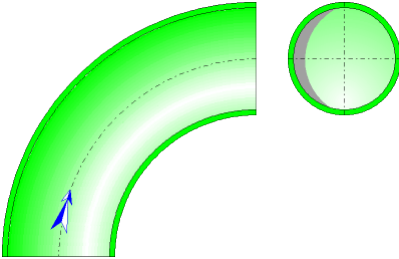




Smooth Bend Circular Cross-Section (MILLER)



Model description:

This model of component calculates the head loss (pressure drop) of a bend smoothly curved whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

An option allows to take into account the effect of the straight length at the exit of the bend. The friction loss in this straight length is not taken into account in this component.

Model formulation:

Hydraulic diameter (m):

$$D = d$$

Cross-section area (m²):

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

Mean velocity (m/s):

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

Length measured along the axis (m):

$$L = 2 \cdot \pi \cdot r \cdot \frac{\theta_b}{360}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m³):

$$V = A \cdot L$$

Fluid mass (kg):

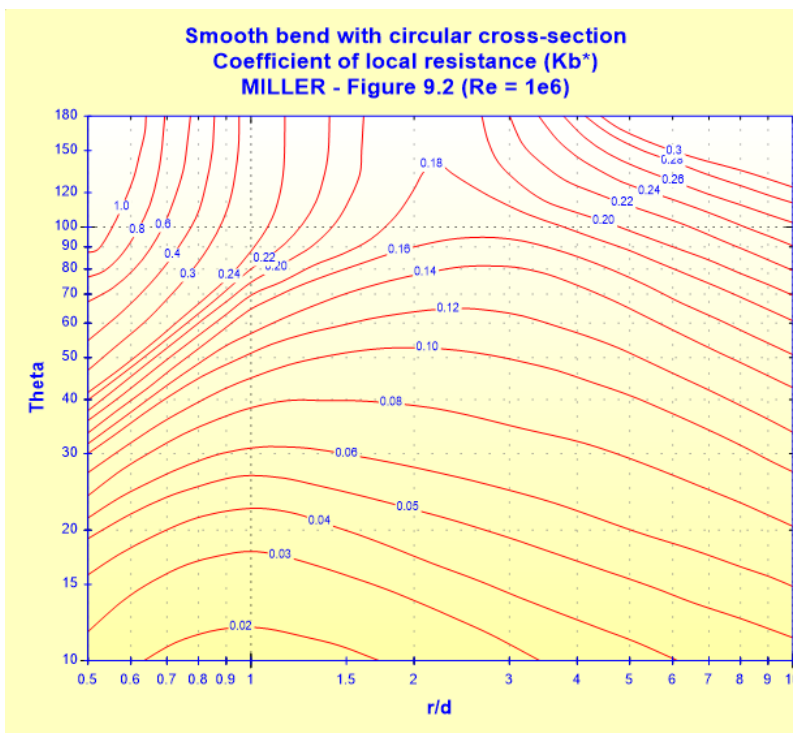
$$M = V \cdot \rho$$

Reynolds number:

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

Basic resistance coefficient:

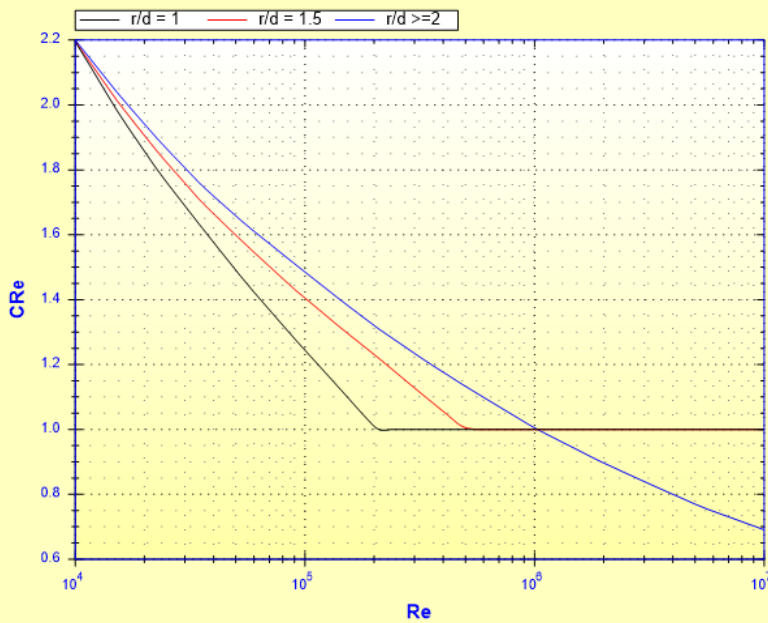
$$K_b^* = f\left(\frac{r}{d}, \theta_b\right) \quad ([1] \text{ figure 9.2})$$



Reynolds number correction factor:

$$C_{Re} = f\left(Re, \frac{r}{d}\right) \quad ([1] \text{ figure 9.3})$$

Smooth bend
Reynolds number correction factor (C_{Re})
MILLER - Figure 9.3



■ $r/d \geq 1$

$$C_{Re} = f\left(Re, \frac{r}{d}\right) \quad ([1] \text{ figure 9.3})$$

■ $r/d < 1$

- $r/d > 0.7$ or $K_b^* < 0.4$

$$C_{Re} = f\left(Re, \frac{r}{d}\right) \quad ([1] \text{ figure 9.3 with } r/d=1)$$

- otherwise ($r/d \leq 0.7$ and $K_b^* \geq 0.4$)

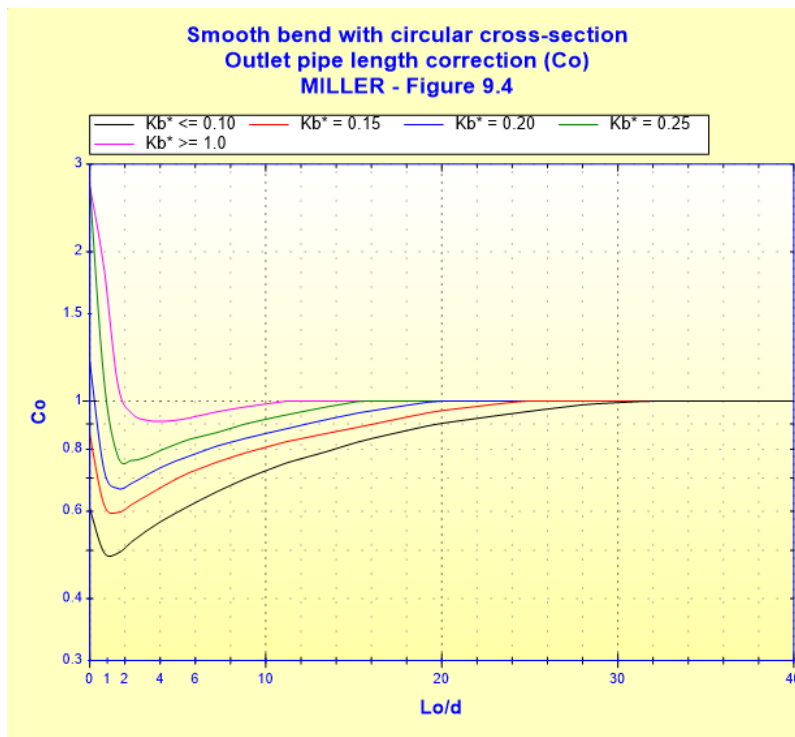
$$C_{Re} = \frac{K_b^*}{K_b^* - 0.2C'_{Re} + 0.2} \quad ([1] \text{ equation 9.2})$$

with:

$$C'_{Re} = f\left(Re, \frac{r}{d}\right) \quad ([1] \text{ figure 9.3 with } r/d=1)$$

Outlet pipe length correction factor (optional):

$$C_o = f\left(\frac{L_o}{d}, K_b^*\right) \quad ([1] \text{ figure 9.4})$$



- $r/d < 3$ et $\theta_b < 100^\circ$

$$C_o = f\left(\frac{L_o}{d}, K_b^*\right) \quad ([1] \text{ figure 9.4})$$

- otherwise ($r/d > 3$ and/or $\theta_b > 100^\circ$)

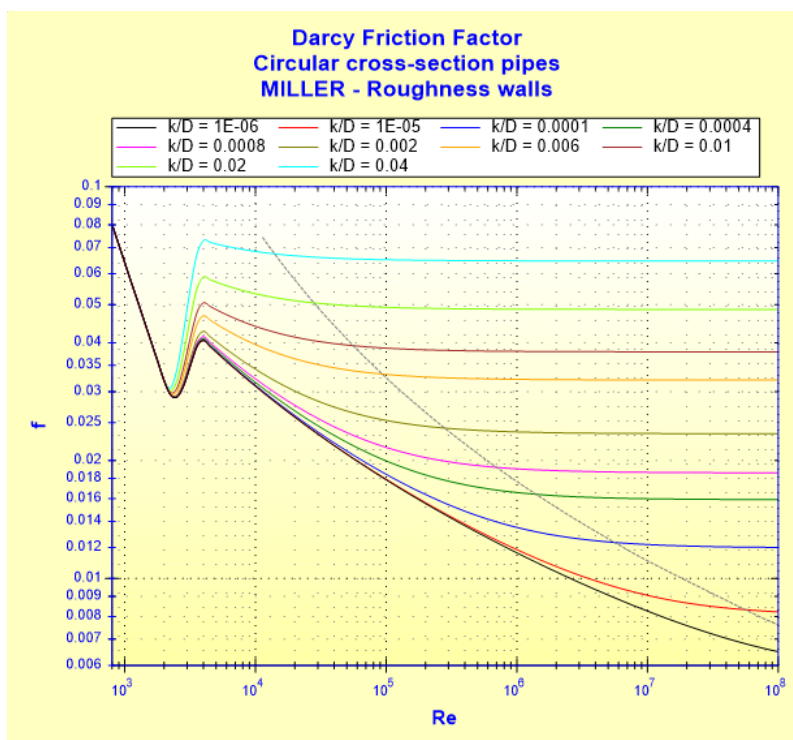
$$C_o = 1 \quad (\text{negligible effect})$$

If this option is not activated, the factor C_o is equal to unity.

Darcy friction factor:

$$f = f\left(\text{Re}, \frac{k}{D}\right)$$

See [Straight Pipe - Circular Cross-Section and Roughness Walls \(MILLER\)](#)



Roughness correction factor:

$$C_f = \frac{f_{rough}}{f_{smooth}} \quad ([1] \text{ equation 9.3})$$

with:

f_{rough} : Darcy friction factor for rough pipe at Re

f_{smooth} : Darcy friction factor for smooth pipe ($k = 0$) at Re

For $Re > 10^6$, C_f is calculated from equation (9.3) for $Re = 10^6$

Corrected loss coefficient:

$$K_b = K_b^* \cdot C_{Re} \cdot C_o \cdot C_f$$

Total pressure loss coefficient (based on the mean velocity in the bend)

$$K = K_b$$

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):

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

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{d}{f_{rough}}$$

Symbols, Definitions, SI Units:

D	Bend hydraulic diameter (m)
d	Bend internal diameter (m)
A	Cross-section area (m ²)
Q	Volume flow rate (m ³ /s)
U	Mean velocity (m/s)
L	Length measured along the axis (m)
r	Radius of curvature (m)
θ_b	Curvature angle (°)
G	Mass flow rate (kg/s)
V	Fluid volume (m ³)
M	Fluid mass (kg)
Re	Reynolds number ()
K_b^*	Basic loss coefficient ()
C_{Re}	Reynolds number correction factor ()
C_o	Outlet pipe length correction factor ()
L_o	Length of the straight section downstream of the bend (m)
f	Darcy friction factor ()
k	Absolute roughness of walls (m)
C_f	Roughness correction factor ()
K_b	Corrected loss coefficient ()
K	Total pressure loss coefficient (based on the mean velocity in the bend) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
L_{eq}	Straight length of equivalent pressure loss (m)
ρ	Fluid density (kg/m ³)
ν	Fluid kinematic viscosity (m ² /s)
g	Gravitational acceleration (m/s ²)

Validity range:

- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream bend
- curvature angle: 10 - 180°
- relative radius of curvature 'r/d': lower than 10

Example of application:

HydrauCalc 2018b - [Smooth bend with circular cross-section - MILLER (2nd 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: ρ 998.2061 kg/m³
Dynamic Viscosity: μ 0.00100159 N.s/m²
Kinematic Viscosity: ν 1.00340E-06 m²/s

Density Dyn. Visc. Kn. Visc.

Divers

Geometrical characteristics

Help Info

Calculate

Pressure loss
 ΔP 0.00200893 bar
 ΔH 0.0205 m of fluid

Option: Outlet pipe length correction factor
 Use outlet pipe length correction factor
Straight length: ≥ 1.783442 m

Complementary results

Designation	Symbol	Value	Unit
Hydraulic diameter	D	0.0703	m
Cross-sectional area	A	0.003881508	m ²
Relative radius of curvature	r/d	2.489331	
Developed straight length from the axis	L	0.2748893	m
Internal bend volume	V	0.001066985	m ³
Internal bend volume	M	1.065071	kg
Basic coefficient (Figure 9.2)	K_b^*	0.1540387	
Reynolds number correction factor (Figure 9.3)	CR_e	1.510147	
Outlet tangent correction (Figure 9.4)	C_o	1	
Relative roughness	k/D	0.0001422475	
Roughness correction	Cf	1.042765	
Reynolds number	Re	90251	
Corrected pressure loss coefficient	K_b	0.2425692	
Pressure loss coefficient (based on the mean bend velocity)	K	0.2425692	
Hydraulic power loss	Wh	1.004465	W
Straight length of equivalent pressure loss	Leq	0.8959863	m

References:

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