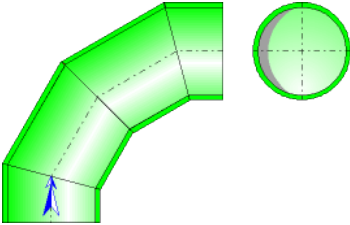




Composite Bend 90° (3 × 30°) Circular Cross-Section (MILLER)



Model description:

This model of component calculates the head loss (pressure drop) of a composite bend 90° (3 × 30°) 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.

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):

$$L = 6 \cdot r \cdot \operatorname{tg}\left(\frac{90^\circ}{6}\right)$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m³):

$$V = A \cdot L$$

Fluid mass (kg):

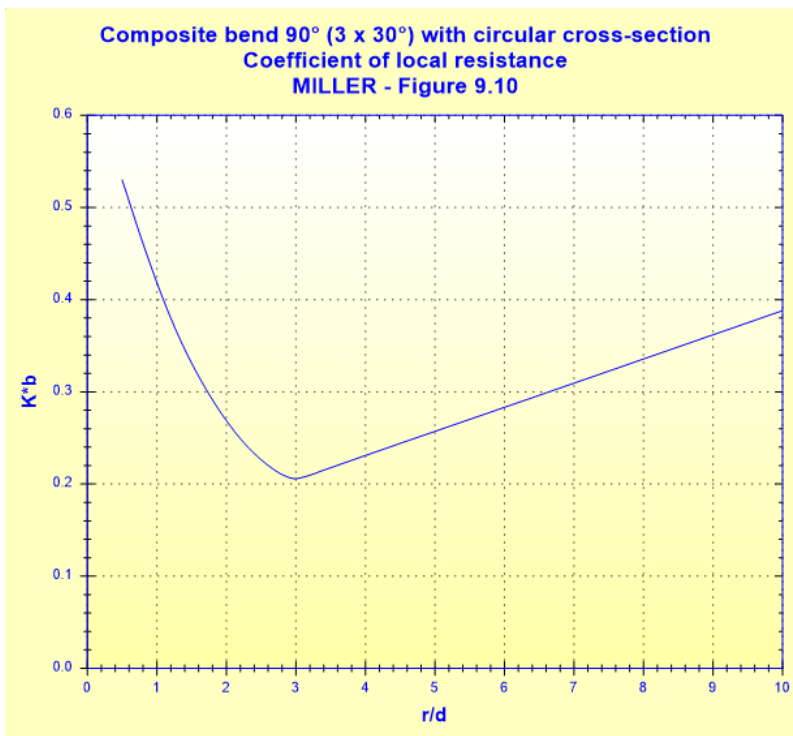
$$M = V \cdot \rho$$

Reynolds number:

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

Basic resistance coefficient:

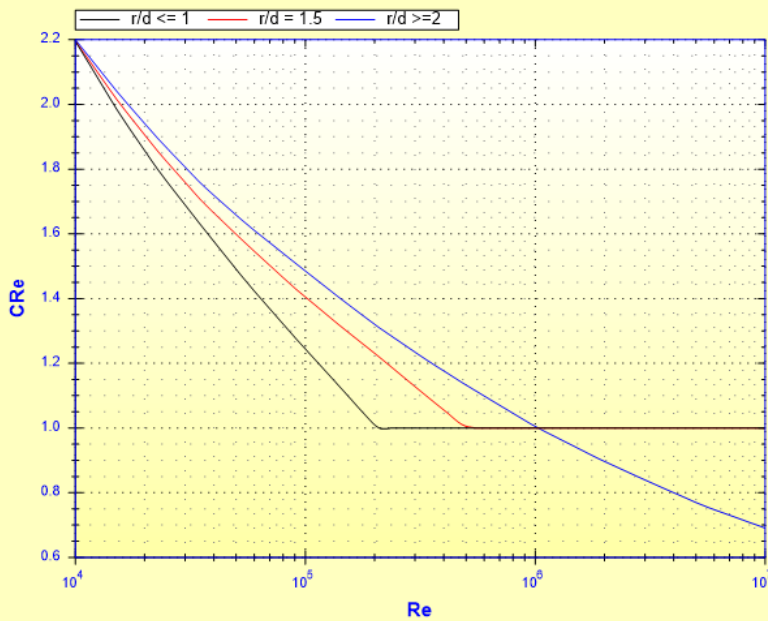
$$K_b^* = f\left(\frac{r}{d}\right) \quad ([1] \text{ figure 9.10})$$



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 (CRe)
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:

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

Local resistance coefficient:

- $Re \geq 10^4$ (turbulent flow)

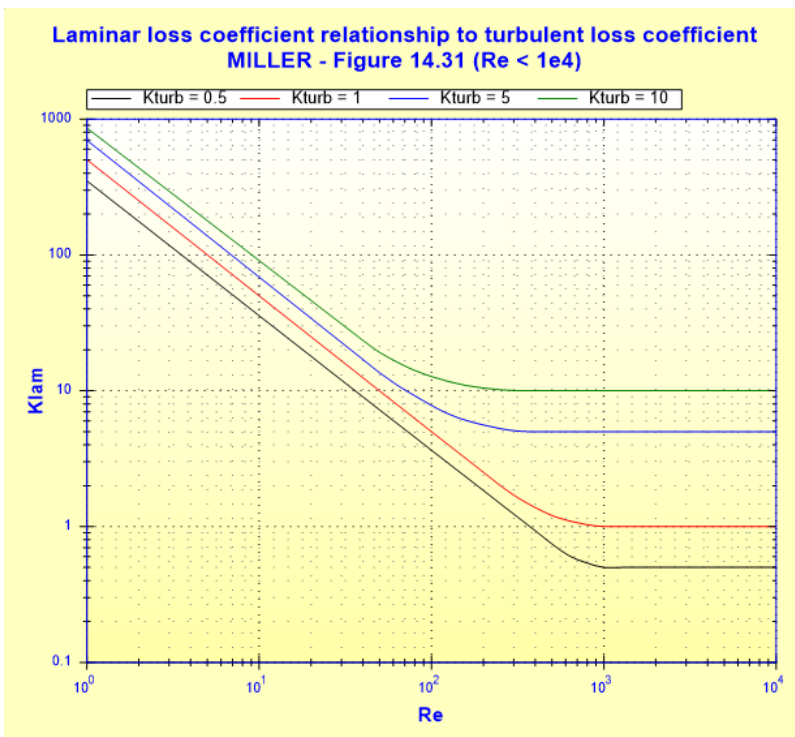
$$K_{turb} = K_b^* \cdot C_{Re}$$

- $Re < 10^4$ (laminar flow)

$$K_{lam} = f(K_{turb}, Re) \quad ([1] \text{ figure 14.31})$$

where:

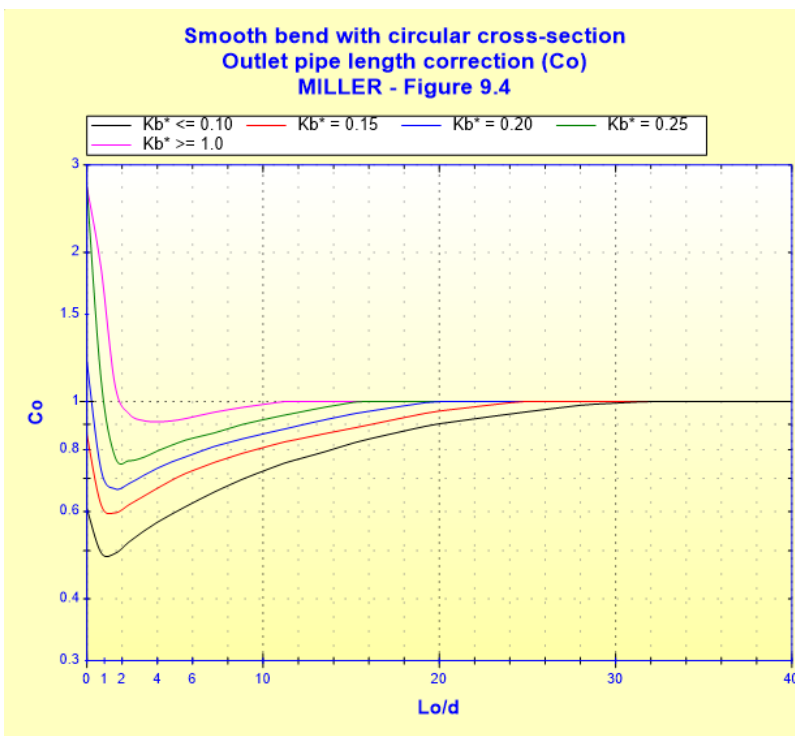
K_{turb} is the resistance coefficient in turbulent regime for $Re = 10^4$



Outlet pipe length correction factor (optional):

- $r/d < 3$

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



- otherwise ($r/d \leq 3$)

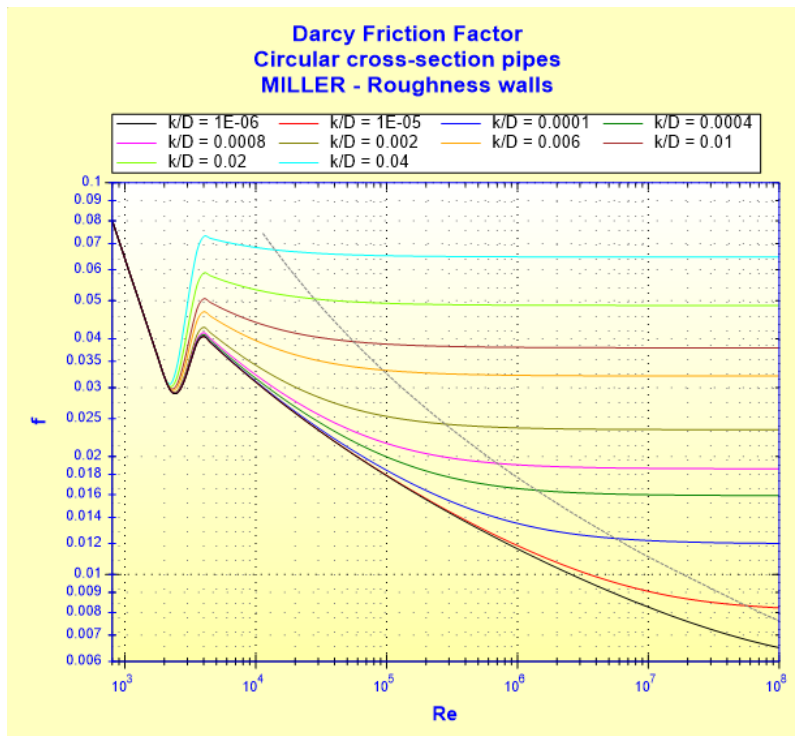
$$C_o = 1 \quad (\text{negligible effect})$$

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:

- turbulent flow ($Re \geq 10^4$):

$$K_b = K_{turb} \cdot C_o \cdot C_f$$

- laminar flow ($Re < 10^4$):

$$K_b = K_{lam} \cdot C_o \cdot C_f$$

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)
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 ()
K _{turb}	Local resistance coefficient for Re ≥ 10 ⁴ ()
K _{lam}	Local resistance coefficient for Re < 10 ⁴ ()
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:

- any flow regime: laminar and turbulent
note: for laminar flow regime ($Re < 10^4$), the pressure loss coefficient " K_{lam} " is estimated
- stabilized flow upstream bend

Example of application:

The screenshot shows the HydraulCalc 2021a software interface for a 90-degree composite bend. The fluid is Water @ 1 atm [HC] with a reference to IAPWS IF97. The temperature is 20 °C and the pressure is 1.013 bar. The density is 998.2061 kg/m³, dynamic viscosity is 0.00100159 N.s/m², and kinematic viscosity is 1.00340E-06 m²/s. The flow rate is 4.9910 kg/s (0.005 m³/s) and the velocity is 1.288 m/s (Turbulent). The bend has a diameter of 0.0703 m, a relative radius of curvature of 0.175 m, and a roughness of 1.0E-05 m. The pressure loss is 0.002959098 bar, which is equivalent to 0.0302 m of fluid. The straight length of equivalent pressure loss is 1.319763 m.

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.

Density (kg/m³) vs Temperature (°C) graph showing a decreasing trend from approximately 998 kg/m³ at 20°C to 970 kg/m³ at 100°C.

Geometrical characteristics

Hydraulic diameter: 0.0703 m
Relative radius of curvature: 0.175 m
Roughness: 1.0E-05 m
Bend angle: 90°

Flow rate: $m = 4.9910$ kg/s, $Q = 0.005$ m³/s
Velocity: $U = 1.288$ m/s (Turbulent)

Pressure loss: $\Delta P = 0.002959098$ bar
 $\Delta H = 0.0302$ m of fluid

Option: Outlet pipe length correction factor
 Use outlet pipe length correction factor
Straight length: ≥ 1.2803 m

Complementary results

Designation	Symbol	Value	Unit
Hydraulic diameter	D	0.0703	m
Passage cross-section area	A	0.003881508	m²
Relative radius of curvature	r/d	2.489331	
Developed straight length from the axis	L	0.2813466	m
<input checked="" type="checkbox"/> Basic coefficient (Figure 9.10)	K_b^*	0.2268947	
<input checked="" type="checkbox"/> Reynolds number correction factor (Figure 9.3)	CRe	1.510147	
Coefficient of local resistance	K_{turb}	0.3426444	
<input checked="" type="checkbox"/> 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	0.3572977	
Pressure loss coefficient (based on the mean bend velocity)	K	0.3572977	
Hydraulic power loss	Wh	1.479549	W
Straight length of equivalent pressure loss	Leq	1.319763	m

References:

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