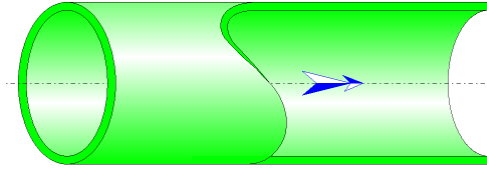




Straight Pipe Circular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



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 (m²):

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

Mean velocity (m/s):

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

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (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:

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

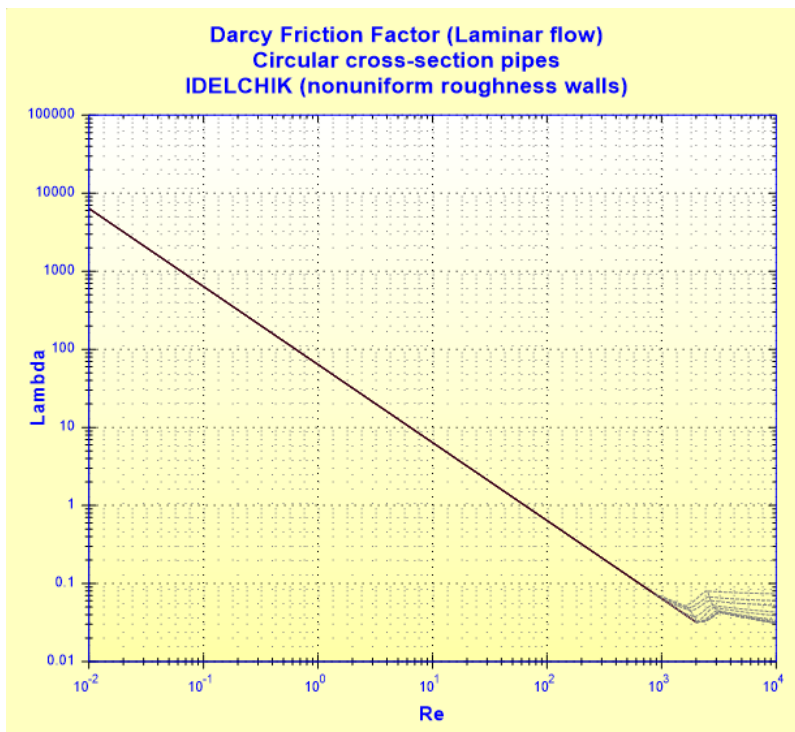
Darcy friction factor:

- 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

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

([1] diagram 2.4)

Reynolds number at which pipe cease to be hydraulically smooth:

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

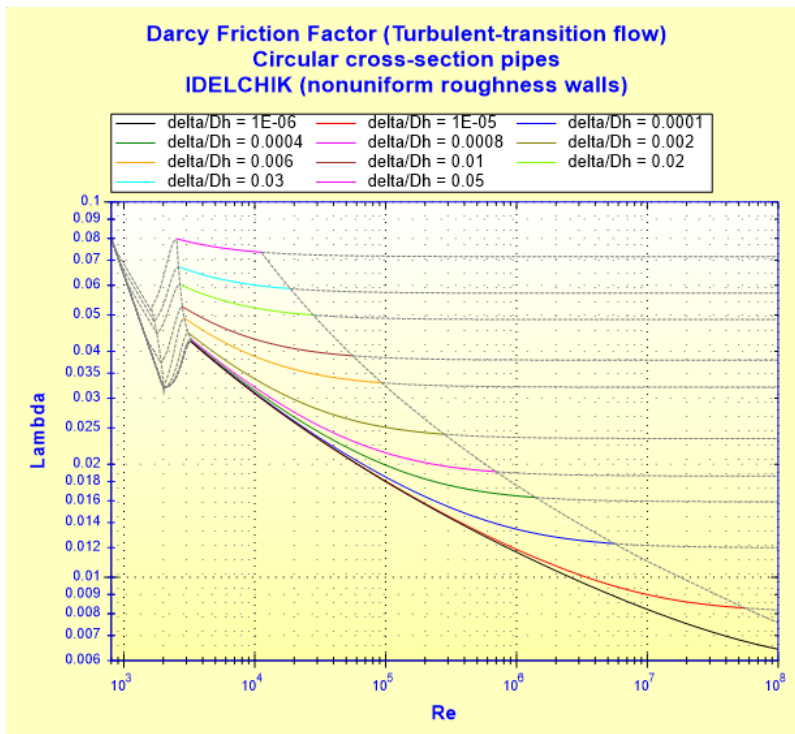
([1] §2.23)

Reynolds number corresponding to the beginning of complete turbulence:

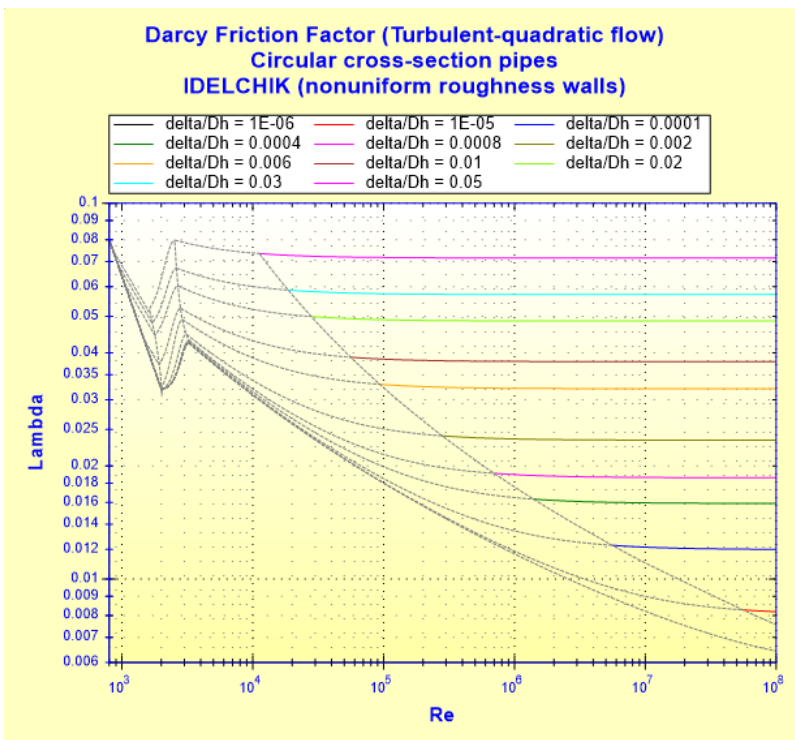
$$\text{Re}''_{\text{lim}} = \frac{560}{\bar{\Delta}}$$

([1] diagram 2.4)

Transition region



Complete turbulence region



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

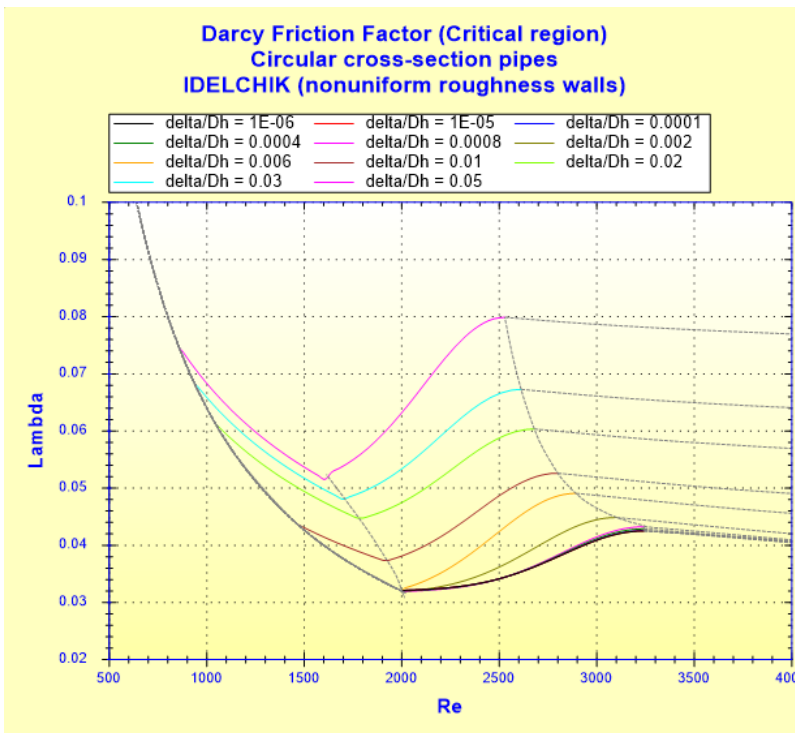
$$\lambda = f(Re, \bar{\Delta}) \quad ([1] \text{ diagram 2.3})$$

Reynolds number of start of critical zone:

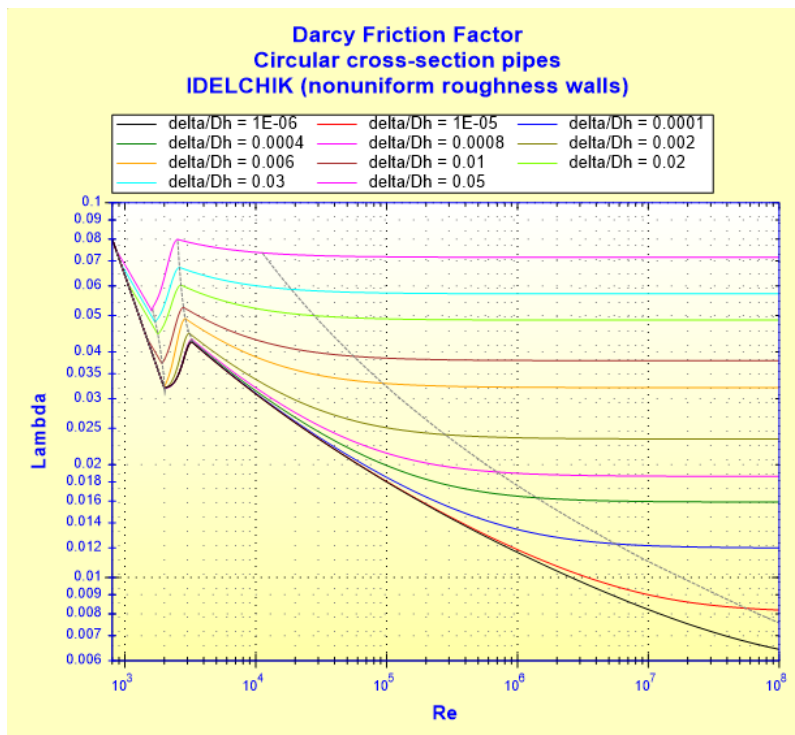
$$Re_0 = 754 \exp\left(\frac{0.0065}{\bar{\Delta}}\right) \quad ([1] \text{ §2.21})$$

Reynolds number at end of critical zone:

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



■ all flow regimes:



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

$$\zeta = \lambda \cdot \frac{l}{D_h} \quad ([1] \text{ equation 2-2})$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot w_0^2}{2} \quad ([1] \text{ equation 2-2})$$

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:

The screenshot shows the HydraCalc 2016a software interface. The main window is titled "HydraCalc 2016a - [Straight pipe circular cross-section and nonuniform roughness walls (IDELCHIK)]". The interface is divided into several sections:

- Fluid characteristics:**
 - Fluid: Water @ 1 atm
 - Ref.: IAPWS IF97
 - Temperature: T = 20 °C
 - Pressure: P = 1.013 bar
 - Density: $\rho = 998.2061$ kg/m³
 - Dynamic viscosity: $\mu = 0.00100159$ N.s/m²
 - Kinematic viscosity: $\nu = 1.00340E-06$ m²/s
 - Selected: Density (radio button)
- Geometrical characteristics:**
 - Help, Info, Moody Chart, Calculate buttons
 - Diagram of a pipe with a roughness profile. Parameters shown:
 - Flow rate: 4.9910 kg/s
 - Volume flow rate: 0.005 m³/s
 - Mean velocity: $w_0 = 1.288$ m/s (Turbulent)
 - Relative roughness: $\bar{\Delta} = 1.0E-05$
 - Length: $l = 1$ m
 - Pressure loss: $\Delta P = 0.002247313$ bar
 - Head loss: $\Delta H = 0.0230$ m of fluid
 - Hydraulic diameter: $D_0 = 0.0703$ m
- Complementary results:**

Designation	Symbol	Value	Unit
Hydraulic diameter	D_h	0.0703	m
Pipe cross-section area	F_0	0.003881508	m ²
Internal pipe volume	V	0.003881508	m ³
Mass of fluid in the pipe	M	3.874545	kg
'Length / Diameter' ratio	l/D_0	14.22475	
Relative roughness	$\bar{\Delta}$	0.0001422475	
Reynolds number	Re	90251	
Friction factor	λ	0.01907611	
Pressure loss per length unit		0.002247313	bar/m
Pressure loss coefficient (based on the mean pipe velocity)	ζ	0.2713529	
Hydraulic power loss	Wh	1.123657	W

References:

