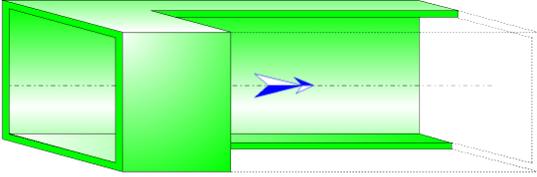




## Straight Pipe Rectangular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



### 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:

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Hydraulic diameter (m):

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

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

$$F_0 = a_0 \cdot b_0$$

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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:

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

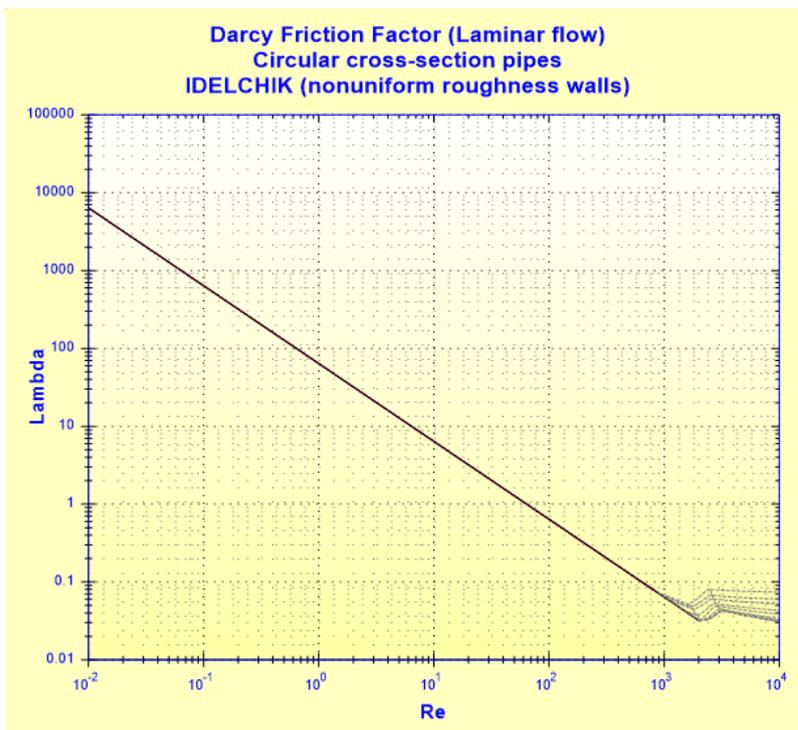
Darcy friction factor for circular cross-section:

- 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:

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

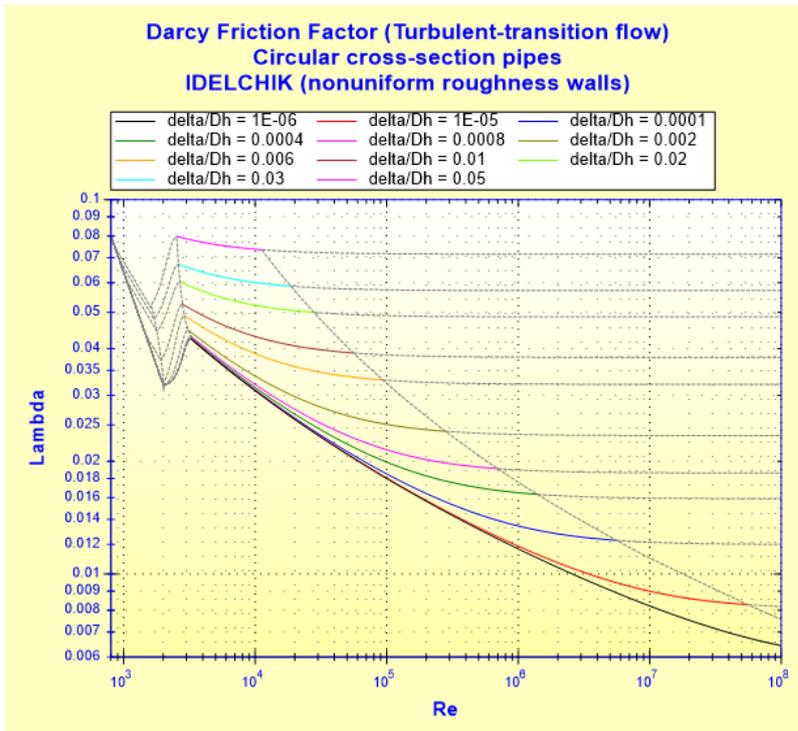
([1] §2.23)

Reynolds number corresponding to the beginning of complete turbulence:

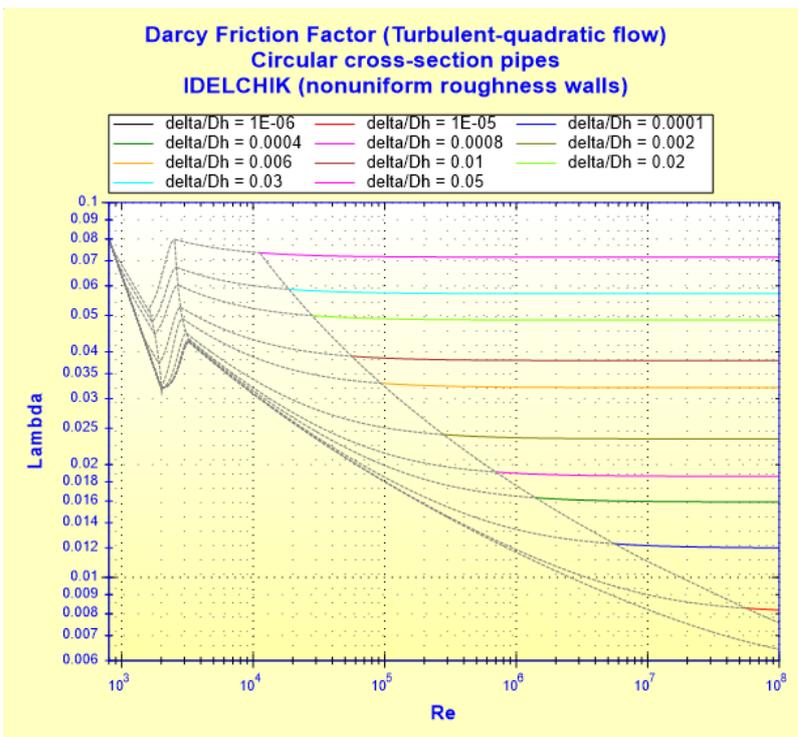
$$\text{Re}''_{\text{lim}} = \frac{560}{\bar{\Delta}}$$

([1] diagram 2.4)

Transition region



Complete turbulence region



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

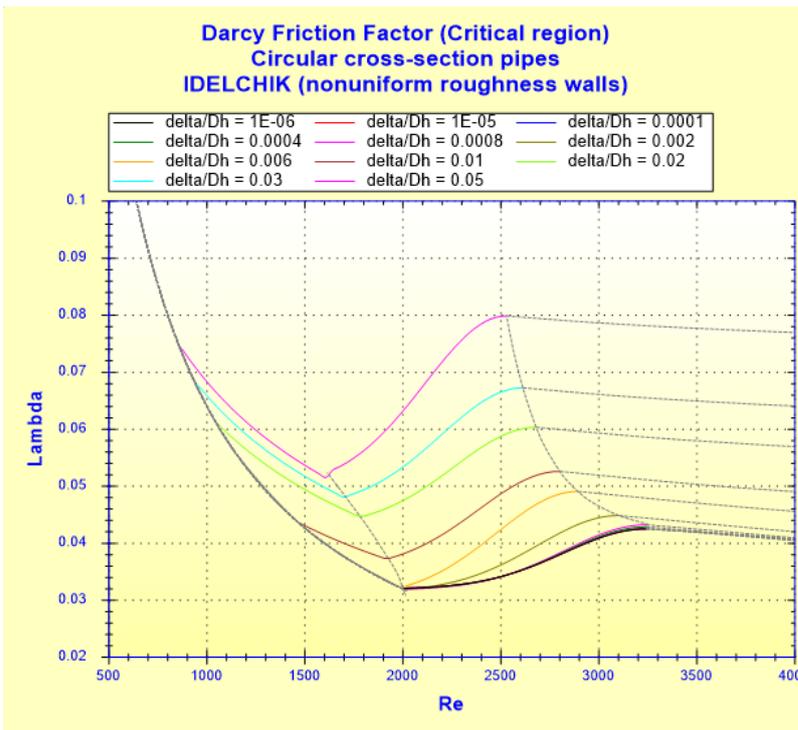
$$\lambda = f(Re, \bar{\Delta}) \quad ([1] \text{ diagram 2.3})$$

Reynolds number of start of critical zone:

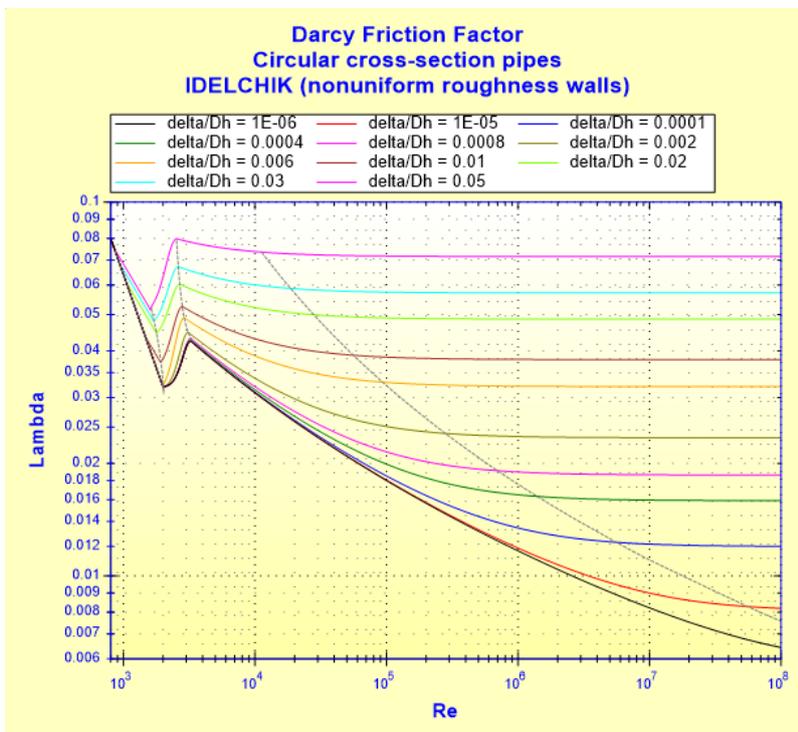
$$Re_0 = 754 \exp\left(\frac{0.0065}{\bar{\Delta}}\right) \quad ([1] \text{ §2.21})$$

Reynolds number at end of critical zone:

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



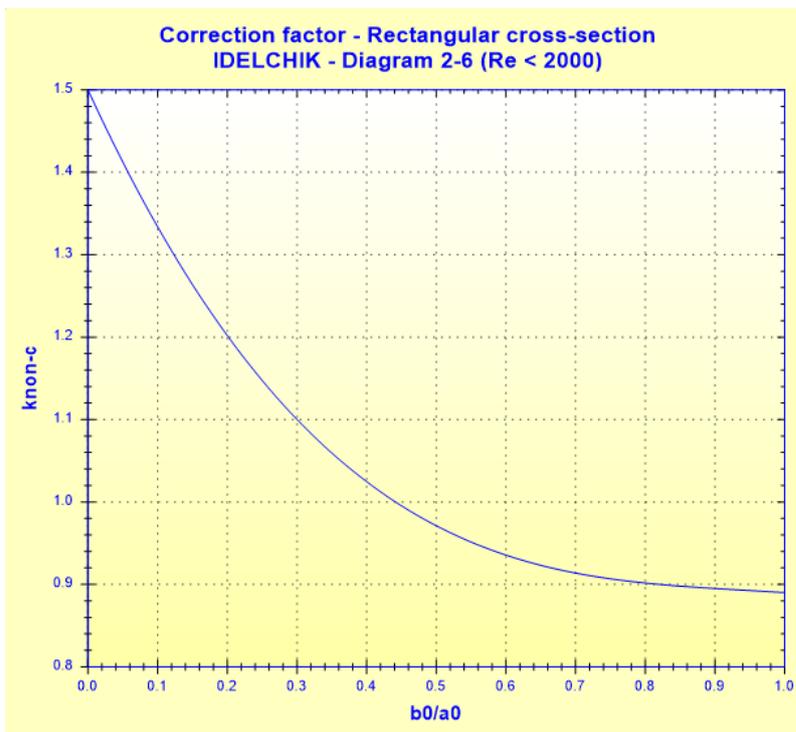
■ all flow regimes:



Correction for Darcy friction factor for noncircular cross-section:

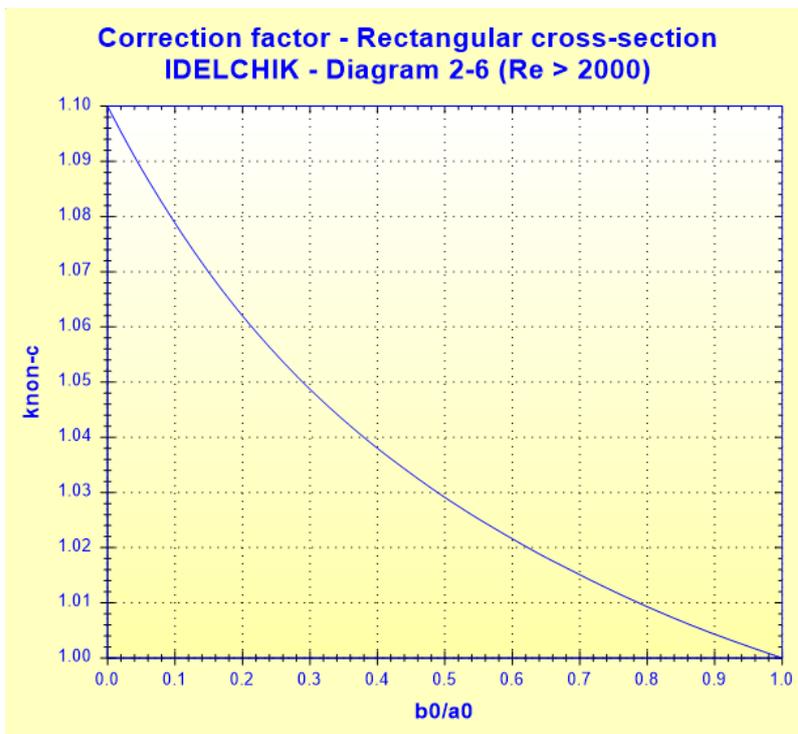
- laminar flow ( $Re \leq 2000$ ):

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



- turbulent flow ( $Re > 2000$ ):

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



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

$$\zeta = \lambda \cdot k_{non-c} \cdot \frac{l}{D_h} \quad ([1] \text{ diagram 2.6})$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot w_0^2}{2} \quad ([1] \text{ diagram 2.6})$$

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 <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 ( )

$Re_0$	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 ( )
$\Delta$	Absolute roughness of walls (m)
$\bar{\Delta}$	Relative roughness of walls ( )
$\lambda$	Darcy friction factor for circular cross-section ( )
$k_{non-c}$	Correction for Darcy friction factor for noncircular cross-section ( )
$\zeta$	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 <sup>3</sup> )
$\nu$	Fluid kinematic viscosity (m <sup>2</sup> /s)
$g$	Gravitational acceleration (m/s <sup>2</sup> )

### 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 2017a software interface. The window title is "HydraulCalc 2017a - [Straight pipe rectangular cross-section and nonuniform roughness walls - IDELCHIK (3rd Ed.)]".

**Fluid characteristics:**

- Fluid: Water @ 1 atm [HC]
- Ref.: IAPWS IF97
- Temperature: T = 20 °C
- Pressure: P = 1.013 bar
- Density:  $\rho = 998.2061$  kg/m<sup>3</sup>
- Dynamic Viscosity:  $\mu = 0.00100159$  N.s/m<sup>2</sup>
- Kinematic Viscosity:  $\nu = 1.00340E-06$  m<sup>2</sup>/s

**Geometrical characteristics:**

- Hydraulic diameter:  $D_h = 0.06666667$  m
- Pipe cross-section area:  $F_0 = 0.005$  m<sup>2</sup>
- 'b0/a0' ratio:  $b_0/a_0 = 0.5$
- Internal pipe volume:  $V = 0.005$  m<sup>3</sup>
- Mass of fluid in the pipe:  $M = 4.991031$  kg
- 'Length / Diameter' ratio:  $l/D_h = 15$
- Relative roughness:  $\bar{\Delta} = 0.00015$
- Reynolds number:  $Re = 66440.97$
- Friction factor for circular cross-section:  $\lambda = 0.02024362$
- Correction factor for rectangular cross-section:  $k_{non-c} = 1.0291$
- Pressure loss per length unit:  $0.001559649$  bar/m
- Pressure loss coefficient (based on the mean pipe velocity):  $\zeta = 0.3124906$
- Hydraulic power loss:  $Wh = 0.7798247$  W

**Complementary results:**

Designation	Symbol	Value	Unit
Hydraulic diameter	$D_h$	0.06666667	m
Pipe cross-section area	$F_0$	0.005	m <sup>2</sup>
'b0/a0' ratio	$b_0/a_0$	0.5	
Internal pipe volume	$V$	0.005	m <sup>3</sup>
Mass of fluid in the pipe	$M$	4.991031	kg
'Length / Diameter' ratio	$l/D_h$	15	
Relative roughness	$\bar{\Delta}$	0.00015	
Reynolds number	$Re$	66440.97	
Friction factor for circular cross-section	$\lambda$	0.02024362	
Correction factor for rectangular cross-section	$k_{non-c}$	1.0291	
Pressure loss per length unit		0.001559649	bar/m
Pressure loss coefficient (based on the mean pipe velocity)	$\zeta$	0.3124906	
Hydraulic power loss	$Wh$	0.7798247	W

## References:

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

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HydrauCalc

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