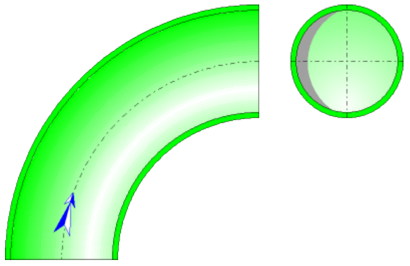
Smooth Bend
Circular Cross-Section
(CRANE)



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.

Model formulation:

Cross-section area (m^2):

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

Mean velocity (m/s):

$$v = \frac{q}{A}$$

Length measured along the axis (m):

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

Mass flow rate (kg/s):

$$w = q \cdot \rho$$

Fluid volume (m^3):

$$V = A \cdot L$$

Fluid mass (kg):

$$M = Vol \cdot \rho_m$$

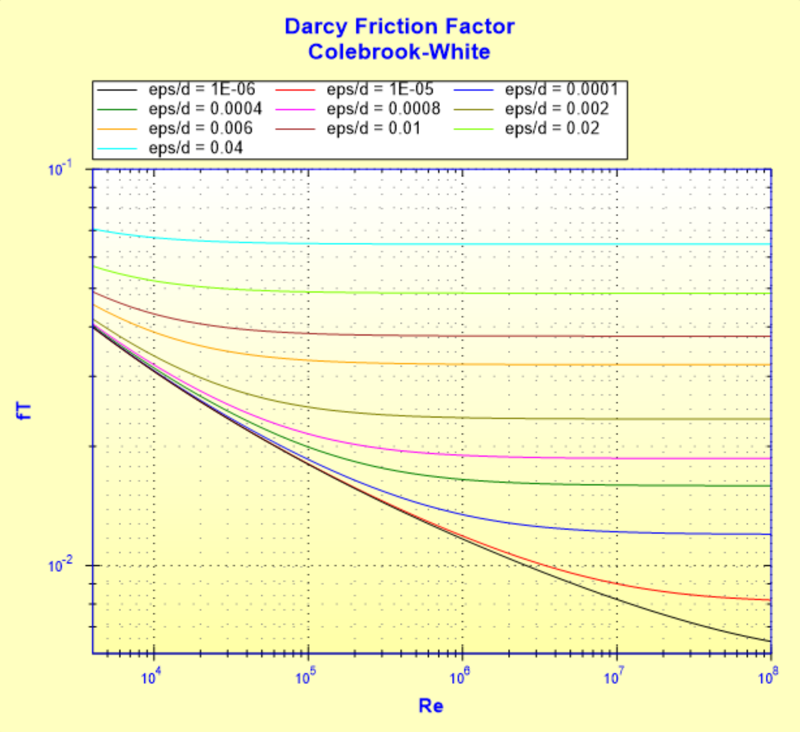
Reynolds number:

$$\mathrm{Re} = \frac{v \cdot d}{\nu}$$

Darcy friction factor:

$$f_T = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d} + \frac{2.51}{\mathrm{Re} \cdot \sqrt{f_T}}\right)\right]^2}$$

Colebrook-White equation

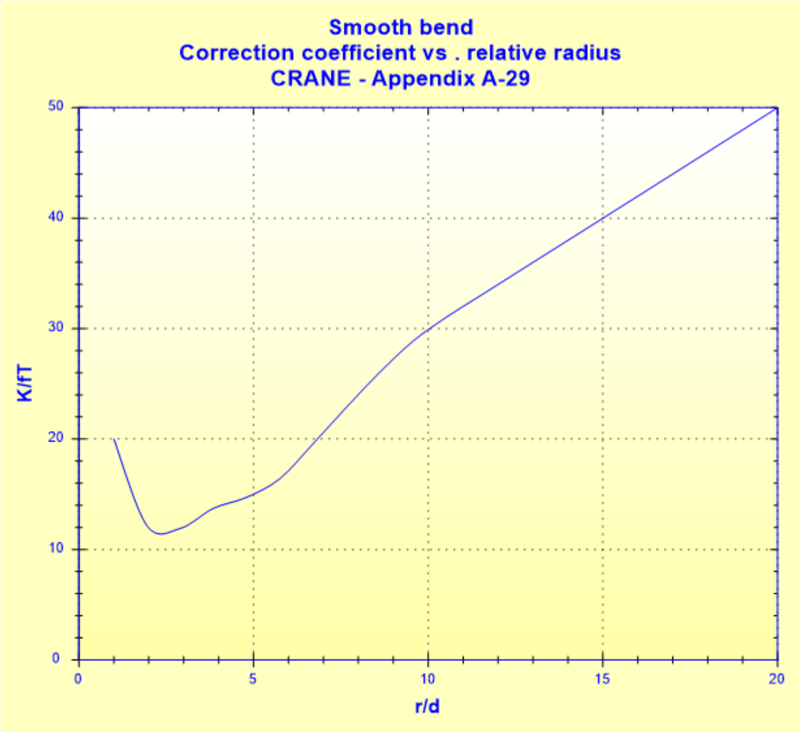


Resistance coefficient for one 90° smooth bend:

$$K = f\left(\frac{r}{d}, f_T\right)$$

([1] Appendix A-29)

r/d	K	K/f_T
1	20 f_T	20
1.5	14 f_T	14
2	12 f_T	12
3	12 f_T	12
4	14 f_T	14
6	17 f_T	17
8	24 f_T	24
10	30 f_T	30
12	34 f_T	34
14	38 f_T	38
16	42 f_T	42
20	50 f_T	50



Correction coefficient for angle lower than 90°:

$$K_{corr} = \alpha \cdot \left(0.0142 - 3.703 \cdot 10^{-5} \cdot \alpha\right)$$ ([2])

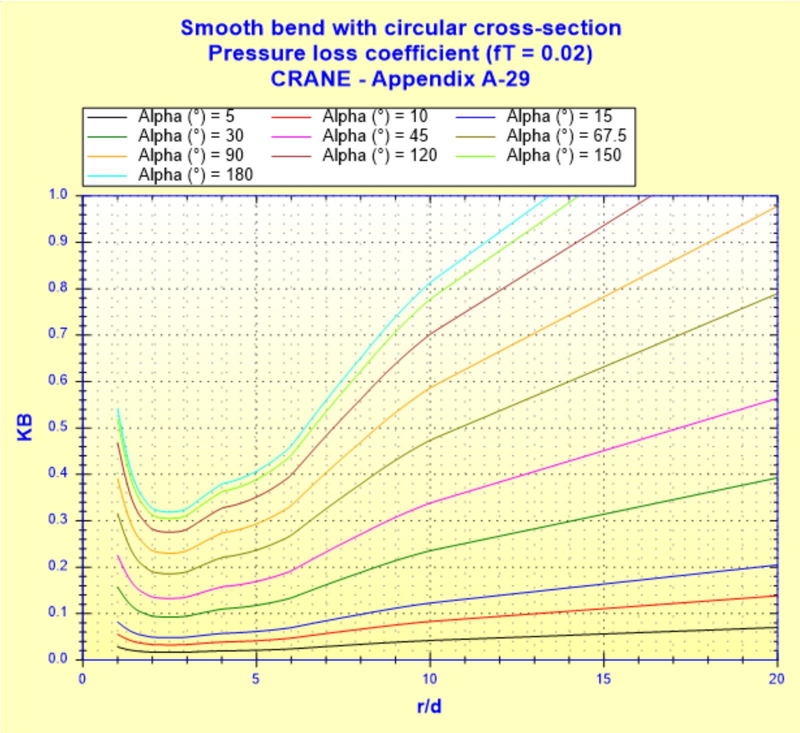
Total pressure loss coefficient (based on mean velocity in bend):

- $\alpha \geq 90°$

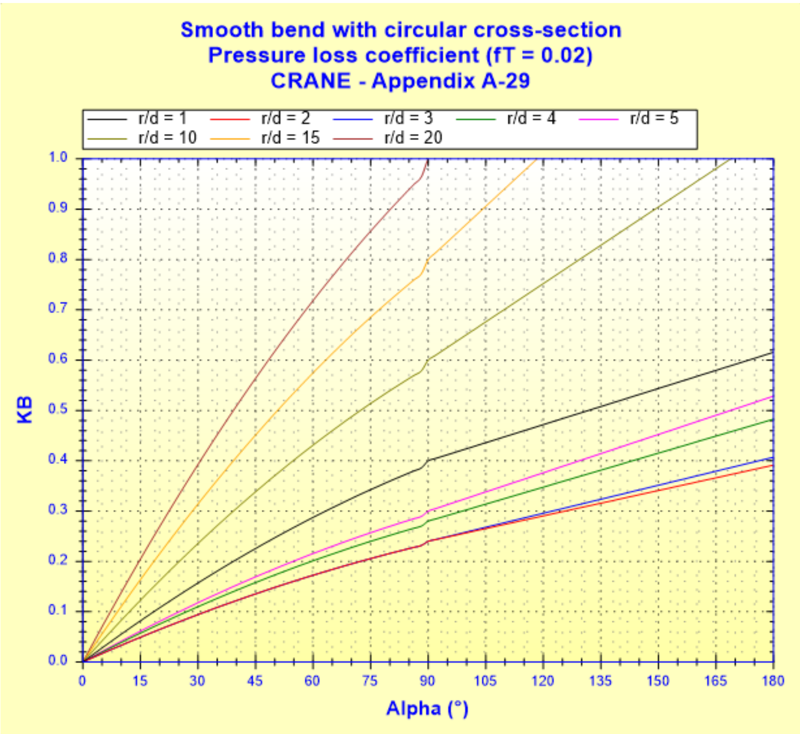
$$K_B = \left(\frac{\alpha}{90} - 1\right)\left(0.25 \cdot \pi \cdot f_T \cdot \frac{r}{d} + 0.5 \cdot K\right) + K$$ ([1] Appendix A-29)

- $\alpha < 90°$

$$K_B = K \cdot K_{corr}$$ (([1] Appendix A-29 & [2])



(with f_T = 0.02)



(with f_T = 0.02)

Total pressure loss (Pa):

$$\Delta P = K_B \cdot \frac{\rho \cdot v^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K_B \cdot \frac{v^2}{2 \cdot g}$$

Hydraulic power loss (W):

$$Wh = \Delta P \cdot q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K_B \cdot \frac{d}{f_T}$$

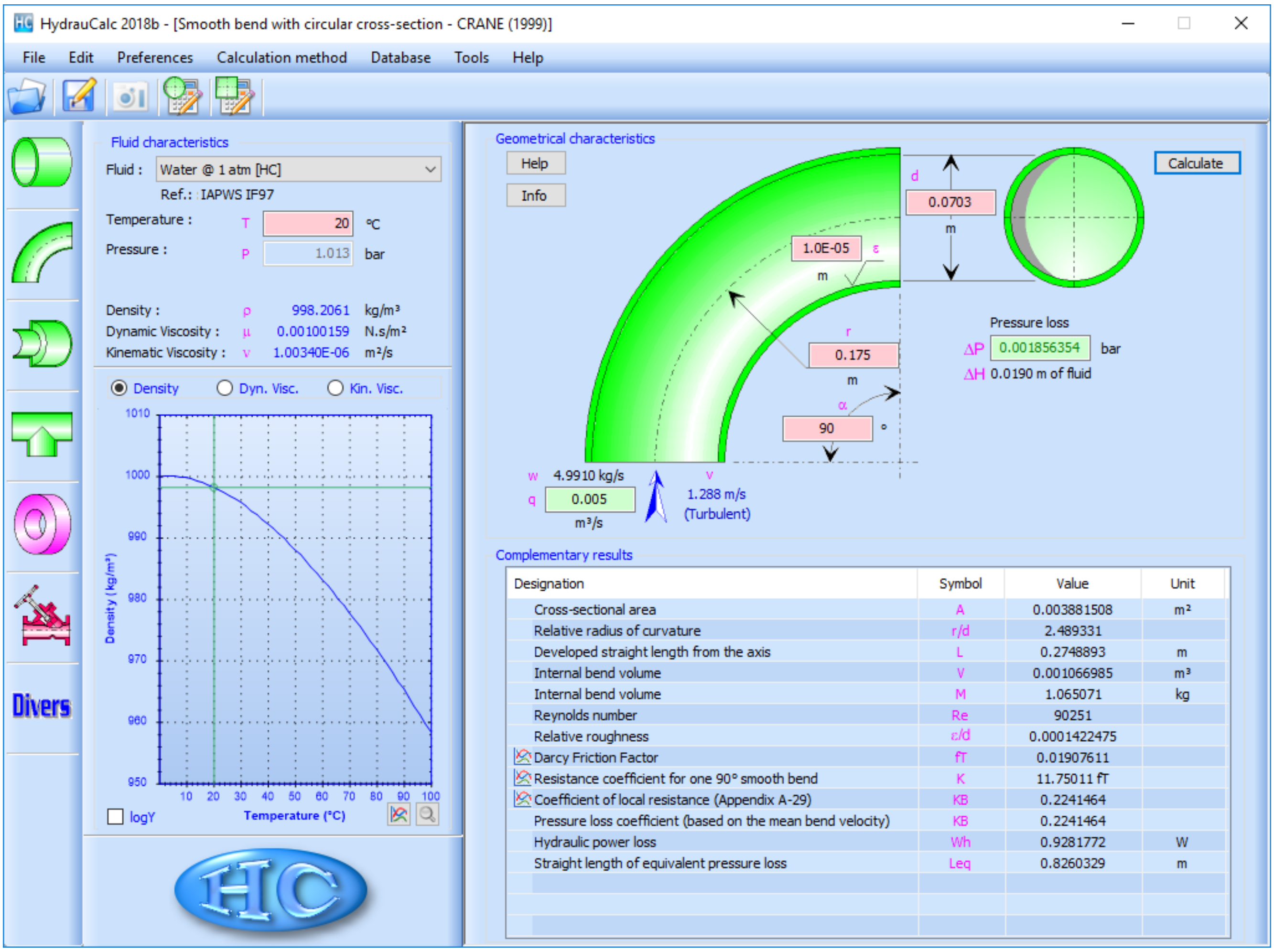
Symbols, Definitions, SI Units:

d	Pipe internal 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 (°)
w	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
f_T	Darcy friction factor
ε	Absolute roughness of walls (m)
K	Resistance coefficient for one 90° smooth bend ()
K_{corr}	Correction coefficient for angle lower than 90° ()
K_B	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	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 of the bend
- curvature angle between 0° and 180°
- relative radius of curvature (r/d) range between 1 and 20
  for relative radii 'r/d' between 0.5 and 1 or those greater than 20, the coefficient 'K' is linearly extrapolated.

Example of application:



References:

[1] CRANE - Flow of Fluids Through Valves, Fitting and Pipe - Technical Paper No. 410 - Edition 1999

[2] George R. Keller, Hydraulic System Analysis, Published by the Editors of Hydraulics & Pneumatics Magazine, 1970