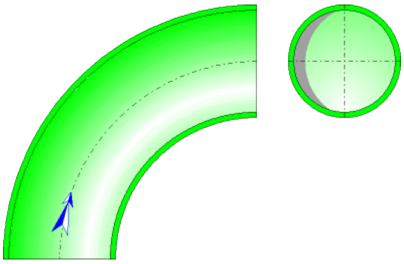
Smooth Bend
Circular Cross-Section
(MILLER)



Model description:

This model of component calculates the head loss (pressure drop) of a bend smoothly curved 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. The friction loss in this straight length is not taken into account in this component.

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):

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

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

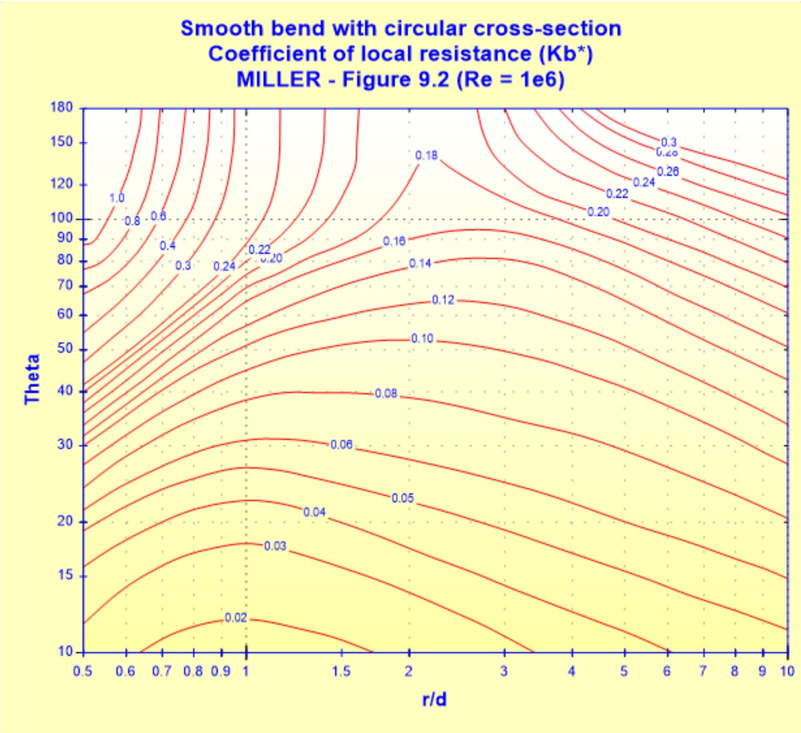
$$M = V \cdot \rho$$

Reynolds number:

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

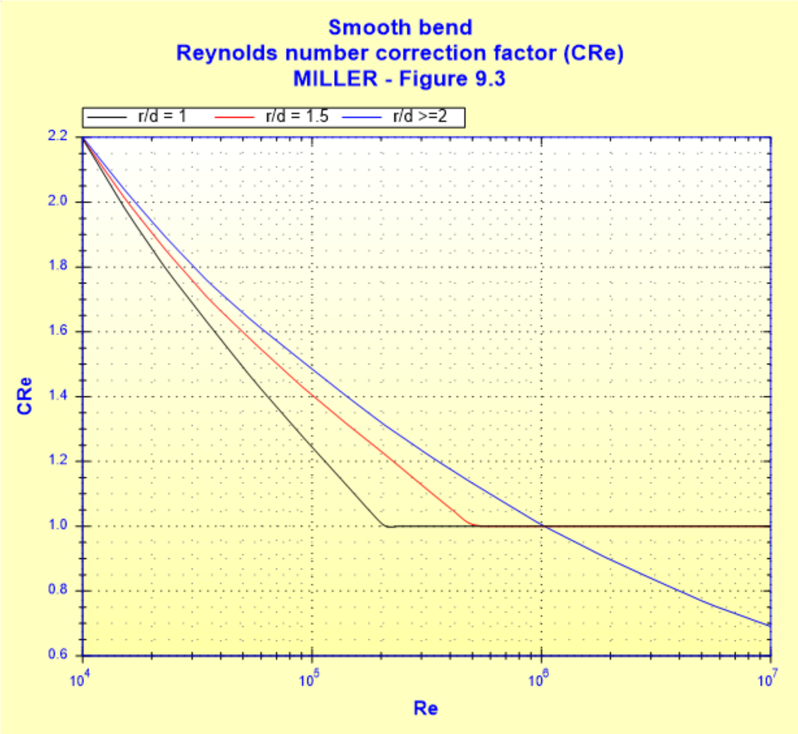
Basic resistance coefficient:

$$K_b^* = f\left(\frac{r}{d}, \theta_b\right)$$ ([1] figure 9.2)



Reynolds number correction factor:

$$C_{Re} = f\left(Re, \frac{r}{d}\right)$$ ([1] figure 9.3)



- r/d ≥ 1

$$C_{\mathrm{Re}} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3)

- r/d < 1
  - r/d > 0.7 or $K_b^* < 0.4$

$$C_{\mathrm{Re}} = f\left(\mathrm{Re}, \frac{r}{d}\right)$$ ([1] figure 9.3 with r/d=1)

  - otherwise (r/d ≤ 0.7 and $K_b^* \geq 0.4$)

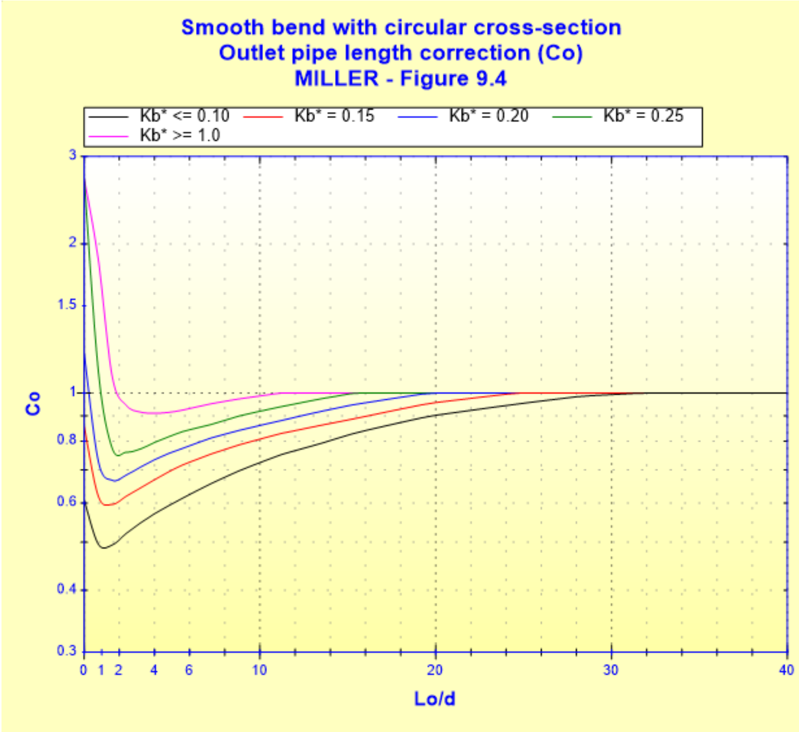
$$C_{\mathrm{Re}} = \frac{K_b^*}{K_b^* - 0.2C'_{\mathrm{Re}} + 0.2}$$ ([1] equation 9.2)

with:

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

Outlet pipe length correction factor (optional):

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



- r/d < 3 et θ_b < 100°

$$C_o = f\left(\frac{L_o}{d}, K_b^*\right)$$

([1] figure 9.4)

- otherwise (r/d > 3 and/or θ_b > 100°)

$$C_o = 1$$

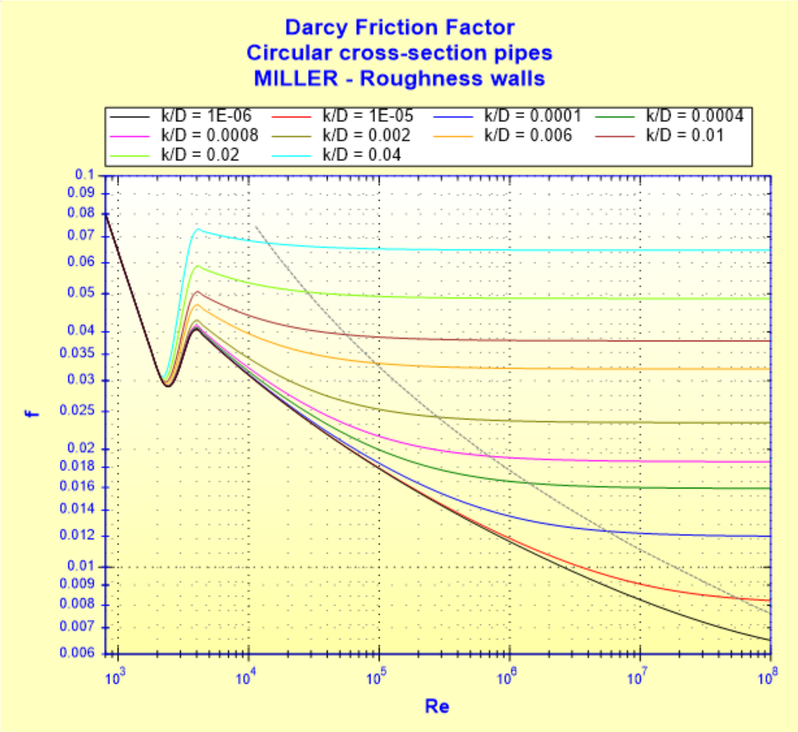
(negligible effect)

If this option is not activated, the factor C_o is equal to unity.

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{D}\right)$$

See Straight Pipe - Circular Cross-Section and Roughness Walls (MILLER)



Roughness correction factor:

$$C_f = \frac{f_{rough}}{f_{smooth}}$$ ([1] 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:

$$K_b = K_b^* \cdot C_{Re} \cdot C_o \cdot C_f$$

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

$$K = K_b$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([1] equation 8.1b)

Total head loss of fluid (m):

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

Hydraulic power loss (W):

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

Straight length of equivalent pressure loss (m):

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

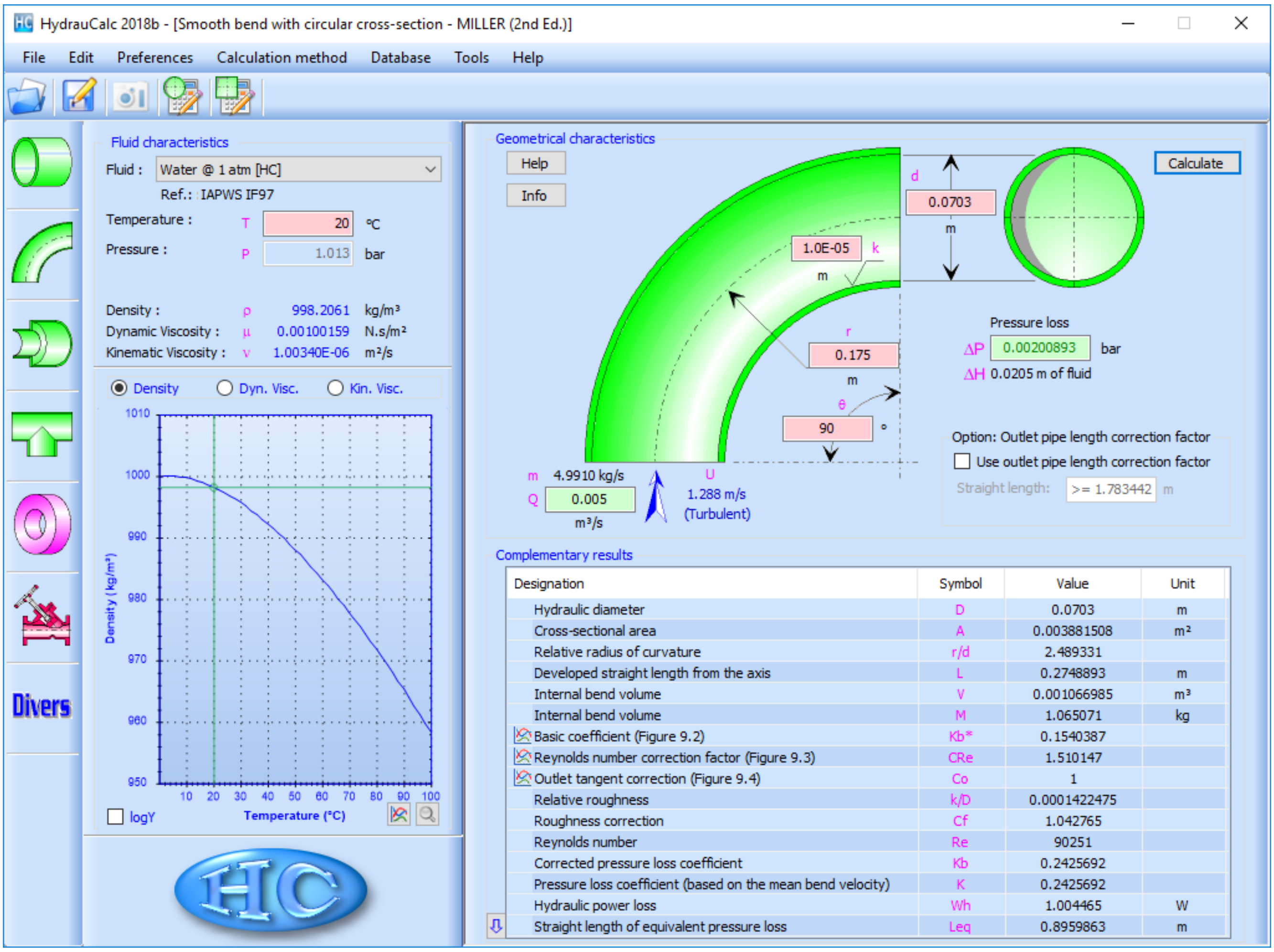
Symbols, Definitions, SI Units:

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)
θ_b	Curvature angle (°)
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 ()
C_o	Outlet pipe length correction factor ()
L_0	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:

- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream bend
- curvature angle: 10 - 180°
- relative radius of curvature 'r/d': lower than 10

Example of application:



References:

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