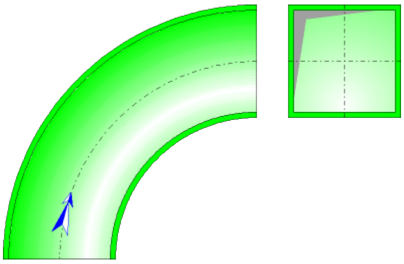
Smooth Bend
Circular Cross-Section
(Pipe Flow - Guide)



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:

Hydraulic diameter (m):

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

Cross-section area (m²):

$$\boxed{A = w \cdot h}$$

Mean velocity (m/s):

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

Length measured along the axis (m):

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

Mass flow rate (kg/s):

$$\boxed{G = Q \cdot \rho_m}$$

Fluid volume (m³):

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

Fluid mass (kg):

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

Reynolds number:

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

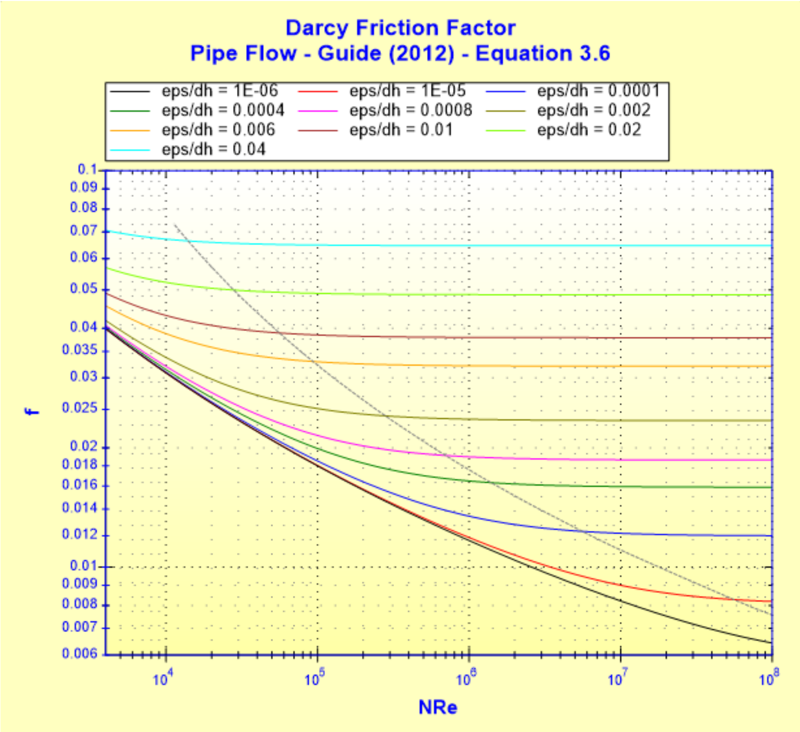
Relative roughness:

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

Darcy friction factor:

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

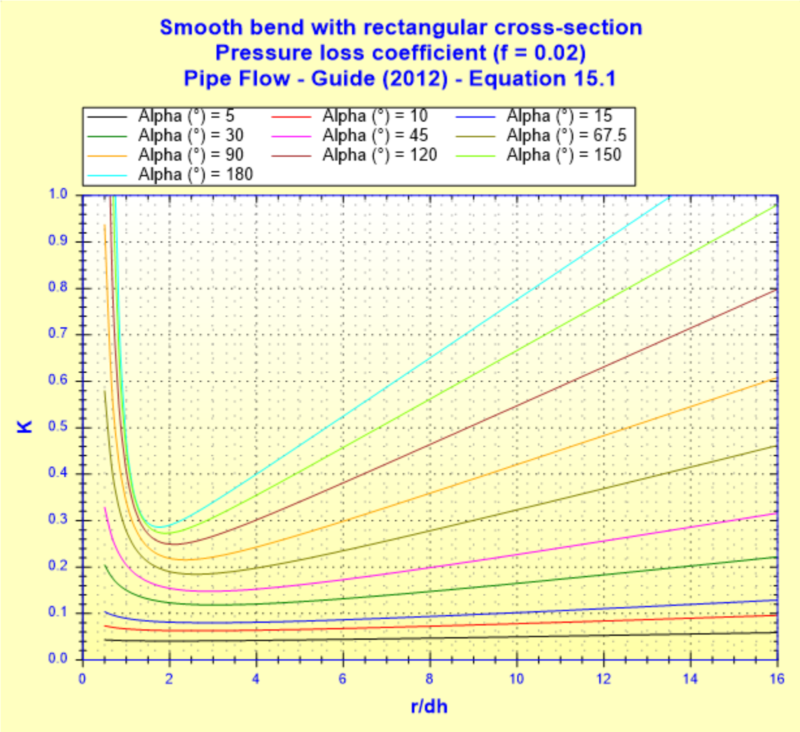
Colebrook-White equation ([1] equation 3.6)



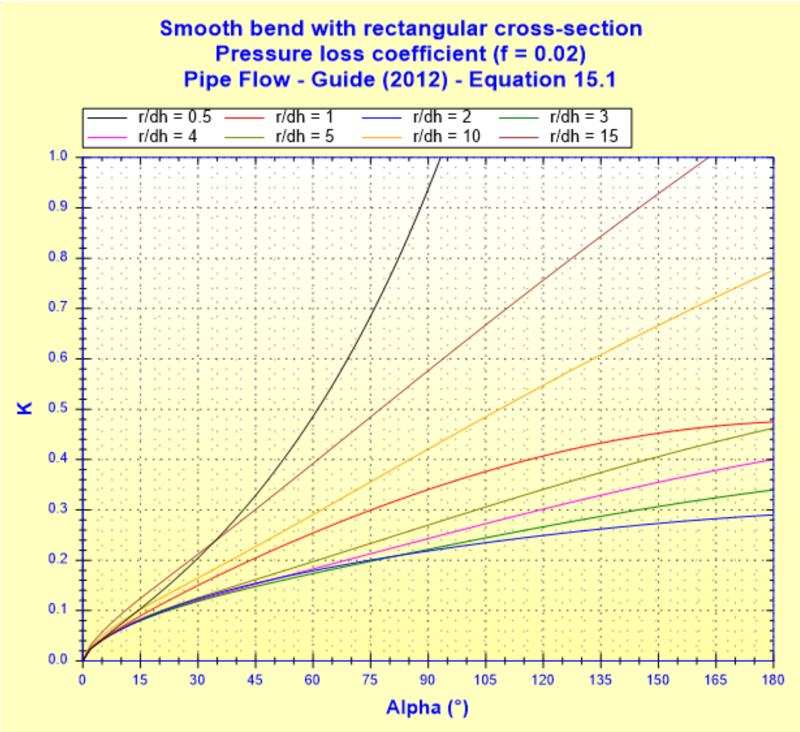
Total pressure loss coefficient (based on mean velocity in bend):

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

([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):

$$\boxed{Wh = \Delta P \cdot Q}$$

Straight length of equivalent pressure loss (m):

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

Symbols, Definitions, SI Units:

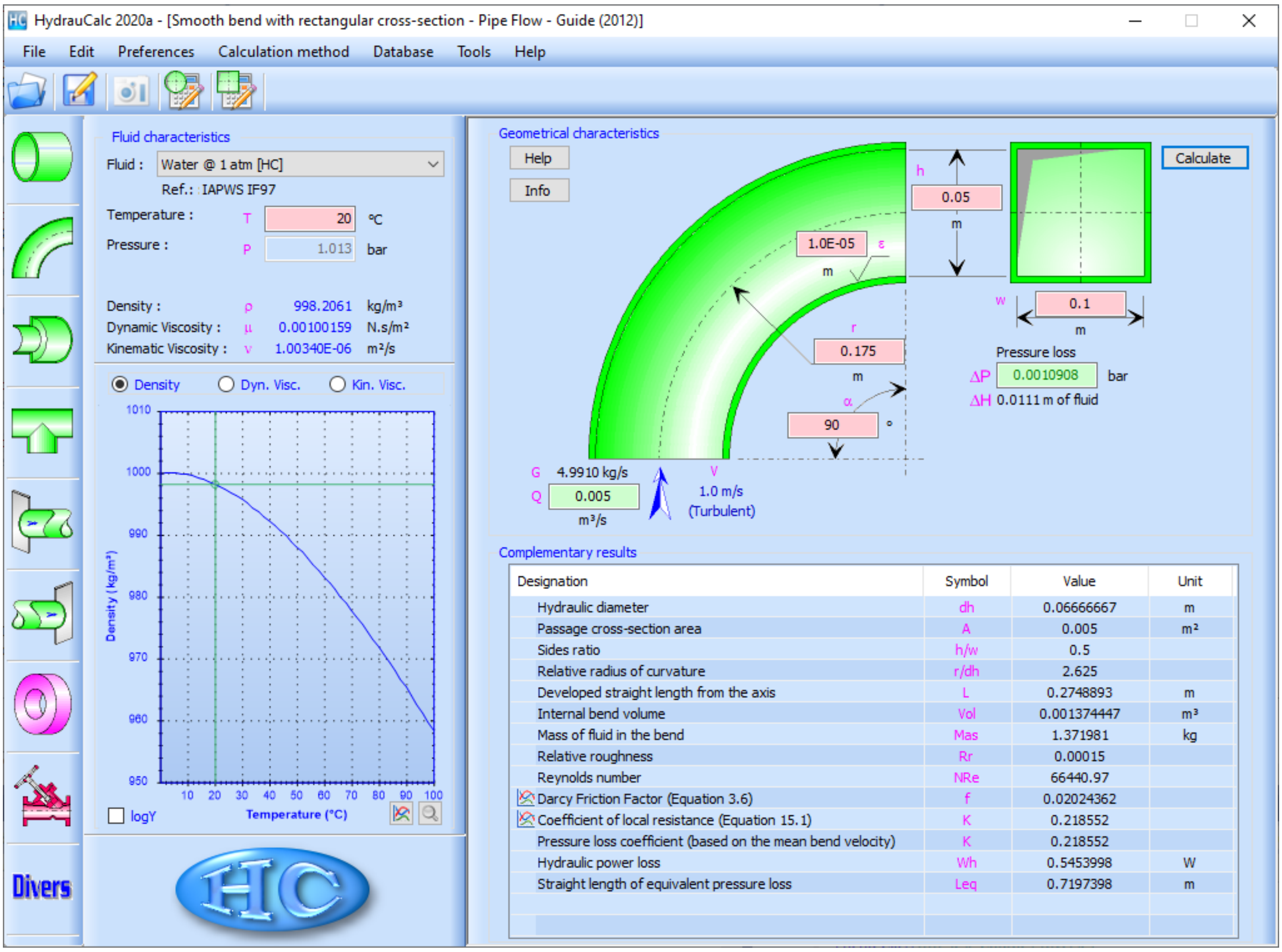
w	Rectangular cross-section width (m)
h	Rectangular cross-section height (m)
d_h	Bend hydraulic diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
V	Mean velocity (m/s)
L	Length measured along the axis (m)
r	Radius of curvature (m)
α	Curvature angle (°)
G	Mass flow rate (kg/s)
Vol	Fluid volume (m^3)
Mas	Fluid mass (kg)
N_{Re}	Reynolds number ()
R_r	Relative roughness ()
ε	Absolute roughness of walls (m)
f	Darcy friction factor
K	Total pressure loss coefficient (based on mean velocity in 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_m	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

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

---

Example of application:



References:

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