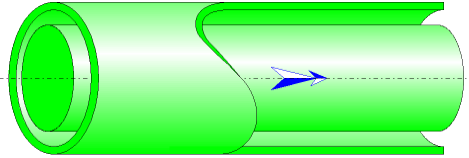




Straight Pipe Annular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



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 (m²):

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

Mean velocity (m/s):

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

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m³):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

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

Relative roughness:

$$\frac{\Delta}{D_h}$$

Relative eccentricity:

$$\frac{e}{D_0 - d}$$

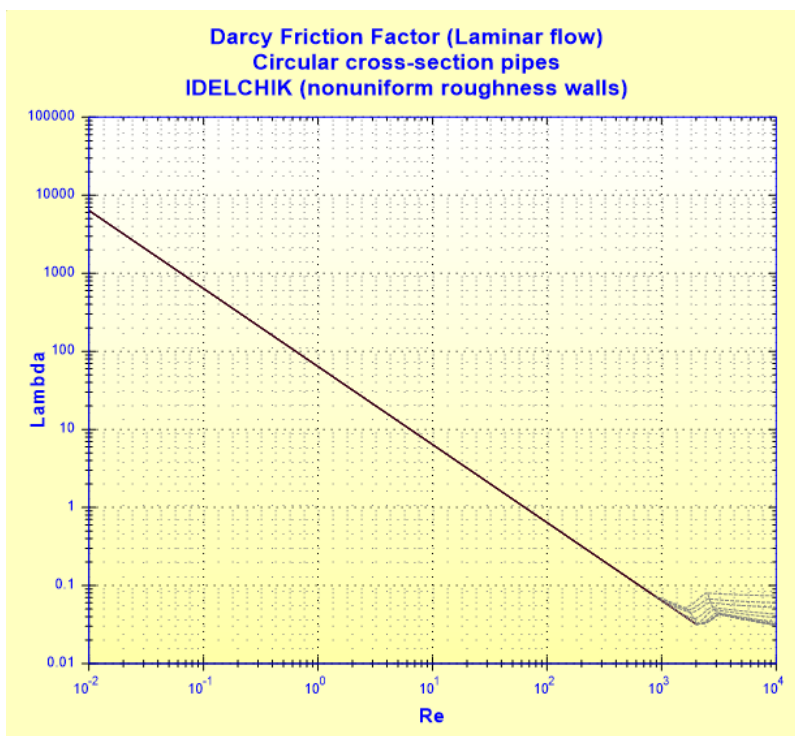
Darcy friction factor for circular cross-section:

- 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

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

([1] diagram 2.4)

Reynolds number at which pipe cease to be hydraulically smooth:

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

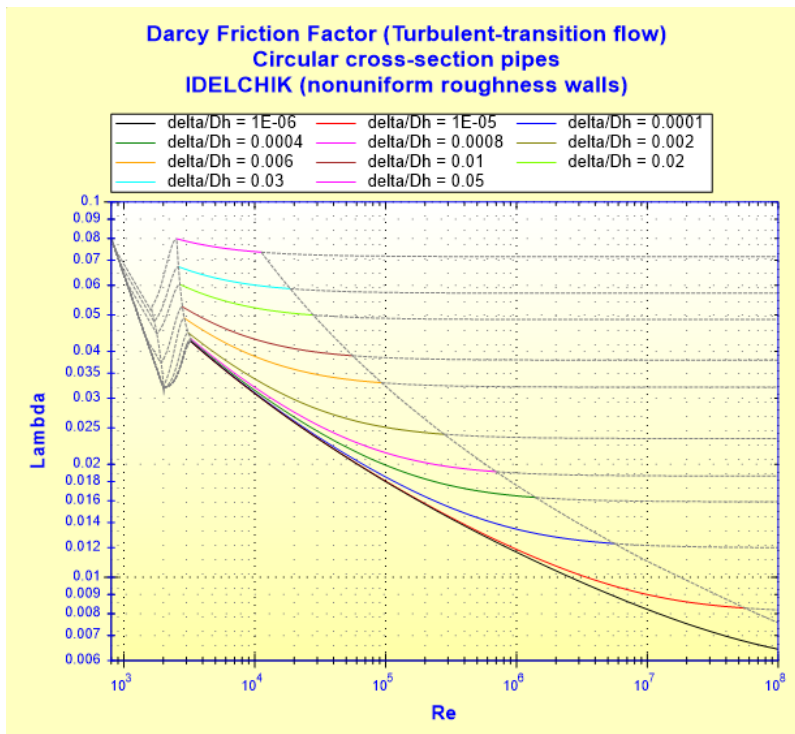
([1] §2.23)

Reynolds number corresponding to the beginning of complete turbulence:

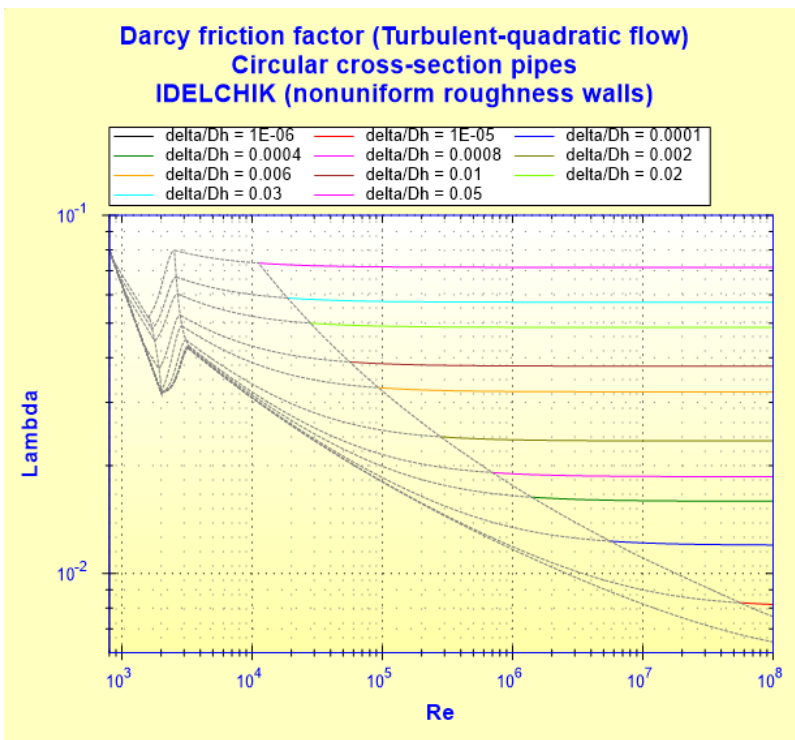
$$Re''_{lim} = \frac{560}{\bar{\Delta}}$$

([1] diagram 2.4)

Transition region



Complete turbulence region



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

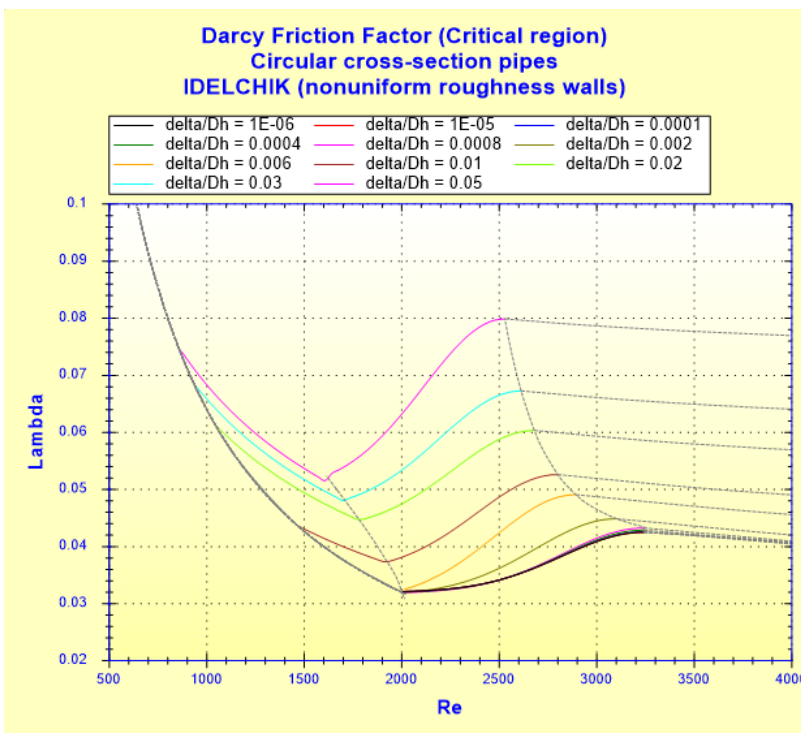
$$\lambda_{circ} = f(Re, \Delta) \quad ([1] \text{ diagram 2.3})$$

Reynolds number of start of critical zone:

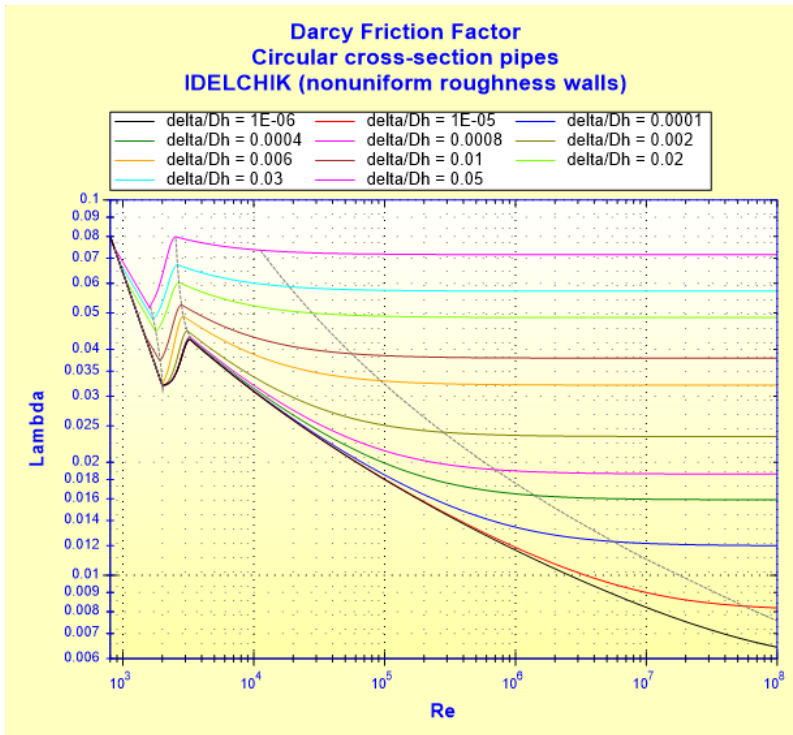
$$Re_0 = 754 \exp\left(\frac{0.0065}{\Delta}\right) \quad ([1] \text{ §2.21})$$

Reynolds number at end of critical zone:

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



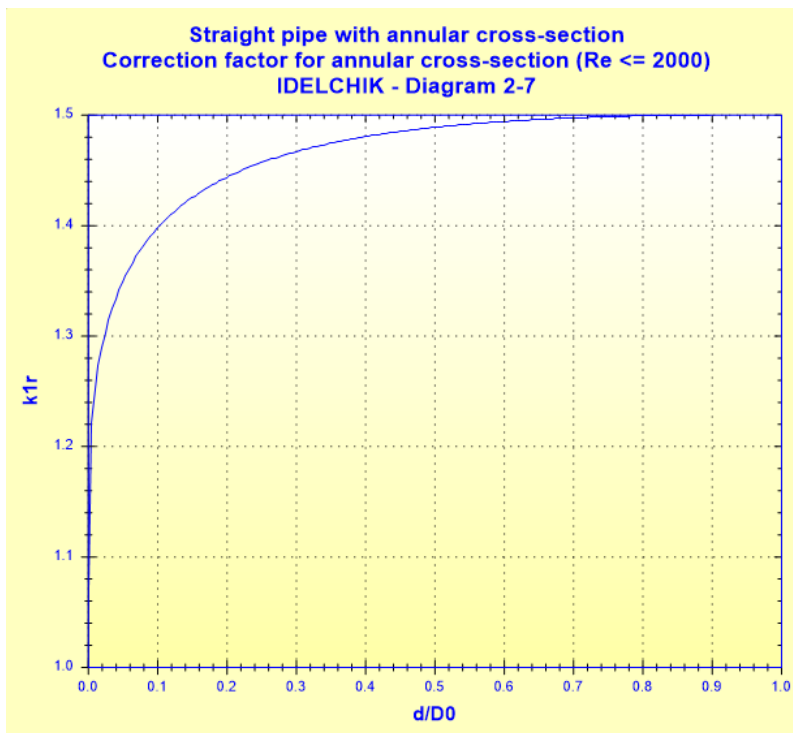
- all flow regimes:



Correction for Darcy friction factor for annular cross-section:

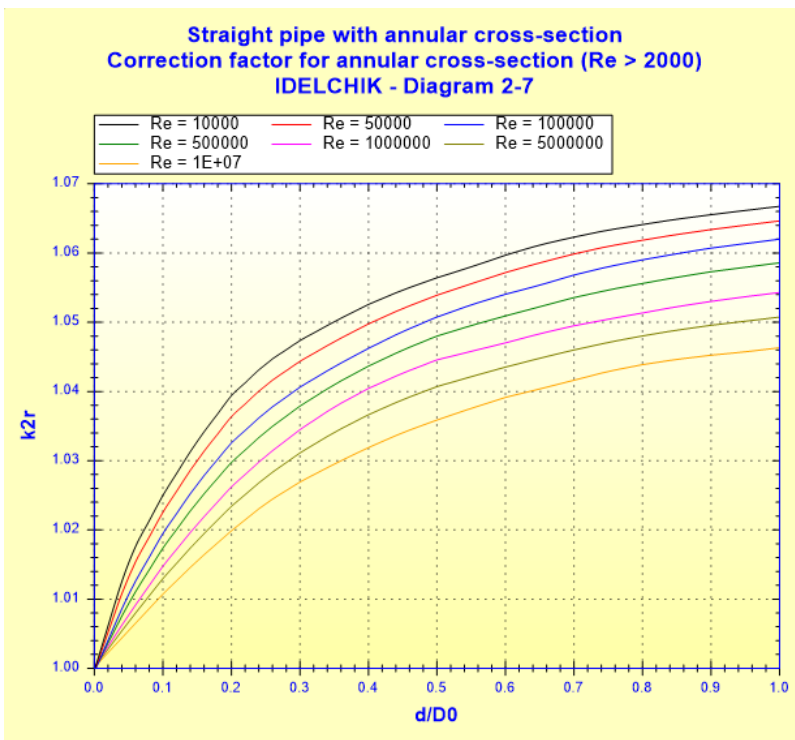
- laminar flow ($Re \leq 2000$):

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



- turbulent flow ($Re > 2000$):

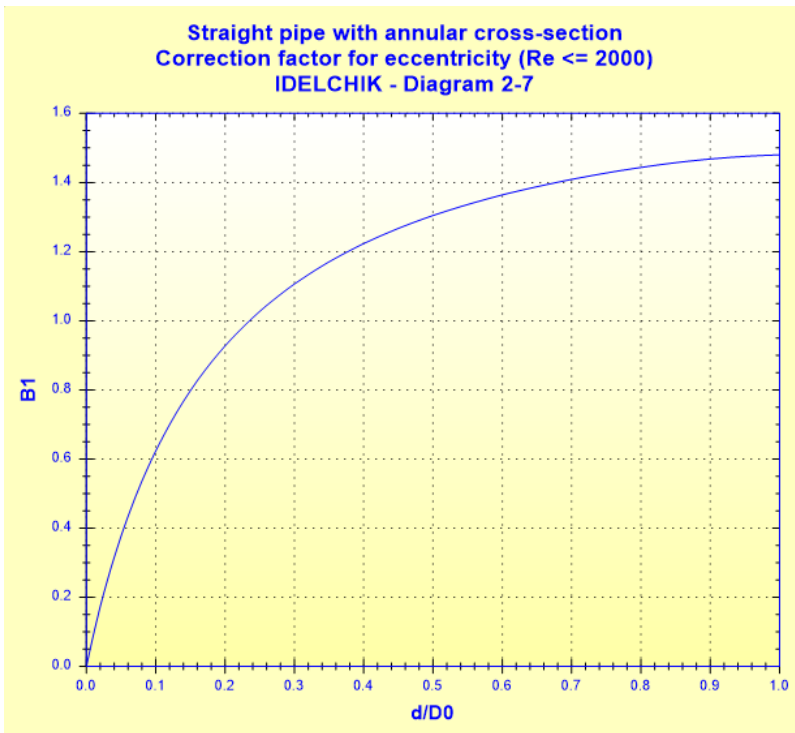
$$k_{2r} = f(d/D_0, Re) \quad ([1] \text{ diagram 2.7})$$



Correction for Darcy friction factor for axis eccentricity:

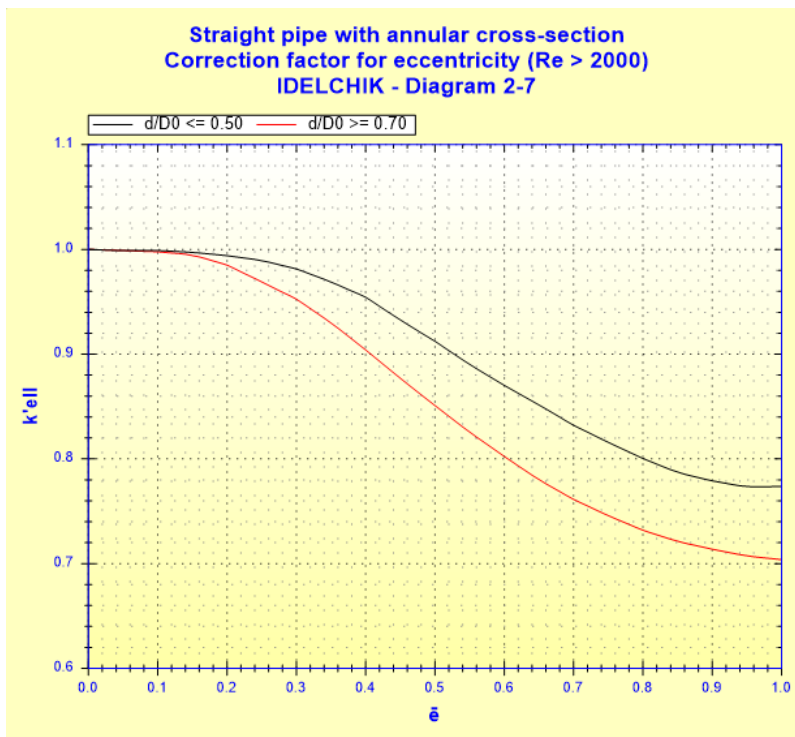
■ laminar flow (Re ≤ 2000):

$$B_1 = f(d/D_0) \quad ([1] \text{ diagram 2.7})$$



■ turbulent flow (Re > 2000):

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



Darcy friction factor for annular cross-section:

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

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

- 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 ($Re \leq 2000$):

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

- turbulent flow ($Re > 2000$):

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

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

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

Total pressure loss (Pa):

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

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:

HydrauCalc 2019b - [Straight pipe annular cross-section and nonuniform roughness walls - IDELCHIK (3rd Ed.)]

File Edit Preferences Calculation method Database Tools Help

Fluid characteristics

Fluid: Water @ 1 atm [HC]
Ref.: IAPWS IF97

Temperature: T 20 °C
Pressure: P 1.013 bar

Density: ρ 998.2061 kg/m³
Dynamic Viscosity: μ 0.00100159 N.s/m²
Kinematic Viscosity: ν 1.00340E-06 m²/s

Density Dyn. Visc. Kin. Visc.

Geometrical characteristics

Help Info Moody Chart Calculate

Pressure loss ΔP 0.01793669 bar
 ΔH 0.1832 m of fluid

Complementary results

Designation	Symbol	Value	Unit
Hydraulic diameter	Dh	0.0272	m
Annulus cross-section area	F0	0.002422545	m ²
Annulus volume	V	0.002422545	m ³
Mass of fluid in the annulus	M	2.418199	kg
Diameters ratio	d/D0	0.6130868	
Relative roughness	Δ	0.0003676471	
Relative eccentricity	e	0	
Reynolds number	Re	55949.25	
<input checked="" type="checkbox"/> Friction factor for circular cross-section	λ_{circ}	0.02170587	
<input checked="" type="checkbox"/> Correction factor for annular cross-section (Diag 2-7)	k2r	1.057176	
<input checked="" type="checkbox"/> Correction factor for eccentricity (Diag 2-7)	k'ell	1	
Friction factor for annular cross-section	λ_{annu}	0.02294693	
Pressure loss per length unit		0.01793669	bar/m
Pressure loss coefficient (based on the mean pipe velocity)	ζ	0.8436373	
Hydraulic power loss	Wh	8.968347	W

References:

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

HydrauCalc

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