Orifice flow rate and Orifice diameter Calculations

Version-1

Contents

1. **Introduction:**
   Orifice flow rate and Orifice diameter calculations are done for both incompressible and compressible fluids. For compressible fluids un-choked and choked conditions are possible during the flow, these are taken into consideration and calculations are performed. ISO-5167 documents along with Fluid Mechanics books and Journals are referred to understand the definitions and limitations of flow conditions.

1.1 Nature of fluid:

- The fluid may be either compressible or considered as being incompressible.
- The fluid shall be such that it can be considered as being physically and thermally homogeneous and single-phase.
- Colloidal solutions with a high degree of dispersion (such as milk), and only those solutions, are considered to behave as a single-phase fluid.

2. Algorithm:

- The principle of the method of measurement is based on the installation of an orifice plate into a pipeline in which a fluid is running full. The presence of the orifice plate causes a static pressure difference between the upstream and downstream sides of the plate. The mass flowrate, Qm, can be determined using following equation:

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \varepsilon \frac{\pi}{4} d^2 \sqrt{2 \Delta p \rho_1}$$

Where,

C is Coefficient of discharge

β is Diameter ratio: $\beta = d/D$

- The discharge coefficient, C, is given by the *Reader-Harris/Gallagher (1998):*

$$C = 0{,}5961 + 0{,}0261\beta^2 - 0{,}216\beta^8 + 0{,}000521\left(\frac{10^6 \beta}{Re_D}\right)^{0{,}7} + (0{,}0188 + 0{,}0063A)\beta^{3{,}5}\left(\frac{10^6}{Re_D}\right)^{0{,}3}$$
$$+ (0{,}043 + 0{,}080e^{-10L_1} - 0{,}123e^{-7L_1})(1 - 0{,}11A)\frac{\beta^4}{1-\beta^4} - 0{,}031(M'_2 - 0{,}8M'^{1{,}1}_2)\beta^{1{,}3}$$

Where $D < 71.12$ mm (2.8 in), the following term shall be added to above Equation:

$$+0{,}011(0{,}75 - \beta)\left(2{,}8 - \frac{D}{25{,}4}\right)$$

In the above equations:

β is the diameter ratio, with the diameters d and D expressed in millimeters;

Re_D is the Reynolds number calculated with respect to D;

L_1 (= l_1/D) is the quotient of the distance of the upstream tapping from the upstream face of the plate and the pipe diameter;

L'_2 (= l'_2/D) is the quotient of the distance of the downstream tapping from the downstream face of the plate and the pipe diameter (L'_2 denotes the reference of the downstream spacing from the downstream face, while L_2 would denote the reference of the downstream spacing from the upstream face);

$$M'_2 = \frac{2L'_2}{1-\beta}$$

$$A = \left(\frac{19\,000\beta}{Re_D}\right)^{0,8}$$

The values of L_1 and L'_2 to be used in this equation, when the spacing's are in accordance with the requirements:

Corner tappings: $L_1 = L'_2 = 0$

D and D/2 tappings: $L_1 = 1$, $L'_2 = 0.47$

Flange tappings: $L_1 = L'_2 = 25.4/D$

where D is expressed in millimeters.

For the three types of tapping arrangement, for computing the expansibility [expansion] factor, ε, is as follows:

$$\varepsilon = 1-\left(0,351+0,256\beta^4+0,93\beta^8\right)\left[1-\left(\frac{p_2}{p_1}\right)^{1/\kappa}\right]$$

2.1 Incompressible and compressible (un-choked) fluid:

- The following algorithm is used to calculate orifice flow rate and orifice diameter for both incompressible and compressible (un-choked) conditions:

Problem	$q =$	$d =$
At given values of	$\mu_1, \rho_1, D, d, \Delta p$	$\mu_1, \rho_1, D, q_m, \Delta p$
Please find	q_m and q_V	d and β
Invariant "A_n"	$A_1 = \frac{\varepsilon d^2 \sqrt{2 \Delta p \rho_1}}{\mu_1 D \sqrt{1-\beta^4}}$	$A_2 = \frac{\mu_1 Re(D)}{D \sqrt{2 \Delta p \rho_1}}$
Iteration equation	$\frac{Re_D}{C} = A_1$	$\frac{C \varepsilon \beta^2}{\sqrt{1-\beta^4}} = A_2$
Variable in linear algorithm	$X_1 = Re_D = C A_1$	$X_2 = \frac{\beta^2}{\sqrt{1-\beta^4}} = \frac{A_2}{C \varepsilon}$
Precision criterion (where n is chosen by the user)	$\left\lvert \frac{A_1 - \frac{X_1}{C}}{A_1} \right\rvert < 1 \times 10^{-n}$	$\left\lvert \frac{A_2 - X_2 C \varepsilon}{A_2} \right\rvert < 1 \times 10^{-n}$
First guess	$C = C_\infty$	$C = 0{,}606$ (orifice plate), $C = 1$ (other primary devices) $\varepsilon = 0{,}97$ (or 1)
Results	$q_m = \frac{\pi}{4} \mu_1 D X_1$ $q_V = \frac{q_m}{\rho_1}$	$d = D \left(\frac{X_2^2}{1+X_2^2} \right)^{0{,}25}$ $\beta = \frac{d}{D}$

Fig: 1 Algorithm for orifice flow rate and orifice diameter calculations

The expansibility factor, ε, is equal to unity when the fluid is considered incompressible (liquid) and is less than unity when the fluid is compressible (gaseous).

2.2 Compressible (choked) fluid:

- Mass flow rate of compressible-choked flows are given by:

$$\dot{m}_{\text{choked}} = A_t p_0 \sqrt{\frac{k}{R T_0} \left(\frac{2}{k+1} \right)^{(k+1)/2(k-1)}}$$

Where

At	Throat area (m2)
K	Isentropic exponent
Po	Inlet Pressure(Pa)
R	Gas constant(J/KgK)
To	Inlet Temp (K)

4. Limitations:

4.1 Un-choked compressible and incompressible flows:

- This is applicable only to a flow which remains subsonic throughout the measuring section and where the fluid can be considered as single phase.

- This is not applicable to the measurement of pulsating flow. It does not cover the use of orifice plates in pipe sizes less than 50 mm or more than 1000 mm, or for pipe Reynolds numbers below 5000.
- For orifice plates with corner or with D and D/2 pressure tapping's:
  - $d \geq 12,5$ mm;
  - 50 mm $\leq D \leq$ 1000 mm;
  - $0.1 \leq \beta \leq 0.75$;
  - $Re_D \geq 5000$ for $0.1 \leq \beta \leq 0.56$;
  - $Re_D \geq 16000\ \beta^2$ for $\beta > 0.56$;
- For orifice plates with flange tapping's:
  - $d \geq 12.5$ mm;
  - 50 mm $\leq D \leq$ 1000 mm;
  - $0.1 \leq \beta \leq 0.75$.

  Both $Re_D \geq 5000$ and $Re_D \geq 170\beta^2 D$

  Where D is expressed in mm.
- Temperature affects are not taken into account in these calculations for both compressible and incompressible fluids.
- Uncertainty of discharge coefficient and expansibility factor are not calculated.
- Flow conditioners are not considered in the flow and not taken into account for calculations.

4.2 choked compressible flows:

- This is not applied when the pressure ratio P_2/P_1 is greater than the critical value (Pcr).
- The diameter of the pressure tap should be small enough in comparison with the diameter of the pipe ($d \geq 12.5$ mm).
- This is applicable only to a flow which remains choked throughout the measuring section and where the fluid can be considered as single phase.
- This is not applicable to the measurement of pulsating flow.
- Temperature affects are not taken into account in these calculations.
- Uncertainty of discharge coefficient and expansibility factor are not calculated.
- Flow conditioners are not considered in the flow and not taken into account for calculations.

References:

1. (J.P.HOLMAN)
2. (ISO-5167-1, 2003)
3. (ISO-5167-2, 2003)
4. (Manish S.Shah a, 2011)
5. (Andersson†, 1997)
6. (Jitschin*, 2004)