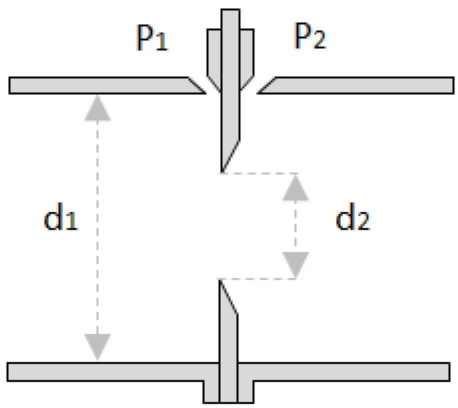
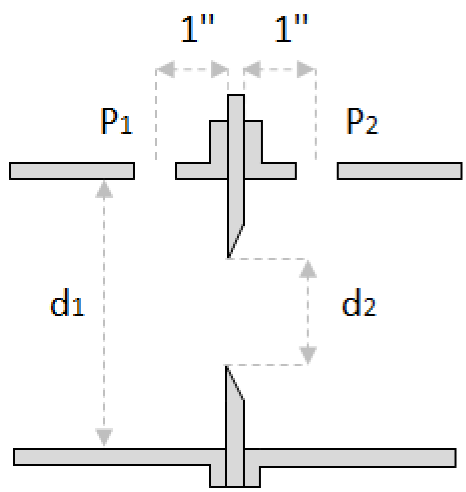
Large Diameter Orifice Flow Meter For Gases

This application determines the flowrate through a large diameter orifice meter using the equations defined in ISO 5167

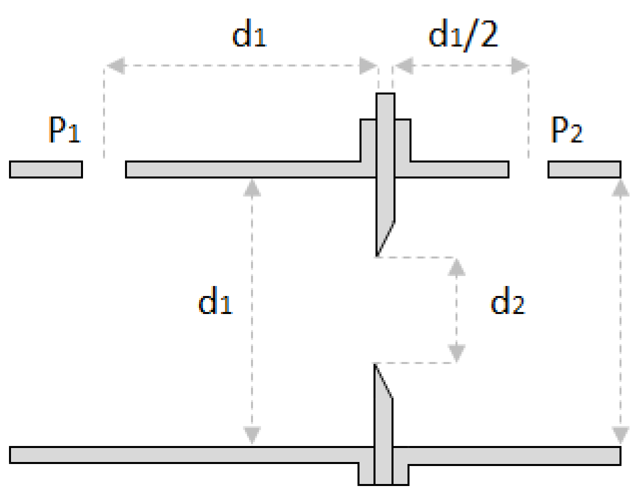
Corner taps



Flange taps



D-D/2 taps



Recommended parameters:

For all taps
d2 >= 1.25 cm
5 cm <= d1 <= 1 m
0.1 <= d2/d1 <= 0.75

Corner and D-D/2 taps
Rey >= 4000 for 0.1 <=d2/d1 <= 0.5
Rey >= 16000 (d2/d1)^2 for d2/d1 > 0.5

Flange taps
Rey >= 4000
Rey >= 170000 D*(d2/d1)^2 where D is in meters

Expansibility equation is valid for pressure ratio P2/P1 >= 0.75

Reference:
ISO 5167-1:2003. Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full

Parameters

Tap type ("corner", "flange" or "D-D/2")	taptype := "flange"
Gas	gas := "air"
Temperature	$T := 313$
Upstream pressure	$P_1 := 111000$
Density	$\rho :=$ ThermophysicalData:-Property(density, gas, temperature = T, pressure = P_1) $\rho = 1.236$
Viscosity	$\mu :=$ ThermophysicalData:-Property(viscosity, gas, temperature = T, pressure = P_1) $\mu = 1.916 \times 10^{-5}$

Differential pressure

$$\Delta P := P_1 - 103000 = 8000$$

Pressure ratio

$$PR := \frac{P_1 - \Delta P}{P_1} = 0.928$$

Isentropic expansion coefficient

$$K := \frac{\text{ThermophysicalData:-Property}\left(\text{Cpmass, gas, temperature} = T, \text{pressure} = P_1\right)}{\text{ThermophysicalData:-Property}\left(\text{Cvmass, gas, temperature} = T, \text{pressure} = P_1\right)}$$

$$K = 1.401$$

Pipe diameter

$$d_1 := 0.075$$

Orifice diameter

$$d_2 := 0.01$$

Standard temperature and pressure

$$T_{std} := 288.9$$

$$P_{std} := 101325$$

Equations

Throat area

$$A_{throat} := \frac{\pi \cdot {d_2}^2}{4} = 7.854 \times 10^{-5}$$

Pipe area

$$A_{pipe} := \frac{\pi \cdot {d_1}^2}{4} = 0.004$$

Diameter ratio

$$\beta := \frac{d_2}{d_1} = 0.133$$

Discharge coefficient

$$Cd_{base} := 0.5961 + 0.0261\cdot\beta^2 - 0.216\cdot\beta^8 + 0.000521\cdot\left(\frac{10^6\cdot\beta}{Rey}\right)^{0.7} + \left(0.0188 + 0.0063\cdot\left(\frac{19000\cdot\beta}{Rey}\right)^{0.8}\right)\cdot\left(\frac{10^6}{Rey}\right)^{0.3}\cdot\beta^{3.5} + \left(0.043 + 0.08\cdot e^{-10\cdot L_1} - 0.123\cdot e^{-7\cdot L_1}\right)\cdot\left(1 - 0.11\cdot\left(\frac{19000\cdot\beta}{Rey}\right)^{0.8}\right)\cdot\frac{\beta^4}{1-\beta^4} - 0.031\cdot\left(\frac{2\cdot L_2}{1-\beta} - 0.8\cdot\left(\frac{2\cdot L_2}{1-\beta}\right)^{1.1}\right)\cdot\beta^{1.3}$$

$$Cd_{base} := \begin{cases} Cd_{base} + 0.011\cdot(0.75-\beta)\cdot\left(2.8 - \frac{d_1}{0.0254}\right) & d_1 < 0.07112 \\ Cd_{base} & \text{otherwise} \end{cases}$$

$$L_1 := \begin{cases} 0 & taptype = \text{"corner"} \\ \frac{0.0254}{d_1} & taptype = \text{"flange"} \\ 1 & taptype = \text{"D-D/2"} \end{cases} \qquad L_2 := \begin{cases} 0 & taptype = \text{"corner"} \\ \frac{0.0254}{d_1} & taptype = \text{"flange"} \\ 0.47 & taptype = \text{"D-D/2"} \end{cases}$$

$$DragCoeff := Cd = Cd_{base}$$

Gas expansion factor (Buckingham equation)

$$e := 1 - \left(0.41 + 0.35\cdot\beta^4\right)\cdot\frac{\Delta P}{K\cdot P_1} = 0.979$$

Mass flowrate

$$MassFlowrate := Q_m = \frac{e\cdot Cd\cdot A_{throat}\cdot\sqrt{2\cdot\rho\cdot\Delta P}}{\sqrt{1-\beta^4}} = Q_m = 0.011\cdot Cd$$

Gas velocity

$$V_{pipe} := \frac{Q_m}{A_{pipe}\cdot\rho} = 183.175\cdot Q_m$$

Reynolds number

$$Reynolds := Rey = \frac{V_{pipe}\cdot d_1\cdot\rho}{\mu} = Rey = 8.861\times10^5\cdot Q_m$$

Numerical Solution and Results

Equations $eqs := \{DragCoeff, MassFlowrate, Reynolds\}$

Parameters to solve for $vars := indets(eqs, name) = \{Cd, Q_m, Rey\}$

Numerical solution $res := \mathit{fsolve}(eqs, vars) = \{Cd = 0.601, Q_m = 0.006, Rey = 5.758 \times 10^3\}$

$$Cd := eval(Cd, res) = 0.601$$

$$Q_m := eval(Q_m, res) = 0.006$$

$$Rey := eval(Rey, res) = 5.758 \times 10^3$$

Static pressure loss from a distance d1 upstream and 6 d1 downstream of the orifice

$$w := \frac{\sqrt{1-\beta^4} - Cd\cdot\beta^2}{\sqrt{1-\beta^4} + Cd\cdot\beta^2}\cdot\Delta P = 7.831 \times 10^3$$

Minor loss coefficient $K_m := \frac{2\cdot w}{\rho\cdot V_{pipe}^2} = 8.946 \times 10^3$

Volumetric flowrate $Q_a := \frac{Q_m}{\rho} = 0.005$

Volumetric flowrate at standard conditions $Q_s := Q_a\cdot\frac{P_1\cdot T_{std}}{P_{std}\cdot T} = 0.005$