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"Experimental Investigation of Influence of Pipe Elbow on Coefficient of Discharge of Orifice Meter"

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ABSTRACT

The performance of Orifice meters with different diameter ratios have been evaluated experimentally and its influence on Discharge Coefficient for Reynolds number studied. The experiments are conducted using water as working fluid for incompressible flow situation. The effects of locations of elbows at different upstream distances from orifice are investigated. Five different β (beta) ratios (0.2, 0.3, 0.4, 0.5 and 0.6) are considered. The upstream distance from the elbow to the Orifice meter of 1D, 2D, 3D, 4D, 5D, 8D, 12D, 16D and 20D are considered during experimentation.

Keywords*: *Orifice, flow through elbows, Discharge coefficient, Reynolds number.

I. INTRODUCTION

The measurement of fluid flow is important in applications ranging from measurements of blood flow rates in a human artery to the measurement of the flow of liquid oxygen in a rocket. Many research projects and industrial processes depend on a measurement of fluid flow to furnish important data for analysis.

Differential pressure devices such as orifice plates and nozzles are extensively applied in several industries in order to estimate the mass flow rate running through a conduit by correlating the measured pressure loss and the mass flow rate. The discharge coefficient C_d relates the actual mass flow rate to the theoretical flow rate through the device. [1]

For many industrial and operations, the accuracy of a fluid flow measurement is directly related to profit. Accurate flow measurement is one of the greatest concerns among many industries a simple example is the water meter at home.

In this work, the effect of pipe elbow and upstream length that effects on the performance of Nozzle meter is studied. The performance of the flow meter is evaluated for different distances between elbow and flow meter, different flow rates and different elbows (90deg and 45 deg elbows are considered). The performance is determined in terms of percentage change of co-efficient of discharge for different distances of elbow from Nozzle meter.

II. DESCRIPTION OF ORIFICES

Five different orifices are fabricated according to the ISA1932 standards. Aluminium is used for the fabrication of the orifices. Fig 2.1 shows the dimensional considerations for the fabrication of the orifices.

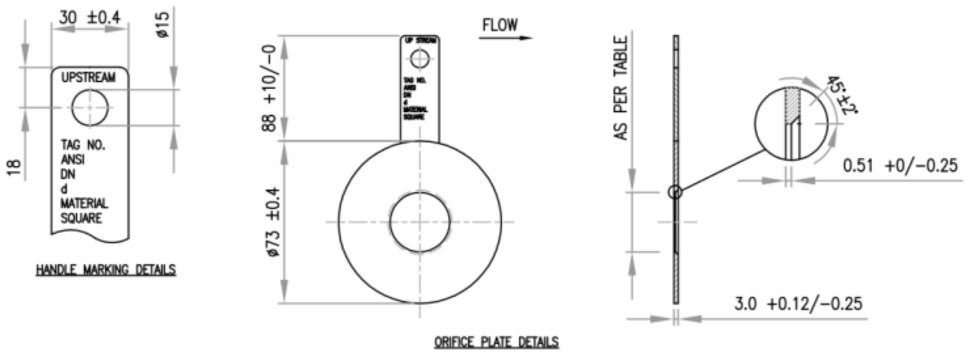

Fig 1: Dimensional considerations for the fabrication of the orifices (ISA1932)

Each orifice have different Beta ratio (β). Beta ratio is defined as the ratio of inside diameter of the orifice to the inside diameter of the inlet pipe.

Beta ratio, $\beta = \frac{\text{Inside diamter of the orifice}}{\text{Inside diameter of the inlet pipe}}$ (1)

Beat ratio (β) considered are 0.2, 0.3, 0.4, 0.5 and 0.6. Upstream pipe dimensions are based on non-dimensional length known as L/D which is the ratio of upstream length after bend to the inside diameter of the pipe. L/D ratios considered for the analysis are 2D, 4D, 6D, 8D and 10D.

Table shows the dimensions for Orifices for Beta ratios 0.2, 0.3, 0.4, 0.5 and 0.6 respectively. The dimensions are according to ISA 1932 standard as shown in the Fig 1 above.

BETA	**BORE – ‘d’**
0.2	Ø 5.33 ± 0.03
0.3	Ø 7.99 ± 0.03
0.4	Ø 10.66 ± 0.03
0.5	Ø 13.32 ± 0.03
0.6	Ø 15.98 ± 0.03

Table 1: Design specifications for Orifice

The following figures show assembly details of orifice plates

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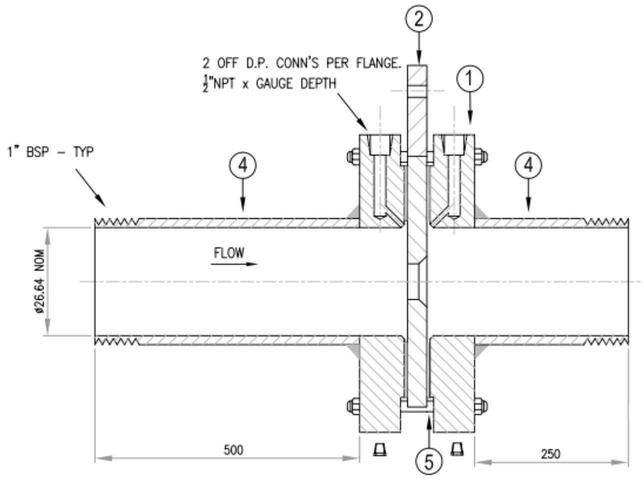
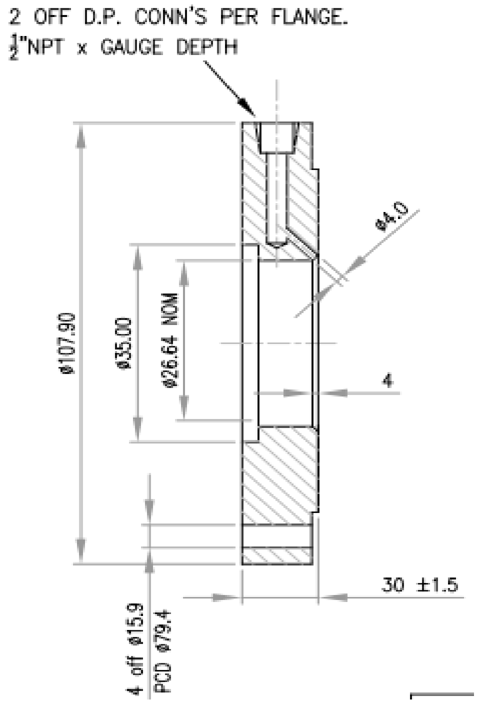


ITEM	QTY	DESCRIPTION	MATERIAL
1	2	SORF FLANGE	MILD STEEL
2	5	ORIFICE PLATE	ASTM A240 TP 316L
3	2	PIPE - 1" SCH.40	MILD STEEL
4	4	FASTENERS	MILD STEEL
5	2	GASKET	CAF

Fig 2 : Assembly drawing of orifice



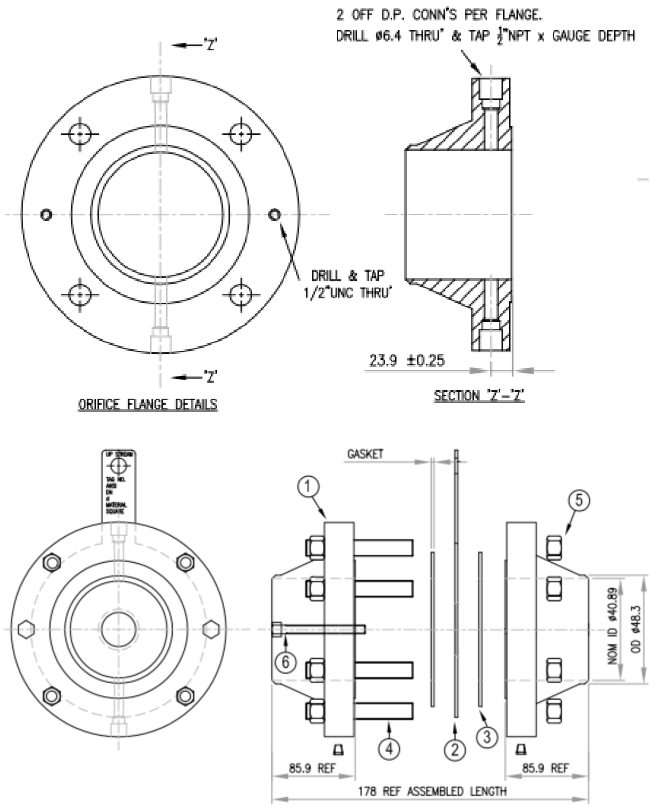


Fig 3: Section views of flanges and orifice

III. EXPERIMENTAL SETUP

This study was conducted in the Fluid Mechanics Laboratory. In the experimental setup, a line size of 2inch (50mm) is considered for the experiment. The orifices for five different beta ratios i.e. 0.2, 0.3, 0.4 0.5 and 0.6 are designed according to the line size. Orifices are assembled using flanges of welded type. The flange and orifices are assembled using four studs. Water as a measuring fluid was pumped by the main feeding pump in the laboratory. The inlet water is controlled by inlet gate valves located before the elbow of 90^{o}. The outflow from the nozzle is controlled by the gate valve located after the nozzle before the collecting tank. The collecting tank is used to collect the water from the nozzle out let to measure the water collected at certain time and hence to calculate the actual and theoretical flow rates to calculate the co-efficient of discharge and Reynolds's number. A differential manometer of u0tube type was tapped at corner of the flanges assembly to measure the differential pressure head. By using the pressure difference across the orifices inlet and outlet, the pressure head is calculated and hence the actual discharge is calculated. The upstream length is the distance between the elbow and the inlet to the nozzle. In the experiment, five different upstream lengths are considered i.e. 2D, 4D, 6D, 8D and 10D. Where D represents the diameter of the pipe or line size. To prevent the leakages at the assembly of the orifices and pipe line, the gaskets are used between the flanges and orifices. The pipe line is of material of galvanized iron and orifices are of aluminium. Flanges are made up of mild steel. The gaskets used are of type

CAF.

IV. EXPERIMENTAL WORK

The designed and fabricated different beta ratio (d/D=0.2, 0.3, 0.4, 0.5, 0.6) Orifice meters are calibrated with water. In which the convergent side of the Nozzle meters is connected to the upstream length and 90^0 elbows which are connected to the inlet valve and divergent side is connected to the gate valve and connecting tank. The pressure taps of convergent and throat is connected to simple U – tube mercury manometer. In the divergent side, the gate valve is fixed through which the flow is controlled. When the gate valve is in closed position the mercury level in the manometer is in balanced condition. Then the gate valve at the downstream side of the nozzle is opened gradually till we get the required deflection in manometer. The stop watch is used to measure the time required to collect the 20cm of water in collecting tank. Adjust the discharge until we get required deflection in the manometer. Note down the pressure difference 'h' and calculate the theoretical discharge Q_{th} by using the value of 'h'. Note down the time for collection of 20 cm of water in the measuring tank and determine the actual discharge Q_{act}.. Calculate the coefficient of discharge C_d. Repeat the procedure for at least nine different flow rates i.e. for at least 9 deflections in the manometer. This step is continued for different deflections starts with minimum deflection (15mm to 400mm). After completion of all the required deflections, the collecting time is recorded then. Changing the upstream length and repeating the same procedure for the five different upstream lengths (L/D=2D, 4D, 6D, 8D and 10D). This process is repeated for five different beta ratio (0.2, 0.3, 0.4, 0.5 and 0.6) Orifice meters. For each beta ratio, five different upstream lengths set-up has made and calculated the actual water flow rate, theoretical flow rate and coefficient of discharge for collecting 20 cm of water. By using the data of deflection and time required to collect the 20 cm of water, the actual and theoretical discharge is calculated for each Nozzle meters. The calibration curves for the five different Nozzle meters are drawn for coefficient of discharge vs. Reynolds number.

V. ESTIMATION OF MEASURING PARAMETERS

The primary parameter for estimation of discharge (Q) flow are calculated using following formula.

Pressure head H is calculated using,

$$H = H_m\left(\frac{\rho_m}{\rho_w} - 1\right) \quad \text{.........................} (2)$$

Where,

H_m= Difference in manometer limbs

ρ_m= Density of manometer fluid i.e. Mercury

ρ_w= Density of water

Actual discharge is calculated by using,

$$Qact = \frac{A * \Delta H}{t} \quad \text{.......................} (3)$$

Where,

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A= collecting tank area

ΔH = Height of water collected in collecting tank

t = Time taken to collect 20cm of water in collecting tank

Theoretical discharge is calculated by using,

$$Qth = \frac{\sqrt[2]{A_1 * A_2 (2gH)}}{\sqrt[2]{(A_1^2 - A_2^2)}} \text{ …………… (4)}$$

Where,

A_1= Cross sectional area at the inlet of the orifice

A_2= Cross sectional area at the outlet of the nozzle

The co-efficient of discharge C_d is calculated using,

$$C_d = \frac{Q_{act}}{Q_{th}} \text{ ……………………… (5)}$$

Reynolds number is calculated as,

$$R_e = \frac{(4Q_{act})}{(\pi D \square)} \text{ …………………… (6)}$$

Where,

D= Diameter of the pipe

ν = Kinematic viscosity of water

VI. RESULT AND DISCUSSIONS

The graph is plotted between Cd & Re as given below.

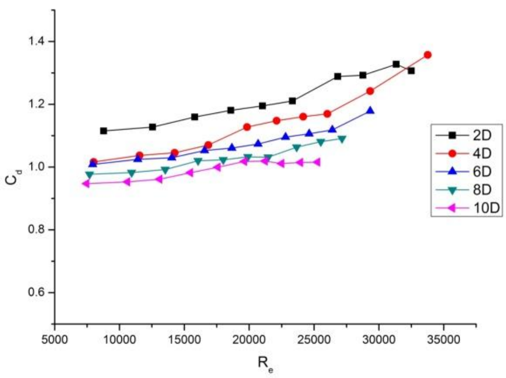

Fig 4: C_d v/s R_e at different upstream lengths for β=0.2

From above graph, Fig 4. it is shown that the coefficient of discharge of orifice with Beta ratio β=0.2 varies from 1.11 to 1.30 at 2D , 1.01 to 1.35 at 4D, 1.00 to 1.17 at 6D, 0.97 to 1.09 at 8D and 0.94 to 1.01 at 10D upstream lengths. The Reynolds's number varies from 7000 to 33000. It is also observed that the coefficient of discharge varies with the both Reynolds number and upstream lengths.

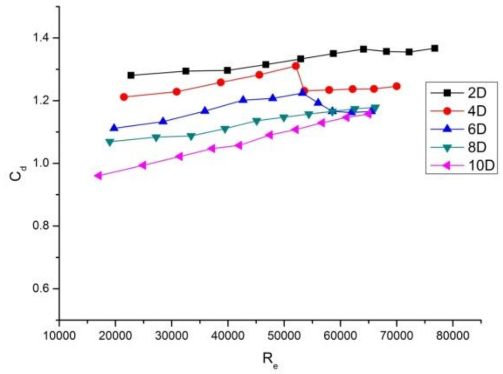

Fig 5: C_d v/s R_e at different upstream lengths for β=0.3

From above graph, Fig 5. it is shown that the coefficient of discharge of orifice with Beta ratio β=0.2 varies from 1.28 to 1.36 at 2D , 1.21 to 1.24 at 4D, 1.11 to 1.16 at 6D, 1.07 to 1.17 at 8D and 0.96 to 1.15 at 10D upstream lengths. The Reynolds's number varies from 17000 to 70000. It is also observed that the coefficient of discharge varies with the both Reynolds number and upstream lengths.

From Fig 6.3, it is shown that the coefficient of discharge of orifice with Beta ratio β=0.2 varies from 1.33 to 1.41 at 2D , 1.22 to 1.32 at 4D, 1.18 to 1.22 at 6D, 1.13 to 1.19 at 8D and 1.09 to 1.11 at 10D upstream lengths. The Reynolds's number varies from 30000 to 120000. It is also observed that the coefficient of discharge varies with the both Reynolds number and upstream lengths.

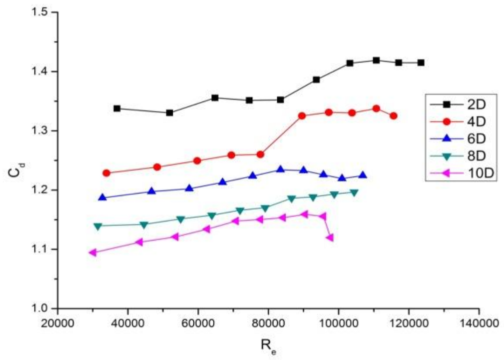

Fig 6: C_d v/s R_e at different upstream lengths for β=0.4

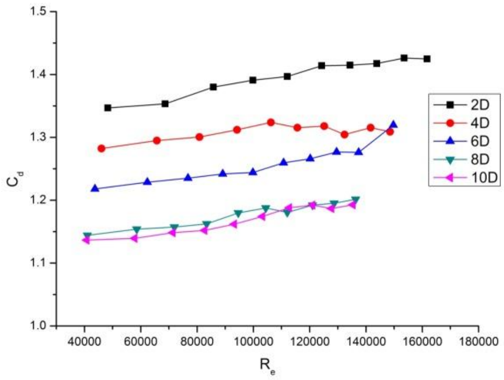

Fig 7: C_d v/s R_e at different upstream lengths for β=0.5

From above graph, it is shown that the coefficient of discharge of orifice with Beta ratio β=0.2 varies from 1.34 to 1.42 at 2D , 1.28 to 1.30 at 4D, 1.21 to 1.31 at 6D, 1.14 to 1.20 at 8D and 1.13 to 1.14 at 10D upstream lengths. The Reynolds's number varies from 40000 to 160000. It is also observed that the coefficient of discharge varies with the both Reynolds number and upstream lengths.

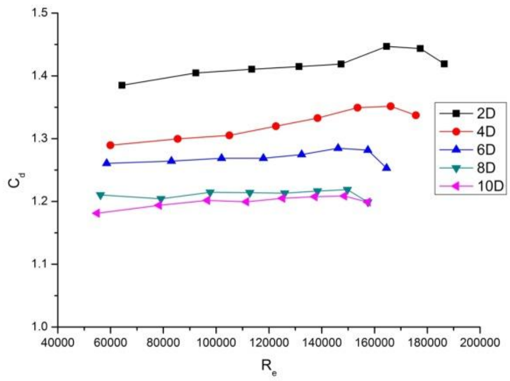

Fig 8: C_d v/s R_e at different upstream lengths for β=0.6

From above graph, it is shown that the coefficient of discharge of orifice with Beta ratio β=0.2 varies from 1.38 to 1.41 at 2D , 1.28 to 1.33 at 4D, 1.26 to 1.28 at 6D, 1.21 to 1.19 at 8D and 1.18 to 1.19 at 10D upstream lengths. The Reynolds's number varies from 54000 to 175000. It is also observed that the coefficient of discharge varies with the both Reynolds number and upstream lengths.

The coefficient of discharge varies with the decrease in the upstream length from 10D to 2D. The coefficient of discharge is largely affected by the upstream length at 2D and 4D. This is due the introduction of 90^o elbow. Due to the sudden change in the flow direction by introducing the elbow, the flow stability is disturbed and there will be pressure drop , hence it affects the coefficient of discharge. At smaller upstream length, i.e. 2D and

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4D, the flow disturbance will be more compared to the larger upstream lengths i.e. 6D to 10D, hence the coefficient of discharge is larger affected by smaller upstream lengths.

The coefficient of discharge varies in nonlinear manner with the variation in the Reynolds's number. It increases first at the smaller Reynolds's number and decreases slightly at the higher Reynolds's number. This is due to the stabilization of the flow at the higher Reynolds's number.

It is observed that the Reynolds's number varies with the upstream length and Beta ratio. With the decrease in the upstream length, the flow will be distorted and turbulence increases and hence Reynolds's number increases with decrease in upstream length. The Reynolds's number is dependent on the throat diameter of the orifices. As the throat diameter increases with the increase in the Beta ratio, the Reynolds's number also increases.
From Fig 4.6, it is noted that the Coefficient of discharge varies from 1.22 to 1.41, 1.14 to 1.32, and 1.07 to 1.26 1.02 to 1.21 and 0.99 to 1.19 with increase in the beat ratios at corresponding upstream lengths 2D, 4D, 6D, 8D and 10D respectively.

The variation of the coefficient of discharge is non linear relationship with the Beta ratio. The coefficient of discharge is more sensitive to Beta ratio in case of lower flow rate. This might be due to the reduction of irreversible losses for lower discharge. It is also observed from above graph that the coefficient of discharge of orifice increases with the decrease in the upstream length.

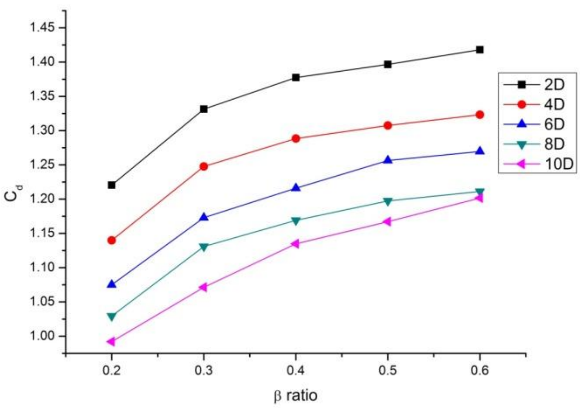

Fig 9: C_d v/s β at different upstream lengths

VII. CONCLUSIONS

The experimental investigation is performed to study the "Influence of pipe elbow on the coefficient of discharge of orifice meter". The experiment was conducted using water, with 90^o elbow at upstream side of the orifice. The following conclusions can be made from the experiment conducted,

1. The introduction of the 90o elbow at upstream side of the orifice affects the performance of the orifice meter. This performance is measured as variation in the coefficient of discharge of the orifice meter.
2. It is found that there is an influence of upstream length on coefficient of discharge if the upstream length is placed at 2D and 4D. The coefficient of discharge increases with decrease in the upstream length.
3. The coefficient of discharge is having positive non-linear relationship with the Reynolds's number. It increases at the lower Reynolds's number and decreases slightly at higher Reynolds's numbers.
4. Coefficient of discharge increases with increase in the Beta ratio.
5. The Reynolds number increases with decrease in the upstream length from 10D to 2D.
6. Reynolds's numbers are small for smaller Beta ratio orifices i.e. For 0.2 and 0.3. Reynolds numbers are larger for larger Beta ratio i.e. for 0.4 to 0.6.

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