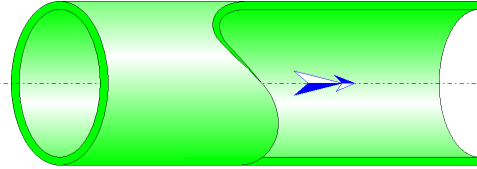




---

## 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):

$$D_h = D$$

---

Cross-section area (m<sup>2</sup>):

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

---

Mean velocity (m/s):

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

---

Mass flow rate (kg/s):

$$m = Q \cdot \rho$$

Fluid volume in the pipe (m<sup>3</sup>):

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

Fluid mass in the pipe (kg):

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

Reynolds number:

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

Head loss of fluid (m):

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

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

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

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:

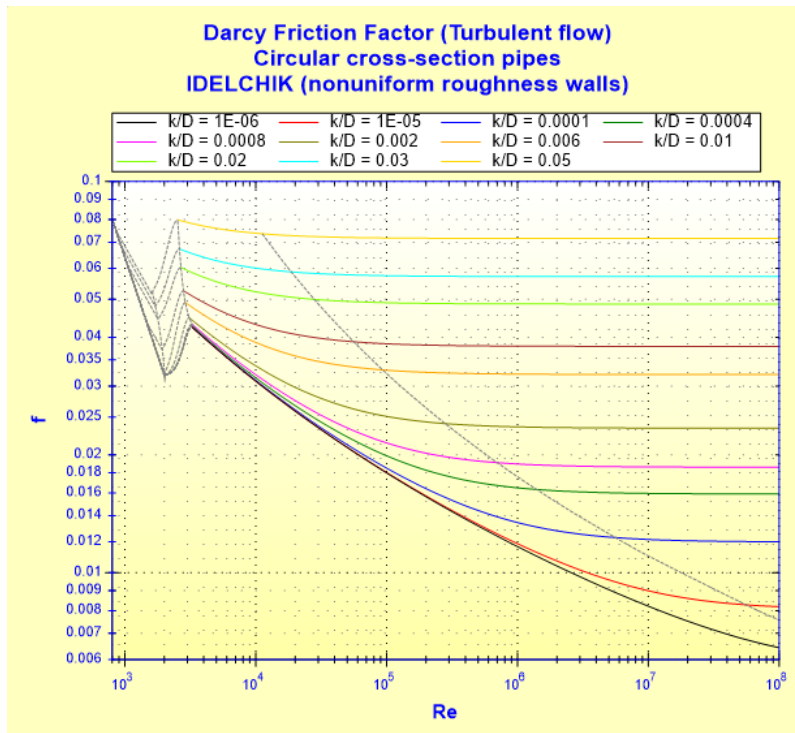
$$f = K \cdot \frac{D}{L}$$

Equivalent relative roughness (turbulent regime -  $Re \geq 4000$ ):

## 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 ( $\text{m}^2$ )
Q	Volume flow rate ( $\text{m}^3/\text{s}$ )
V	Mean velocity (m/s)
m	Mass flow rate (kg/s)
L	Pipe length (m)
$V_{ol}$	Fluid volume in the pipe ( $\text{m}^3$ )
M	Fluid mass in the pipe (kg)
Re	Reynolds number ( )
$C_{HW}$	Hazen-Williams roughness coefficient ( $\text{m}^{0.37}/\text{s}$ )
$H_f$	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) ( )
$\Delta P$	Pressure loss (Pa)

- f Equivalent Darcy friction factor ( )
- k Equivalent relative roughness of walls (m)
- $\varepsilon$  Equivalent absolute roughness of walls (m)
- Wh Hydraulic power loss (W)
  
- $\rho$  Fluid density (kg/m<sup>3</sup>)
- $\nu$  Fluid kinematic viscosity (m<sup>2</sup>/s)
- g Gravitational acceleration (m/s<sup>2</sup>)

### Validity range:

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

### Example of application:

The screenshot shows the HydraulCalc 2019b software interface. The main window is titled "HydrauCalc 2019b - [Straight pipe circular cross-section and roughness walls - HAZEN-WILLIA... frm\_MDI\_Principal". The interface is divided into several sections:

- Fluid characteristics:**
  - Fluid: Water @ 1 atm [HC]
  - Ref.: IAPWS IF97
  - Temperature: T = 15 °C
  - Pressure: P = 1.013 bar
  - Density:  $\rho = 999.1011 \text{ kg/m}^3$
  - Dynamic Viscosity:  $\mu = 0.00113756 \text{ N.s/m}^2$
  - Kinematic Viscosity:  $\nu = 1.13859E-06 \text{ m}^2/\text{s}$
  - Selected: Density (radio button)
  - Graph: Density (kg/m<sup>3</sup>) vs Temperature (°C) showing a curve from 1000 to 950 kg/m<sup>3</sup> over 100 °C.
- Geometrical characteristics:**
  - Help, Info, Moody Chart, Hazen-Williams roughness coefficient (Chw = 120), Calculate
  - Diagram of a pipe with length L = 1 m and diameter D = 0.0703 m.
  - Flow rate: Q = 0.005 m<sup>3</sup>/s
  - Mass flow rate: M = 4.9955 kg/s
  - Mean velocity: V = 1.288 m/s (Turbulent)
  - Pressure loss:  $\Delta P = 0.003339767 \text{ bar}$
  - Head loss: HF = 0.0341 m of fluid
- Complementary results:**

Designation	Symbol	Value	Unit
Hydraulic diameter	Dh	0.0703	m
Hydraulic radius	Rh	0.017575	m
Pipe cross-section area	A	0.003881508	m <sup>2</sup>
Internal pipe volume	Vol	0.003881508	m <sup>3</sup>
Mass of fluid in the pipe	M	3.878019	kg
'Length / Diameter' ratio	L/D	14.22475	
Head loss per unit length of the pipe	S	0.03408679	
Reynolds number	Re	79534.65	
Equivalent relative roughness (Colebrook-White equation)	k/D	0.003262264	
Equivalent absolute roughness	k	0.0002293372	m
Equivalent Darcy Friction Factor	f	0.02832391	
Pressure loss per length unit		0.003339767	bar/m
Pressure loss coefficient (based on the mean pipe velocity)	K	0.4029005	
Hydraulic power loss	Wh	1.669883	W

### References:

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

