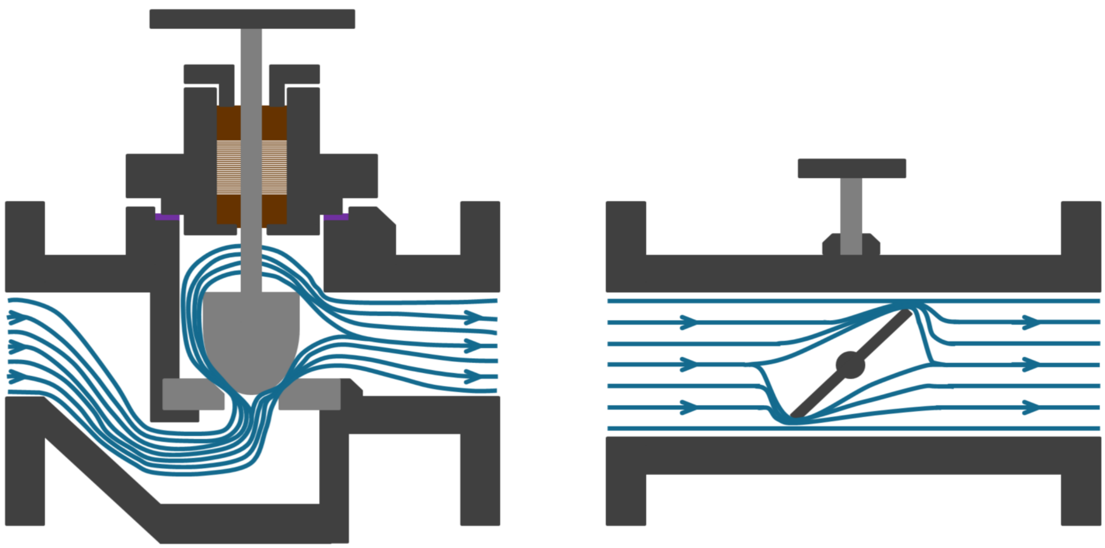
Fundamentals of Valve 1 - Incompressible flow

This document is a part of the series of the fundamental calculations related to Valves. In this worksheet, the orifice equation with discharge coefficient and Valve sizing equation which is defined in ANSI/ISA 75.01 are compared as the basic knowledge of Valve.



References:

- Peter Beater (2007), "Pneumatic Drives - System Design, Modeling and Control", Springer, ISBN 978-3-540-69471-7
- Emerson Automation Solutions (2017), "Control Valve Handbook 5th Edition", Fisher.

1. Calculation for Incompressible flow

In this section, 2 types of equations for Incompressible flow are compared.

1-1. With Discharge coefficient

The following equation is often used to express flow throught an orifice. This is effective model for turbulent flow if the discharged coefficient is known.

$$Eq_{cd} := Q = A \cdot C_d \cdot \sqrt{\frac{2 \cdot dp}{\rho}}$$

Volume flow rate : Q $\frac{m^3}{s}$

Pressure difference : dp **Pa**

(Upstream p_1 - Downstream p_2)

Discharge coefficient : C_d

Flow area : A m^2

Fluid density : ρ $\frac{kg}{m^3}$

1-2. With Flow coefficient (ANSI/ISA 75.01, IEC 60534-2-1/2)

The next equation is for Non-choked turbulent flow without attached fittings, defined in ISA 75.01. As flow coefficient, C_v is used.

$$Eq_{cv} := Q = C_v \cdot N_1 \cdot \sqrt{\frac{dp}{SG}}$$

Volume flow rate : Q **gpm**

Pressure difference : dp **psi**

(Upstream p_1 - Downstream p_2)

Flow coefficient : C_v

Constant : N_1 (For this units, $N_1 = 1$)

Specific gravity of the fluid : SG (for water = 1)

If use K_v instead of C_v, the equation will be converted to.

$$Eq_{kv} := Q = K_v \cdot N_1 \cdot \sqrt{\frac{dp}{SG}}$$

Volume flow rate : Q $\frac{m^3}{h}$

Pressure difference : dp **bar**

(Upstream p_1 - Downstream p_2)

Flow coefficient : C_v

Constant : N_1 (For this units, $N_1 = 1$)

Specific gravity of the fluid : SG (for water = 1)

2. Comparison with plotting

In the following plot, the comparison of three equations is shown. Water is used as the fluid.

For the discharged coefficient based equation, the coefficient and flow area is adjusted in order to match to other characteristic.

$$p1 := \text{plot}\left(\text{eval}\left(\text{rhs}\left(Eq_{cd}\right), \left[C_d = 0.65, A = 0.055^2, \rho = 1000\right]\right), dp = 0.1..101325, \text{color} = \text{red}, \text{legend} = \text{"Cd"}\right)$$

Regarding Cv flow coefficient based, Cv is specified with 116 as an example. And, the unit of volume flow rate and pressure is converted to be $\frac{m^3}{s}$ and Pa .

$$p2 := \text{plot}\left(\text{eval}\left(\text{rhs}\left(Eq_{cv}\right)\cdot\left(\frac{gpm}{\frac{m^3}{s}}\right), \left[C_v = 116, N_1 = 1, SG = 1, dp = dp\cdot\left(\frac{Pa}{psi}\right)\right]\right), dp = 0.1..101325, \text{color} = \text{blue}, \text{linestyle} = \text{dash}, \text{legend} = \text{"Cv"}\right)$$

For Kv, the coefficient is changed with the conversion coefficient 0.865, and the unit of volume flow rate and pressure is converted to be $\frac{m^3}{s}$ and Pa .

$$p3 := \text{plot}\left(\text{eval}\left(\text{rhs}\left(Eq_{kv}\right)\cdot\left(\frac{\frac{m^3}{h}}{\frac{m^3}{s}}\right), \left[K_v = 116\cdot 0.865, N_1 = 1, SG = 1, dp = dp\cdot\left(\frac{Pa}{bar}\right)\right]\right), dp = 0.1..101325, \text{color} = \text{green}, \text{linestyle} = \text{dot}, \text{legend} = \text{"Kv"}\right)$$

Then, you can see all three characteristics are the same.

plots:-display([p1, p2, p3]) =