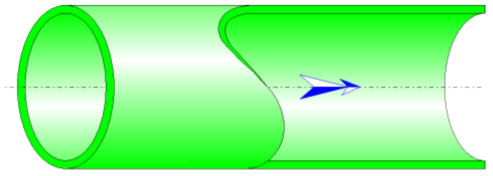
Straight Pipe
Circular Cross-Section and Roughness Walls
(HAZEN-WILLIAMS)



Model description:

This model of component calculates the major head loss (pressure drop) of a horizontal straight pipe of circular and constant cross-section.
In addition, the flow is assumed fully developed and stabilized.

The head loss is due to the friction of the fluid on the inner walls of the piping and is calculated with the Hazen-Williams equation.

The Hazen–Williams equation is an empirical relationship which relates the flow of water in a pipe with the physical properties of the pipe and the pressure drop caused by friction. It is used in the design of water pipe systems such as fire sprinkler systems, water supply networks, and irrigation systems.

The Hazen–Williams equation has the advantage that the coefficient C is not a function of the Reynolds number, but it has the disadvantage that it is only valid for water. Also, it does not account for the temperature or viscosity of the water.

Model formulation:

Hydraulic diameter (m):

$$\mathrm{D_h} = D$$

Cross-section area (m^2):

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

Mean velocity (m/s):

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

Mass flow rate (kg/s):

$$m = Q \cdot \rho$$

Fluid volume in the pipe (m^3):

$$V_{ol} = A \cdot L$$

Fluid mass in the pipe (kg):

$$M = V_{ol} \cdot \rho$$

Reynolds number:

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

Head loss of fluid (m):

$$H_f = L \cdot \left[\frac{V}{\left(0.849 \cdot C_{HW} \cdot \left(\frac{D}{4} \right)^{0.63} \right)} \right]^{\frac{1}{0.54}}$$

Note: this equation is derived from the following Hazen-Williams relationship adapted to SI units:

$$V = 0.849 \cdot C_{HW} \cdot R_h^{0.63} \cdot S^{0.54}$$ ([1])

with:

$$R_h = \frac{D}{4}$$

and:

$$S = \frac{H_f}{L}$$

Pressure loss coefficient:

$$K = H_f \cdot \frac{2 \cdot g}{V^2}$$

Pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot V^2}{2}$$

Equivalent Darcy friction factor:

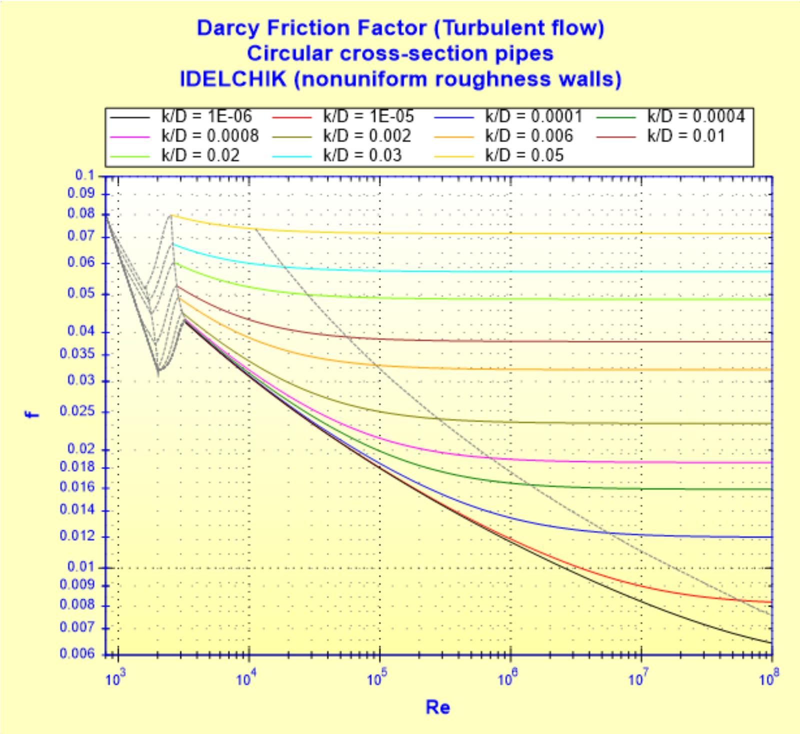
$$f = K \cdot \frac{D}{L}$$

Equivalent relative roughness (turbulent regime - Re ≥ 4000):

Colebrook-White equation

$$f = \frac{1}{\left[2 \cdot \log\left(\frac{2.51}{\text{Re} \cdot \sqrt{f}} + \frac{k}{3.7 \cdot D}\right)\right]^2}$$

where k is calculated by solving the equation.



Equivalent absolute roughness (m):

$$\varepsilon = k \cdot D$$

Hydraulic power loss (W):

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

Symbols, Definitions, SI Units:

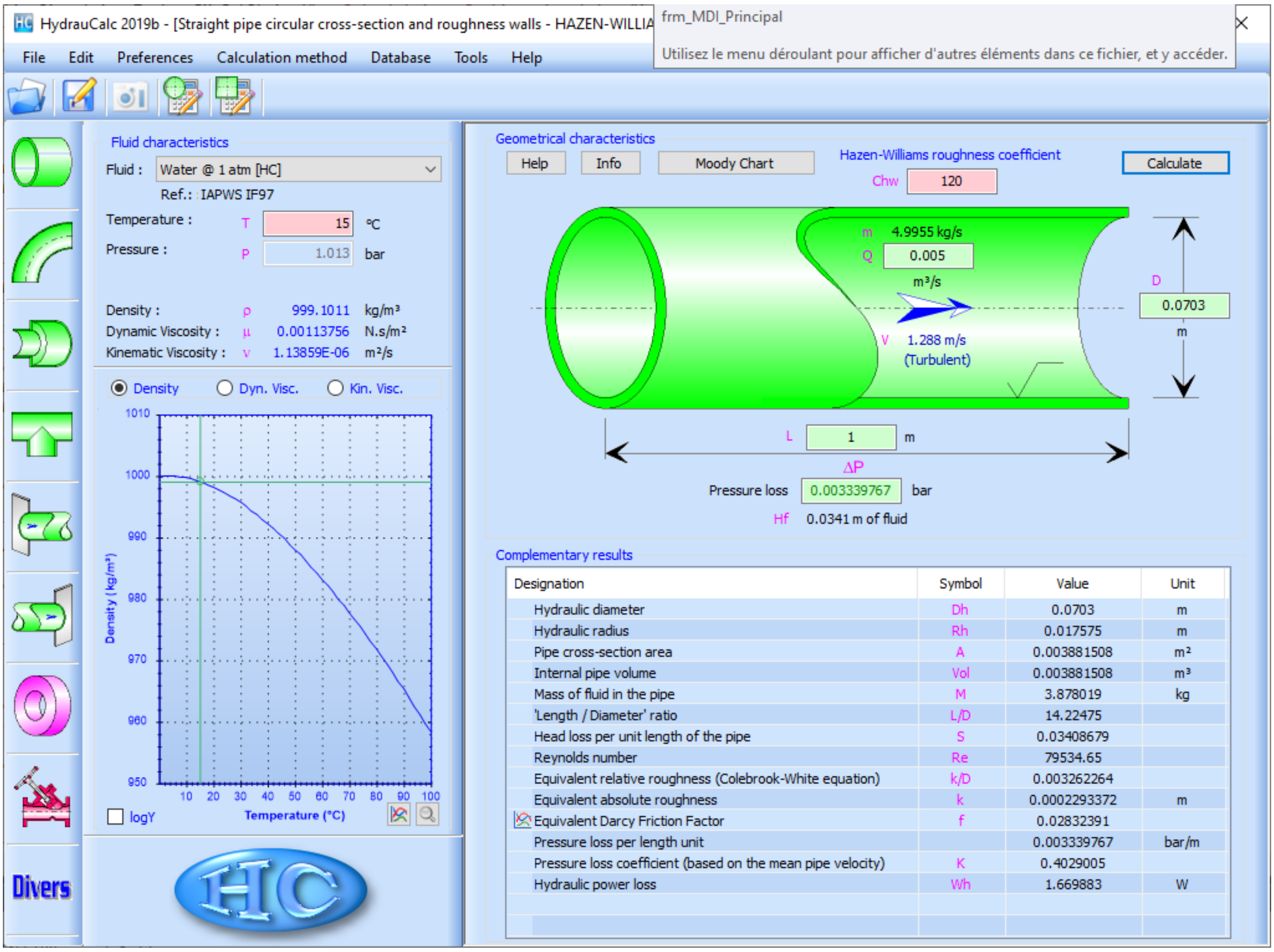
D	Internal diameter (m)
D_h	Hydraulic diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
V	Mean velocity (m/s)
m	Mass flow rate (kg/s)
L	Pipe length (m)
V_{ol}	Fluid volume in the pipe (m^3)
M	Fluid mass in the pipe (kg)
Re	Reynolds number ()
C_{HW}	Hazen-Williams roughness coefficient ($m^{0.37}/s$)
H_f	Head loss of fluid (m)
R_h	Hydraulic radius (m)
S	Head loss per unit length of the pipe ()
K	Pressure loss coefficient (based on the mean pipe velocity) ()
ΔP	Pressure loss (Pa)

f	Equivalent Darcy friction factor ()
k	Equivalent relative roughness of walls (m)
ε	Equivalent absolute roughness of walls (m)
Wh	Hydraulic power loss (W)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

Validity range:

- turbulent flow regime ($4{\cdot}10^3 \le Re \le 1{\cdot}10^8$)
- mean velocity lower than or equal to 3 m/s ($V \le 3$ m/s)
- internal diameter of pipe between 0.05 m and 1.85 m (0.05 m $\le D \le$ 1.85 m)
- valid only for fresh water close to 15 °C with a kinematic viscosity of approximately $1.13{\cdot}10^{-6}$ m^2/s
- stabilized flow

Example of application:



References:

[1] G. Williams & A. Hazen; "Hydraulic Tables. The elements of gagings and the friction of water flowing in pipes, aqueducts, sewers, etc." (1914)

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