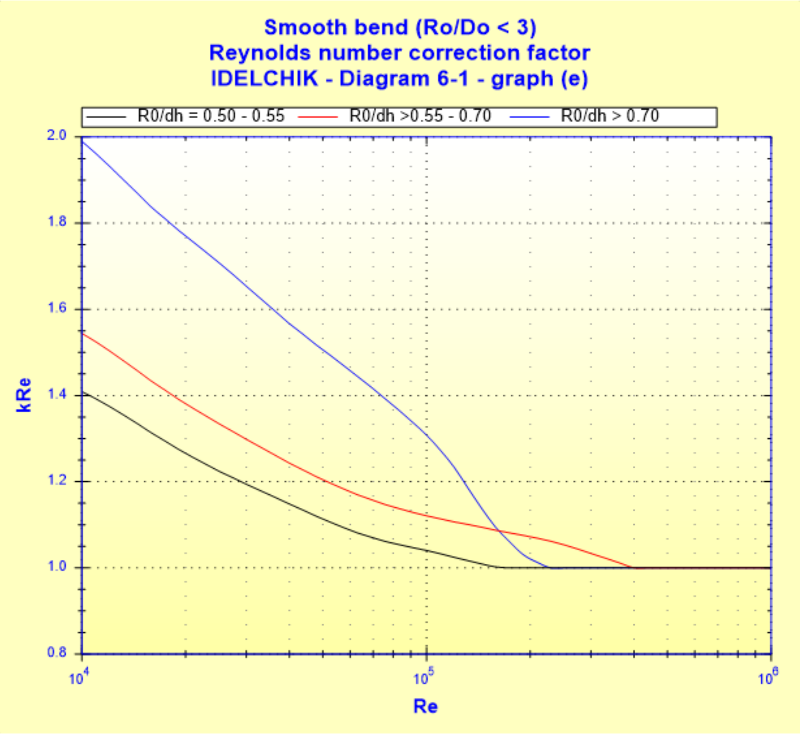
λ_{sm} : Darcy friction factor for hydraulically smooth pipe ($\bar{\Delta}$ = 0) at Re

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

Coefficient of effect of the Reynolds number ($Re \ge 10^4$):

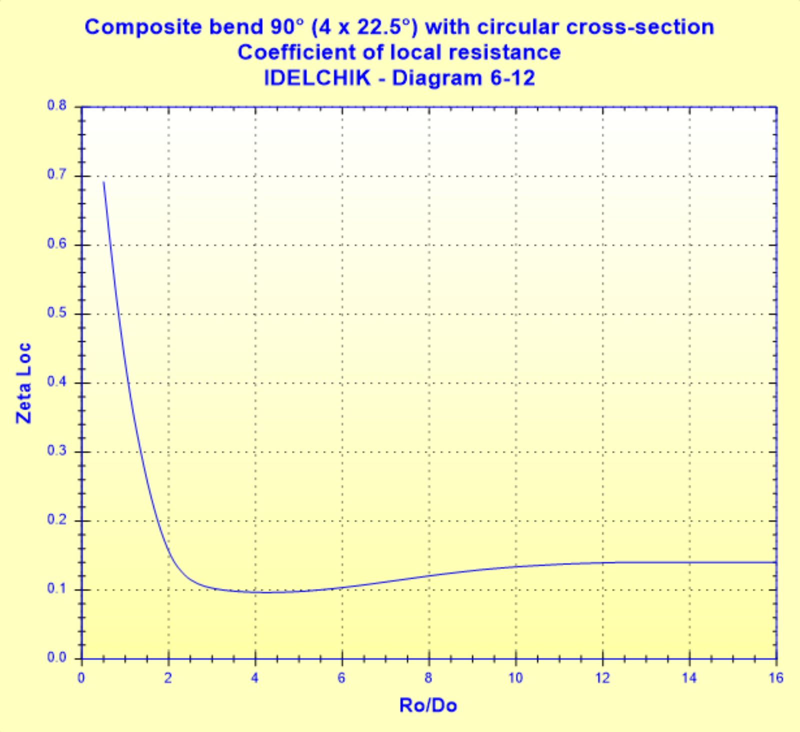
$$k_{Re} = f\left(Re, \frac{R_0}{D_h}\right)$$

([1] diagram 6.1)



Coefficient of local resistance:

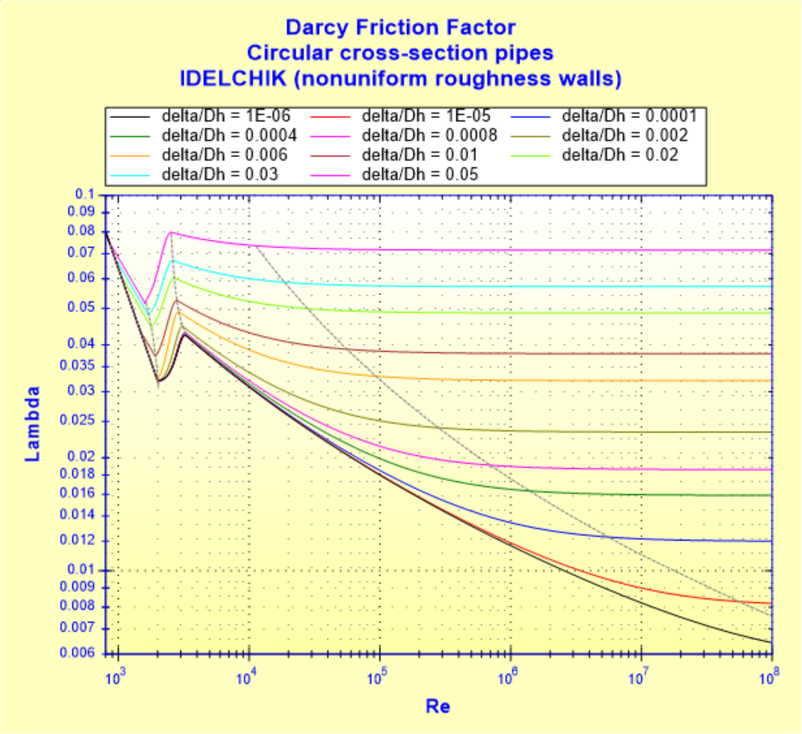
$$\zeta_{loc} = f\left(\frac{R_0}{D_0}\right)$$ ([1] diagram 6.12)



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)

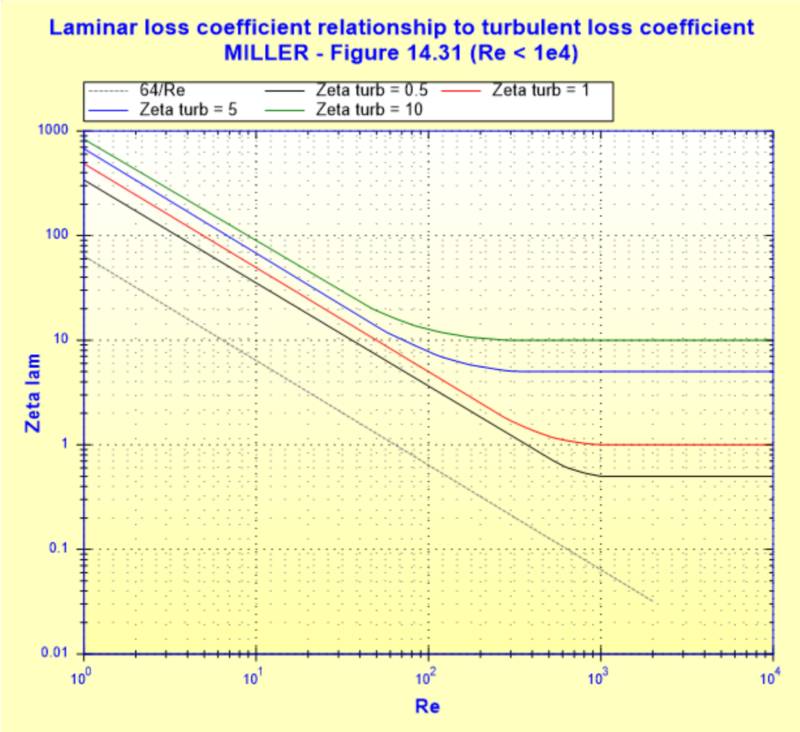
$$\zeta_{turb} = k_{\Delta} \cdot k_{Re} \cdot \zeta_{loc}$$ ([1] diagram 6.12)

- 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)
$\overline{\Delta}$	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
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)

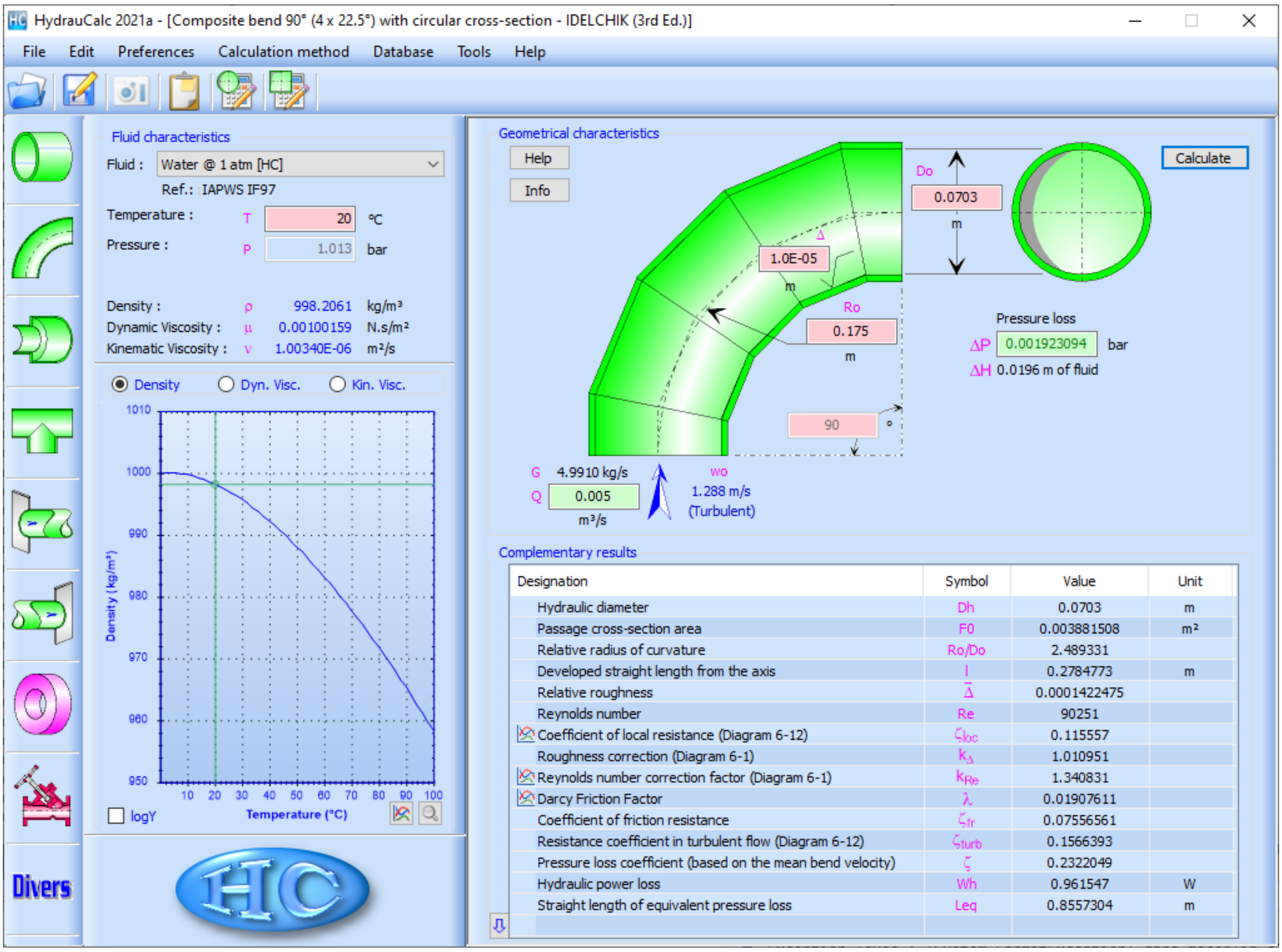
Validity range:

- 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