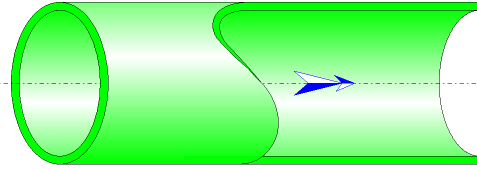




## Straight Pipe Circular Cross-Section and Uniform Roughness Walls (IDELCHIK)



### 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:

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Hydraulic diameter (m):

$$D_h = D_0$$

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Cross-section area (m<sup>2</sup>):

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

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Mean velocity (m/s):

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

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Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume in the pipe (m<sup>3</sup>):

$$V = F_0 \cdot l$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

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

Relative roughness:

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

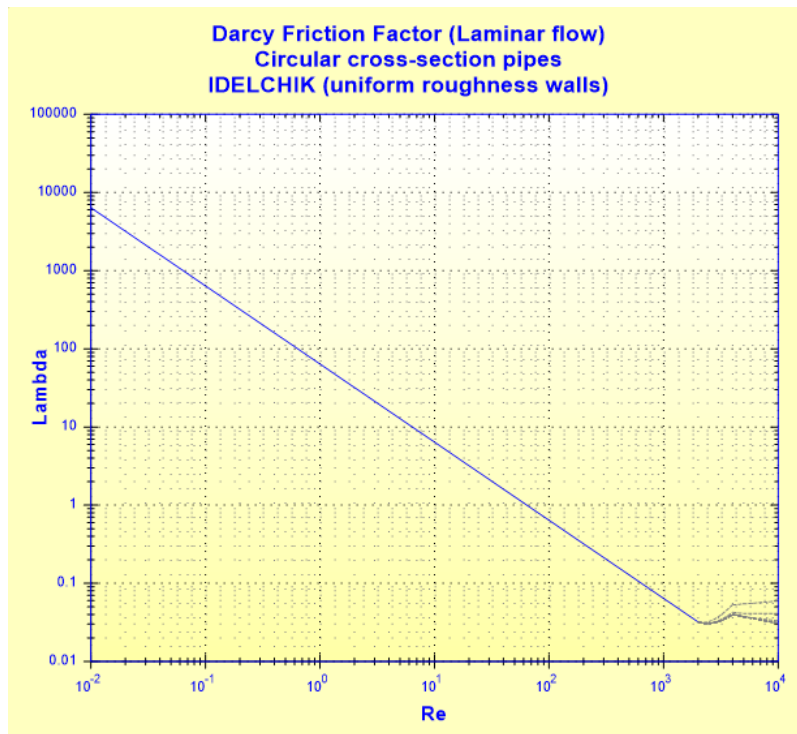
Darcy friction factor:

- laminar flow regime (Re ≤ 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

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

([1] diagram 2.2)

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

$\bar{\Delta} \cdot \text{Re} \cdot \sqrt{\lambda}$	$a_1$	$b_1$	$c_1$
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:

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

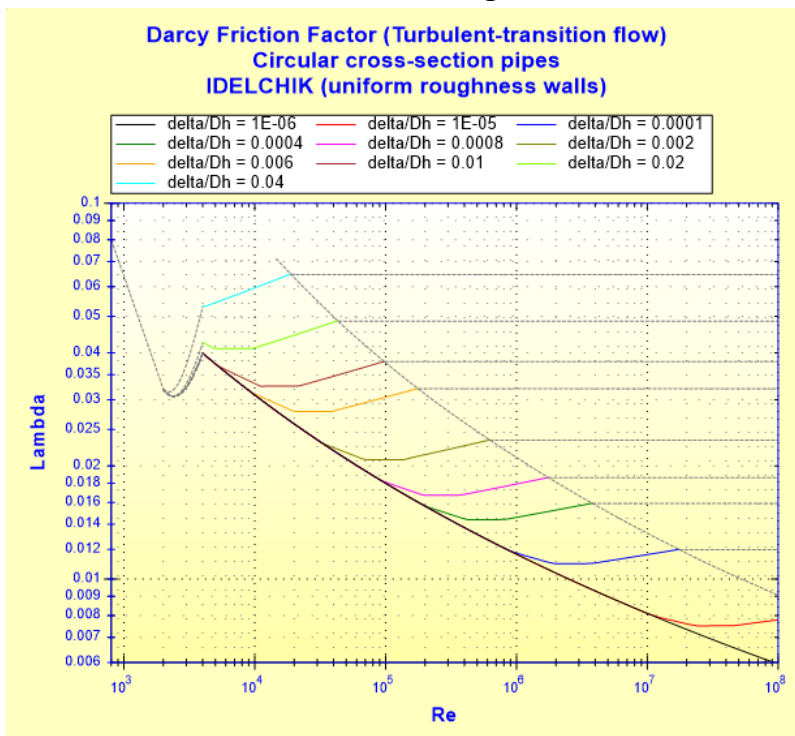
([1] §2.17)

Reynolds number corresponding to the beginning of complete turbulence:

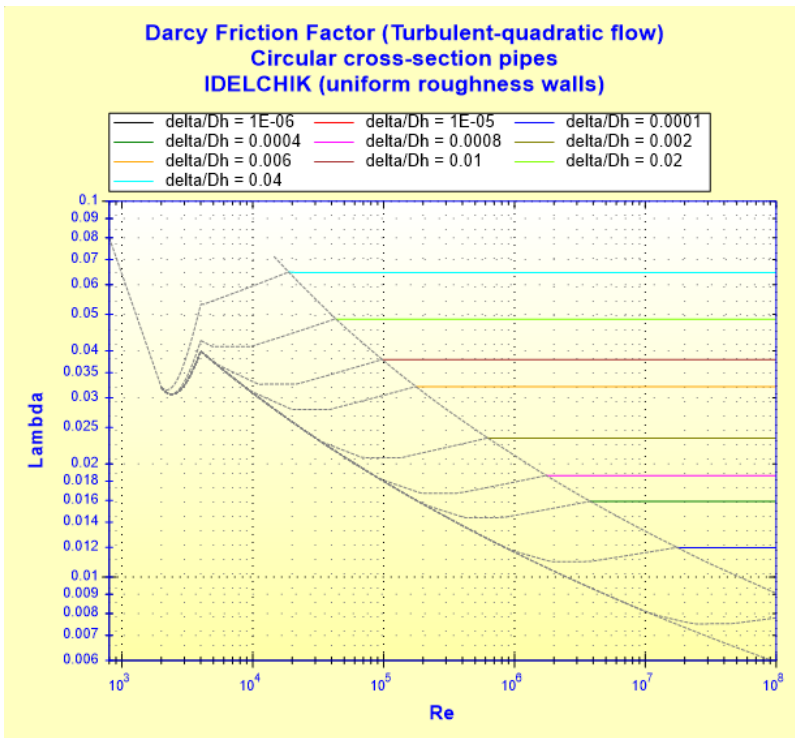
$$\text{Re}''_{\text{lim}} = \frac{217.6 - 382.4 \cdot \log(\bar{\Delta})}{\bar{\Delta}}$$

([1] diagram 2.2)

### Transition region



### Complete turbulence region



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

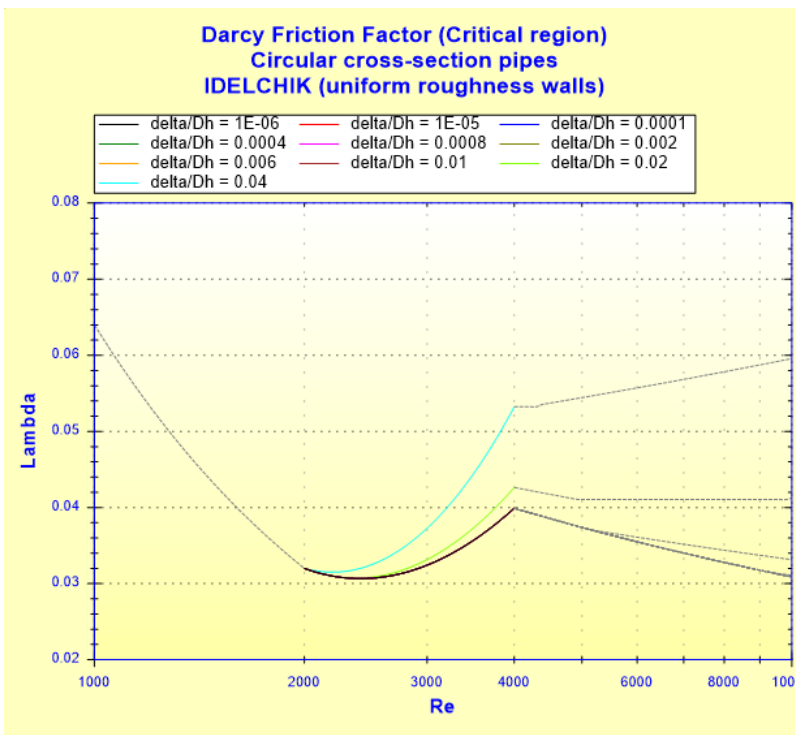
linear interpolation

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

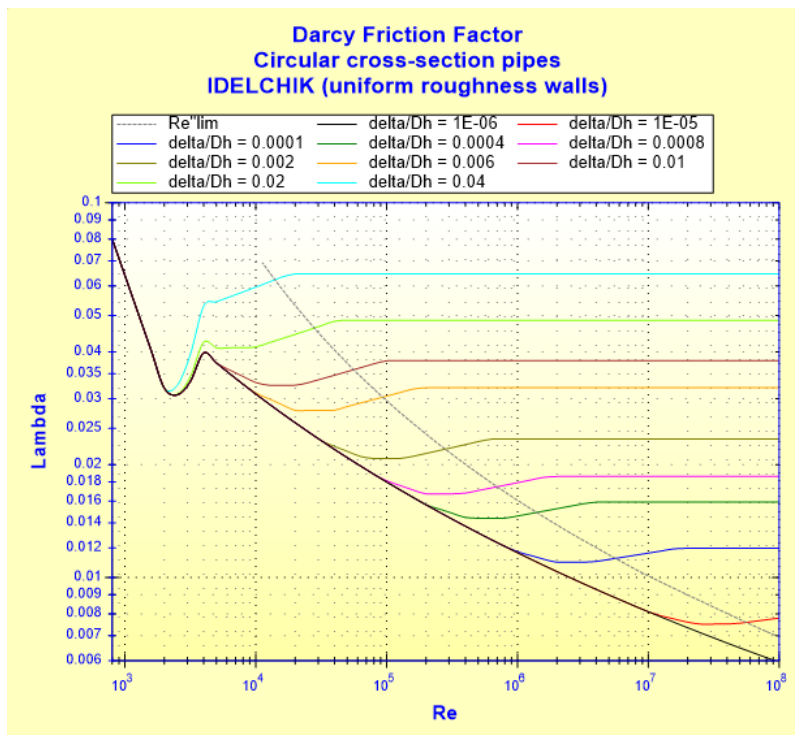
with:

$\lambda_L$  = laminar friction coefficient obtained with  $Re = 2000$

$\lambda_T$  = turbulent friction coefficient obtained with  $Re = 4000$



■ all flow regimes:



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

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

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 <sup>2</sup> )
$Q$	Volume flow rate (m <sup>3</sup> /s)
$G$	Mass flow rate (kg/s)
$w_0$	Mean velocity (m/s)
$l$	Pipe length (m)
$V$	Fluid volume in the pipe (m <sup>3</sup> )
$M$	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 ( )
$\Delta$	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ( )
$\lambda$	Darcy friction factor ( )
$\zeta$	Pressure loss coefficient (based on the mean pipe velocity) ( )
$\Delta P$	Total pressure loss (Pa)
$\Delta H$	Total head loss of fluid (m)
$Wh$	Hydraulic power loss (W)
$\rho$	Fluid density ( $kg/m^3$ )
$\nu$	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:

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

- Fluid characteristics:**
  - Fluid: Water @ 1 atm
  - Temperature: 20 °C
  - Pressure: 1.013 bar
  - Density: 998.2061  $kg/m^3$
  - Dynamic viscosity: 0.00100159  $N.s/m^2$
  - Kinematic viscosity: 1.00340E-06  $m^2/s$
- Geometrical characteristics:**
  - Length (l): 1 m
  - Hydraulic diameter (Dh): 0.0703 m
  - Mass flow rate (G): 4.9910  $kg/s$
  - Volume flow rate (Q): 0.005  $m^3/s$
  - Mean velocity (w0): 1.288  $m/s$  (Turbulent)
  - Relative roughness ( $\bar{\Delta}$ ): 1.0E-05
  - Pressure loss ( $\Delta P$ ): 0.002165757 bar
  - Head loss ( $\Delta H$ ): 0.0221 m of fluid
- Complementary results:**

Designation	Symbol	Value	Unit
Hydraulic diameter	Dh	0.0703	m
Pipe cross-section area	F0	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/D0	14.22475	
Relative roughness	$\bar{\Delta}$	0.0001422475	
Reynolds number	Re	90251	
Friction factor	$\lambda$	0.01838383	
Pressure loss per length unit		0.002165757	bar/m
Pressure loss coefficient (based on the mean pipe velocity)	$\zeta$	0.2615054	
Hydraulic power loss	Wh	1.082879	W

### References:

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

