Effect of Geometrical Parameters in Coefficient of Discharge and Reynolds Number through Venturimeter

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ABSTRACT: The experiment is intended to find the performance characteristics of venturimeter with different beta ratios ($\beta$) 0.6705, 0.67 and 0.56. The type of flow in the pipe and discharge, represent on Reynolds number (Re) and coefficient of discharge (Cd) through the pipe flow. Standard fluid (water) is taken as working fluid having density ($\rho$) 1000 kg/m$^3$ and manometric fluid as mercury, having density ($\rho$) 13600 kg/m$^3$. Kinematic viscosity depends on density and dynamic viscosity. The Dynamic viscosity ($\mu$) of water is 0.0006532 and 0.000798 Ns/m$^2$ taken in two different temperature as 30$^\circ$C and 40$^\circ$C. Upstream length 1.28m, 1.38m and 1.48m are taken in experiment and found that the Reynolds number of the working fluid increases with increase in coefficient of discharge and initially increases and certainly decreases with increase in upstream length.

KEYWORDS: Venturimeter, Beta ratios ($\beta$), coefficient of discharge ($C_d$),Upstream length, Reynolds’s number ($Re$).

I. INTRODUCTIONS

Flow meter are being commonly used in many industries to measure the volumetric flow through the pipe. These flow meter are usually differential pressure type. Venturimeter is an obstruction type flow meter device named after Giovanni Battista Venture (1746-1822) an Italian physicist who introduced Venturi Effect in the fluid flowing through the pipe. Venturi Effect is the reduction of fluid pressure in throat diameter and increase the velocity. Clemens Herschel (1842-1930), an American hydraulic engineer developed an accurate venturimeter which was a first large scale device used to measure the flow rate and widely used in many industries thereafter. Venturimeter works based on the principle of Bernoulli’s, when cross sectional area of the flow is reduced then a pressure difference is created between the different areas of flow and due to which the velocity of fluid increases and then decreases which helps in measuring the difference in pressure.

Venturimeter consists of three part, which are converging, throat and gradual diverging part. The cross sectional area of the converging part of venturimeter decreases as that of inlet pipe, throat section of the venturimeter has small uniform cross sectional area and divergent part is the gradual increase of cross sectional area of the venturimeter. The pressure difference between the inlet and throat is given by the Bernoulli’s equation which states that “In a steady ideal flow an incompressible fluid, the total energy at any point is constant”. The total energy consists of pressure energy, kinetic energy and potential energy.

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + Z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + Z_2$$

But above equation is for ideal fluid and assumed that the flow is steady, non-viscous and irrotational. For real fluids there will be some pressure losses due to friction and roughness of the pipe, hence major losses due to friction is also taken in account to measure the pressure head theoretically. The actual pressure heads is measured with the help of pressure difference between the pipe and throat of the venturimeter which is recorded by differential manometer.

Fig: 2 Schematic representation of experimental setup

The manometer has two pipe in which one is connected to inlet having same diameter as that of pipe and other to the throat of the venturimeter. The fluid velocity increases as passes through convergent section and gradually decreases through the divergent cone. The main advantage of using venturimeter in the experiment is high accuracy of coefficient of discharge. Compared to orifice it has quick pressure recovery.
II. EXPERIMENTAL SETUP AND SPECIFICATION

Three pipes (galvanized iron) of different diameter (20 mm, 25 mm, 30 mm) and different upstream length (1.28m, 1.38m 1.4B) are used in the experiment. All the pipes are connected with single pipe with ‘T’ joint at one end and at other with venturimeter having convergent cone diameter as same as that of inlet pipe and throat diameter (13.47 mm, 16.75 mm, 16.75 mm) respectively. The mercury differential U tube manometer is used where its one limb is connected to all the inlet section of different pipe and another limb is connected to the throat section of different venturimeter.

Centrifugal pump is used to drive the water from tank to the pipes which has following specification (2 phase, 240V, 50Hz, kW/HP: 0.37/0.5, Speed: 2800, Eff: 22%). Gate valves (cast iron) are used to control the flow of water flowing through the pipe. The outlet of all the pipe are connected to single pipe and the water is collected in a surge tank of (40mm x 60mm) dimensions respectively. The surge tank is fitted with piezometer which measures the level of water collected inside the surge tank when the gate valve of bend pipe is closed.

![Schematic Representation of Venturimeter with Manometer](Image)

Fig: 1 Schematic Representation of Venturimeter with Manometer

Pressure head (H) is calculated by the difference of heads of two limbs in manometer as shown below and then theoretical discharge (Qth) is found by the following formula

\[ H = (h_1 - h_2) \left(\frac{\Delta p_{\text{water}}}{\Delta p_{\text{mercury}}} - 1\right) \times 10^{-2} \ m \]

\[ h_f = \frac{P_1 - P_2}{\rho g} = H \text{ \ meter} \]

\[ Q_{th} = \frac{a_1 \sqrt{2gH}}{\sqrt{a_1^2 - a_2^2}} \ m^3/s \]

The ratio of actual discharge (Qact) and theoretical discharge (Qth) is coefficient of discharge and then tabulated as shown

\[ c_d = \frac{Q_{act}}{Q_{th}} \]

III. PROCEDURE

The experiment is started with removing the air from the pipe and ensured that the manometric pipe are connected tightly to the pipe inlet diameter and center in throat diameter of the pipe. The area of the pipe and throat of different pipe is calculated using the following formula.

\[ a = \frac{\pi d^2}{4} \ m^2 \]

| Inlet pipe 1 | 0.025 | 4.9087 |
| Throat 1 | 0.01675 | 2.2035 |
| Inlet pipe 2 | 0.020 | 3.141 |
| Throat 2 | 0.01341 | 1.4124 |

The pump is switched and the valve of one pipe is initially opened full and then gradually closed to require the appropriate manometric heads. Manometric heads are noted in the tabulation and then actual discharge is found by closing the collecting tank and time is noted for the 5 cm rise of water by observing the rise of water level in fixed piezometer. The below formula is used to find the actual discharge (Qact) of water through the pipe.

\[ Q_{act} = \frac{Ah}{t} \ m^3/s \]

Table: 1 Area of throat and inlet

| Pipe/Throat | Diameter in m | Area in m² in x10⁻⁴ |
|-------------|---------------|---------------------|

Table: 2 parametric values of pipe

| s. no | Time in s for 20 mm pipe | Qact (pipe 20 mm) in X10⁻⁴ m³/s | Time in s for 25 mm pipe | Qact (pipe 25 mm) in X10⁻⁴ m³/s |
|-------|--------------------------|---------------------------------|--------------------------|---------------------------------|
| 1     | 61                       | 1.967                           | 37.06                    | 3.237                           |
| 2     | 35                       | 3.428                           | 21                       | 5.714                           |
| 3     | 28                       | 4.285                           | 16.5                     | 7.272                           |
| 4     | 20                       | 6                               | 13.2                     | 9.090                           |
| 5     | 17                       | 7.058                           | 11.2                     | 10.71                           |
| 6     | 16                       | 7.5                             | 10.4                     | 11.534                          |
| 7     | 14.5                     | 8.275                           | 9.4                      | 13.18                           |
| 8     | 14                       | 8.571                           | 9                        | 13.289                          |
| 9     | 11.4                     | 10.52                           | 8.1                      | 14.814                          |
| 10    | 9.6                      | 12.5                            | 7.7                      | 15.605                          |

Table: 3 parametric values of pipe of diameter 20mm

| h₁ (cm) | h₂ (cm) | H (m) | Qact (m³/s) | Qth (m³/s) | c_d |
|---------|---------|-------|-------------|------------|-----|
| 25.1    | 21      | 0.517 | 1.967       | 5.034      | 0.391 |
| 26.2    | 19.9    | 0.794 | 3.428       | 6.240      | 0.549 |
| 27.4    | 18.7    | 1.096 | 4.285       | 7.332      | 0.584 |
| 28.8    | 17.4    | 1.436 | 6           | 8.394      | 0.715 |
| 30.2    | 15.9    | 1.802 | 7.058       | 9.401      | 0.750 |
| 31.4    | 14.6    | 2.117 | 7.5         | 10.19      | 0.736 |
| 32.7    | 13.4    | 2.432 | 8.275       | 10.921     | 0.758 |
| 35.1    | 10.8    | 3.062 | 8.571       | 12.255     | 0.699 |
| 38.1    | 7.8     | 3.818 | 10.52       | 13.685     | 0.770 |
| 43.7    | 3.4     | 5.204 | 12.5        | 15.977     | 0.782 |
Table: 4 parametric values of pipe of diameter 25mm

| \(d_1\) (cm) | \(d_2\) (cm) | \(H\) (m) | \(Q_{act}\) \(\times 10^{-3}\) m\(^3\)/s | \(Q_{th}\) \(\times 10^{-3}\) m\(^3\)/s | \(C_d\) |
|-------------|-------------|----------|---------------------------------|---------------------------------|--------|
| 25          | 21.6        | 5.714    | 7.149                           | 0.453                           |
| 27          | 20.2        | 5.842    | 10.11                           | 0.565                           |
| 28.7        | 18.4        | 7.272    | 12.44                           | 0.584                           |
| 30.8        | 16.4        | 9.090    | 14.713                          | 0.618                           |
| 32.8        | 14.3        | 10.711   | 16.677                          | 0.642                           |
| 34.9        | 12.3        | 11.534   | 18.432                          | 0.625                           |
| 36.6        | 10.5        | 13.181   | 19.808                          | 0.665                           |
| 38.5        | 8.5         | 13.289   | 21.237                          | 0.625                           |
| 40.3        | 7.4         | 14.814   | 22.239                          | 0.667                           |
| 43.9        | 5.4         | 15.605   | 24.522                          | 0.636                           |

The value of friction factor \(f\), actual velocity \(V_a\) is found by the following equation.

\[
h_f = \frac{4fV_a^2}{2gd}
\]

\[
V_a = \frac{Q_{act}}{a} \text{ m/s}
\]

The Reynolds Number is found by keeping the value of dynamic viscosity with respect to the table as shown.

Table: 5 Dynamic viscosity for different temperature

| Pipe diameter 20 mm | Pipe diameter 25 mm |
|---------------------|---------------------|
| \(\mu = 0.0006532 \text{ Ns/m at 30°C} \) | \(\mu = 0.0006532 \text{ Ns/m at 30°C} \) |
| \(\mu = 0.000798 \text{ Ns/m at 40°C} \) | \(\mu = 0.000798 \text{ Ns/m at 40°C} \) |

\[
Re = \frac{\rho V_a d}{\mu}
\]

IV. NOTATIONS

- \(d_1\) = diameter of the pipe in m
- \(d_2\) = diameter of the throat in m
- \(a_1\) = area of the pipe in m\(^2\)
- \(a_2\) = area of the throat in m\(^2\)
- \(A\) = area of the collecting tank in m\(^2\)
- \(h\) = rise of water in collecting tank (5cm) in cm
- \(H = h_1 + h_2\) = manometric heads in m
- \(S_{mercury} = \text{specific gravity of mercury} = 13.6\)
- \(S_{water} = \text{specific gravity of water} = 1\)
- \(h_1 = H = \text{pressure head in m}\)
- \(Q_{act}=\text{actual discharge in m}^3/\text{s}\)
- \(Q_{th}=\text{theoretical discharge in m}^3/\text{s}\)
- \(C_d=\text{coefficient of discharge}\)
- \(f=\text{friction factor}\)
- \(V_a=\text{actual velocity in m/s}\)
- \(g=\text{acceleration due to gravity (9.81) in m/s}\)
- \(d=\text{diameter of the pipe in m}\)
- \(Re=\text{Reynolds number}\)
- \(\rho=\text{density of the water (1000) in kg/m}^3\)
- \(\mu=\text{Dynamic viscosity in Ns/m}^2\)

V. RESULT & GRAPH ANALYSIS

The influence in coefficient of discharge as the function of Reynolds number for the venturimeter having different \(\beta\) (beta ratio) are experimentally investigated and calibrated in graph.
The Figure 4 to 7 shows that the Reynolds number does not change steadily with the coefficient of discharge for both beta ratio 0.6705 and 0.67. The higher Reynolds number value for beta ratio 0.6705 is found when the discharge coefficient value is nearly 0.758 for both dynamic viscosity values \( \mu = 0.6532 \times 10^{-4}, \mu = 0.798X \times 10^{-4} \) as shown in the figure 4 and figure 6. But the higher reynolds number value for the beta ratio values 0.67 is when the discharge coefficient value is nearly 0.64 for both dynamic viscosity values as shown in the figure 5 and figure 7. Since the reynold’s number varies directly with free stream velocity, the discharge is expected to increase in reynold’s number however it is exception in the case when flow area is too smaller. Conversely when the Reynolds number increases above some threshold value the discharge coefficient decreases dramatically and then started to recover which is a variant point in all the s.

Figure 8 and 9 shows that the discharge through any pipe directly increases with increase in pressure difference in inlet and throat of the venturimeter pipe which is obtained by manometric heads \( h_1 \) and \( h_2 \).

VI. CONCLUSION:
The experiment is conducted with T joints connected to three different pipes having different beta ratio at two different dynamic viscosity values. The readings of all the parameters of venturimeter and its characteristics performance was calibrated and following things are found.
1. Reynolds number and discharge coefficient get influenced by different beta ratios.
2. Reynolds number is higher for the beta ratio 0.6705 and lower for the 0.55.
3. The discharge coefficient increases with increase in Reynolds number.
4. However it is seen that dynamic viscosity of fluid at different temperature has slight influence in the Reynolds number and discharge coefficient.
5. The Reynolds number increases with increase in actual velocity and upstream length initially increase and decrease with increasing upstream length.
6. Discharge increases with increase of pressure heads in pipe flow through venturimeter.

VII. FUTURE SCOPE
From experimental investigation previously done work and adding some work for future scope to get steady flow in laminar.
1. In experimental investigation in future analysis the working fluid can changed to high viscous liquid like alcohol, propyl, acetonitrile, oil etc.
2. Venturimeter shape can be changed to get different beta ratio to find optimum Reynolds number and coefficient of discharge.
3. Upstream length can be take more than five variation in length to get optimum Reynolds number for laminar and turbulent flow in pipe.
4. Analysis the flow in venturi pipe with different phase mixture, like dry steam, wet steam, air mixture, water mixture.

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