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Finite Element Analysis of Pressure Drop in Orifice Meter

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Abstract--**Obstruction type flow meters are widely used in industry for flow measurement. Orifice Plates cover a wide range of applications of fluid and operating conditions. They give acceptable level of uncertainties at lowest cost and long life without regular maintenance. A significant amount of pressure drop occurs in pipelines due to the obstruction present in these types of flow meters. Permanent pressure loss depends on the shape of obstruction, the diameter ratio and also on properties of the fluid. In the present work, Finite Element Analysis has been used to compute the permanent pressure loss and relative pressure loss for incompressible fluid for concentric orifice plate assembly. The outcomes of the simulations in terms of profiles of velocity, pressure, etc. are discussed in detail.**

Keywords— Orifice Plates, pressure drop, diameter ratio, FEA

I. INTRODUCTION

As orifice plate has simple structure, long operating life and reliable measurement data, it is widely applied in chemical industry, process industry to measure the flow rate such as natural gas, steam, and so on [1]. In design and application of orifice plate, the most important issue is to confirm the pressure drop, discharge coefficient, which is usually influenced by the β ratio, ReD, the tube roughness and the viscosity of the fluid, etc [2]. Although orifice meters have higher pressure losses and correspondingly higher pumping cost, they are still the most common meters used for fluid flow measurement because these are rugged, simple in construction and installation/replacement, without having any moving parts, economic, measurement flexibility with high range ability, can be used for liquids, gases or slurries, well suited for use under extreme weather conditions, etc. High pressure drop is frequently required in the process line of power plants. In the situation of low pressure drop, some throttling components such as nozzle, Venturi tube, orifices are mostly used just a single one. However, if the pressure drop is much higher, for example, in the let-down pipe line of coolant system for nuclear plant, the pressure drop may be up to 15 MPa approximately; the combination and multistage structure would be considered. As the outstanding virtue in the structure, the combination of orifice disks is being accepted and used in many process controls. In common, the orifice disk is made of austenitic stainless steel and embedded in a tube, a series of disks with different orifice were assembled by casting or welding. One disk will produce a pressure drop, so it is defined as a "stage" in engineering application [3]. In orifice flow meters, the pressure drop element is simply a flat plate metal with an orifice. Most of these orifices are of the circular type, with the hole having a certain finish to its edge. The major advantage of using these orifice flow meters is that they have no moving parts, require no lubrication or maintenance and the cost of manufacturing does not increase significantly with the pipe size [4, 5].

II. CONSTRUCTION

In the construction, orifice plate is made up of stainless steel, the pipe is made up of Galvanize, and flanges are made up of cast iron.

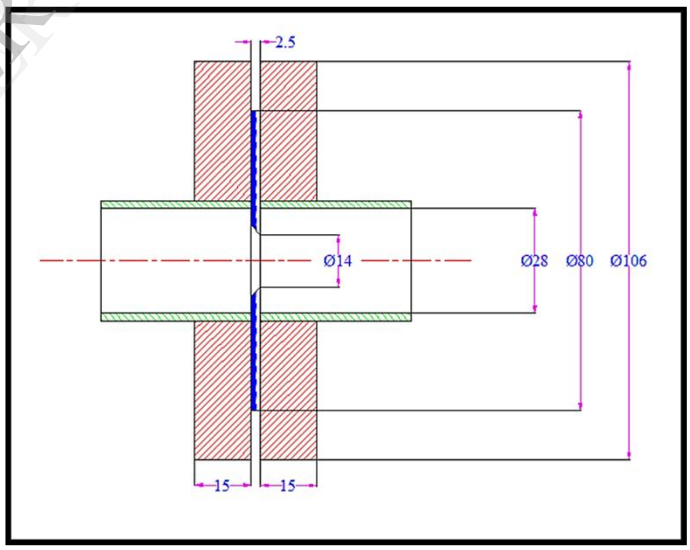


Fig 1: Construction of Orifice meter

The main parameters that affects orifice flow meter are such as density, pressure, temperature, specific gravity, composition, heating value (depending on the method of measurement and quantity units required) must be properly installed, operated, to obtain accurate fluid flow measurement.

The whole instrument is mounted on RCC foundation. The instrument is well balanced and assumed it has little but negligible vibrations. The detailed construction of an orifice plate is shown in the figure.

III. THEORETICAL ANALYSIS OF PRESSURE DROP IN ORIFICE METER

The calculation of fluid flow rate by reading the pressure loss across a pipe restriction is perhaps the most commonly used flow measurement technique in industrial applications. The pressure drops generated by a wide variety of geometrical restrictions have been well characterized over the years these primary or head flow elements come in a wide variety of configurations, each with specific application strengths and weaknesses. Variations on the theme of differential pressure (dp) flow measurement include the use of orifice meter. The theoretical analysis of orifice meter pressure drop can be found from following method:

$$Q = A_1 * A_2 * \frac{\sqrt{2gh}}{\sqrt{A_1^2 - A_2^2}}$$

$$\therefore A_1 * V = A_1 * A_2 * \frac{\sqrt{2g} * \sqrt{h}}{\sqrt{A_1^2 - A_2^2}}$$

$$\therefore \sqrt{h} = V * \sqrt{A_1^2 - A_2^2} / (A_2 * \sqrt{2g})$$

$$\therefore h = V^2 * \frac{A_1^2 - A_2^2}{A_2^2 * 2g}$$

$$\therefore \rho * g * h = \rho * g * V^2 * \frac{A_1^2 - A_2^2}{A_2^2 * 2g}$$

$$\therefore \mathbf{P} = \boldsymbol{\rho} * \mathbf{V^2} * \frac{\mathbf{A_1^2 - A_2^2}}{\mathbf{2 * A_2^2}}$$

Theoretical Pressure Drop = $\rho * V^2 * \frac{A_1^2 - A_2^2}{2 * A_2^2}$

$$= 995.18 * 1.85^2 * \frac{0.00061544^2 - 0.00015386^2}{2 * 0.00015386^2}$$

Theoretical Pressure Drop = 25430.10 Pa

❖ Theoretical calculation of Pressure Drop

S.N.	Velocity	Pressure Drop
1	**1.85**	**25430.10**
2	**1.92**	**27624.53**
3	**1.87**	**26151.49**
4	**1.90**	**26882.96**

IV. BOUNDARY CONDITIONS

In all the simulations, velocity is set at the inlet of the orifice meter, pressure is set at the outlet and no-slip condition is set at the wall.

V. PRACTICAL ANALYSIS

This experiment was performed on this set up. The working medium was water. When we have performed this experiment the temperature of atmosphere was 30°C. At this temperature the density of water is 995.18 kg/m^3, thermal conductivity is 0.6194 Watt/m-K, specific heat is 4070.2 kJ/kg-K, readings were taken. As orifice disk is installed in the pipe, the experiment is designed to investigate the pressure drop for different velocities by measuring pressure in manometer in water column and the flow rate Q.

Fig 2: Experiment set up of Orifice meter

Technical specification of this set up is as follow.

- **Orifice Diameter = 14mm**
- **Pipe Diameter = 28mm**
- **Orifice thickness = 2.5mm**
- **Orifice angle = 45^0**
- **Area of measuring tank = 0.4*0.4 m^2**

❖ Observation Table

MANOMETER READING			MEASURING TANK READING			TIME
HIGH X_2	LOW X_1	$\Delta X = X_2 - X_1$	FINAL h_2	INITIAL h_1	$H = h_2 - h_1$	
25.1	3.3	0.218	8.1	1	0.071	10

As per the observation, the pressure drop δp for the orifice tube can be calculated by the following formula:

HEAD (H) $= \Delta X \times (13.6 - 1) = 0.218 \times (13.6 - 1)$

$= 2.7468$ METER OF WATER

PRESSUREDROP (δp) $= \rho * g * H$

$= 995.18 * 9.81 * 2.7468$

$= 26816.23$ Pa

Practical Pressure Drop = 26816.23 Pa

Similarly if we calculate pressure drop for every reading we find following results:

Theoretical Pressure Drop	Practical Pressure Drop
25430.10	26816.23
27624.53	27677.30
26151.49	26201.18
26882.96	27677.30

➢ Average Difference between theoretical & Practical Pressure drop is **2.2%**

This experiment is authenticated in ANSYS & FEA done for authentication

VI. FE ANALYSIS OF PRESSURE DROP

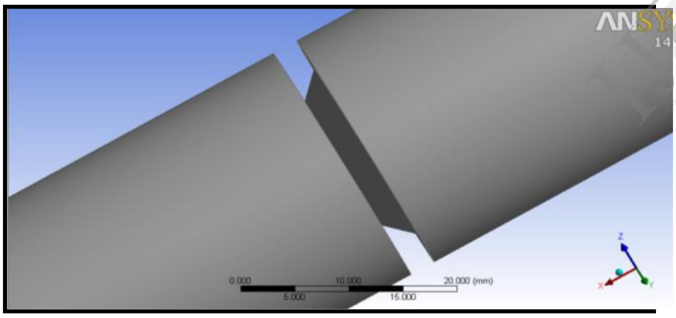


Fig 3: 3-D model of orifice plate

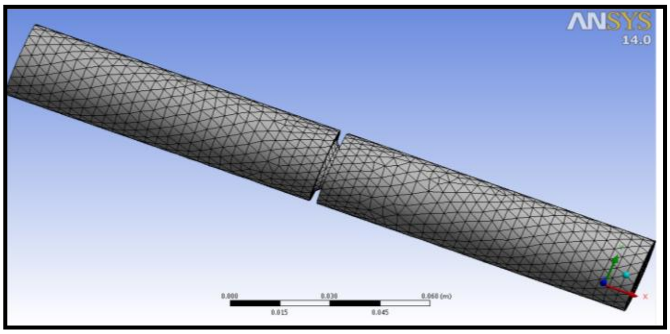


Fig 4: Meshing of the model

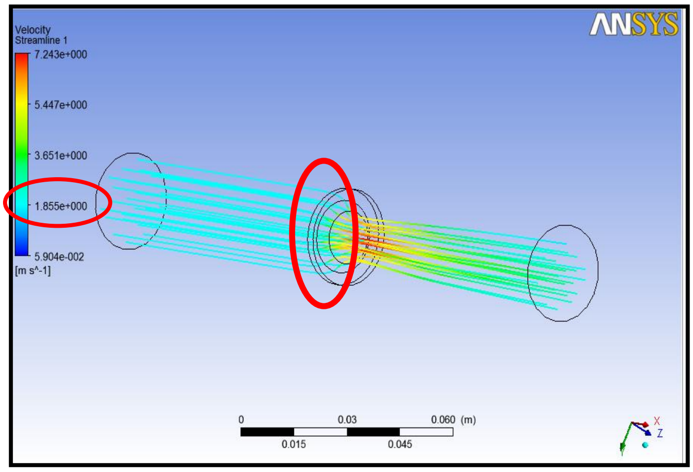


Fig 5: Velocity profile

- From velocity analysis it is clear that **V = 1.85 m/s**

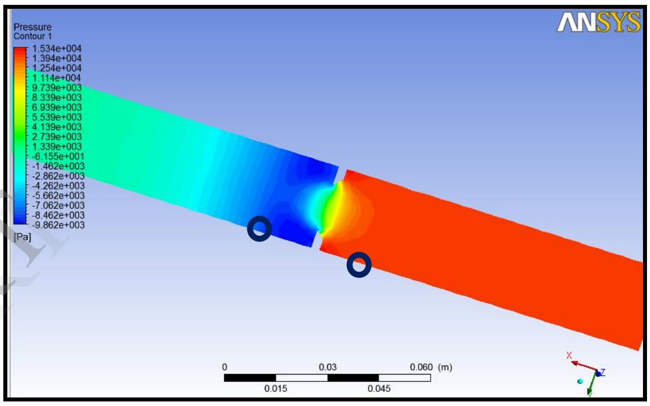
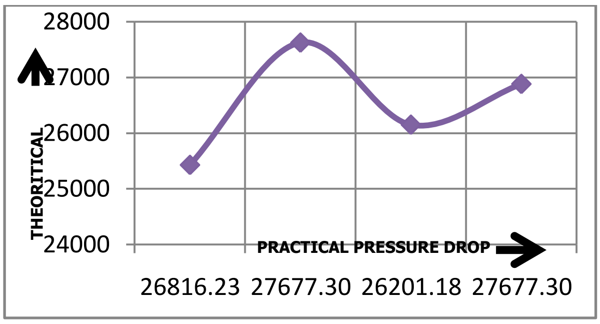


Fig 6: Velocity profile

- From Pressure drop contour it is observed that on position the manometer is fitted from which we take the readings of pressure drop.
- It is clear from the Pressure drop contour that pressure drop = 15339.2 – (- 9862.04) = 25201.24 Pa

➢ Difference between FEA Pressure drop & Practical Pressure drop is **0.9%**

➢ The comparison chart of **FEA Pressure drop & Practical Pressure drop** is also shown.



VII. CONCLUSION

Average Difference between theoretical & Practical Pressure drop is **2.2%**

Difference between FEA Pressure drop & Practical Pressure drop is **0.9%**

We have found good agreement among the three results theoretical Practical & FE analysis. So, we can change the pressure drop by changing velocity, shape of orifice and angle and find out optimum design of orifice.

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C_D *discharge* coefficient

C_p specific heat at constant pressure (kJ/kg K)

D pipe diameter (m)

d orifice meter diameter (m)

δp Pressure difference (Pa)

p static pressure (Pa)

R pipe radius (m)

Re pipe Reynolds number

V pipe velocity (m/s)

Q volume flow rate (m3/s)