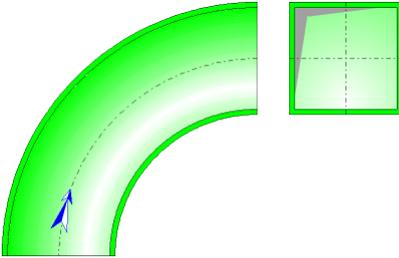




## Smooth Bend Circular Cross-Section (Pipe Flow - Guide)



### Model description:

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

### Model formulation:

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Hydraulic diameter (m):

$$d_h = \frac{2 \cdot w \cdot h}{w + h}$$

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

$$A = w \cdot h$$

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Mean velocity (m/s):

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

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Length measured along the axis (m):

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

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Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

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

$$\text{Vol} = A \cdot L$$

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Fluid mass (kg):

$$\text{Mas} = \text{Vol} \cdot \rho_m$$

Reynolds number:

$$N_{\text{Re}} = \frac{V \cdot d_h}{\nu}$$

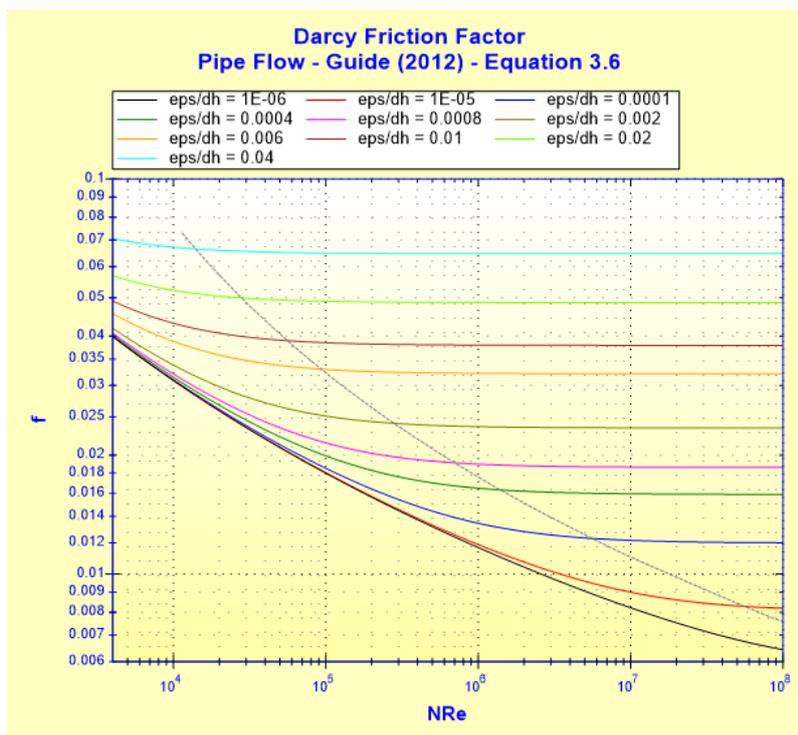
Relative roughness:

$$R_r = \frac{\varepsilon}{d_h}$$

Darcy friction factor:

$$f = \frac{1}{\left[ 2 \cdot \log \left( \frac{\varepsilon}{3.7 \cdot d_h} + \frac{2.51}{N_{\text{Re}} \cdot \sqrt{f}} \right) \right]^2}$$

Colebrook-White equation ([1] equation 3.6)

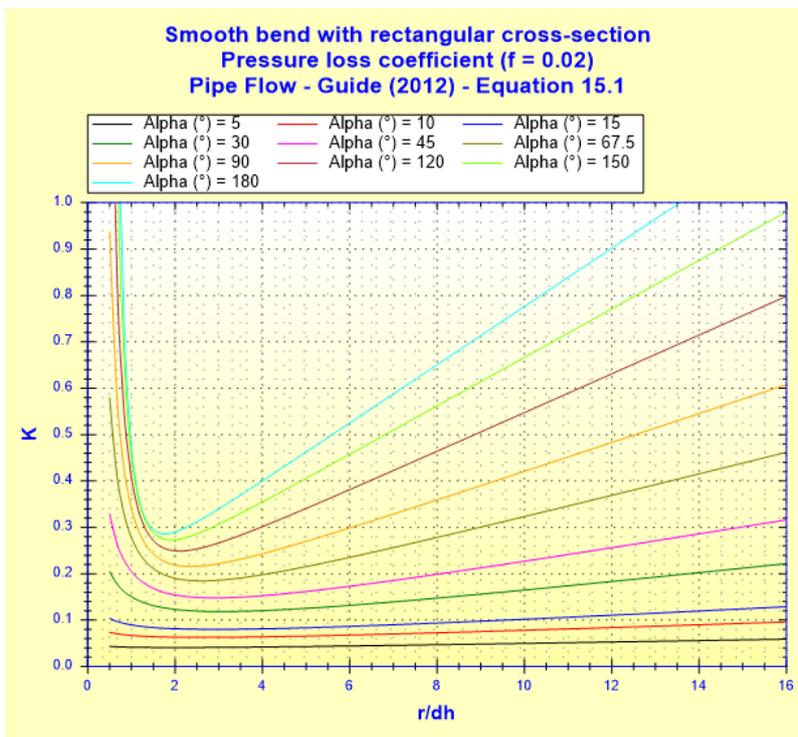


Total pressure loss coefficient (based on mean velocity in bend):

$$K = f \cdot \alpha \cdot \frac{r}{d_h} + (0.10 + 2.4 \cdot f) \cdot \sin(\alpha/2) + \frac{6.6 \cdot f \cdot (\sqrt{\sin(\alpha/2)} + \sin(\alpha/2))}{\left( \frac{r}{d_h} \right)^{\frac{4 \cdot \alpha}{\pi}}}$$

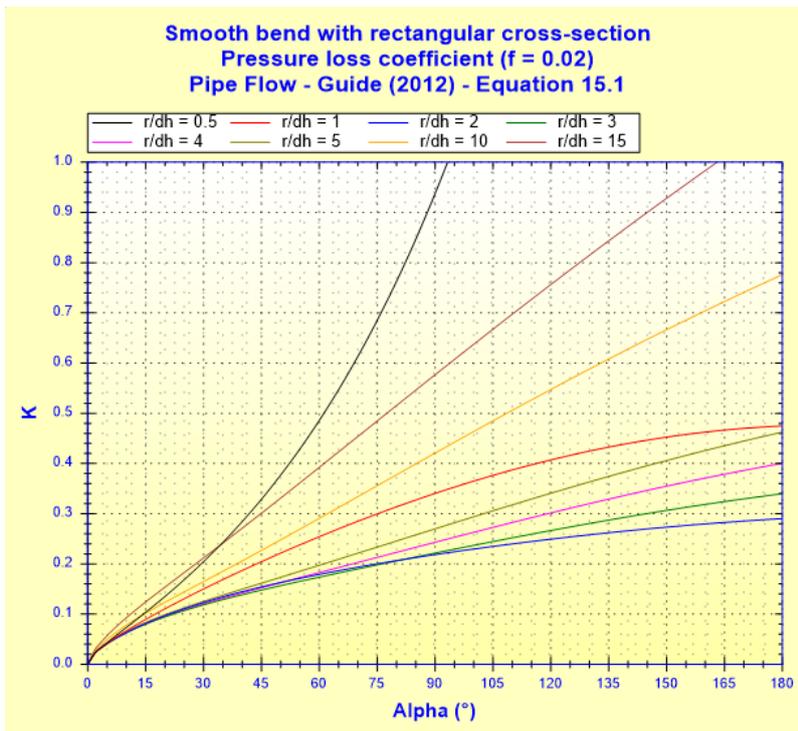
([1] equation

15.1)



([1] equation 15.1 with f =

0.02)



([1] equation 15.1 with f =

0.02)

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho_m \cdot V^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{V^2}{2 \cdot g}$$

Hydraulic power loss (W):

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

Straight length of equivalent pressure loss (m):

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

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**Symbols, Definitions, SI Units:**

w	Rectangular cross-section width (m)
h	Rectangular cross-section height (m)
$d_h$	Bend hydraulic diameter (m)
A	Cross-section area (m <sup>2</sup> )
Q	Volume flow rate (m <sup>3</sup> /s)
V	Mean velocity (m/s)
L	Length measured along the axis (m)
r	Radius of curvature (m)
$\alpha$	Curvature angle (°)
G	Mass flow rate (kg/s)
Vol	Fluid volume (m <sup>3</sup> )
Mas	Fluid mass (kg)
$N_{Re}$	Reynolds number ( )
$R_r$	Relative roughness ( )
$\varepsilon$	Absolute roughness of walls (m)
f	Darcy friction factor
K	Total pressure loss coefficient (based on mean velocity in bend) ( )
$\Delta P$	Total pressure loss (Pa)
$\Delta H$	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
$L_{eq}$	Straight length of equivalent pressure loss (m)
$\rho_m$	Fluid density (kg/m <sup>3</sup> )
$\nu$	Fluid kinematic viscosity (m <sup>2</sup> /s)
g	Gravitational acceleration (m/s <sup>2</sup> )

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**Validity range:**

- turbulent flow regime ( $N_{Re} \geq 10^4$ )
- stabilized flow upstream of the bend
- curvature angle between 0° and 180°
- this formulation is for circular passages, but can be reasonably applied to square ducts or to rectangular ducts of low aspect ratio

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**Example of application:**

HydrauCalc 2020a - [Smooth bend with rectangular cross-section - Pipe Flow - Guide (2012)]

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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.

Geometrical characteristics

Pressure loss  
 $\Delta P$  0.0010908 bar  
 $\Delta H$  0.0111 m of fluid

Complementary results

Designation	Symbol	Value	Unit
Hydraulic diameter	dh	0.06666667	m
Passage cross-section area	A	0.005	m <sup>2</sup>
Sides ratio	h/w	0.5	
Relative radius of curvature	r/dh	2.625	
Developed straight length from the axis	L	0.2748893	m
Internal bend volume	Vol	0.001374447	m <sup>3</sup>
Mass of fluid in the bend	Mas	1.371981	kg
Relative roughness	Rr	0.00015	
Reynolds number	NRe	66440.97	
<input checked="" type="checkbox"/> Darcy Friction Factor (Equation 3.6)	f	0.02024362	
<input checked="" type="checkbox"/> Coefficient of local resistance (Equation 15.1)	K	0.218552	
Pressure loss coefficient (based on the mean bend velocity)	K	0.218552	
Hydraulic power loss	Wh	0.5453998	W
Straight length of equivalent pressure loss	Leq	0.7197398	m

## References:

[1] Pipe Flow: A Practical and Comprehensive Guide. Donald C. Rennels and Hobart M. Hudson. (2012)