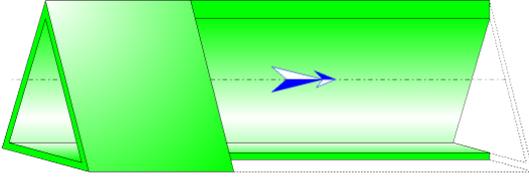




## Straight Pipe Triangular Cross-Section and Nonuniform Roughness Walls (IDELCHIK)



### Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of triangular 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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Half top angle (°):

$$\beta = \tan^{-1}\left(\frac{a_0}{2 \cdot h}\right)$$

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Hydraulic diameter (m):

$$D_h = \frac{2 \cdot h}{1 + \sqrt{\frac{1}{\tan^2(\beta)} + 1}}$$

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

$$F_0 = \frac{a_0}{2} \cdot h$$

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Mean velocity (m/s):

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

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Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

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

$$V = F_0 \cdot l$$

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Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

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Reynolds number:

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

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Relative roughness:

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

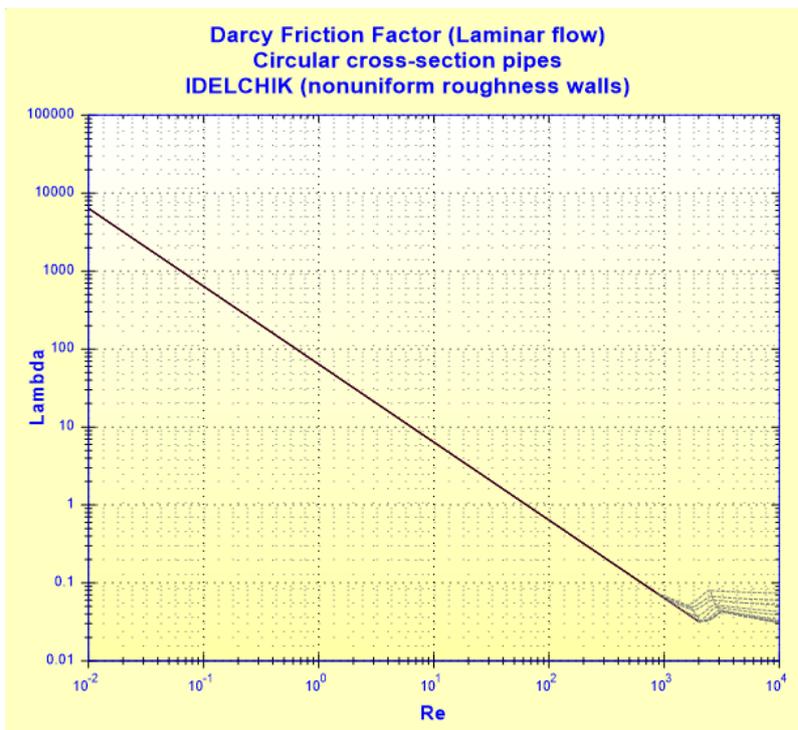
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Darcy friction factor for circular cross-section:

- laminar flow regime ( $Re \leq Re_0$ ):

Hagen-Poiseuille law

$$\lambda_{circ} = \frac{64}{Re} \quad ([1] \text{ diagram 2.1})$$



- 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:

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

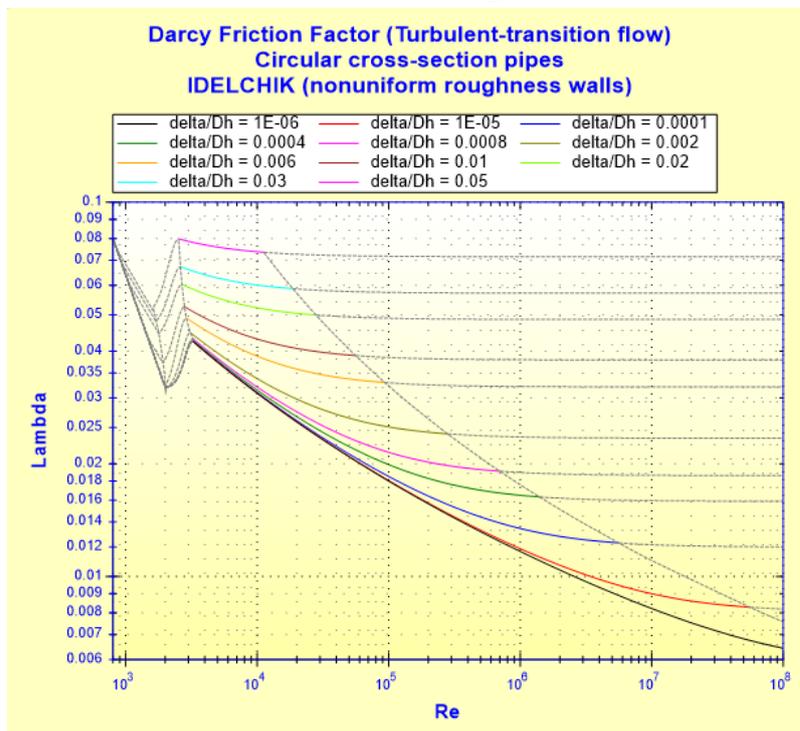
([1] §2.23)

Reynolds number corresponding to the beginning of complete turbulence:

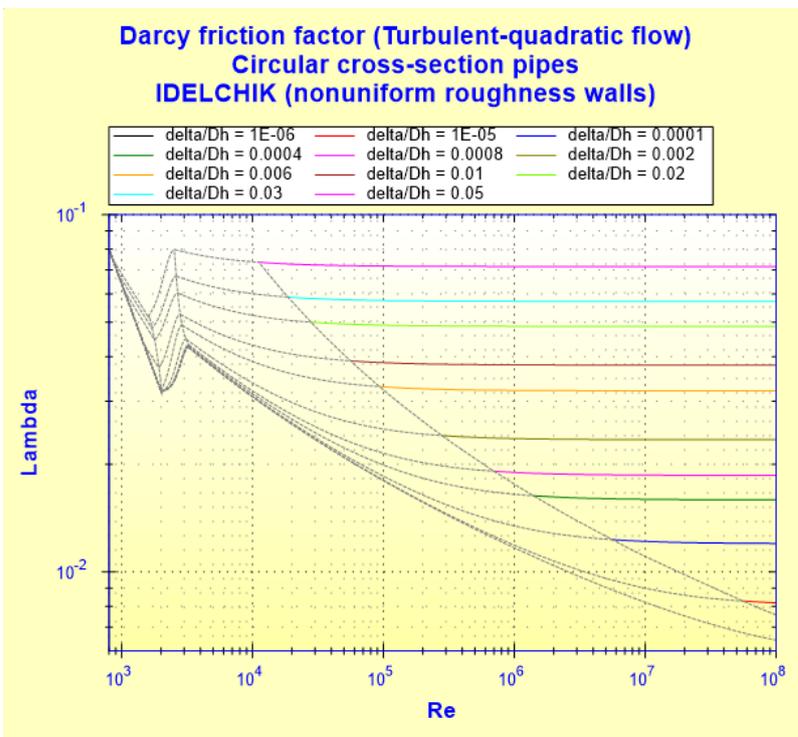
$$Re''_{lim} = \frac{560}{\bar{\Delta}}$$

([1] diagram 2.4)

Transition region



Complete turbulence region



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

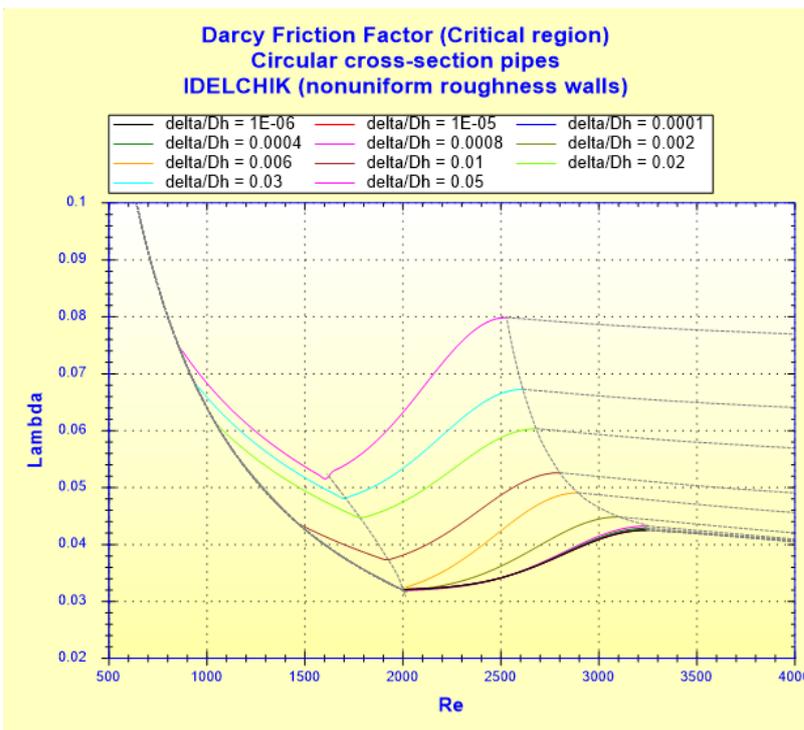
$$\lambda_{circ} = f(Re, \bar{\Delta}) \quad ([1] \text{ diagram 2.3})$$

Reynolds number of start of critical zone:

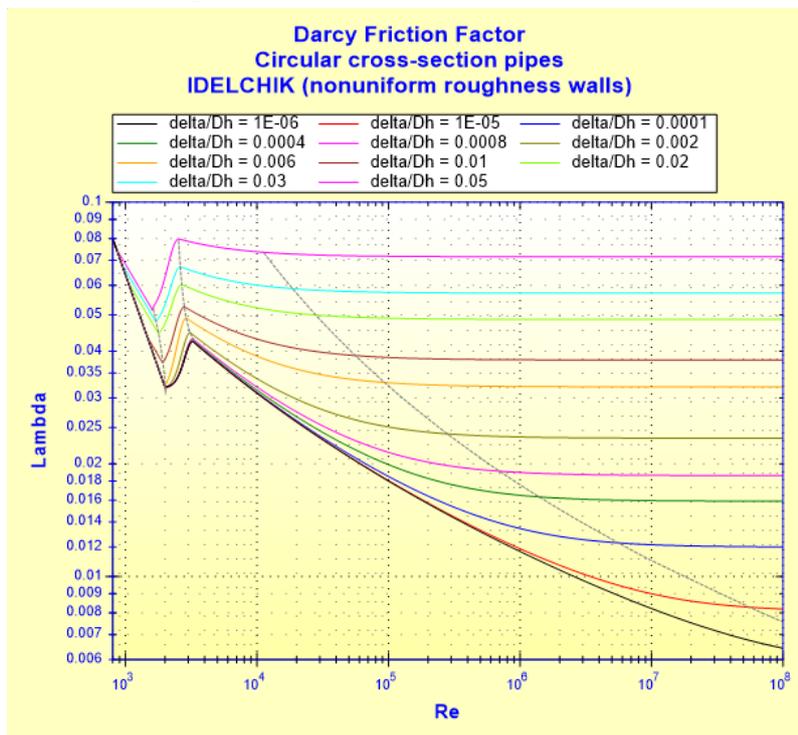
$$Re_0 = 754 \exp\left(\frac{0.0065}{\bar{\Delta}}\right) \quad ([1] \text{ §2.21})$$

Reynolds number at end of critical zone:

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



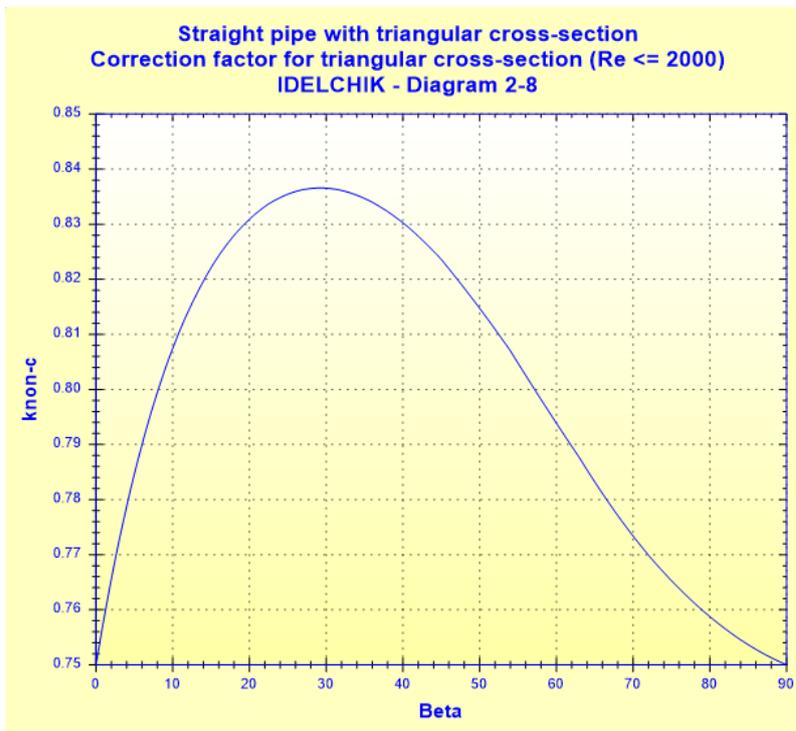
- all flow regimes:



Correction for Darcy friction factor for triangular cross-section:

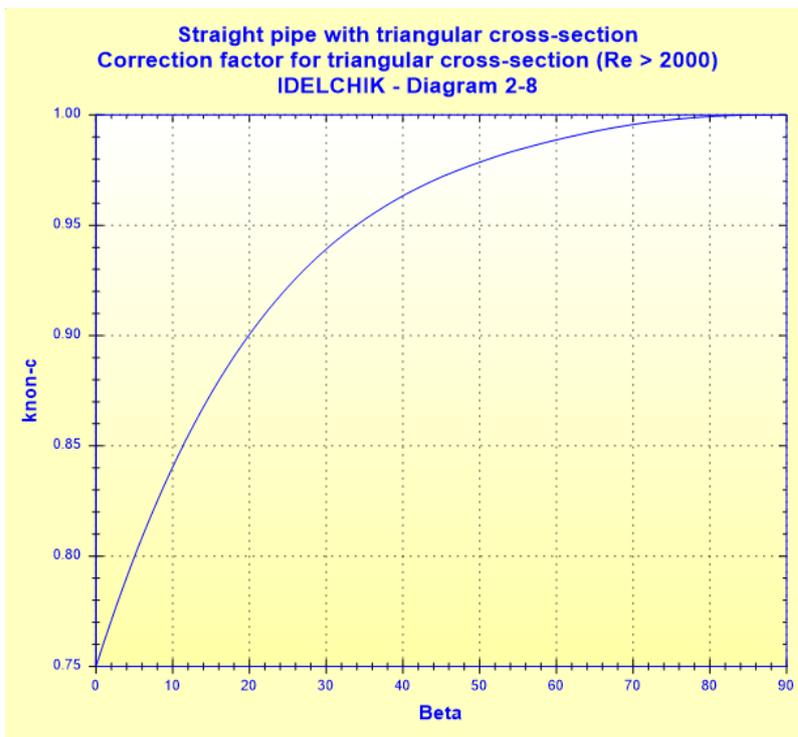
- laminar flow ( $Re \leq 2000$ ):

$$k_{non-c} = f(\beta) \quad ([1] \text{ diagram 2.8})$$



- turbulent flow ( $Re > 2000$ ):

$$k_{non-c} = f(\beta) \quad ([1] \text{ diagram 2.8})$$



Darcy friction factor for triangular cross-section:

$$\lambda_{tria} = \lambda_{circ} \cdot k_{non-c} \quad ([1] \text{ diagram 2.8})$$

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

$$\zeta = \lambda_{tria} \cdot \frac{l}{D_h} \quad ([1] \text{ diagram 2.8})$$

Total pressure loss (Pa):

$$\Delta P = \zeta \cdot \frac{\rho \cdot w_0^2}{2} \quad ([1] \text{ diagram 2.8})$$

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:**

|         |  |
|---------|--|
| $a_0$   | Cross-section base (m)                 |
| $h$     | Cross-section height(m)                |
| $\beta$ | Half top angle (°)                     |
| $D_h$   | Hydraulic diameter (m)                 |
| $F_0$   | Cross-sectional area (m <sup>2</sup> ) |
| $Q$     | Volume flow rate (m <sup>3</sup> /s)   |
| $w_0$   | Mean velocity (m/s)                    |

|                  |  |
|------------------|--|
| $G$              | Mass flow rate (kg/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 ( )  |
| $\Delta$         | Absolute roughness of walls (m)  |
| $\bar{\Delta}$   | Relative roughness of walls ( )  |
| $\lambda_{circ}$ | Darcy friction factor for circular cross-section ( )                   |
| $Re'_{lim}$      | Limiting Reynolds number for hydraulically smooth law ( )              |
| $Re''_{lim}$     | Limiting Reynolds number for quadratic law ( )                         |
| $Re_0$           | Reynolds number of start of critical zone ( )                          |
| $Re_2$           | Reynolds number at end of critical zone ( )                            |
| $k_{non-c}$      | Correction for Darcy friction factor for noncircular cross-section ( ) |
| $\lambda_{tria}$ | Darcy friction factor for triangular 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> )                         |

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#### Validity range:

- any flow regime: laminar, critical and turbulent ( $Re \leq 10^8$ )
- relative roughness  $\bar{\Delta} \leq 0.05$
- stabilized flow

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#### Example of input data and results:

HydrauCalc 2019b - [Straight pipe triangular 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:  $\rho$  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

Density  Dyn. Visc.  Kn. Visc.

Geometrical characteristics

Help Info Moody Chart Calculate

Complementary results

| Designation  | Symbol           | Value        | Unit           |
|--|------------------|--------------|----------------|
| Hydraulic diameter   | Dh               | 0.04142136   | m              |
| Top angle  | $2\beta$         | 90           | °              |
| Pipe cross-section area  | F0               | 0.0025       | m <sup>2</sup> |
| Internal pipe volume   | V                | 0.0025       | m <sup>3</sup> |
| Mass of fluid in the pipe  | M                | 2.495515     | kg             |
| Relative roughness   | $\Delta$         | 0.0002414213 |                |
| Reynolds number  | Re               | 82562.24     |                |
| <input checked="" type="checkbox"/> Friction factor for circular cross-section     | $\lambda_{circ}$ | 0.01982567   |                |
| <input checked="" type="checkbox"/> Correction factor for triangular cross-section | knon-c           | 0.9719       |                |
| Friction factor for triangular cross-section                                       | $\lambda_{tra}$  | 0.01926857   |                |
| Pressure loss per length unit  |                  | 0.009286998  | bar/m          |
| Pressure loss coefficient (based on the mean pipe velocity)                        | $\zeta$          | 0.4651845    |                |
| Hydraulic power loss   | Wh               | 4.643499     | W              |

## References:

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