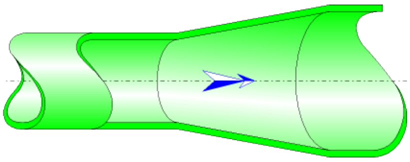
Gradual Expansion
Circular Cross-Section
(Pipe Flow - Guide)



Model description:

This model of component calculates the head loss (pressure drop) generated by the flow in a gradual expansion. The head loss by friction in the gradual expansion is taken into account for cone angles less than 60 °, beyond this angle the head loss by friction becomes negligible.

The head loss by friction in the inlet and outlet piping is not taken into account in this component.

Model formulation:

Ratio of small to large diameter:

$$\beta = \frac{d_1}{d_2}$$

Top angle of cone (°):

$$\alpha = 2 \cdot \tan^{-1}\left(\frac{d_2 - d_1}{2 \cdot l}\right)$$

Minor cross-sectional area (m²):

$$A_1 = \pi \cdot \frac{d_1^{\,2}}{4}$$

Major cross-sectional area (m²):

$$A_2 = \pi \cdot \frac{d_2^{\,2}}{4}$$

Mean velocity in minor diameter (m/s):

$$V_1 = \frac{Q}{A_1}$$

Mean velocity in major diameter (m/s):

$$V_2 = \frac{Q}{A_2}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho_m$$

Fluid volume in the truncated cone (m^3):

$$V = l \cdot \frac{\pi}{3} \cdot \left[\left(\frac{d_1}{2}\right)^2 + \left(\frac{d_2}{2}\right)^2 + \left(\frac{d_1}{2}\right) \cdot \left(\frac{d_2}{2}\right) \right]$$

Fluid mass in the truncated cone (kg):

$$M = V \cdot \rho_m$$

Reynolds number in minor diameter:

$$N_{Re_1} = \frac{V_1 \cdot d_1}{\nu}$$

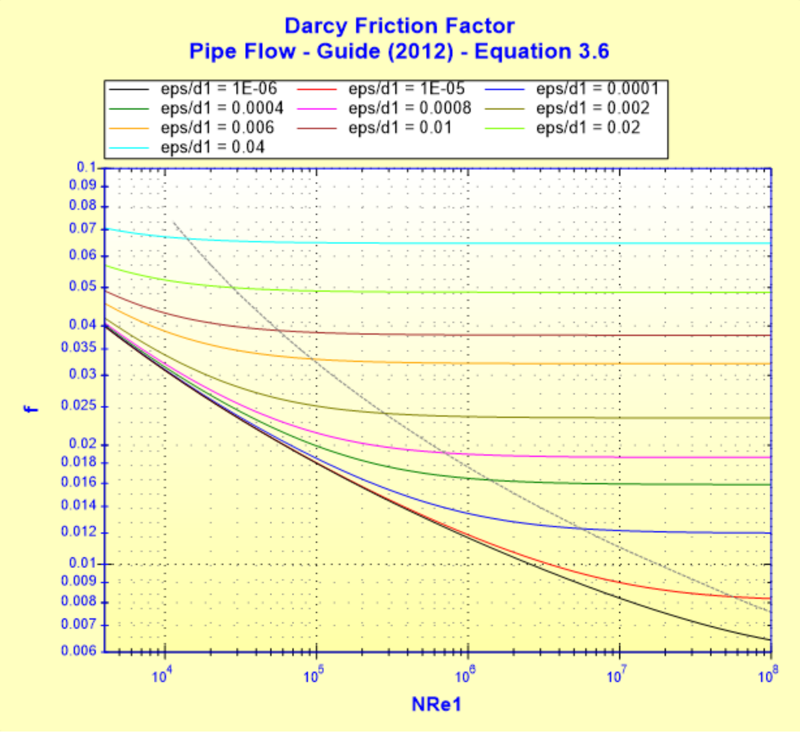
Reynolds number in major diameter:

$$N_{Re_2} = \frac{V_2 \cdot d_2}{\nu}$$

Darcy friction factor:

$$f = \frac{1}{\left[2 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot d_1} + \frac{2.51}{N\mathrm{Re}_1 \cdot \sqrt{f}} \right) \right]^2}$$

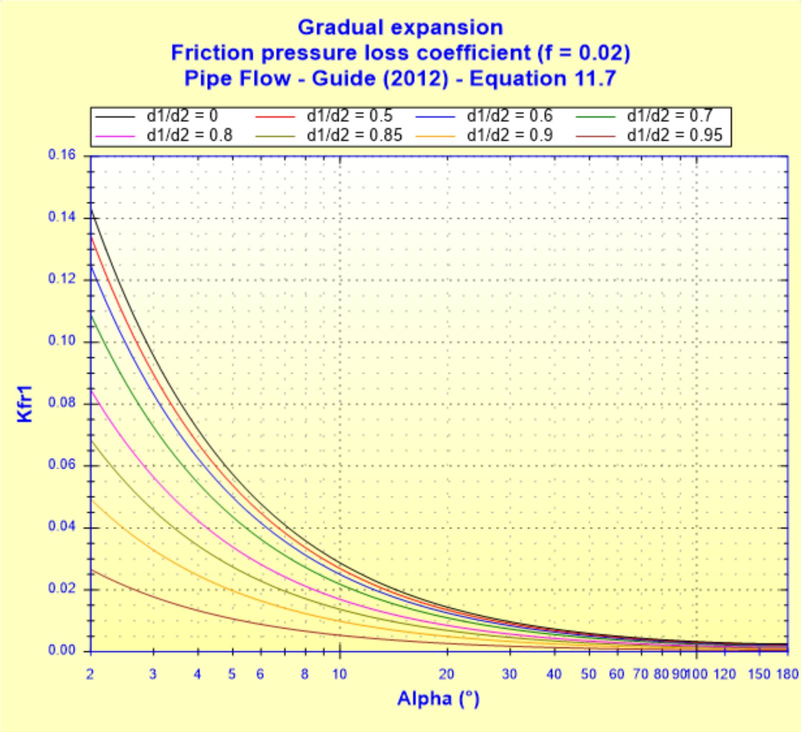
Colebrook-White equation ([1] equation 3.6)



Friction pressure loss coefficient:

$$K_{fr1} = \frac{f \cdot \left(1-\beta^4\right)}{8 \cdot \sin\left(\frac{\alpha}{2}\right)}$$

([1] equation 11.7)



([1] equation 11.7 with f = 0.02)

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

■ 0° ≤ α ≤ 20°:

$$K_1 = 8.30 \cdot \left[\tan\left(\frac{\alpha}{2}\right)\right]^{1.75} \cdot \left(1-\beta^2\right)^2 + \frac{f \cdot \left(1-\beta^4\right)}{8 \cdot \sin\left(\frac{\alpha}{2}\right)}$$

([1] equation 11.8)

■ 20° ≤ α < 60°:

- 0 ≤ β < 0.5

$$K_1 = \left\{1.366 \cdot \sin\left[\left(2 \cdot (\alpha - 15)^{1/2}\right)\right] - 0.170 - 3.28 \cdot \left(\left(0.0625 - \beta^4\right) \cdot \sqrt{\frac{\alpha - 20}{40}}\right)\right\} \cdot \left(1-\beta^2\right)^2 + \frac{f \cdot \left(1-\beta^4\right)}{8 \cdot \sin\left(\frac{\alpha}{2}\right)}$$

([1] equation 11.9a)

- 0.5 ≤ β ≤ 1

$$K_1 = \left\{1.366 \cdot \sin\left[\left(2 \cdot (\alpha - 15)^{1/2}\right)\right] - 0.170\right\} \cdot \left(1-\beta^2\right)^2 + \frac{f \cdot \left(1-\beta^4\right)}{8 \cdot \sin\left(\frac{\alpha}{2}\right)}$$

([1] equation 11.9b)

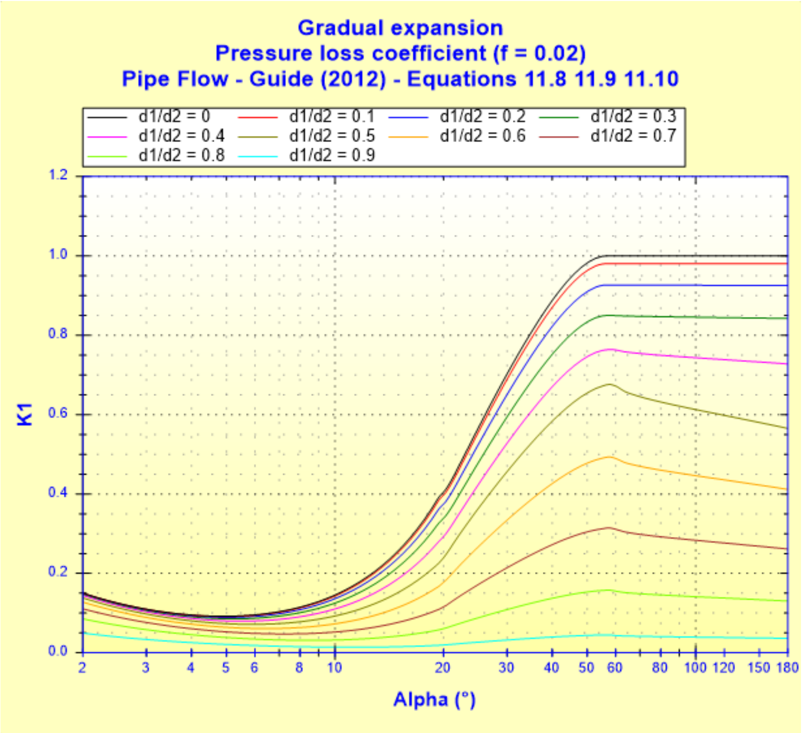
■ $60° \le \alpha \le 180°$:

- $0 \le \beta < 0.5$

$$K_1 = \left[1.205 - 3.28 \cdot \left(0.0625 - \beta^4\right) - 12.8 \cdot \beta^6 \cdot \sqrt{\frac{\alpha - 60}{120}}\right] \cdot \left(1 - \beta^2\right)^2$$ ([1] equation 11.10a)

- $0.5 \le \beta \le 1$

$$K_1 = \left[1.205 - 0.20 \cdot \sqrt{\frac{\alpha - 60}{120}}\right] \cdot \left(1 - \beta^2\right)^2$$ ([1] equation 11.10b)



Local resistance coefficient:

■ $0° \le \alpha < 60°$:

$$K_{L1} = K_1 - K_{fr1}$$

■ $60° \le \alpha \le 180°$:

$$K_{L1} = K_1$$

Total pressure loss (Pa):

$$\Delta P = K_1 \cdot \frac{\rho_m \cdot V_1^2}{2}$$

Total head loss of fluid (m):

$$\Delta H = K_1 \cdot \frac{V_1^2}{2 \cdot g}$$

Hydraulic power loss (W):

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

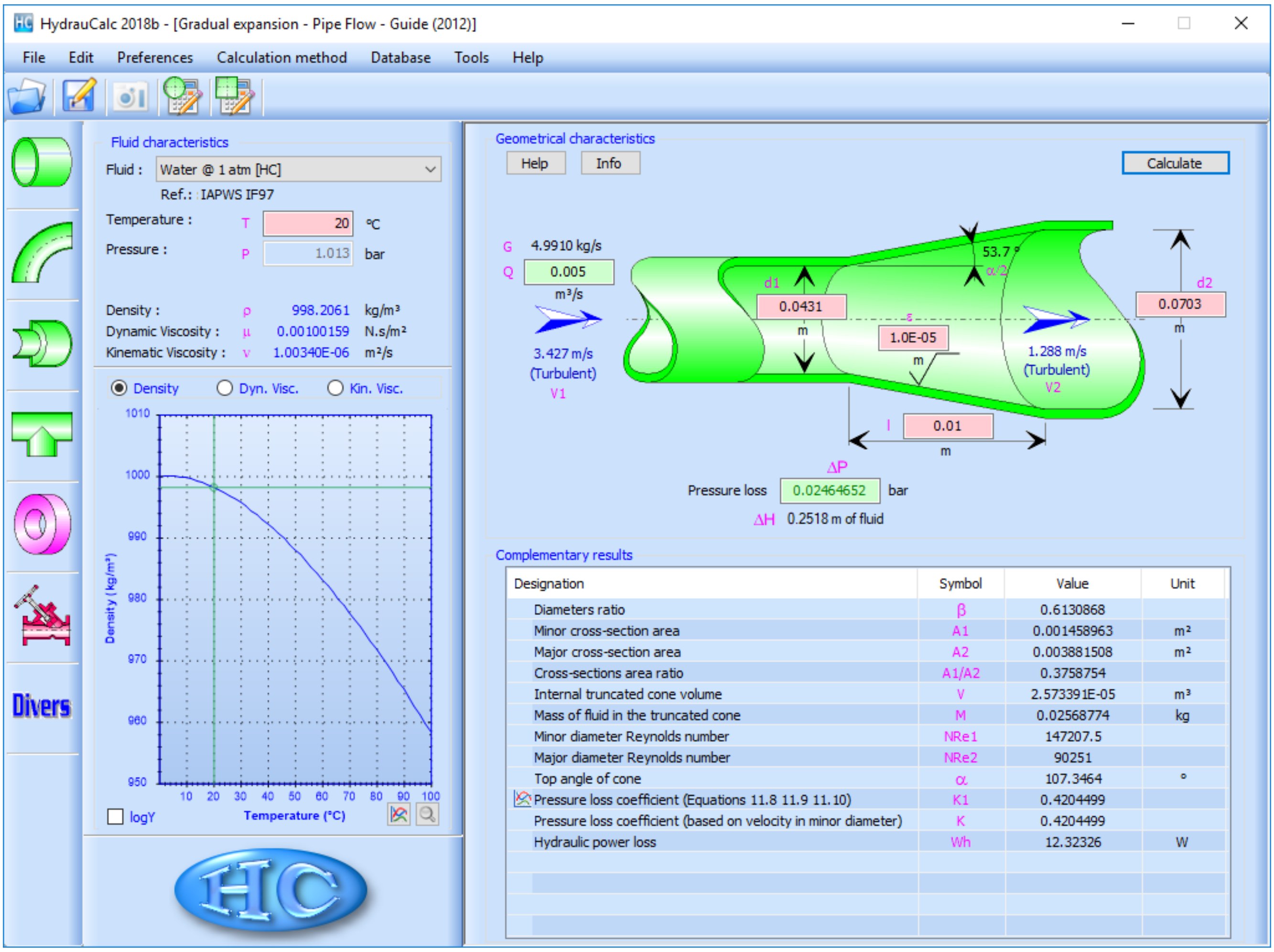
Symbols, Definitions, SI Units:

d_1	Minor diameter (m)
d_2	Major diameter (m)
β	Ratio of small to large diameter ()
α	Top angle of cone (°)
l	Truncated cone length (m)
A_1	Minor cross-sectional area (m^2)
A_2	Major cross-sectional area (m^2)
Q	Volume flow rate (m^3/s)
V_1	Mean velocity in minor diameter (m/s)
V_2	Mean velocity in major diameter (m/s)
G	Mass flow rate (kg/s)
V	Fluid volume in the truncated cone (m^3)
M	Fluid mass in the truncated cone (kg)
NRe_1	Reynolds number in minor diameter ()
NRe_2	Reynolds number in major diameter ()
f	Darcy friction factor ()
ε	Absolute roughness of the cone walls (m)
K_{fr1}	Friction pressure loss coefficient ()
K_{L1}	Local resistance coefficient ()
K_1	Total pressure loss coefficient (based on mean velocity in minor diameter) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
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 in minor diameter ($NRe_1 \geq 10^4$)

Example of application:



References:

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

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