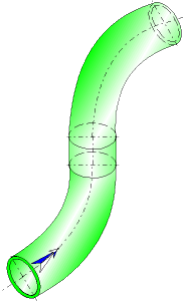




**S-shaped Bends
(with flow in one plane)
Circular Cross-Section
(MILLER)**



Model description:

This model of component calculates the head loss (pressure drop) of S-shaped bends (with flow in one plane) whose cross-section is circular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the first bend.

An option allows to take into account the effect of the straight length at the exit of the second bend.

Model formulation:

Hydraulic diameter (m):

$$D = d$$

Cross-section area (m²):

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

Mean velocity (m/s):

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

Total length measured along the axis (m):

$$L = 2 \cdot \left(2 \cdot \pi \cdot r \cdot \frac{\theta_b}{360} \right) + L_s$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m³):

$$V = A \cdot L$$

Fluid mass (kg):

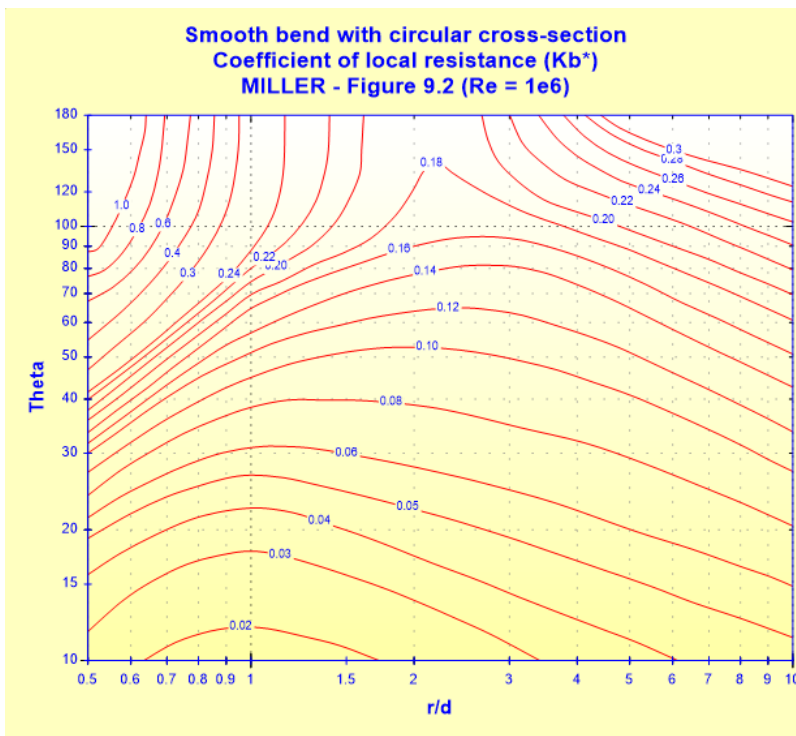
$$M = V \cdot \rho$$

Reynolds number:

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

Basic resistance coefficient for one bend:

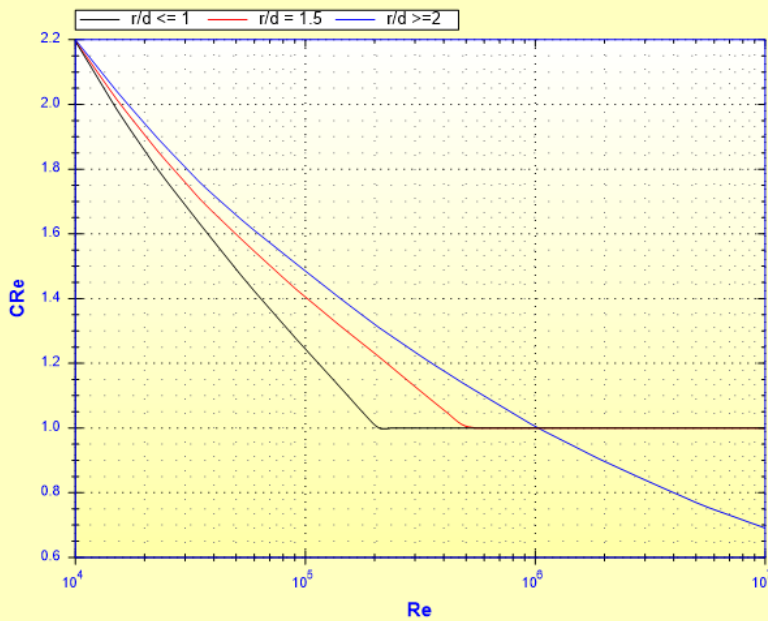
$$K_b^* = f\left(\frac{r}{d}, \theta_b\right) \quad ([1] \text{ figure 9.2})$$



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 $K_b^* \geq 0.4$)

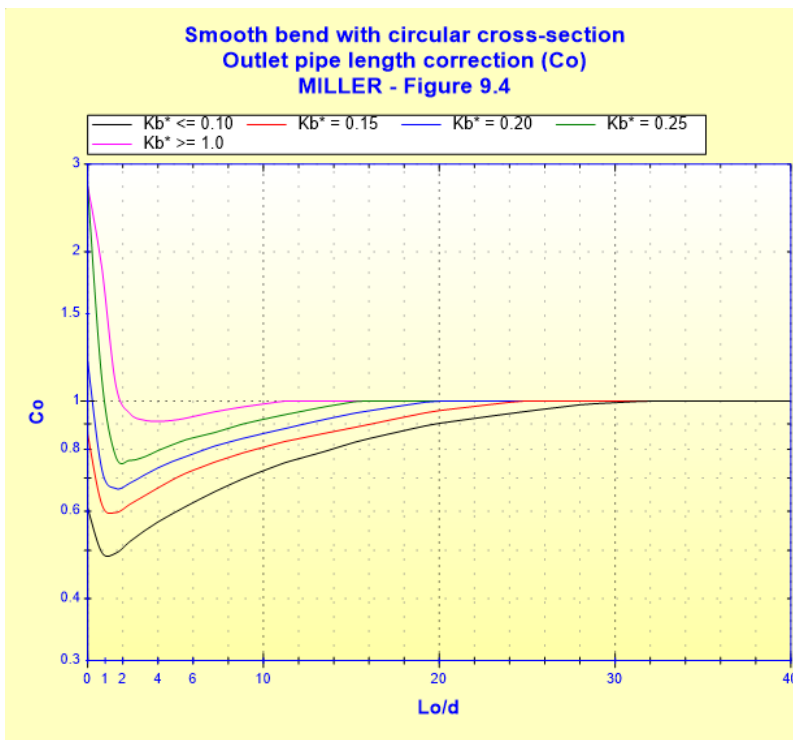
$$C_{Re} = \frac{K_b^*}{K_b^* - 0.2C'_{Re} + 0.2} \quad ([1] \text{ equation 9.2})$$

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 $\theta_b > 100^\circ$)

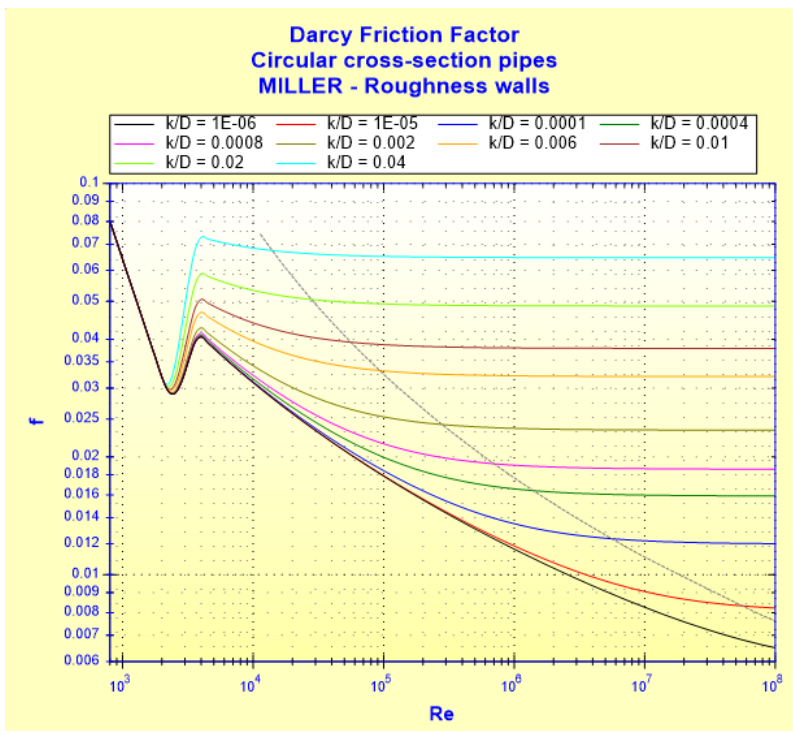
$$C_o = 1 \quad (\text{negligible effect})$$

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 for the first bend:

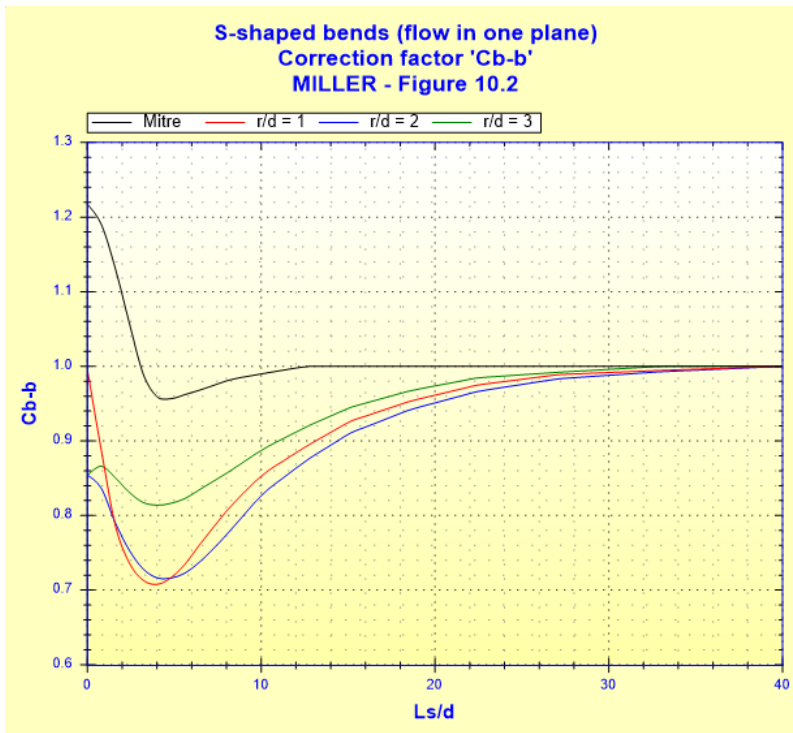
$$K_{b1} = K_b^* \cdot C_{Re} \cdot C_f \quad ([1] \text{ equation 9.4})$$

Corrected loss coefficient for the second bend:

$$K_{b2} = K_b^* \cdot C_{Re} \cdot C_f \cdot C_o \quad ([1] \text{ equation 9.4})$$

Interaction correction factor:

$$C_{b-b} = f\left(\frac{L_s}{d}, \frac{r}{d}\right) \quad ([1] \text{ figure 10.2})$$



Pressure loss coefficient of the two bends:

$$K_{b-b} = (K_{b1} + K_{b2}) \cdot C_{b-b} \quad ([1] \text{ equation 10.1})$$

Friction loss coefficient of the straight length between bends:

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

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

$$K = K_{b-b} + K_f$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{d}{f}$$

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	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 _s	Straight length between the two bends (m)
L	Total length measured along the axis (m)
r	Radius of curvature (m)
θ _b	Curvature angle of each bend (°)
G	Mass flow rate (kg/s)
V	Fluid volume (m ³)
M	Fluid mass (kg)
Re	Reynolds number ()
K _b [*]	Basic loss coefficient of one bend ()
C _{Re}	Reynolds number correction factor ()
C _o	Outlet pipe length correction factor ()
L ₀	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 _{b1}	Corrected loss coefficient for the first bend ()
K _{b2}	Corrected loss coefficient for the second bend ()
C _{b-b}	Interaction correction factor ()
K _{b-b}	Pressure loss coefficient of the two bends ()

K_f	Friction loss coefficient of the straight length between bends ()
K	Total pressure loss coefficient (based on the mean velocity in the bend) ()
L_{eq}	Straight length of equivalent pressure loss (m)
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
W_h	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:

- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream bend
- relative radius of curvature ' r/d ': greater than or equal to 0.5 and lower than or equal to 10

for relative radius of curvature ' r/d ' greater than 3, the pressure loss coefficient ' K ' is estimated by taking into account the interaction correction factor ' C_{b-b} ' corresponding to a relative radius of curvature ' r/d ' of value 3.

- curvature angle: between 10° and 180°

the interaction correction factor ' C_{b-b} ' is only applicable for angles ' θ_b ' between 70° and 90° ,

for angles ' θ_b ' less than 70° or greater than 90° , the pressure loss coefficient ' K ' is estimated by taking into account the interaction correction factor ' C_{b-b} ' applicable to angles ' θ_b ' between 70° and 90°

Example of application:

HydrauCalc 2023a - [S-shaped bends with circular cross-section (flow in one plane) - 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. Kin. Visc.

logY

Geometrical characteristics

Help Info Calculate

Pressure loss
 ΔP 0.003547327 bar
 ΔH 0.0362 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
Passage cross-section area	A	0.003881508	m ²
Relative radius of curvature	r/d	2.489331	
Length between elbows / diameter ratio	ls/d	1.422475	
<input checked="" type="checkbox"/> Basic coefficient (Figure 9.2)	K_b^*	0.1540387	
<input checked="" type="checkbox"/> Reynolds number correction factor (Figure 9.3)	CR _e	1.510147	
<input checked="" type="checkbox"/> Outlet tangent correction (Figure 9.4)	C _o	1	
Relative roughness	k/D	0.0001422475	
Roughness correction	C _f	1.042765	
Reynolds number	Re	90251	
<input checked="" type="checkbox"/> Interaction correction factor (Figure 10.2)	C _{b-b}	0.8270851	
Pressure loss coefficient of the two bends	K _{b-b}	0.4012507	
Friction loss coefficient of the spacer length	K _f	0.02707287	
Pressure loss coefficient (based on the mean bend velocity)	K	0.4283236	
Hydraulic power loss	Wh	1.773663	W
Straight length of equivalent pressure loss	Le _q	1.582114	m

References:

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