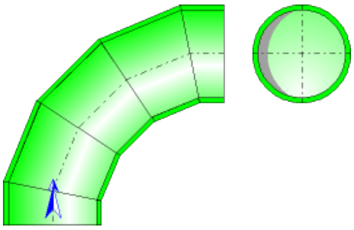
Composite Bend 90° (4 x 22.5°)
Circular Cross-Section
(MILLER)



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:

Hydraulic diameter (m):

$$D = d$$

Cross-section area (m^2):

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

Mean velocity (m/s):

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

Length measured along the axis (m):

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

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

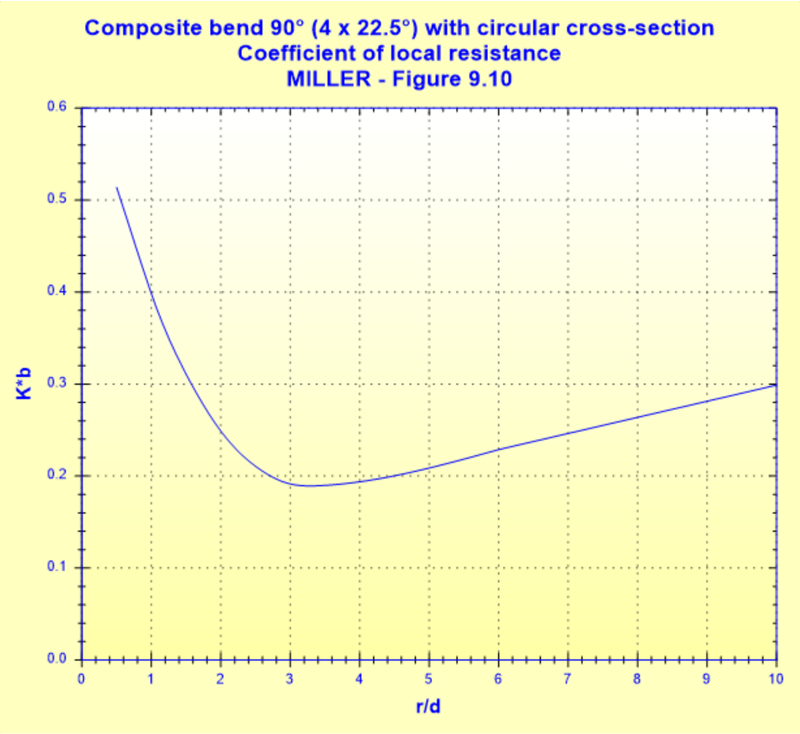
$$M = V \cdot \rho$$

Reynolds number:

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

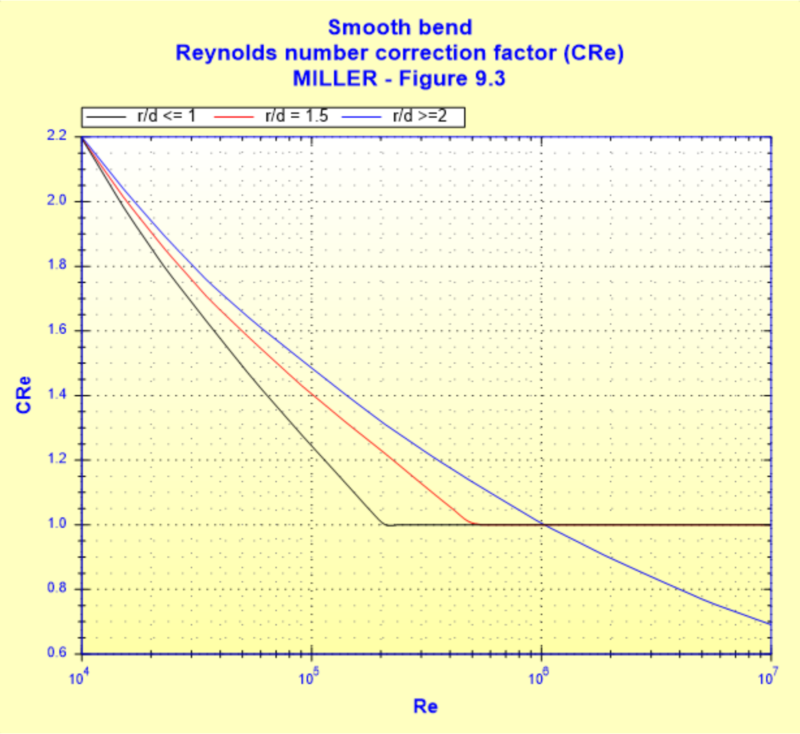
Basic resistance coefficient:

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



Reynolds number correction factor:

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



- $r/d \geq 1$

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

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

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

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

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

    with:

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

Local resistance coefficient:

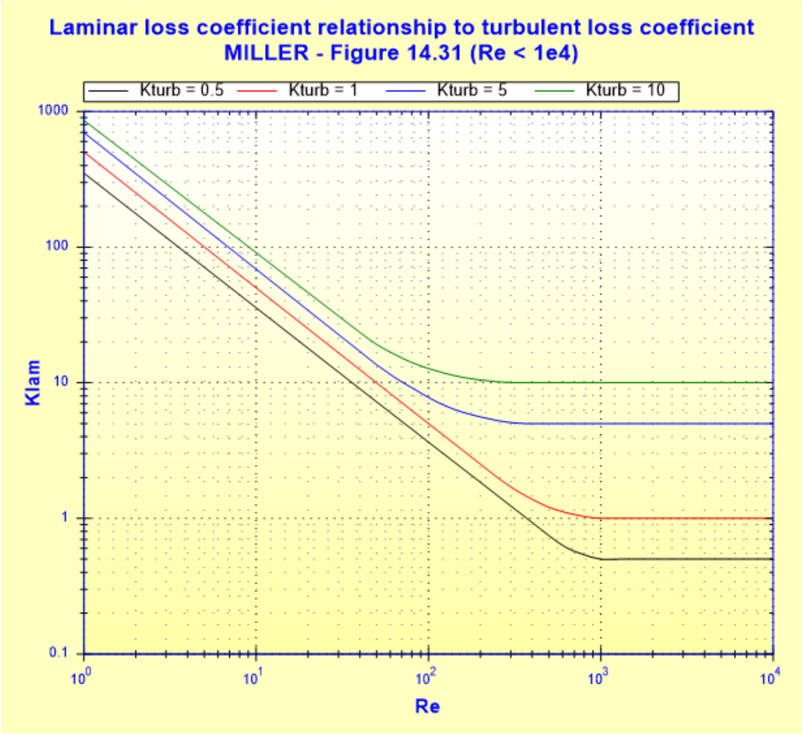
- $Re \geq 10^4$ (turbulent flow)

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

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

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

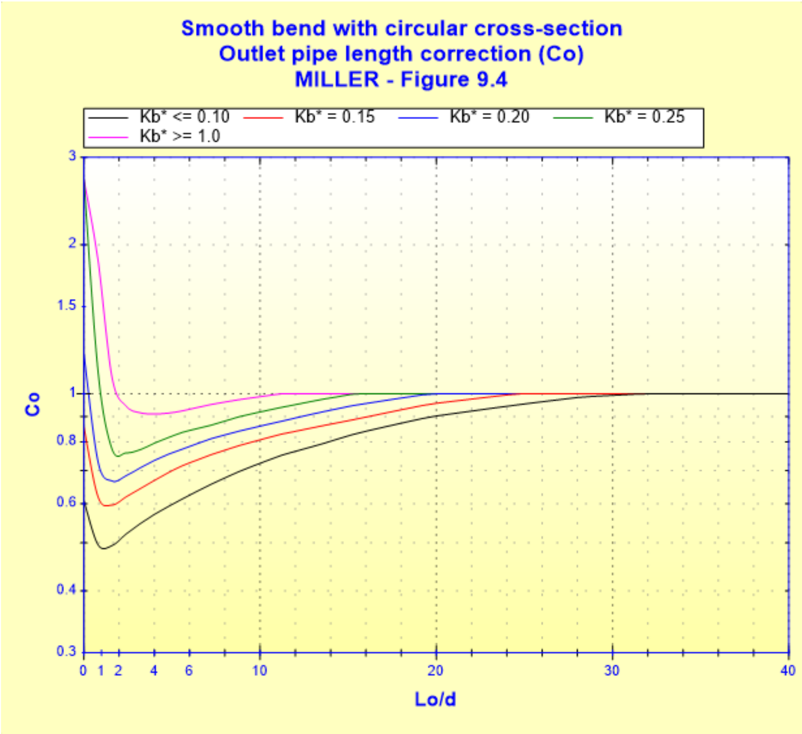
where:
K_{turb} is the resistance coefficient in turbulent regime for Re = 10^4



Outlet pipe length correction factor (optional):

- r/d < 3

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



- otherwise (r/d ≤ 3)

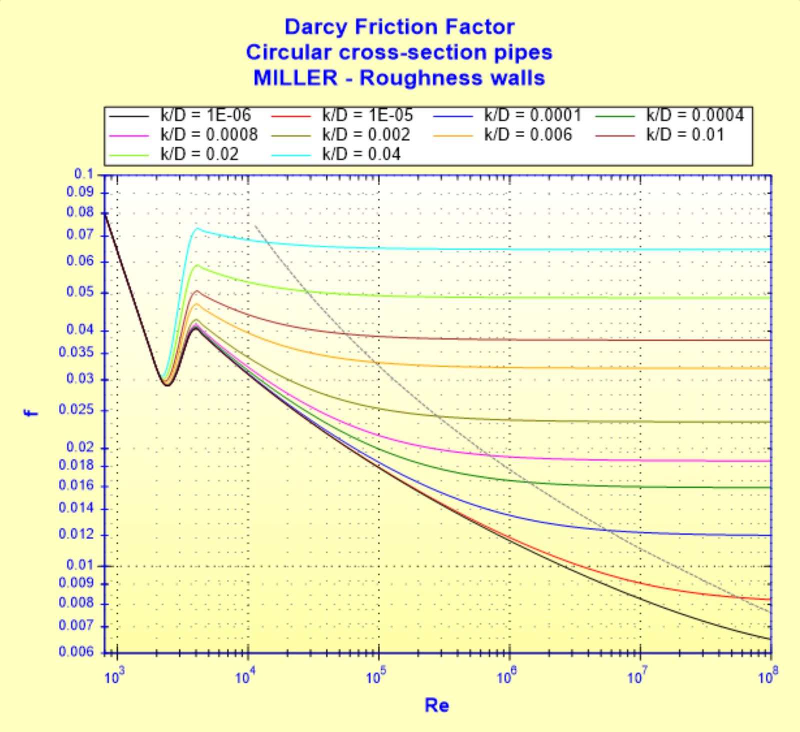
$$C_o = 1$$ (negligible effect)

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:

- 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):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$ ([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):

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

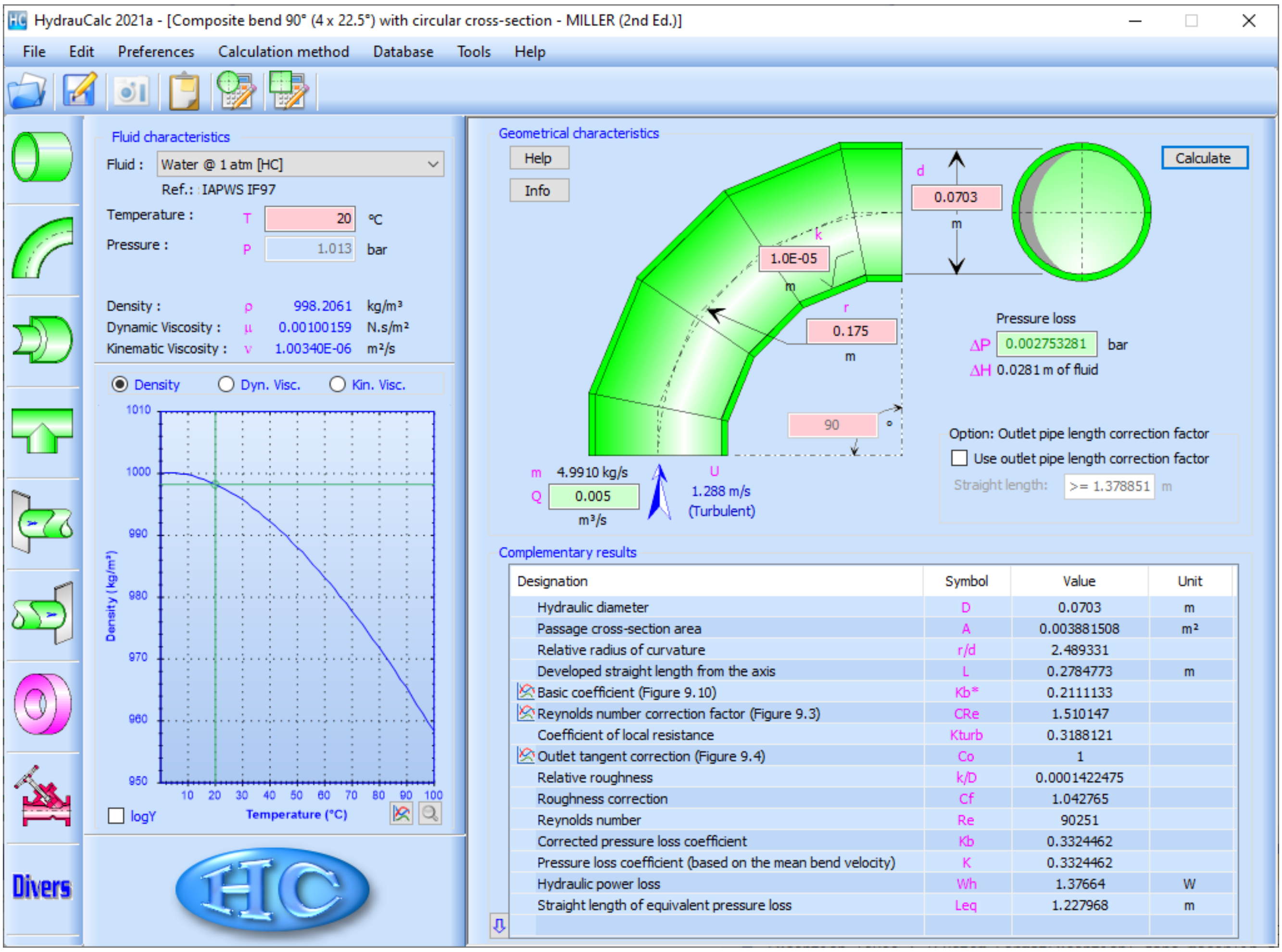
Symbols, Definitions, SI Units:

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)
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 $Re \geq 10^4$ ()
K_{lam}	Local resistance coefficient for $Re < 10^4$ ()
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:

- 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:



References:

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