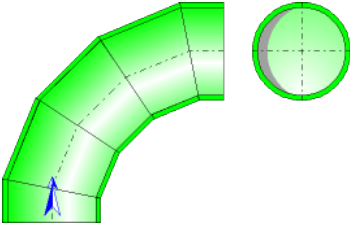




## Composite Bend 90° (4 x 22.5°) Circular Cross-Section (MILLER)



### Model description:

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

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Hydraulic diameter (m):

$$D = d$$

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Cross-section area (m<sup>2</sup>):

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

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Mean velocity (m/s):

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

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Length measured along the axis (m):

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

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Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

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Fluid volume (m<sup>3</sup>):

$$V = A \cdot L$$

Fluid mass (kg):

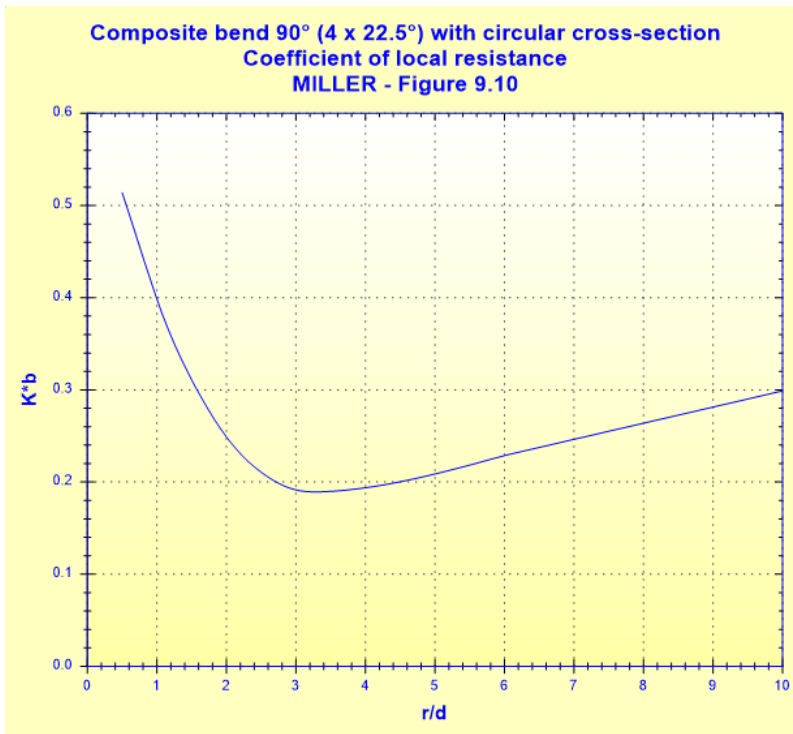
$$M = V \cdot \rho$$

Reynolds number:

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

Basic resistance coefficient:

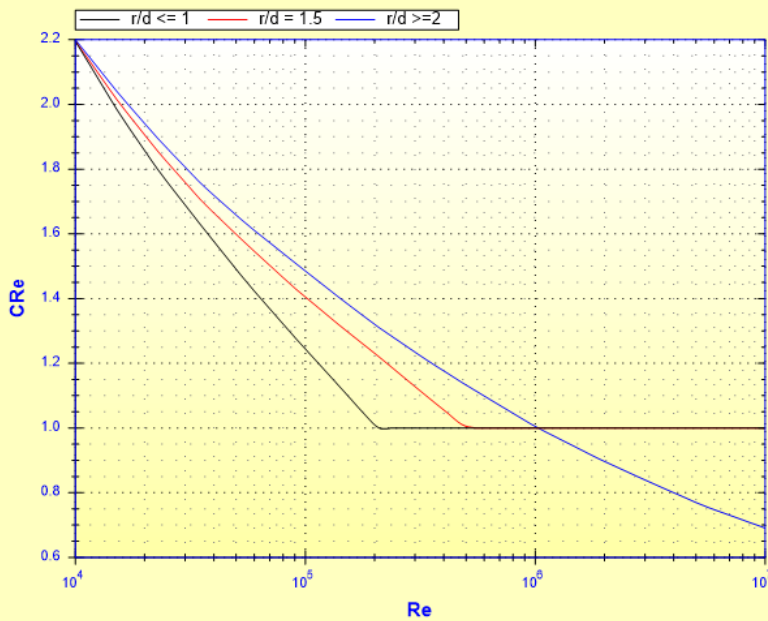
$$K_b^* = f\left(\frac{r}{d}\right) \quad ([1] \text{ figure 9.10})$$



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)

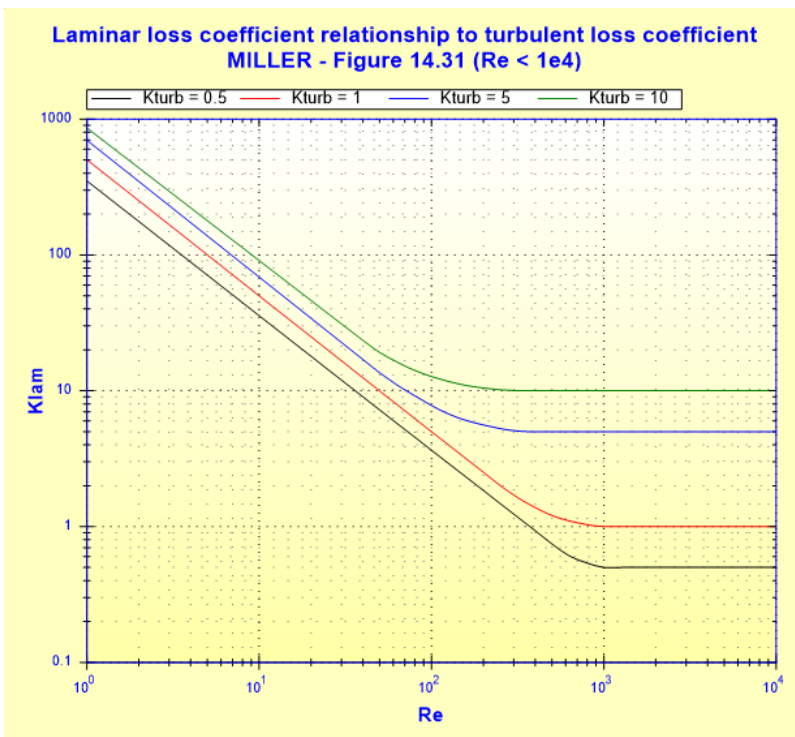
$$K_{turb} = K_b^* \cdot C_{Re}$$

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

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

where:

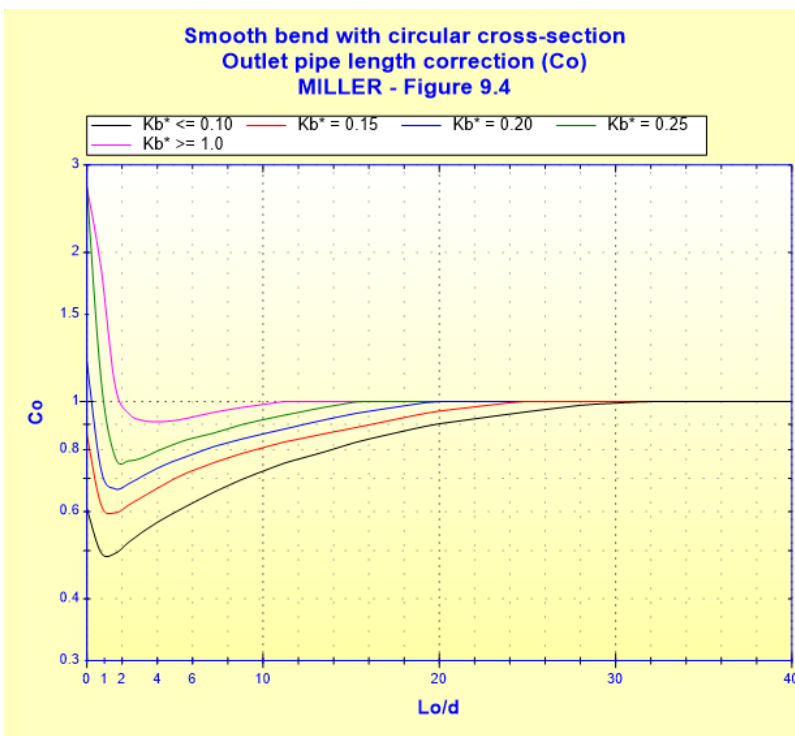
$K_{turb}$  is the resistance coefficient in turbulent regime for  $Re = 10^4$



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 ( $r/d \leq 3$ )

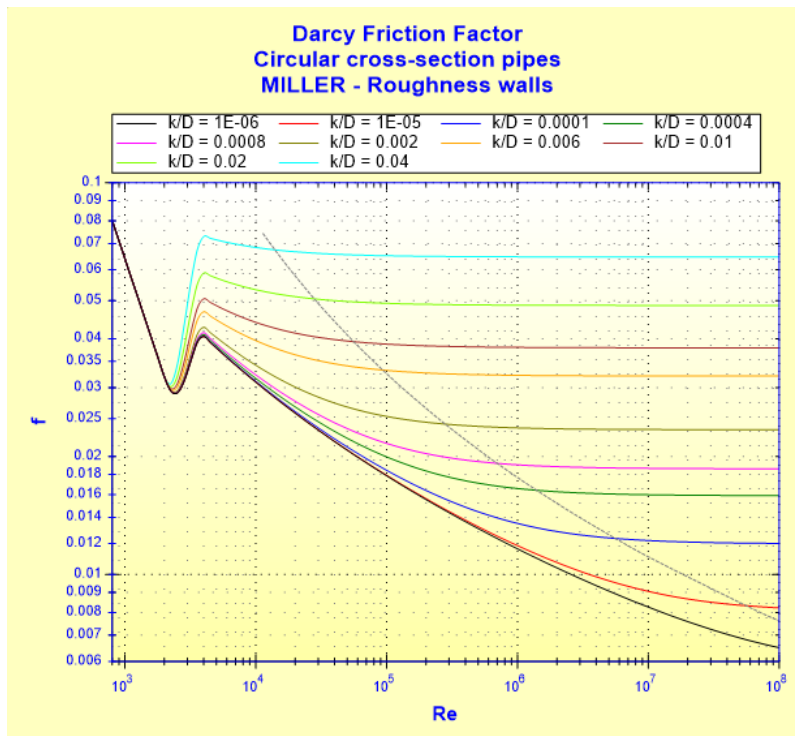
$$C_o = 1 \quad (\text{negligible effect})$$

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):

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

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Hydraulic power loss (W):

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

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Straight length of equivalent pressure loss (m):

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

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### Symbols, Definitions, SI Units:

D	Bend hydraulic diameter (m)
d	Bend internal diameter (m)
A	Cross-section area (m <sup>2</sup> )
Q	Volume flow rate (m <sup>3</sup> /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 <sup>3</sup> )
M	Fluid mass (kg)
Re	Reynolds number ( )
K <sub>b</sub> <sup>*</sup>	Basic loss coefficient ( )
C <sub>Re</sub>	Reynolds number correction factor ( )
K <sub>turb</sub>	Local resistance coefficient for Re ≥ 10 <sup>4</sup> ( )
K <sub>lam</sub>	Local resistance coefficient for Re < 10 <sup>4</sup> ( )
C <sub>o</sub>	Outlet pipe length correction factor ( )
L <sub>o</sub>	Length of the straight section downstream of the bend (m)
f	Darcy friction factor ( )
k	Absolute roughness of walls (m)
C <sub>f</sub>	Roughness correction factor ( )
K <sub>b</sub>	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 <sub>eq</sub>	Straight length of equivalent pressure loss (m)
ρ	Fluid density (kg/m <sup>3</sup> )
ν	Fluid kinematic viscosity (m <sup>2</sup> /s)
g	Gravitational acceleration (m/s <sup>2</sup> )

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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:

**Fluid characteristics**

Fluid: Water @ 1 atm [HC]  
Ref.: IAPWS IF97

Temperature:  $T = 20$  °C  
Pressure:  $P = 1.013$  bar

Density:  $\rho = 998.2061$  kg/m<sup>3</sup>  
Dynamic Viscosity:  $\mu = 0.00100159$  N.s/m<sup>2</sup>  
Kinematic Viscosity:  $\nu = 1.00340E-06$  m<sup>2</sup>/s

Density  Dyn. Visc.  Kin. Visc.

Density (kg/m<sup>3</sup>) vs Temperature (°C) graph showing a decreasing trend from approximately 1000 kg/m<sup>3</sup> at 10°C to 960 kg/m<sup>3</sup> at 100°C.

**Geometrical characteristics**

Hydraulic diameter:  $d = 0.0703$  m  
Relative radius of curvature:  $r/d = 0.175$   
Developed straight length from the axis:  $L = 0.2784773$  m  
Basic coefficient:  $K_b^* = 0.2111133$   
Reynolds number correction factor:  $C_{Re} = 1.510147$   
Coefficient of local resistance:  $K_{turb} = 0.3188121$   
Outlet tangent correction:  $C_o = 1$   
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

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

Option: Outlet pipe length correction factor  
 Use outlet pipe length correction factor  
Straight length:  $\geq 1.378851$  m

Flow parameters:  $m = 4.9910$  kg/s,  $Q = 0.005$  m<sup>3</sup>/s,  $U = 1.288$  m/s (Turbulent)

**Complementary results**

Designation	Symbol	Value	Unit
Hydraulic diameter	$D$	0.0703	m
Passage cross-section area	$A$	0.003881508	m <sup>2</sup>
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