Experiment No.4: Flow through Venturi meter

Background and Theory

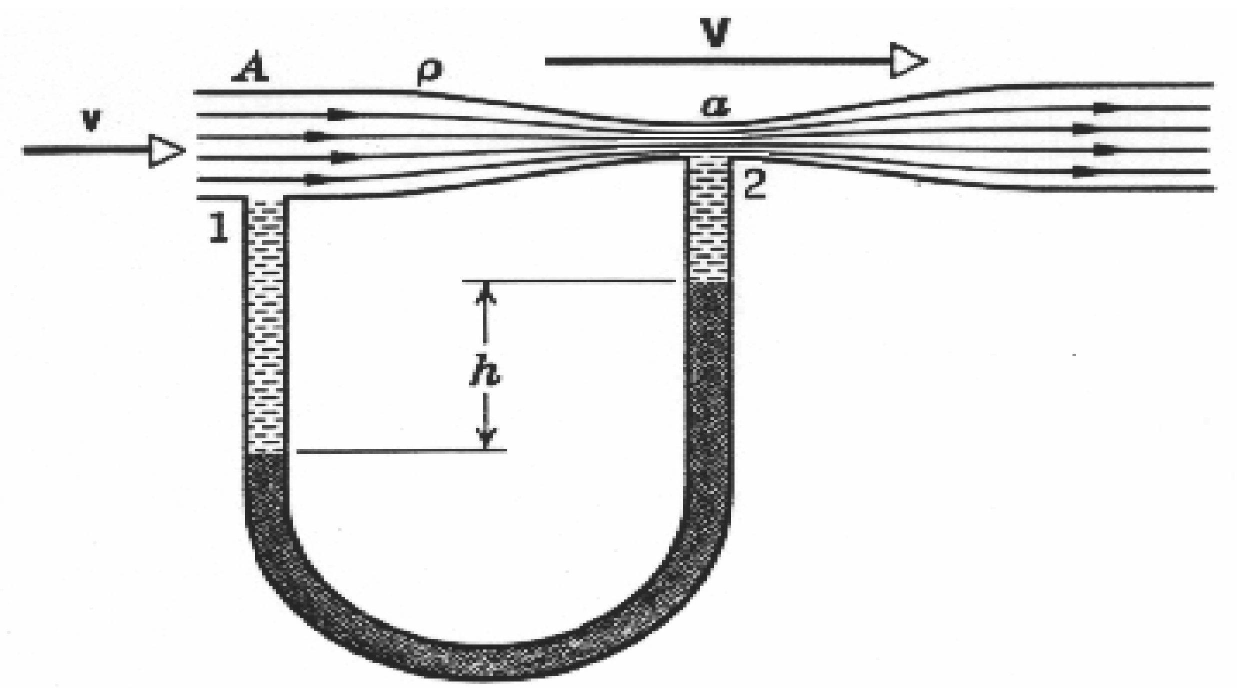
Introduction

Flow meters are used in the industry to measure the volumetric flow rate of fluids. Differential pressure type flow meters (Head flow meters)measure flow rate by introducing a constriction in the flow. The pressure difference caused by the constriction is correlated to the flow rate using Bernoulli's theorem.

If a constriction is placed in a pipe carrying a stream of fuid,there will be an increase in velocity,and hence an increase in kinetic energy ,at the point of constriction.From an energy balance as given by Bernoulli’s theorem,there must be a corresponding reduction in pressure.Rate of discharge from the constriction can be calculated by knowing this pressure reduction,the area available for flow at the constriction ,the density of the fluid and the coefficient of discharge C_d. Coefficient of discharge is the ratio of actual flow to the theoretical flow and makes allowances for stream contraction and frictional effects. Venturi meter, orifice meter, and Pitot tube are widely used head flow meters in the industry. The Pitot-static is often used for measuring the local velocity in pipes or ducts. For measuring flow in enclosed ducts or channels, the Venturi meter and orifice meters are more convenient and more frequently used. The Venturi is widely used particularly for large volume liquid and gas flows since it exhibits little pressure loss. However, for smaller pipes orifice meter is a suitable choice. In order to use any of these devices for measurement it is necessary to empirically calibrate them. That is, pass a known volume through the meter and note the reading in order to provide a standard for measuring other quantities.

Venturi meter:

One of the disadvantages of orifice meters is the large irreversible pressure loss across the orifice, which results in substantial pumping costs in case of large diameter pipes. However, the same principle can be exploited with only minimal pressure loss with the use of a Venturi meter. In this case, the meter consists of a section with both a smooth contraction and a smooth expansion. Because of the smoothness of the contraction and expansion, the irreversible pressure loss is low. However, in order to obtain a significant measurable pressure drop, the downstream pressure tap is placed at the "throat" of the meter; i.e., at the point of the smallest diameter. Venturimeter is used to measure the rate of flow through a pipe. Venturimeter consists of a converging portion, throat and a diverging portion. The function of the converging portion is to increase the velocity of the fluid and temporarily lower its static pressure. The pressure difference between inlet and throat is developed. This pressure difference is correlated to the rate of flow. The expression for theoretical flow rate is obtained by applying the continuity equation and energy equation at inlet and throat section.



For measuring discharge we should apply Bernoulli's equation at point 1 and at point 2.The following treatment is limited to incompressible fluids. Friction is neglected , the meter is assumed to be horizontal and there is no pump. If v1 and v2 are the average velocities at point 1 and point 2 respectively and ρ is the density of fluid**.**

$$\mathbf{(P_1/\rho g) + (v_1^2/2g) + z_1 = (P_2/\rho g) + (v_2^2/2g) + z_2}$$

Since $z_1=z_2$

$$\mathbf{(v_2^2/2g) - (v_1^2/2g) = (P_1/\rho g) - (P_2/\rho g)}$$

$(v_2^2 - v_1^2)/2g = (P_1/\rho g) - (P_2/\rho g)$ ------- (1)

Now applying the equation of continuity at both points, we have

$A_1 v_1 = A_2 v_1$ ------(2)

$v_2 = (A_1 \times v_1)/ A_2$ --------(3)

$v_2=(d_1^2 \times v_1)/ d_2^2$--------- (4)

where d_1 and d_2 are the diameters at point 1(pipe) and at point 2(throat) respectively.

Now putting the value of V_2 in the above expression (1) and if $\beta= d_2/d_1$, we have

$$v_2 = \sqrt{\frac{2(P_1-P_2)}{\rho(1-\beta^4)}} \qquad (5)$$

$Q = A_2.v_2$ (6)

$$Qth = A_2\sqrt{\frac{2(P_1-P_2)}{\rho(1-\beta^4)}} \qquad (6)$$

Qth is the theoretical flow rate as computed from Eq.(6) and applies to frictionless flow of incompressible fluids. Actual flow includes frictional loss between point 1 and 2.So to account for small friction between points 1 and 2,

$$Q = C_D.Q_{th}=C_D A_2\sqrt{\frac{2(P_1-P_2)}{\rho(1-\beta^4)}} \qquad (6)$$

Where C_D is called as co-efficient of discharge and it depends upon the type of flow, type of fluid and dimensions of venture tube and pipe.

$$C_D = \frac{Q}{A_2}\sqrt{\frac{\rho(1-\beta^4)}{2(P_1-P_2)}} \qquad \textbf{(6)}$$

It is the ratio of actual flow rate to the theoretical flow rate.

For a well designed venture the constant C_D is about 0.98 for pipe diameters of 2 to 8inches and about 0.99 fro larger sizes.

The equation relating flow rate to pressure drop is

$$Q = C_d A_t \sqrt{\frac{2(p_1 - p_2)}{\sqrt{(1-\beta^4)\rho}}}$$

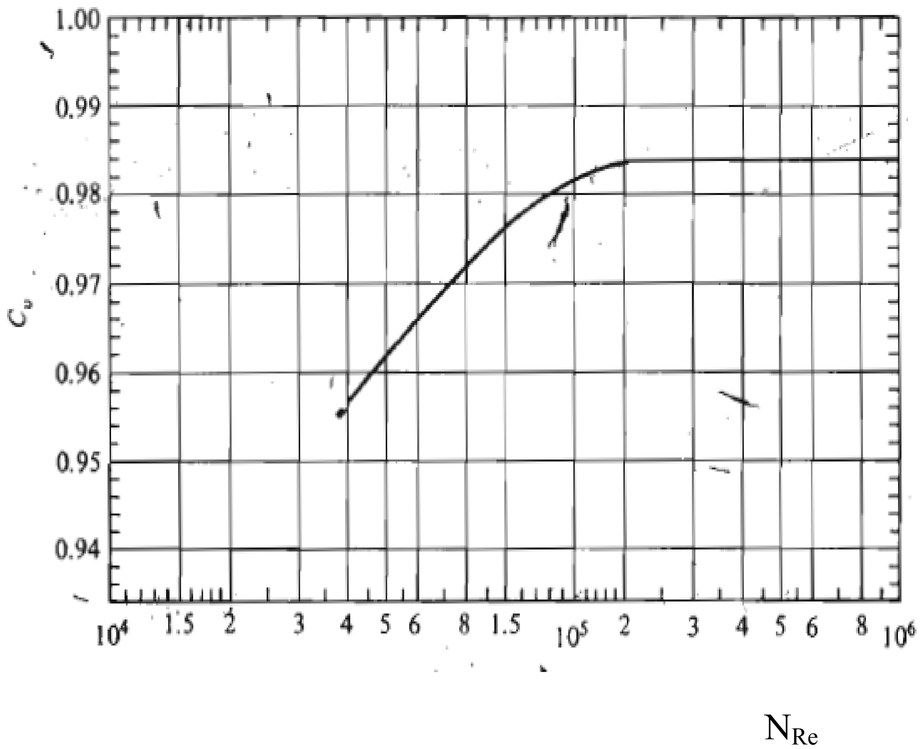
Where C_D is the coefficient of discharge for venturimeter. A_t is the crosssectional area of the throat and β is the ratio of throat diameter to pipe diameter.

For a Venturi, $C_d = 0.99$ for $10^5 < N_{Re} < 10^7$ is a useful approximation

The pressure recovery is much better for the venturi meter than for the orifice plate.

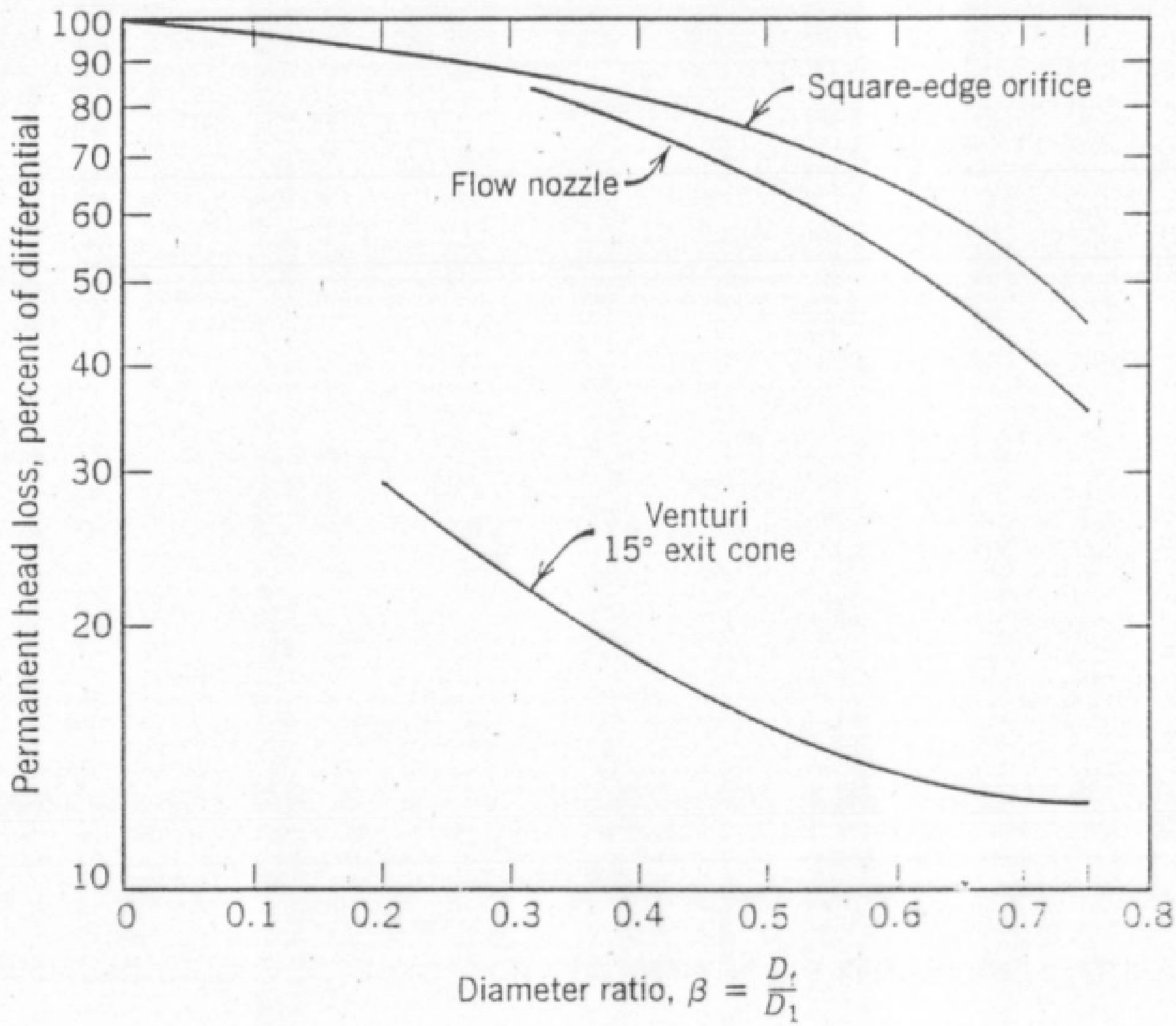
The main advantages of the Venturi over the orifice plate are
- low head loss.Around 90% of the pressure is recovered.
- less affected by upstream flow disturbance
- good performance at higher β
- even more robust
- The venturi tube is suitable for clean, dirty and viscous liquid and some slurry services
- self-cleaning
- less affected by erosion

The disadvantages compared to the orifice are
- occupies longer length of pipe
- more expensive (manufacture and installation)



Discharge Coefficients against Reynold’s Number($\frac{\rho D_t V_t}{\mu}$)

D_t and V_t are the thoat diameter and velocity at the throat respectevily.



Comparison of permanent head loss caused by different head meters

Venturimeter

Venturimeter

- Throat to diameter ratio 0.25 to 0.75
- Discharge co-efficient – 0.9 to 1.0
- Made of cast iron, gun metal, stainless steel