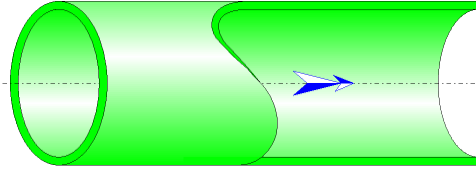




Straight Pipe Circular Cross-Section and Roughness Walls (MILLER)



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.

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 explicit Swamee-Jain equation (dependent of the value of relative roughness), the explicit Swamee-Jain equation is a Colebrook-White equation approximation,
- for critical flow regime by interpolation between friction factors of laminar and turbulent flow.

Model formulation:

Hydraulic diameter (m):

$$D = d$$

Cross-section area (m²):

$$A = \pi \cdot \frac{d^2}{4}$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Mass flow rate (kg/s):

$$m = Q \cdot \rho$$

Fluid volume in the pipe (m³):

$$V = A \cdot L$$

Fluid mass in the pipe (kg):

$$M = V \cdot \rho$$

Reynolds number:

$$Re = \frac{U \cdot D}{\nu}$$

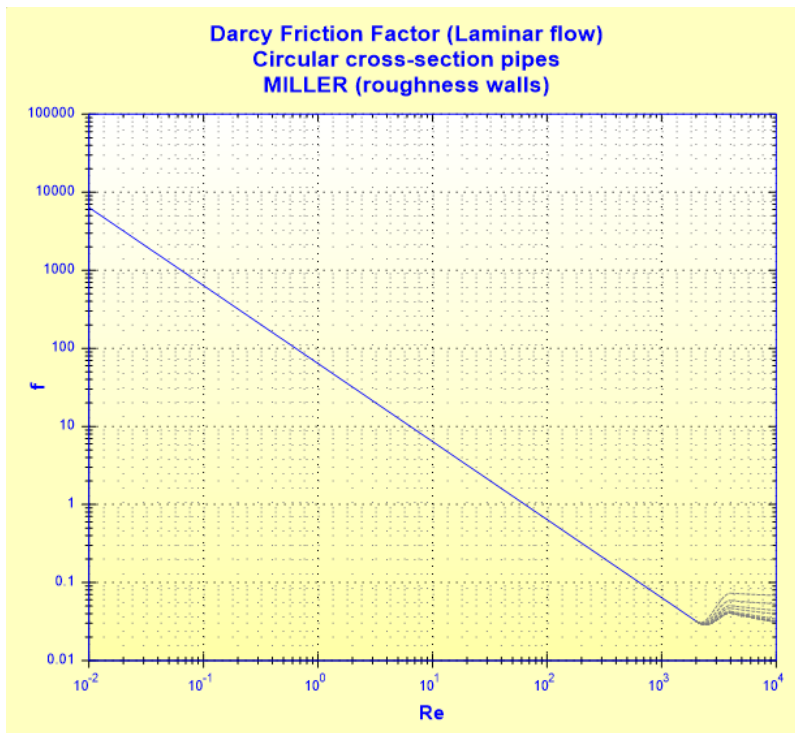
Darcy friction factor:

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

Hagen-Poiseuille law

$$f = \frac{64}{Re}$$

([1] equation 8.7)



- turbulent flow regime - transition region and complete turbulence region ($Re \geq 4000$):

Swamee-Jain equation (Colebrook-White equation approximation)

$$f = \frac{0.25}{\left[\log \left(\frac{k}{3.7 \cdot D} + \frac{5.74}{Re^{0.9}} \right) \right]^2}$$

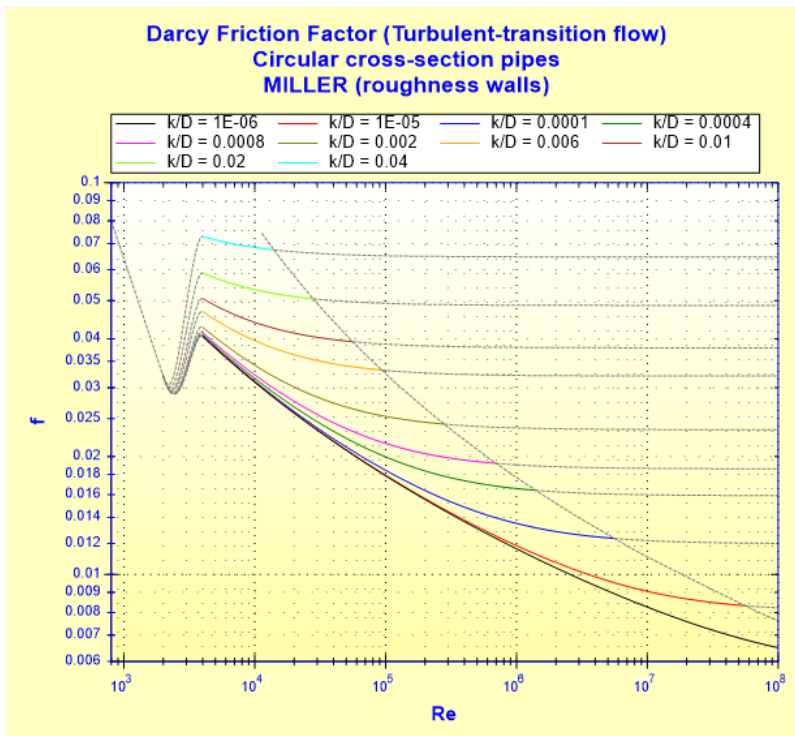
([1] equation 8.4)

Reynolds number corresponding to the beginning of complete turbulence:

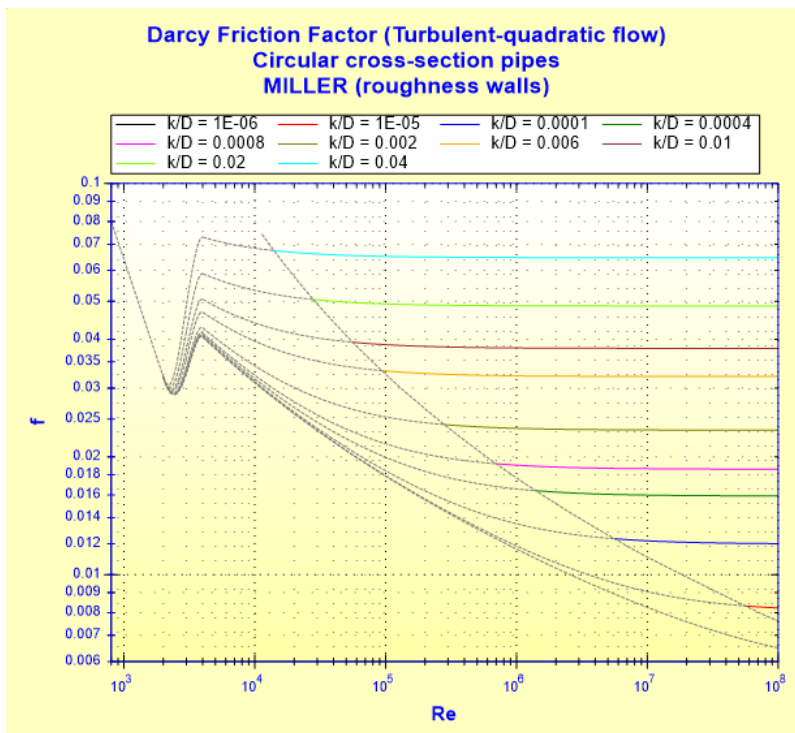
$$\text{Re}_{\text{lim}}'' = \frac{560}{\Delta}$$

([2] diagram 2.4)

Transition region



Complete turbulence region



■ critical flow regime ($2000 < \text{Re} < 4000$):

cubic interpolation

$$f = (X1 + R \cdot (X2 + R \cdot (X3 + X4)))$$

([3])

with:

$$R = \frac{Re}{2000}$$

$$X1 = 7 \cdot FA - FB$$

$$X2 = 0.128 - 17 \cdot FA + 2.5 \cdot FB$$

$$X3 = -0.128 + 13 \cdot FA - 2 \cdot FB$$

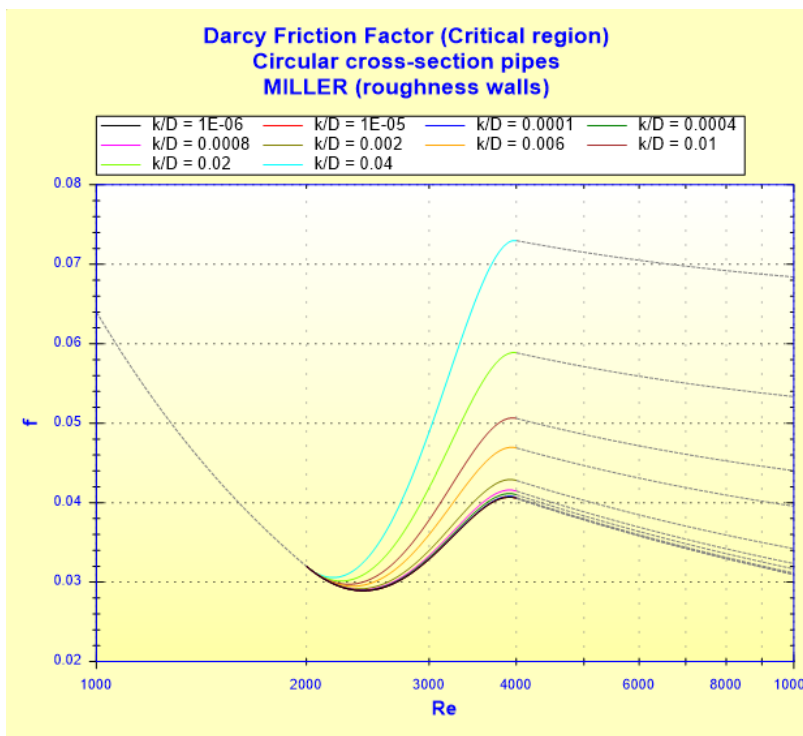
$$X4 = R \cdot (0.032 - 3 \cdot FA + 0.5 \cdot FB)$$

$$FA = Y3^{-2}$$

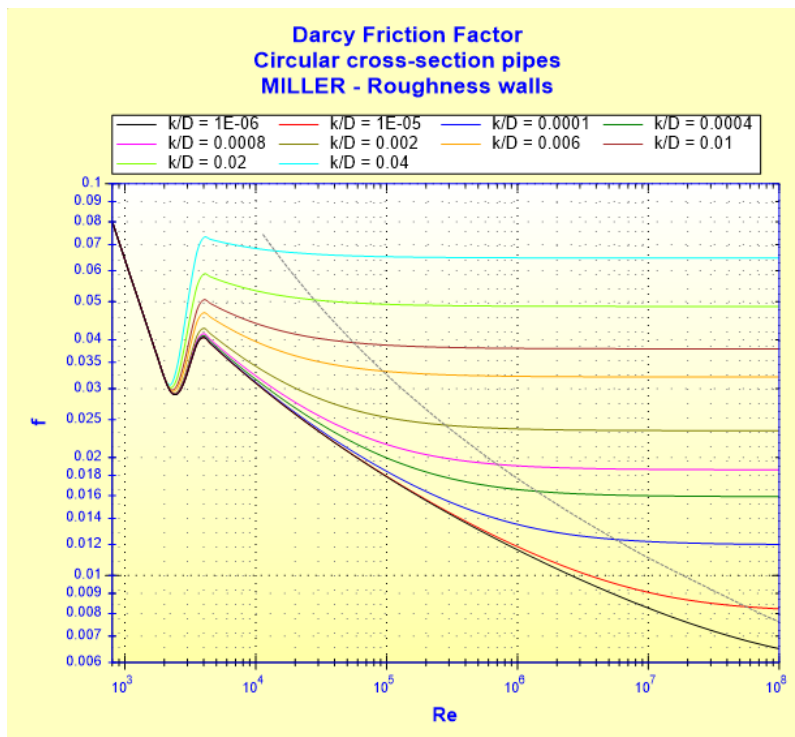
$$FB = FA \cdot \left(2 - \frac{0.00514215}{Y2 \cdot Y3} \right)$$

$$Y2 = \frac{k}{3.7 \cdot D} + \frac{5.74}{Re^{0.9}}$$

$$Y3 = -0.86859 \cdot \ln \left(\frac{k}{3.7 \cdot D} + \frac{5.74}{4000^{0.9}} \right)$$



■ all flow regimes:



Friction pressure loss coefficient:

$$K_f = f \cdot \frac{L}{D} \quad ([1] \text{ equation 8.3})$$

Total pressure loss coefficient (based on the mean pipe velocity):

$$K = K_f$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2} \quad ([1] \text{ equation 8.1b})$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g} \quad ([1] \text{ equation 8.1a})$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Symbols, Definitions, SI Units:

D	Hydraulic diameter (m)
d	Internal diameter (m)
A	Cross-section area (m ²)
Q	Volume flow rate (m ³ /s)
m	Mass flow rate (kg/s)
U	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'' _{lim}	Nombre de Reynolds correspondant au début de la turbulence complète ()
k	Absolute roughness of walls (m)
f	Darcy friction factor ()
K _f	Friction pressure loss coefficient ()
K	Total 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 ($Re \leq 10^8$)
- $k/D \leq 0.05$
- 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 roughness walls (MILLER)]". 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: ρ = 998.2061 kg/m³
 - Dynamic viscosity: μ = 0.00100159 N.s/m²
 - Kinematic viscosity: ν = 1.00340E-06 m²/s
 - Graph: Density (kg/m³) vs Temperature (°C) showing a decreasing trend from approximately 998 kg/m³ at 20°C to 980 kg/m³ at 100°C.
- Geometrical characteristics:**
 - Mass flow rate: 4.9910 kg/s
 - Flow velocity: 1.288 m/s (Turbulent)
 - Relative roughness: k/D = 1.0E-05
 - Length: L = 1 m
 - Pressure loss: ΔP = 0.002242143 bar
 - Head loss: ΔH = 0.0229 m of fluid
 - Hydraulic diameter: D = 0.0703 m
- Complementary results:**

Designation	Symbol	Value	Unit
Hydraulic diameter	D	0.0703	m
Pipe cross-section area	A	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	14.22475	
Relative roughness	k/D	0.0001422475	
Reynolds number	Re	90251	
Friction factor	f	0.01903223	
Pressure loss per length unit		0.002242143	bar/m
Pressure loss coefficient (based on the mean pipe velocity)	K	0.2707287	
Hydraulic power loss	Wh	1.121072	W

References:

[1] Internal Flow System, Second Edition, D.S. Miller (1990)

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

[3] Dunlop (1991)

HydrauCalc

Edition: February 2018

© François Corre 2017-2018