## FLOW MEASUREMENTS

The flow rate of a fluid flowing in a pipe under pressure is measured for a variety of applications, such as monitoring of pipe flow rate and control of industrial processes. Differential pressure flow meters, consisting of orifice, flow nozzle, and venturi meters, are widely used for pipe flow measurement and are the topic of this course. All three of these meters use a constriction in the path of the pipe flow and measure the difference in pressure between the undisturbed flow and the flow through the constriction. That pressure difference can then be used to calculate the flow rate. Flow meter is a device that measures the rate of flow or quantity of a moving fluid in an open or closed conduit.

Flow measuring devices are generally classified into four groups. They are

1. **Mechanical type flow meters**

   Fixed restriction variable head type flow meters using different sensors like orifice plate, venturi tube, flow nozzle, pitot tube, dall tube, quantity meters like positive displacement meters, mass flow meters etc. fall under mechanical type flowmeters.

2. **Inferential type flow meters**

   Variable area flow meters (Rotameters), turbine flow meter, target flow meters etc.

3. **Electrical type flow meters**

   Electromagnetic flow meter, Ultrasonic flow meter, Laser doppler Anemometers etc. fall under electrical type flow meter.

4. **Other flowmeters**

   Purge flow regulators, Flow meters for Solids flow measurement, Cross-correlation flow meter, Vortex shedding flow meters, flow switches etc.

**Orifice FlowMeter**

An Orifice flow meter is the most common head type flow measuring device. An orifice plate is inserted in the pipeline and the differential pressure across it is measured.

**Principle of Operation**

The orifice plate inserted in the pipeline causes an increase in flow velocity and a corresponding decrease in pressure. The flow pattern shows an effective decrease in cross section beyond the orifice plate, with a maximum velocity and minimum pressure at the venacontracta.

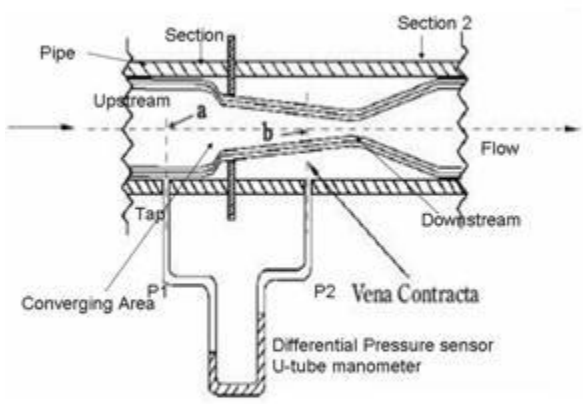


**Fig 5.16 Orifice Meter**

The flow pattern and the sharp leading edge of the orifice plate which produces it are of major importance. The sharp edge results in an almost pure line contact between

the plate and the effective flow, with the negligible fluid-to-metal friction drag at the boundary.

**Types of Orifice Plates**

The simplest form of orifice plate consists of a thin metal sheet, having in it a square edged or a sharp edged or round edged circular hole.

There are three types of orifice plates namely

1. Concentric

2. Eccentricand
3. Segmentaltype.

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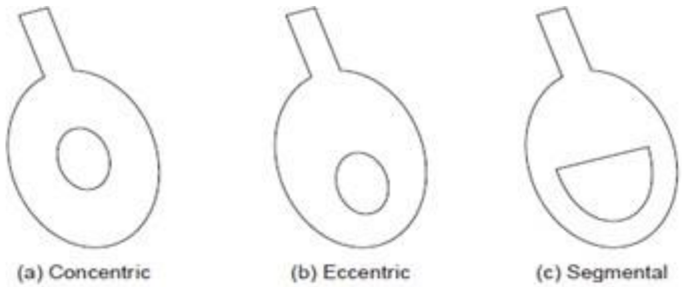



**Fig 5.17 Types of Orifice Plates**

The concentric type is used for clean fluids. In metering dirty fluids, slurries and fluids containing solids, eccentric or segmental type is used in such a way that its lower edge coincides with the inside bottom of the pipe. This allows the solids to flow through without any obstruction. The orifice plate is inserted into the main pipeline between adjacent flanges, the outside diameters of the plate being turned to fit within the flange bolts. The flanges are either screwed or welded to the pipes.

**Applications**

- The concentric orifice plate is used to measure flow rates of pure fluids and has a wide applicability as it has been standardized
- The eccentric and segmental orifice plates are used to measure flow rates of fluids containing suspended materials such as solids, oil mixed with water and wet steam.

**Advantages**

- It is very cheap and easy method to measure flowrate
- It has predictable characteristics and occupies lessspace
- Can be used to measure flow rates in largepipes

**Limitations**

- The vena-contracta length depends on the roughness of the inner wall of the pipe and sharpness of the orifice plate. In certain case it becomes difficult to tap the minimum pressure due the abovefactor

- Pressure recovery at downstream is poor, that is, overall loss varies from 40 to 90% of the differentialpressure.
- In the upstream straightening vanes are a must to obtain laminar flowconditions.
- The orifice plate gets corroded and due to this after sometime, inaccuracy occurs. The coefficient of discharge islow.

**Venturi Meter**

Venturi tubes are differential pressure producers, based on Bernoulli's Theorem. General performance and calculations are similar to those for orifice plates. In these devices, there is a continuous contact between the fluid flow and the surface of the primary device.

It consists of a cylindrical inlet section equal to the pipe diameter, a converging conical section in which the cross sectional area decreases causing the velocity to increase with a corresponding increase in the velocity head and a decrease in the pressure head; a cylindrical throat section where the velocity is constant so that the decreased pressure head can be measured and a diverging recovery cone where the velocity decreases and almost all of the original pressure head is recovered. The unrecovered pressure head is commonly called as headloss.

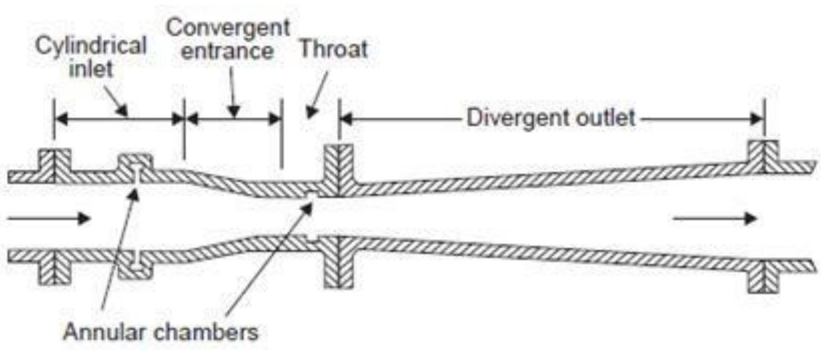



**Fig 5.18 Long form Venturi**

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

where

$p$ is pressure (N/m$^2$)
$v$ is velocity (m/s)
$\rho$ is the density of the liquid (kg/m$^3$).

$$\therefore \dot{Q} = \frac{a_1 a_2}{\sqrt{(a_1^2 - a_2^2)}} \sqrt{\frac{2}{\rho}(p_1 - p_2)} \text{ m}^3/\text{s}$$

$$\dot{Q} = a_2 \sqrt{\frac{2(p_1 - p_2)}{\rho(1-\beta^4)}}$$

$\beta$ is the ratio : $\frac{\text{throat diameter}}{\text{pipe diameter}}$

**Limitations**

This flow meter is limited to use on clean, non-corrosive liquids and gases, because it is impossible to clean out or flush out the pressure taps if they clog up with dirt ordebris.

**Short Form Venturi Tubes**

In an effort to reduce costs and laying length, manufactures developed a second generation, or short-form venturi tubes shown in Figure 5.19.

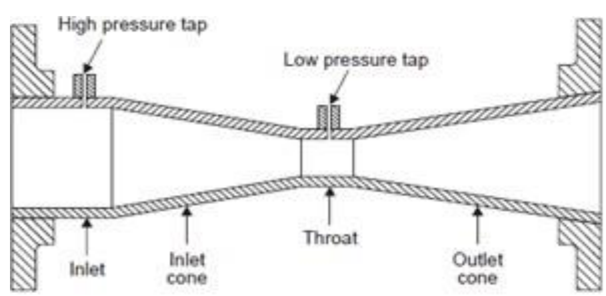



**Fig 5.19 Short-form Venturi Tube**

There were two major differences in this design. The internal annular chamber was replaced by a single pressure tap or in some cases an external pressure averaging chamber, and the recovery cone angle was increased from 7 degrees to 21 degrees. The short form venture tubes can be manufactured from cast iron or welded from a variety of materials compatible with the application.

The pressure taps are located one-quarter to one-half pipe diameter upstream of the inlet cone and at the middle of the throat section. A piezometer ring is sometimes used for differential pressure measurement. This consists of several holes in the plane of the tap locations. Each set of holes is connected together in an annular ring to give an average pressure. Venturis with piezometer connections are unsuitable for use with purge systems used for slurries and dirty fluids since the purging fluid tends to short circuit to the nearest tap holes. Piezometer connections are normally used only on very large tubes or where the most accurate average pressure is desired to compensate for variations in the hydraulic profile of the flowing fluid. Therefore, when it is necessary to meter dirty fluids and use piezometer taps, sealed sensors which mount flush with the pipe and throat inside wall should be used. Single pressure tap venturis can be purged in the normal manner when used with dirty fluids. Because the venturi tube has no sudden changes in contour, no sharp corners, and no projections, it is often used to measure slurries and dirty fluids which tend to build up on or clog of the primarydevices.

## Flow Nozzle

### Flange Type Flow Nozzle

The Flow nozzle is a smooth, convergent section that discharges the flow parallel to the axis of the downstream pipe. The downstream end of a nozzle approximates a short tube and has the diameter of the venacontracta of an orificeof equal capacity. Thus the diameter ratio for a nozzle is smaller or its flow coefficient is larger. Pressure recovery is better than that of an orifice. Figure shows a flow nozzle of flange type.

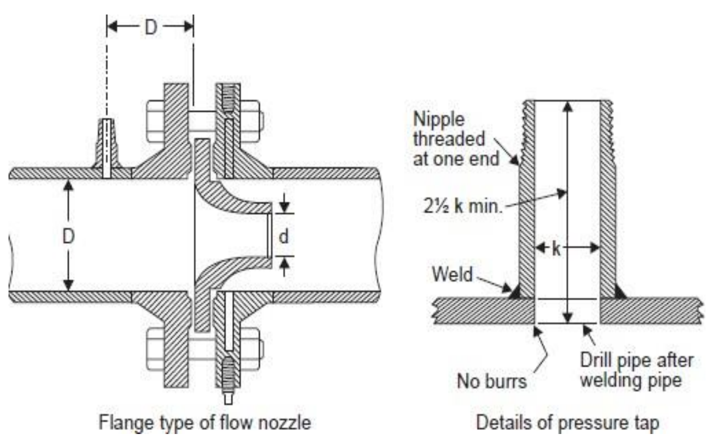



Fig 5.20 Flow Nozzle

### Advantages

4. Permanent pressure loss lower than that for an orificeplate.

5. It is suitable for fluids containing solids thatsettle.

6. It is widely accepted for high pressure and temperature steamflow.

**Disadvantages**

1. Cost is higher than orificeplate.

2. It is limited to moderate pipe sizes, it requires moremaintenance.

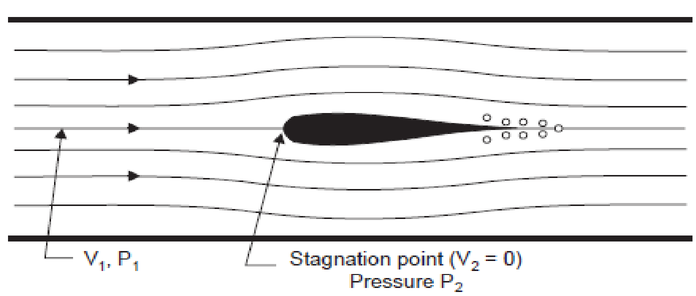
## Pitot tube

An obstruction type primary element used mainly for fluid velocity measurement is the Pitot tube.

**Principle**

Consider Figure which shows flow around a solid body. When a solid body is held centrally and stationary in a pipeline with a fluid streaming down, due to the presenceofthebody,thefluidwhileapproachingtheobjectstartslosingitsvelocitytill

directly in front of the body, where the velocity is zero. This point is known as the stagnation point. As the kinetic head is lost by the fluid, it gains a static head. By measuring the difference of pressure between thatat normal flow line and thatat the stagnation point, the velocity is found out. This principle is used in pitot tube sensors.




Flow around a solid body

**Fig 5.21 Flow through solid body**

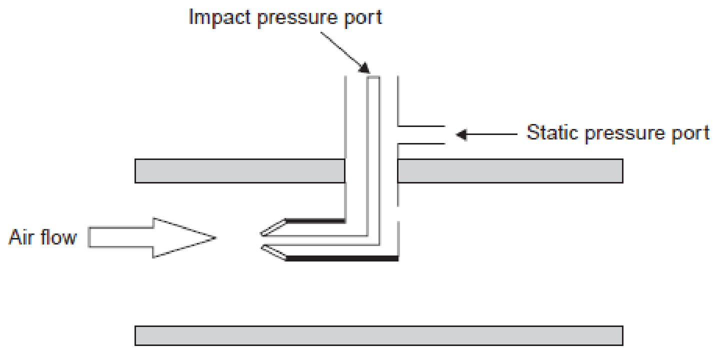



**Fig 5.22 Pitot tube**

A common industrial type of pitot tube consists of a cylindrical probe inserted into the air stream, as shown in Figure. Fluid flow velocity at the upstream face of the probe is reduced substantially to zero. Velocity head is converted to impact pressure, whichissensedthroughasmallholeintheupstreamfaceoftheprobe.Acorresponding

small hole in the side of the probe senses static pressure. A pressure instrument measures the differential pressure, which is proportional to the square of the stream velocity in the vicinity of the impact pressure sensing hole.

The velocity equation for the pitot tube is given by,

$$v = Cp\sqrt{2gh}$$

**Advantages**

7. No pressureloss.
8. It is relativelysimple.
9. It is readily adapted for flow measurements made in very large pipes orducts

**Disadvantages**

1. Pooraccuracy.
2. Not suitable for dirty or sticky fluids and fluids containing solidparticles.
3. Sensitive to upstreamdisturbances.

## Rotameter

The orificemeter, Venturimeter and flow nozzle work on the principle of constant area variable pressure drop. Here the area of obstruction is constant, and the pressure drop changes with flow rate. On the other hand Rotameter works as a constant pressure drop variable area meter. It can be only be used in a vertical pipeline. Its accuracy is also less (2%) compared to other types of flow meters. But the major advantages of rotameter are, it is simple in construction, ready to install and the flow rate can be directly seen on a calibrated scale, without the help of any other device, e.g. differential pressure sensor etc. Moreover, it is useful for a wide range of variation of flow rates(10:1).

The basic construction of a rotameter is shown in figure. It consists of a vertical pipe, tapered downward. The flow passes from the bottom to the top. There is cylindrical type metallic float inside the tube. The fluid flows upward through the gap between the tube and the float. As the float moves up or down there is a change in the gap, as a result changing the area of the orifice. In fact, the float settles down at a position, where the pressure drop across the orifice will create an upward thrust that will balance the downward force due to the gravity. The position of the float is calibrated with the flow rate.

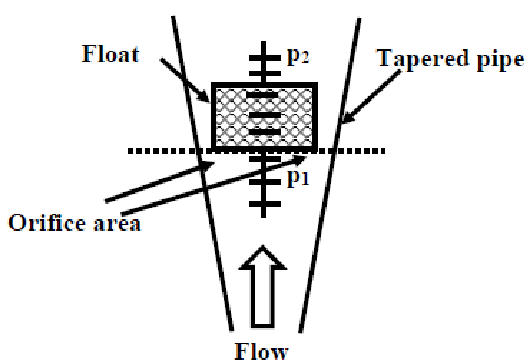


Fig 5.23 Rotameter

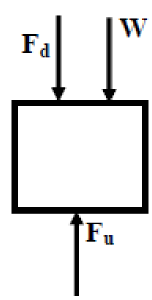


Fig 5.24 Force acting on float

$\gamma_1$= Specific weight of the float

$\gamma_2$= specific weight of the fluid v= volume of the float

$A_f$= Area of the float.

$A_t$= Area of the tube at equilibrium (corresponding to the dotted line)

$$Q = \frac{C_d A_2}{\sqrt{1-(\frac{A_2}{A_1})^2}} \sqrt{\frac{2g}{\gamma_2}(p_1 - p_2)}$$

$F_d$ = Downward thrust on the float

$F_u$ = Upward thrust on the float

The major source of error in rotameter is due to the variation of density of the fluid. Besides, the presence of viscous force may also provide an additional force to the float.

**Applications**

- Can be used to measure flow rates of corrosivefluids
- Particularly useful to measure low flowrates

**Advantages**

- Flow conditions arevisible
- Flow rate is a linear function(uniform flowscales)
- Can be used to measure flow rates of liquids, gases andvapour
- By changing the float, tapered tube or both, the capacity of the rotameter can be changed.

**Limitations**

- They should be installedvertically
- They cannot be used for measurements in movingobjects
- The float will not be visible when coloured fluids are used, that is, when opaque fluid areused.
- For high pressure and temperature fluid flow measurements, they areexpensive
- They cannot be used for fluids containing high percentage of solids insuspension.