

Complex orifice flow calculations as per AGA3 can be made simpler

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Abstract – Orifice flow calculations are highly inaccurate. Improved accuracies may be obtained using AGA 3 equations for flow calculations. Theoretically, AGA3 equations call for measurement of complex parameters like Discharge coefficient for flow, Gas expansion factor, Velocity of approach factor and density. Practically, it would be very expensive to make such measurements. In this paper, it is shown that, on closer analysis, it would be understood that, measurement of only three parameters, viz., Differential pressure across the orifice, Process temperature and pressure would be enough to make AGA 3 calculations.

Index terms – Orifice flow, AGA3, flow calculations, analysis, complex parameters, measured parameters, made simpler



1 INTRODUCTION

The objective of installing flow meter in a process is to measure the flow rate. Flow meters are divided basically into two functional groups - One measuring the quantity (Positive displacement) and the other measuring rate of flow (Inferential). There are various Inferential type of flow meters available in the market. One has to choose a flow meter most suitable to one's application. There could be one or more types of meters suitable for a particular application. In such a case, factors like meter cost, installation cost, accuracy, turndown ratio etc become key in selection.

Among the various inferential flow meters available, orifice type Differential pressure (DP) measurement is popular for its lower cost and acceptable accuracy levels. Where, accuracy is not prime requisite, Orifice type is the most economical solution.

The basic flow equation for an orifice may be written as:

$$Q = k C_d \sqrt{\frac{\Delta P}{\rho}}$$

Where:

- Q = Flow rate
- K = Constant
- Cd = Discharge coefficient
- ΔP = Diff. pressure (Inlet P1 - Outlet P2)

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Using this equation, the inaccuracy is measured to be in the range of ±2 to 3%. This inaccuracy is mainly due to the difference between actual temperature and pressure as compared to the design temperature and pressure used in the Orifice plate bore calculations.

2 IMPROVED FLOW CALCULATIONS

To improve the accuracy in flow measurement, the more appropriate formula for calculating mass flow of liquids, gases and steam using orifice would be:

$$Q_m = N C_d E_v Y_1 d^2 \sqrt{\Delta P \rho}$$

(as per American Gas Association AGA report 3, part1)

Where:

- Q_m = Mass flow rate
- N = Units factor
- C_d = Discharge coefficient
- E_v = velocity of approach factor
- Y₁ = Gas expansion factor (=1 for liquids)
- d = Orifice bore diameter
- ΔP = Diff. pressure across the orifice
- ρ = Density of fluid

It is obvious from the equation, that, there are few factors that are difficult to measure. To resolve this, let us closely examine each factor.

N - Is a unit conversion factor and is a constant. Does not require any measurement.

C_d Discharge coefficient.

The ratio of true flow to theoretical flow is known as Discharge coefficient. For concentric square edged, flange tapped orifice meter, the coefficient of discharge is given as per ISO equation:

$$\begin{aligned}
 C_d &= 0.5961 \\
 &+ 0.0261 \beta^2 - 0.216 \beta^8 + 0.000521 \left[\frac{10^6 \beta}{Re_D} \right]^{0.7} \\
 &+ \left[0.0188 + 0.0063 \left[\frac{19000 \beta}{Re_D} \right]^{0.8} \right] \left[\frac{10^6}{Re_D} \right]^{0.3} \beta^{3.5} \\
 &+ \left[0.043 + 0.08 e^{-10L_1} \right. \\
 &\quad \left. - 0.123 e^{-7L_1} \right] \left[1 \right. \\
 &\quad \left. - 0.11 \left[\frac{19000 \beta}{Re_D} \right]^{0.8} \right] \frac{\beta^4}{1 - \beta^4} - 0.031 \left[\frac{2L_2}{1 - \beta} \right. \\
 &\quad \left. - 0.8 \left[\frac{2L_2}{1 - \beta} \right]^{1.1} \right] \beta^{13}
 \end{aligned}$$

Where:

β = diameter relation d/D

Re = Reynolds number

L_1 and L_2 are functions of the tap type where:

$L_1 = L_2 = 0$ for corner taps

$L_1 = 1$ and $L_2 = 0.47$ for D and $D/2$ taps

L_1 and L_2 are constants. The variables in these calculations are β and Reynolds Number Re_D .

Ratio of orifice bore dia and pipe internal dia is known as 'Beta ratio' and is denoted by β , which is normally a constant. But, the diameter of both the orifice and pipeline may vary depending on process temperature, thereby changing the value of β . It may be concluded, that β is dependent on process temperature.

Reynolds Number is calculated using the formula: $Re_D = \frac{\rho V D}{\mu}$

Where, V is velocity, D is pipe diameter, ρ is fluid density and μ is fluid viscosity.

From Bernoulli's theorem, we can deduce that, $\Delta p = p_1 - p_2 = \frac{1}{2} \rho V_2^2 - \frac{1}{2} \rho V_1^2$. This shows that velocity can be calculated from Differential pressure.

Fluid density is dependent both on pressure and temperature.

$$\rho = \rho_0 / (1 + \alpha (t_1 - t_0)) \text{ and } \rho = \rho_0 / (1 - (p_1 - p_0) / E)$$

Where: ρ = final density (kg/m³), ρ_0 = initial density (kg/m³), α = volumetric temperature expansion coefficient (m³/m³ oC), t_1 = final temperature (oC), t_0 = initial temperature (oC), E = bulk modulus fluid elasticity (N/m²), p_1 = final pressure (N/m²) and p_0 = initial pressure (N/m²)

Fluid Viscosity μ varies with temperature.

All the above observations conclude that Discharge coefficient C_d is dependent on Process temperature, pressure and Differential pressure.

EV Velocity of approach factor.

In the process of deriving an equation (from Bernoulli's theorem), for flow through an orifice, we arrive at a complex expression for flow shown as:

$$Q = \frac{\pi d^2}{4} \sqrt{\frac{2 \cdot \Delta p}{\rho} \frac{1}{1 - \left(\frac{d}{D}\right)^2}}$$

It is known that d/D , the ratio of orifice bore dia to Pipe dia, is known as Beta ratio and is denoted by β . In the above equation, replacing the denominator and other constants with a term called as Velocity of approach factor EV.

$$E_V = \sqrt{\frac{1}{1 - \beta^2}} \quad \text{and} \quad Q = E_V d^2 \sqrt{\frac{2 \Delta p}{\rho}}$$

Therefore, EV depends on β , which in turn is dependent on Process temperature

Y1 Gas expansion factor (for gases)

In an orifice, the flow is through a smaller bore dia of the orifice and expanding to a higher dia, on the downstream. Such a stream of gas flow is considered to be an adiabatic expansion. Under such conditions, the mass flow rate is given by Darcy formula:

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$$W = 1.111 \times 10^{-6} Y d^2 \sqrt{\frac{\Delta p \rho}{K}}$$

Where:

W – mass flow rate, Y – Gas expansion factor, d – internal pipe diameter, Δp – Pressure difference, ρ – density and K – Total resistance coefficient

It shows that the Gas expansion factor Y is a factor of Δp , density ρ , d the pipe internal diameter and Isentropic coefficient. In other words, Gas expansion factor Y can be calculated using pressure, differential pressure and process temperature,

ρ Density of fluid

The ideal gas equation is $PV = nRT$ where P is the absolute pressure, V is the gas volume, R is the gas constant, n is the number of moles present and T is the absolute temperature.

Density of the gas can be calculated from the equation above. Density ρ is defined as $\frac{\text{Mass of material}}{\text{Volume of the material}}$.

In order to determine the mass of material present we need an additional piece of information; the molecular weight of the substance, M. The mass present is then given by mass = Mn. Density of the fluid can be deduced using the Compressibility factor (constant), Gas constant, Molecular weight (constant), process pressure and process temperature.

3 CONCLUSIONS

This paper analysis the orifice type flow calculations using AGA 3 standards. Each factor in the formula is analyzed. From the above analysis, one can come to a conclusion that to obtain orifice flow measurement using AGA 3 calculations, few parameters are to be measured, some are to be calculated and others are constants. These observations are reflected in Table 1.

It is evident from this table, that for measuring an accurate flow through an orifice a total of 07 parameters are required. To obtain these 07 parameters:

- Only three parameters, viz., Temperature, Inlet pressure and differential pressure are to be measured
- Data like orifice bore diameter, pipe internal dia, Isentropic exponent, Compressibility factor, gas constant, molecular weight and fluid constants have to be fed from tables.
- All the other parameters like fluid velocity, fluid viscosity, fluid density, beta ratio factor and corrected orifice bore diameter can be calculated using the above two.

Though to look at the AGA 3 (American Gas Association report 3, part 1, API) calculations appear to be very complex, measuring inlet pressure, temperature and differential pressure will be enough to make the complete calculations and obtain improved accuracies in orifice flow measurement.

Table 1. List of parameters that are to be entered, calculated and measured

Parameter	Data entered	Data calculated	Data measured
N Units conversion factor	Yes	-	-
Cd Discharge Coefficient	Orifice bore dia, pipe internal dia,	Velocity, Viscosity, density	Temperature, Pressure
EV Velocity of approach factor	-	Beta ratio	Temperature
Y Gas expansion factor	Isentropic exponent	Beta ratio	Pressure, Differential pressure and Temperature
D Orifice bore	-	Corrected bore dia	Temperature
Δp Differential pressure	-	-	Differential pressure
ρ Fluid Density	Compressibility factor, Gas constant, Molecular weight, Fluid constants	Density	Pressure, Temperature

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