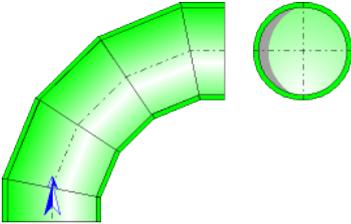




Composite Bend 90° (4 × 22.5°) Circular Cross-Section (MILLER)



Model description:

This model of component calculates the head loss (pressure drop) of a composite bend 90° (4 × 22.5°) 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):

$$L = 8 \cdot r \cdot \operatorname{tg}\left(\frac{90^\circ}{8}\right)$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m³):

$$V = A \cdot L$$

Fluid mass (kg):

$$M = V \cdot \rho$$

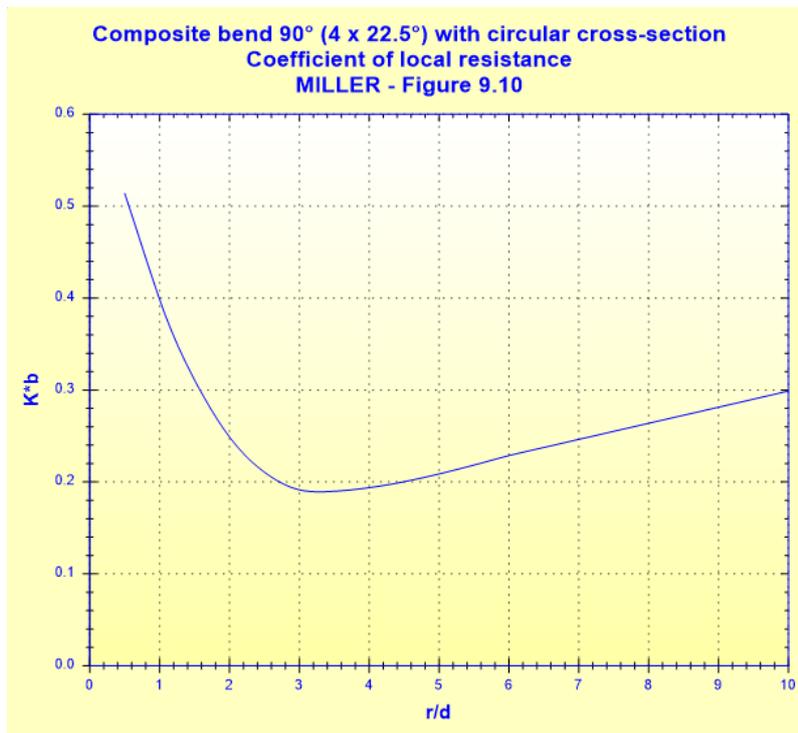
Reynolds number:

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

Basic resistance coefficient:

$$K_b^* = f\left(\frac{r}{d}\right)$$

([1] figure 9.10)

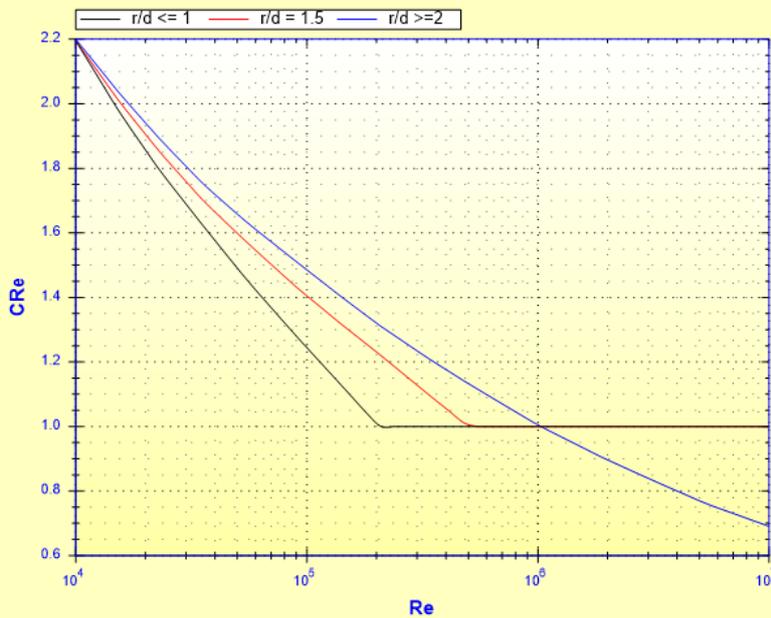


Reynolds number correction factor:

$$C_{\text{Re}} = f\left(\text{Re}, \frac{r}{d}\right)$$

([1] 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)

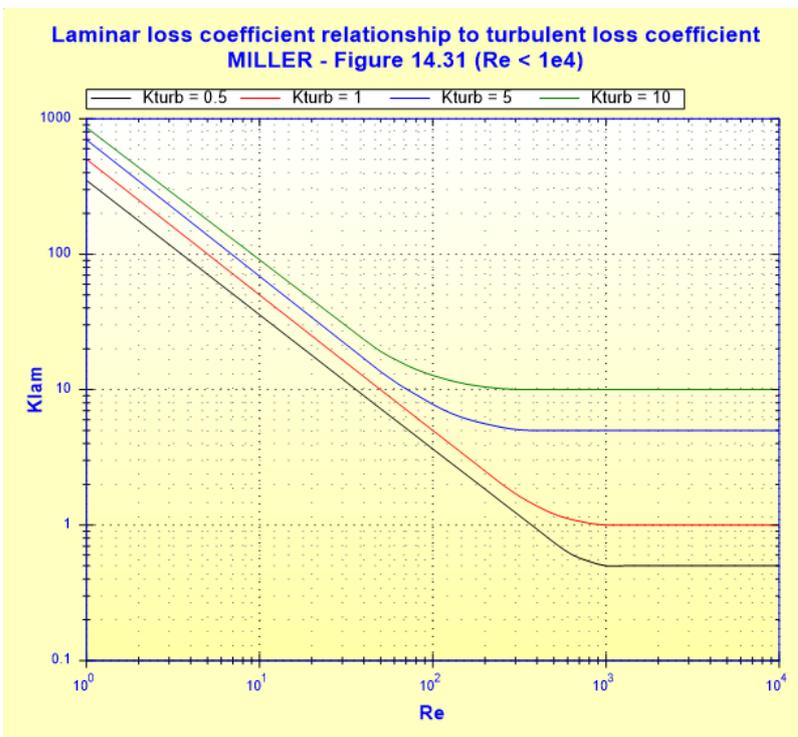
$$K_{turb} = K_b^* \cdot C_{Re}$$

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

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

where:

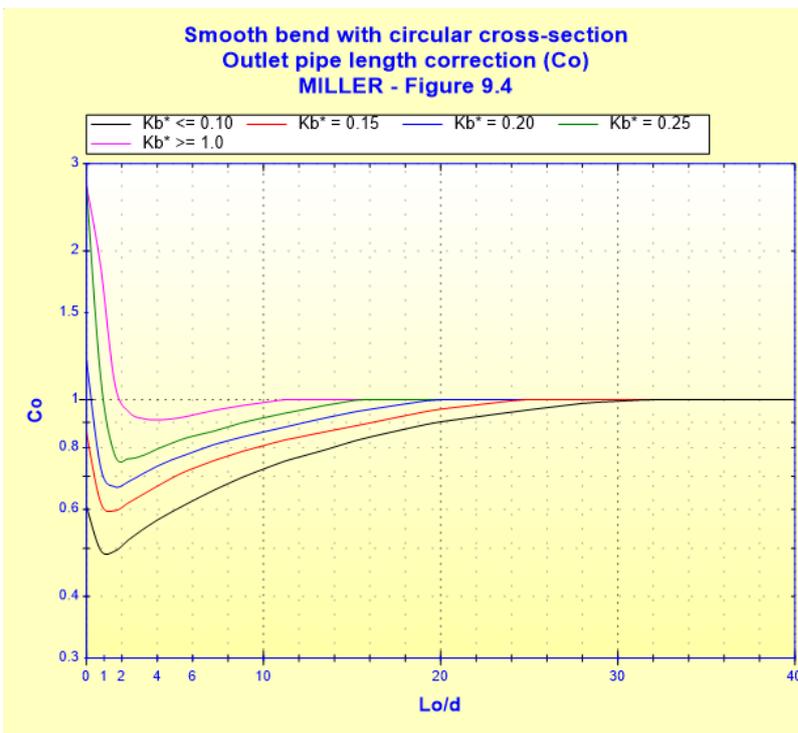
K_{turb} is the resistance coefficient in turbulent regime for $Re = 10^4$



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 ($r/d \leq 3$)

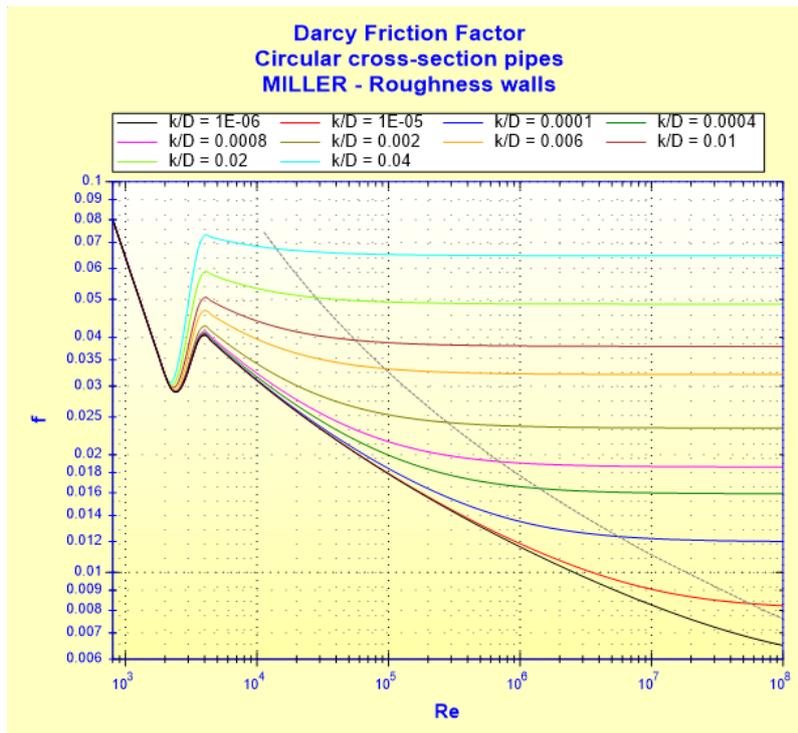
$$C_o = 1 \quad (\text{negligible effect})$$

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 composite bend calculation. The main window displays the following information:

Fluid characteristics:
 Fluid: Water @ 1 atm [HC]
 Ref.: IAPWS IF97
 Temperature: $T = 20$ °C
 Pressure: $P = 1.013$ bar
 Density: $\rho = 998.2061$ kg/m³
 Dynamic Viscosity: $\mu = 0.00100159$ N.s/m²
 Kinematic Viscosity: $\nu = 1.00340E-06$ m²/s

Geometrical characteristics:
 Bend angle: 90°
 Hydraulic diameter: $d = 0.0703$ m
 Relative radius of curvature: $r/d = 0.175$
 Surface roughness: $k = 1.0E-05$ m
 Mass flow rate: $m = 4.9910$ kg/s
 Volumetric flow rate: $Q = 0.005$ m³/s
 Mean velocity: $U = 1.288$ m/s (Turbulent)

Pressure loss:
 $\Delta P = 0.002753281$ bar
 $\Delta H = 0.0281$ m of fluid

Complementary results table:

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	
Developed straight length from the axis	L	0.2784773	m
Basic coefficient (Figure 9.10)	K_b^*	0.2111133	
Reynolds number correction factor (Figure 9.3)	C_{Re}	1.510147	
Coefficient of local resistance	K_{turb}	0.3188121	
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	
Corrected pressure loss coefficient	K_b	0.3324462	
Pressure loss coefficient (based on the mean bend velocity)	K	0.3324462	
Hydraulic power loss	Wh	1.37664	W
Straight length of equivalent pressure loss	Leq	1.227968	m

References:

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