# FLUID FLOW

✓A fluid is a substance that continually deforms (flows) under an applied shear stress. Fluids are a subset of the phases of matter and include liquids, gases both.

✓Fluid flow may be defined as the flow of substances that do not permanently resist distortion.

✓The subject of fluid flow can be divided into fluid statics and fluid dynamics.

**Identification of type of flow is important in**

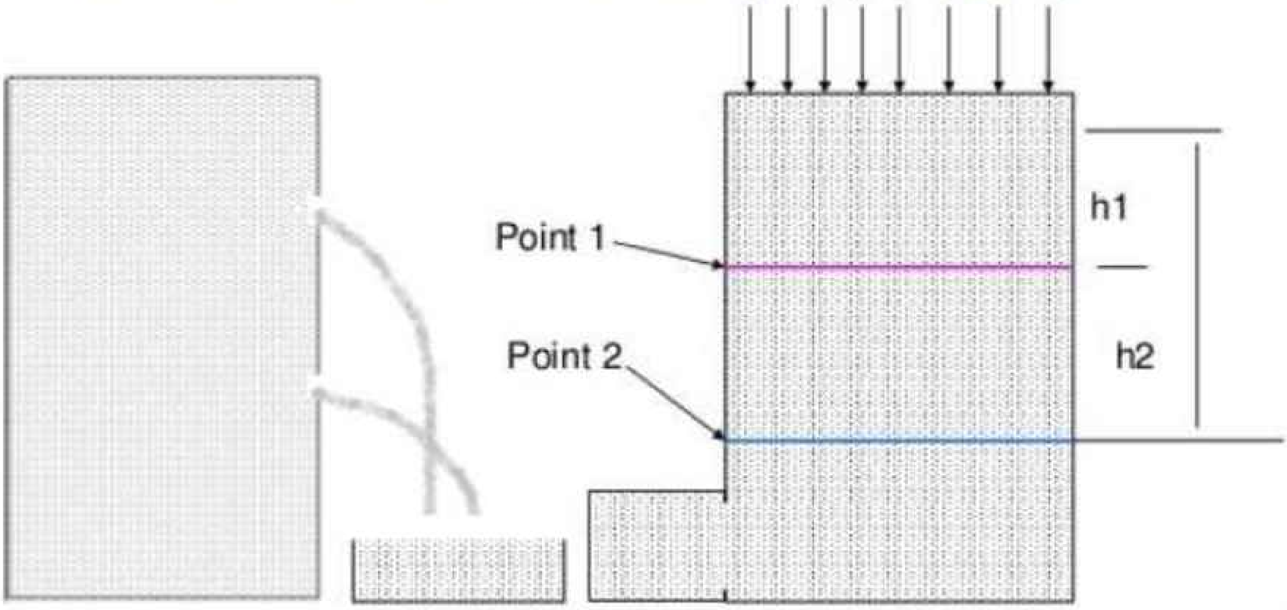
✓Manufacture of dosage forms

✓Handling of drugs for administration

## FLUID STATICS

- Fluid statics deals with the fluids at rest in equilibrium,
- Behavior of liquid at rest
- Nature of pressure it exerts and the variation of pressure at different layers

### Pressure differences between layers of liquids

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Consider a column of liquid with two openings Which are provided at the wall of the vessel at different height

The rate of flow through these opening s are different due to the pressure exerted at the different height

Consider a stationary column the pressure $p_s$ is acting on the surface of the fluid, column is maintained at constant pressure by applying pressure

The force acting below and above the point 1 are evaluated

Force acting on the liquid At point 1 = Force on the surface + Force excreted by the liquid Above point 1

Substituting the force with pressure x area of cross section in the above equation

Pressure at point 1 x Area = Pressure on the surface x area + mass x acceleration

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$$P_1S = P_sS + \text{volume} \times \text{density} \times \text{acceleration}$$

$$= P_sS + \text{height} \times \text{area} \times \text{density} \times \text{acceleration}$$

$$P_1S = P_sS + h_1 S \rho g$$

Since surface area is same

$$P_1 = P_s + h_1 \rho g$$

Pressure acting on point 2 may be written as

$$P_2 = P_s + h_2 \rho g$$

Difference in the pressure is obtained by

$$P_2 - P_1 = g (P_s + h_2 \rho) - (P_s + h_1 \rho) g$$

$$\Delta P = (P_s + h_2 \rho - P_s - h_1 \rho) g$$

$$= \Delta h \rho g$$

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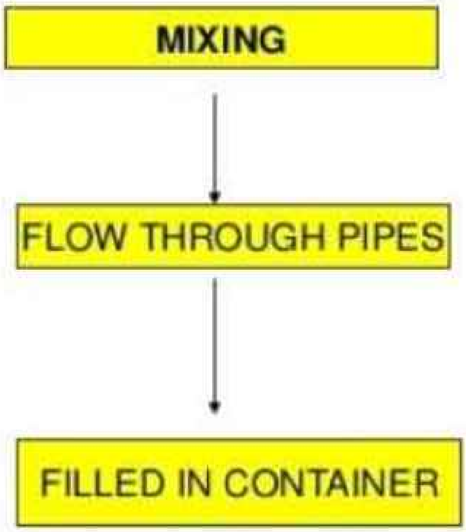
## FLUID DYNAMICS

- Fluid dynamics deals with the study of fluids in motion
- This knowledge is important for liquids, gels, ointments which will change their flow behavior when exposed to different stress conditions



- ✓ The flow of fluid through a closed channel can be *viscous* or *turbulent* and it can be observed by;

❖ **Reynolds experiment**

- ✓ Consider Glass tube which is connected to reservoir of water, rate of flow of water is adjusted by a valve, a reservoir of colored solution is connected to one end of the glass tube with help of nozzle colored solution is introduced into the nozzle as fine stream.

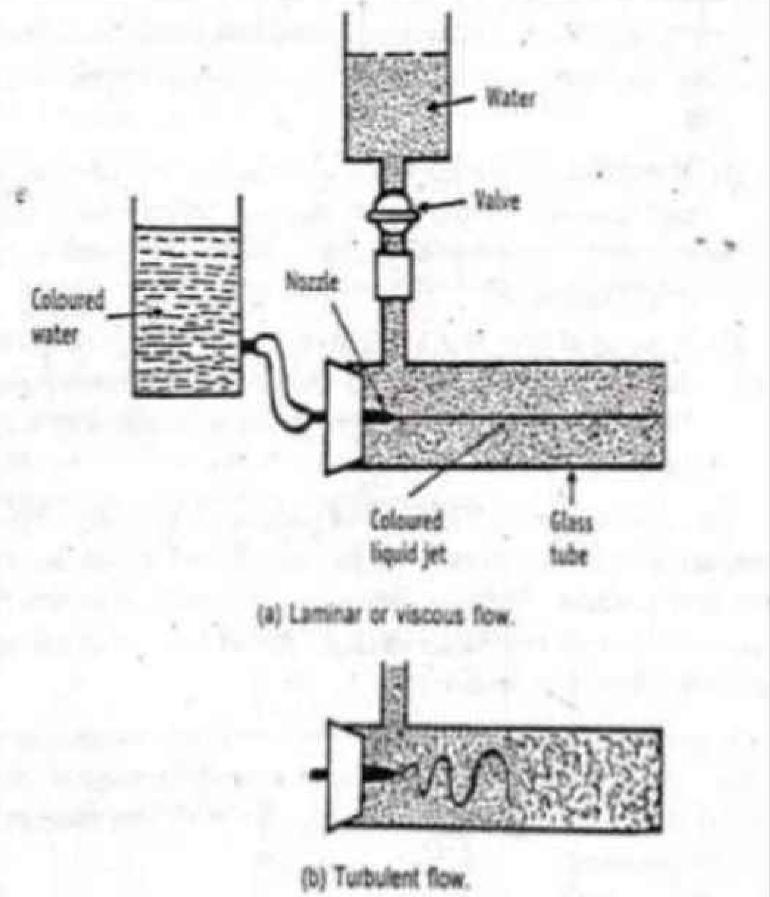



Figure 2-4. The assembly of the apparatus of the Reynold's experiment.

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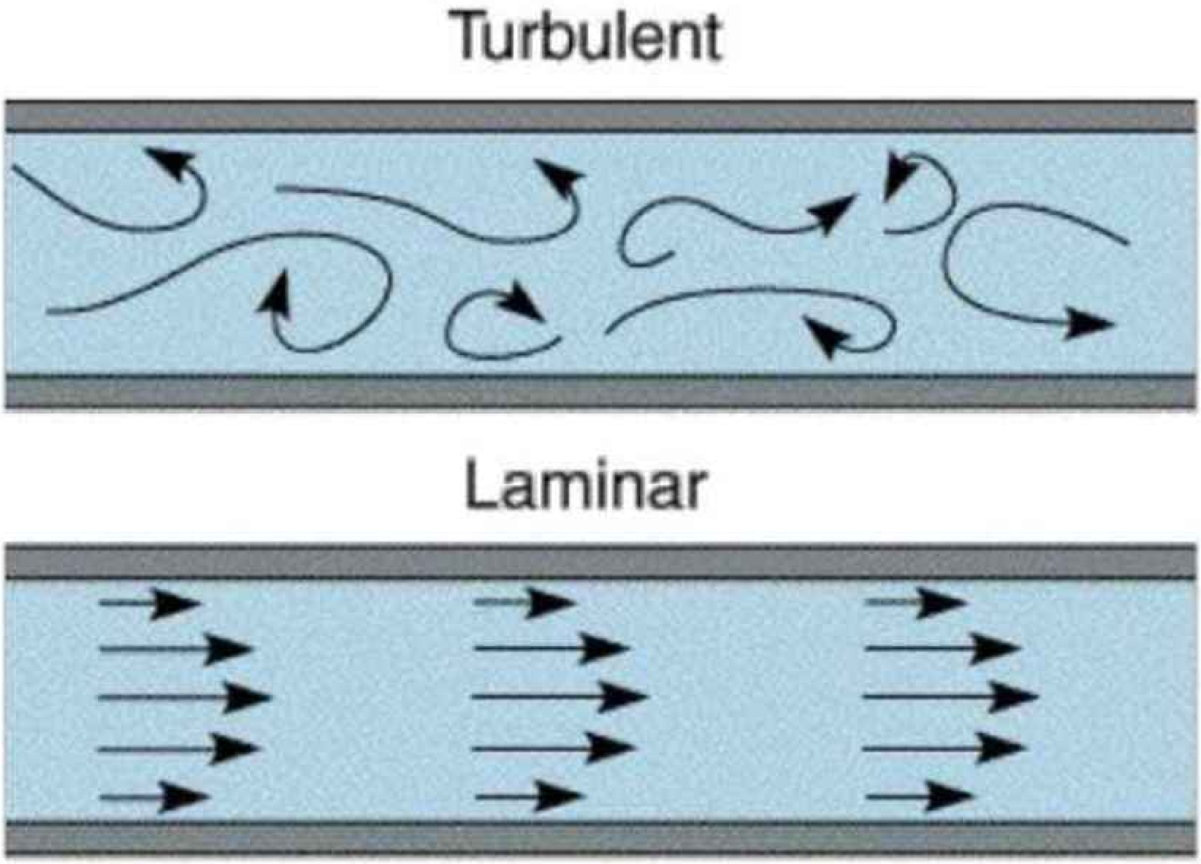


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- **Laminar flow** is one in which the fluid particles move in layers or laminar with one layer sliding with other.
- There is no exchange of fluid particles from one layer to other.
- When velocity of the water is increased the thread of the colored water disappears and mass of the water gets uniformly colored, indicates complete mixing of the solution and the flow of the fluid is called as **turbulent flow.**
- The velocity at which the fluid changes from laminar flow to turbulent flow that velocity is called as **critical velocity**.

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# REYNOLDS NUMBER

In Reynolds experiment the flow conditions are affected by

- Diameter of pipe
- Average velocity
- Density of liquid
- Viscosity of the fluid

This four factors are combined in one way as Reynolds number

Reynolds number is obtained by the following equation

$$\frac{D\,u\,\rho}{\eta}$$

$$= \frac{\text{INERTIAL FORCES}}{\text{VISCOUS FORCES}} = \frac{\text{MASS X ACCELERATION OF LIQUID FLOWING}}{\text{SHEAR STRESS X AREA}}$$

- Inertial forces are due to mass and the velocity of the fluid particles trying to diffuse the fluid particles
- viscous force if the frictional force due to the viscosity of the fluid which make the motion of the fluid in parallel

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- If Re < 2000 the flow is said to be laminar
- If Re > 4000 the flow is said to be turbulent
- If Re lies between 2000 to 4000 the flow change between laminar to turbulent

## ❑ APPLICATIONS

- Reynolds number is used to predict the nature of the flow
- Stocks law equation is modified to include Reynolds number to study the rate of sedimentation in suspension

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## BERNOULLI'S THEOREM

When the principals of the law of conservation energy is applied to the flow of the fluids the resulting equation is called Bernoulli's theorem

*Bernoulli's theorem* states that in a steady state ideal flow of an incompressible fluid, the total energy per unit mass, which consists of pressure energy, kinetic energy and datum energy, at any point of the fluid is constant.

- Consider a pump working under isothermal conditions between points A and B as shown in figure;

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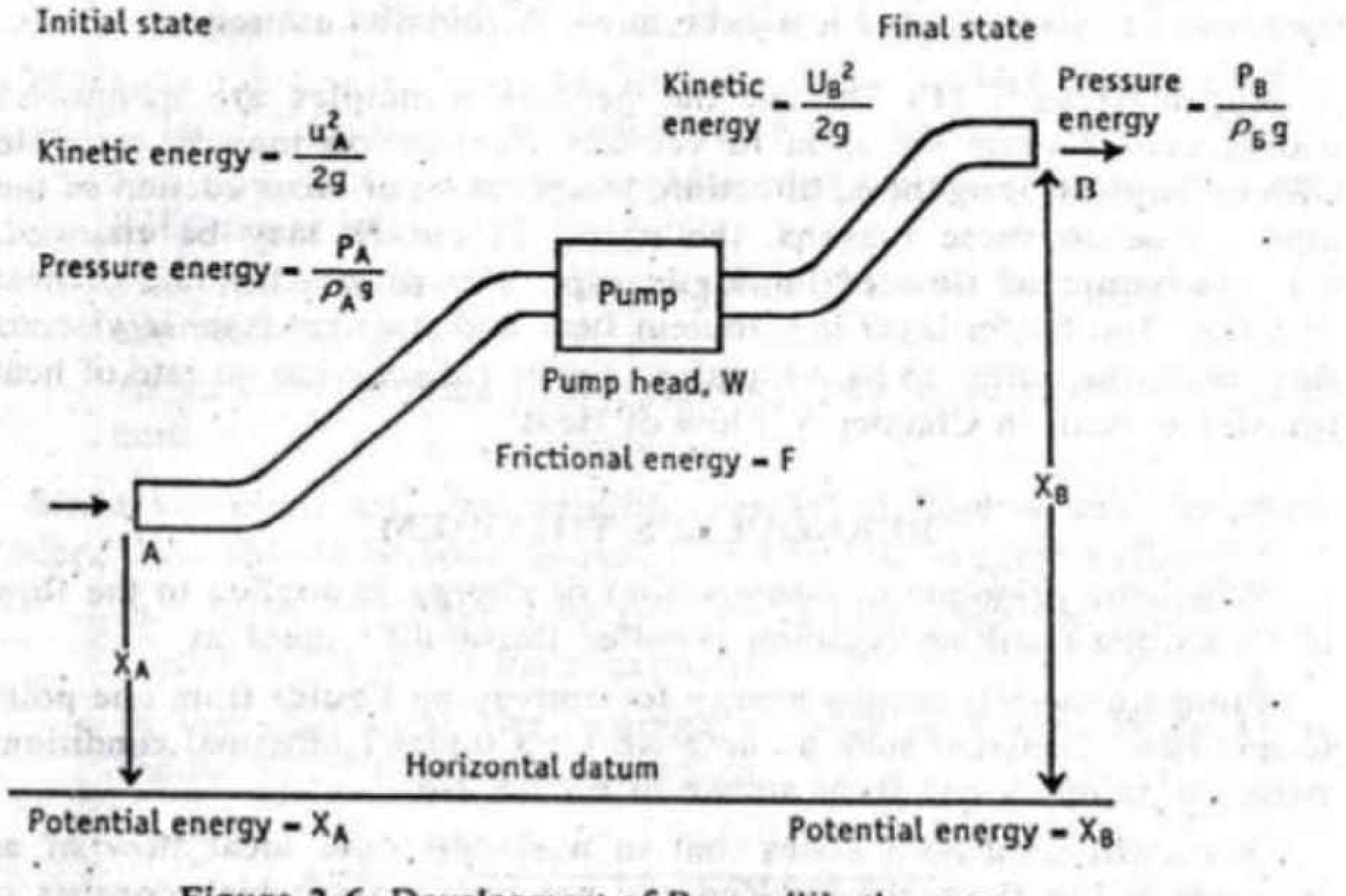


**Figure 2-6.** Development of Bernoulli's theorem.

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- At point a one kilogram of liquid is assumed to be entering at this point, pressure energy at joule can be written as

$$\text{Pressure energy} = P_a / g\ \rho_A$$

Where $P_a$ = Pressure at point a

$g$ = Acceleration due to gravity

$\rho_A$ = Density of the liquid

Potential energy of a body is defined as the energy possessed by the body by the virtue of its position or configuration

$$\text{Potential energy} = X_A$$

Kinetic energy of a body is defined as the energy possessed by the body by virtue of its motion,

$$\text{kinetic energy} = U_A^2 / 2g$$

Total energy at point A = Pressure energy + Potential energy+ Kinetic energy

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Total energy at point A = $P_a / g \rho_A + X_A + U_A^2 / 2g$

According to the Bernoulli's theorem the total energy at point A is constant

Total energy at point A = $P_a / g \rho_A + X_A + U_A^2 / 2g$ = Constant

After the system reaches the steady state, whenever one kilogram of liquid enters at point A, another one kilogram of liquid leaves at point B

Total energy at point B = $P_B / g \rho_B + X_B + U_B^2 / 2g$

**INPOUT = OUT PUT**

$$P_a / g \rho_A + X_A + U_A^2 / 2g = P_B / g \rho_B + X_B + U_B^2 / 2g$$

Theoretically all kids of the energies involved in fluid flow should be accounted, pump has added certain amount of energy

**Energy added by the pump = + wJ**

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During the transport some energy is converted to heat due to frictional Forces

**Loss of energy due to friction in the line = FJ**

$$P_a/g\,\rho_A + X_A + U_A^2/2g - F + W = P_B/g\,\rho_B + X_B + U_B^2/2g$$

**This equation is called as Bernoulli's equation**

Application

- Used in the measurement of rate of fluid flow
- It applied in the working of the centrifugal pump, in this kinetic energy is converted in to pressure

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## ENERGY LOSS

- ✓ According to the law of conversation of energy ,energy balance have to be properly calculated
- ✓ fluids experiences energy losses in several ways while flowing through pipes, they are
  - ➢ Frictional losses
  - ➢ Losses in the fitting
  - ➢ Enlargement losses
  - ➢ Contraction losses

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## FRICTIONAL LOSSES

During flow of fluids frictional forces causes a loss in pressure Type of fluid flow also influences the losses

In general pressure drop will be

PRESSURE DROP α VELOCITY (u)

α Density of fluid($\rho$)

α Length of the pipe (L)

α 1 / diameter of the pipe (D)

These relationships are proposed in Fanning equation for calculating friction losses

Fanning equation $\Delta p = 2fu^2L\rho / D$

*F = frictional factor*

*For viscous flow pressure drop Hagen –Poiseullie equation*

$= 32\ Lu\eta / D^2$

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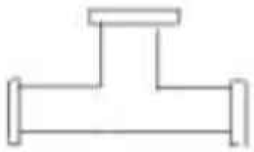
## LOSSES IN FITTING

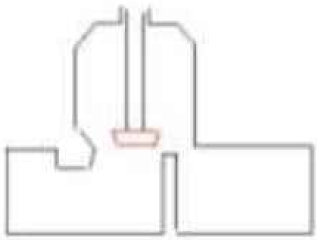
Fanning equation is applicable for the losses in straight pipe When fitting are introduced into a straight pipe, They cause disturbance in the flow, Which result in the additional loss of energy

losses in fitting may be due to

- Change in direction
- Change in the type of fittings



Tee fitting
Equivalent length = 90



Globe valve equivalent length = 300

Equivalent length of fitting = Equivalent length x internal diameter

For globe valve = 300 x 50

= 15 meter

That means globe valve is equal to 15 meters straight line, so this length is substituted in fanning equation

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## ENLARGEMENT LOSS

If the cross section of the pipe enlarges gradually, the fluid adapts itself to the changed section with out any disturbance So no loss of energy


If the cross section of the pipe changes suddenly then loss in energy is observed due to eddies These are greater at this point than straight line pipe

Than $u_2 < u_1$

For sudden enlargement = $\Delta H = (u_1 - u_2)^2 / 2g$

$\Delta H$ = loss of head due to sudden enlargement

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## CONTRACTION LOSSES

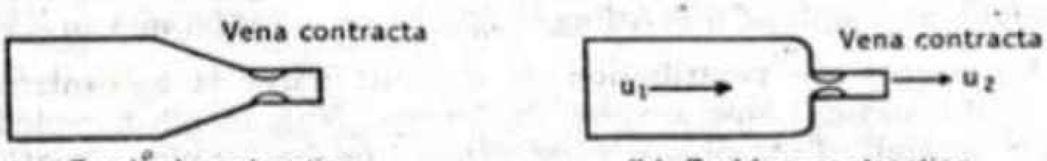
If the cross section of the pipe is reduced suddenly the fluid flow is disturbed, the diameter of the fluid stream is less than the initial value of diameter this point of minimum cross section is known as *vena contracta*.

the velocity of fluid at smaller cross section will be greater than at larger cross section, $u_2 > u_1$

$u_1$ may be considered negligible. The losses due to additional eddying are observed. Such contraction losses can be expressed as:

$$\text{Sudden contraction losses:} \quad \Delta H_c = \frac{K u_2^2}{2g} \qquad (28)$$

where $\Delta H_c$ = loss in head due to sudden contraction, m
$K$ = constant
$u_2$ = velocity, m/s




(a) Gradual contraction
No loss of energy

(b) Sudden contraction
Loss of energy

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# MANOMETERS

Manometers are the devices used for measuring the pressure difference

Different type of manometers are;

1) Simple manometer
2) Differential manometer
3) Inclined manometer

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## SIMPLE MANOMETER

- **This manometer is the most commonly used one**
- **It consists of a glass U shaped tube filled with a liquid A- of density** $\rho_A$ kg /meter cube and above A the arms are filled with liquid B of density $\rho_B$ .
- The liquid A and B are immiscible and the interference can be seen clearly
- If two different pressures are applied on the two arms the meniscus of the one liquid will be higher than the other
- Let pressure at point 1 will be P1 Pascal's and point 5 will be P2 Pascal's
- The pressure at point 2 can be written as

$$= P_1 + (m + R)\,\rho_B g$$

(m + R ) = distance from 3 to 5

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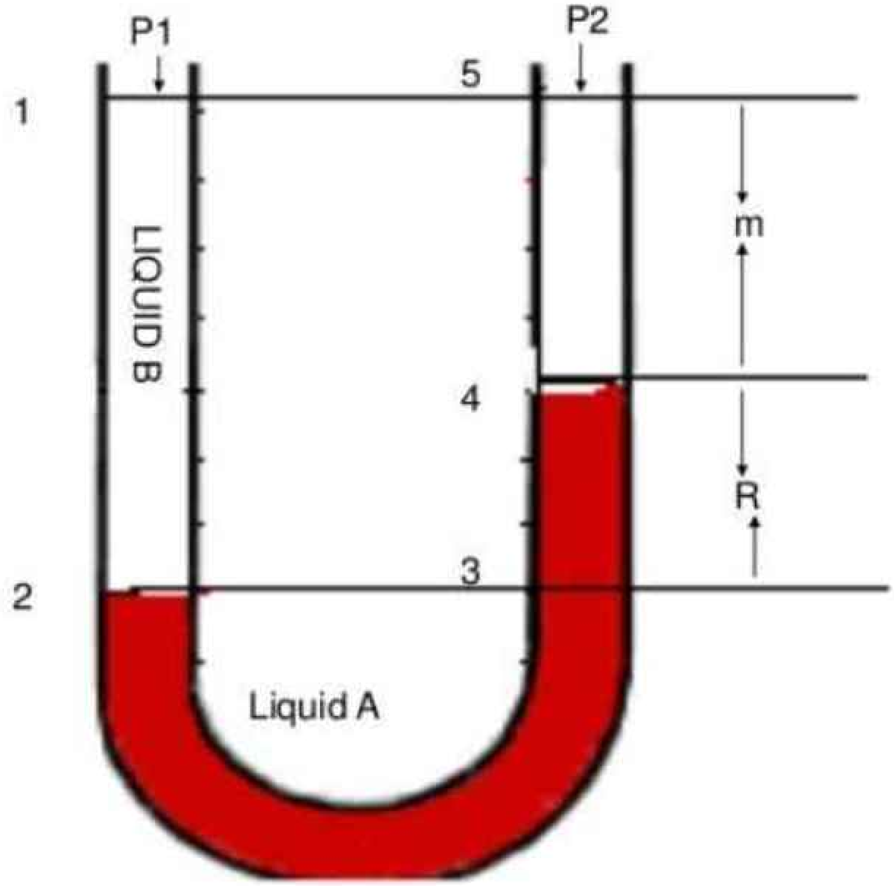


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Since the points 2 and 3 are at same height the pressure at 3 can be written as

$$\text{Pressure at 3} = P_1 + (m + R)\,\rho_B g$$

Pressure at 4 can be written as

$$= P_2 + gm\,\rho_B$$

or

$$= P_1 + \rho_B\,(m + R)\,g - \rho_a R g$$

Both the equations should be equal

$$P_2 + gm\,\rho_B = P_1 + \rho_B\,(m + R)\,g - \rho_a R g$$

$$P_1 - P_2 = gm\,\rho_B - \rho_B\,(m + R)\,g + \rho\,A\,R\,g$$

$$\Delta P = gm\,\rho_B - gm\,\rho_B - R\,\rho_B g + R\,\rho_A$$

$$= R\,(\rho_A - \rho_B)g$$

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## DIFFERENTIAL MANOMETERS

- These manometers are suitable for measurement of small pressure differences
- It is also known as *two – Fluid* U- *tube manometer*
- It contains two immiscible liquids A and B having nearly same densities
- The U tube contains of enlarged chambers on both limbs,
- Using the principle of simple manometer the pressure differences can be written as

$$\Delta P = P_1 - P_2 = R\,(\rho_c - \rho_A)\,g$$

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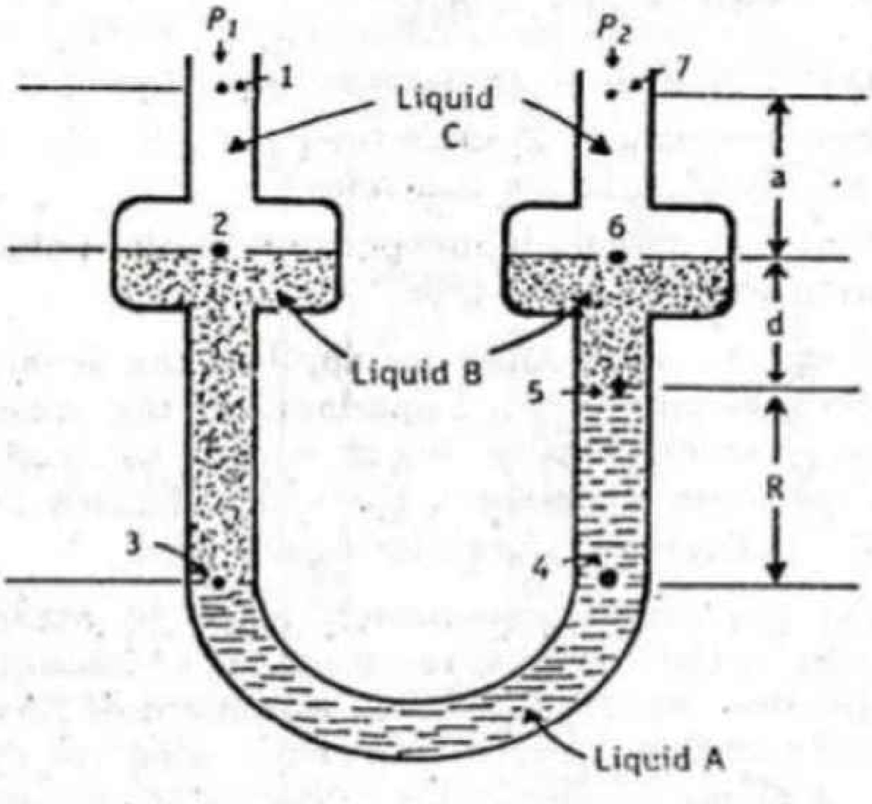


**Figure 2-3.** Construction of a differential manometer.

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## INCLINED TUBE MANOMETERS

Many applications require accurate measurement of low pressure such as drafts and very low differentials, primarily in air and gas installations

In these applications the manometer is arranged with the indicating tube inclined, as in Figure, therefore providing an expanded scale

This enables the measurement of small pressure changes with increased accuracy

$$P_1 - P_2 = g\,R\,(\rho_A - \rho_B)\sin\alpha$$

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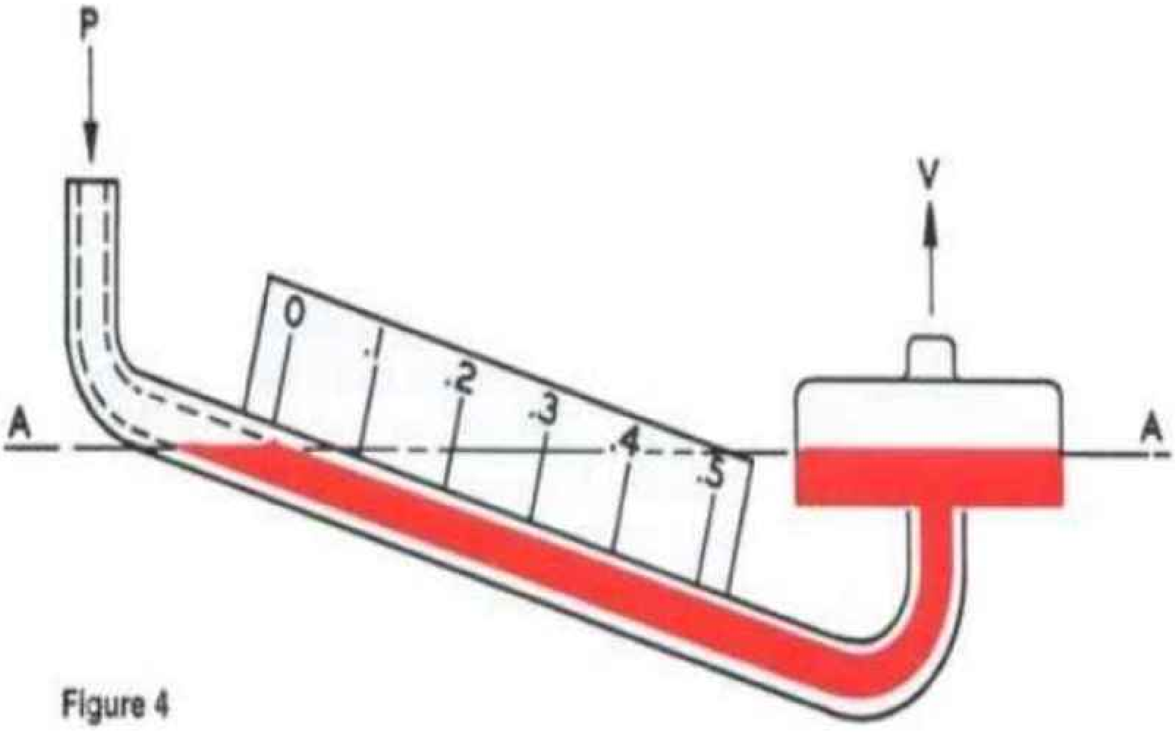


Figure 4

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# MEASUREMENT OF RATE OF FLOW OF FLUIDS

When ever fluid are used in a process it is necessary to measure the rate at which the fluid is flowing through the pipe,

Methods of measurement are

- Direct weighing or measuring
- Hydrodynamic methods
  - ✓ Orifice meter
  - ✓ Venturi meter
  - ✓ Pitot meter
  - ✓ Rotameter
- Direct displacement meter

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## DIRECT WEIGHING OR MEASURING

The liquid flowing through a pipe is collected for specific period at any point and weighed or measured, and the rate of flow can be determined.

Gases can not be determined by this method.

## ORIFICE METER

Principle:

- Orifice meter is a thin plate containing a narrow and sharp aperture
- When a fluid stream is allowed to pass through a narrow constriction the velocity of the fluid increase compared to up stream
- This results in decrease in pressure drop and the difference in the pressure may be read from a manometer

The velocity of the fluid at thin constriction may be written as

$$U_0 = C_0 \sqrt{2g \Delta H}$$

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$\Delta H$ = difference in height, can be measured by manometer

$C_0$ = constant

$U_0$ = velocity of fluid at the point of orifice meter

## CONSTRUCTION

- It is consider to be a thin plate containing a sharp aperture through which fluid flows
- Normally it is placed between long straight pipes
- For present discussion plate is introduced into pipe and manometer is connected at points A and B

## WORKING

- ✓ Orifice meter is referred as the variable head meter, ie it measure the variation in the pressure across a fixed construction placed in the path of flow

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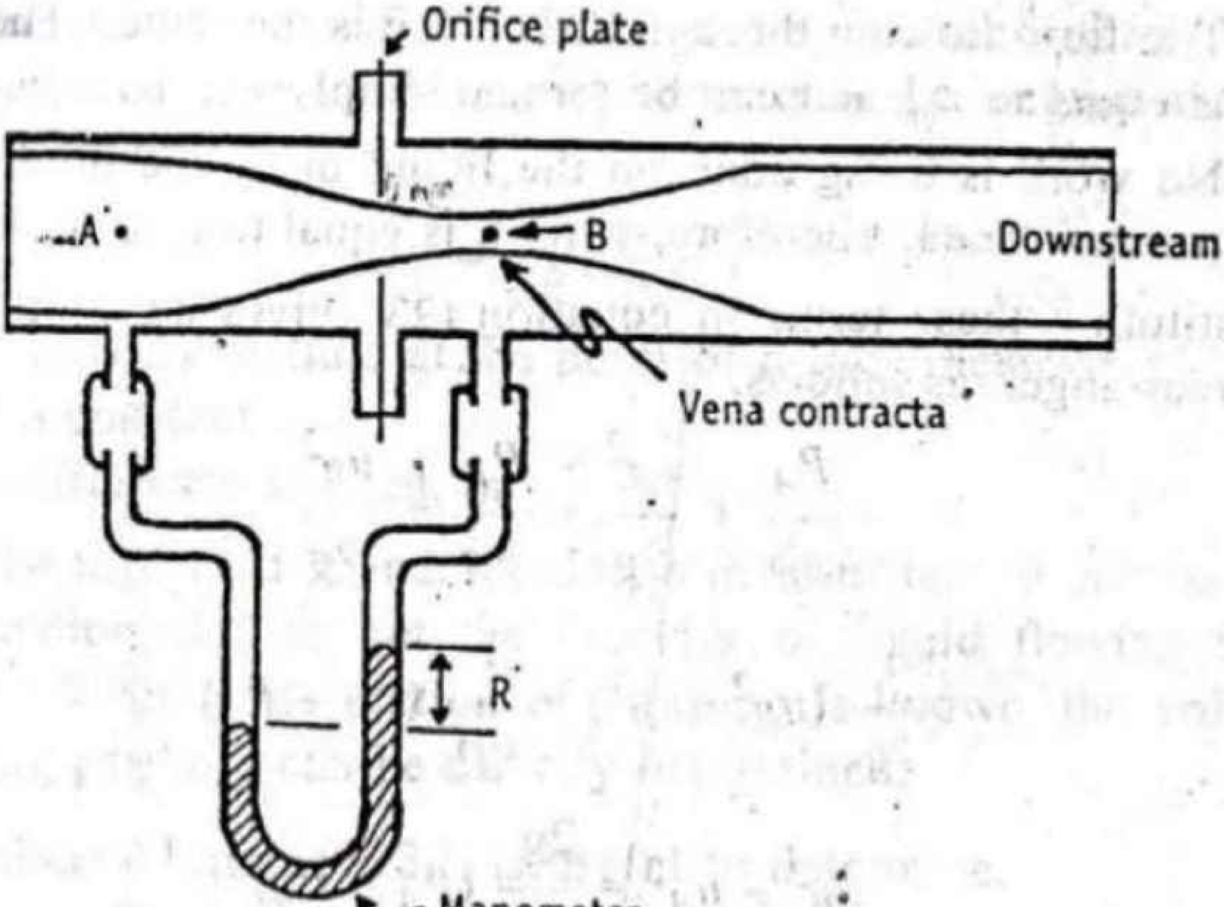


Figure 2-8. Construction and assembly of orifice meter. 33

- ✓ When fluid is allowed to pass through the orifice the velocity of the fluid at point B increase, as a result at point A pressure will be increased
- ✓ Difference in the pressure is measured by manometer
- ✓ Bernoulli's equation is applied to point A and point B for experimental conditions

$$\sqrt{\mu_0^2 - \mu_A^2} = C_0 \sqrt{2g\ \Delta H}$$

$\mu_0$ = velocity of fluid at orifice

$\mu_A$ = velocity of fluid at point A

$C_0$ = constant

- ✓ If the diameter of the orifice is 1/5 or less of the pipe diameter then $\mu_A$ is neglected so, $\mu_0 = C_0 \sqrt{2g\ \Delta H}$

Applications

- Velocity at either of the point A and B can be measured
- Volume of liquid flowing per hour can be determined

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# VENTURI METER

- Principle:

✓ Venturi meter consist of two tapered sections in the pipe line with a gradual constriction at its centre.

✓ When fluid stream is allowed to pass through the narrow throat the velocity of the fluid increases at the venturi compared to velocity of the upstream.

✓ This results in decrease in the pressure head.

✓ This resulting decrease in the pressure head is measured directly from the manometer.

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**Construction :** A venturi meter consists of two tapered sections inserted in a pipeline (Figure 2-9). Normally, venturi meter is placed between long straight pipes, so that other fittings will not alter the flow rate that is being measured. The upstream cone is normally shorter than the down stream. The tapers are smooth and gradual. Therefore, eddies in the down stream are absent and no power loss is observed. In addition, the cross-section of the high velocity part of the stream is well defined. A manometer is connected at points A and B as shown in Figure 2-9.

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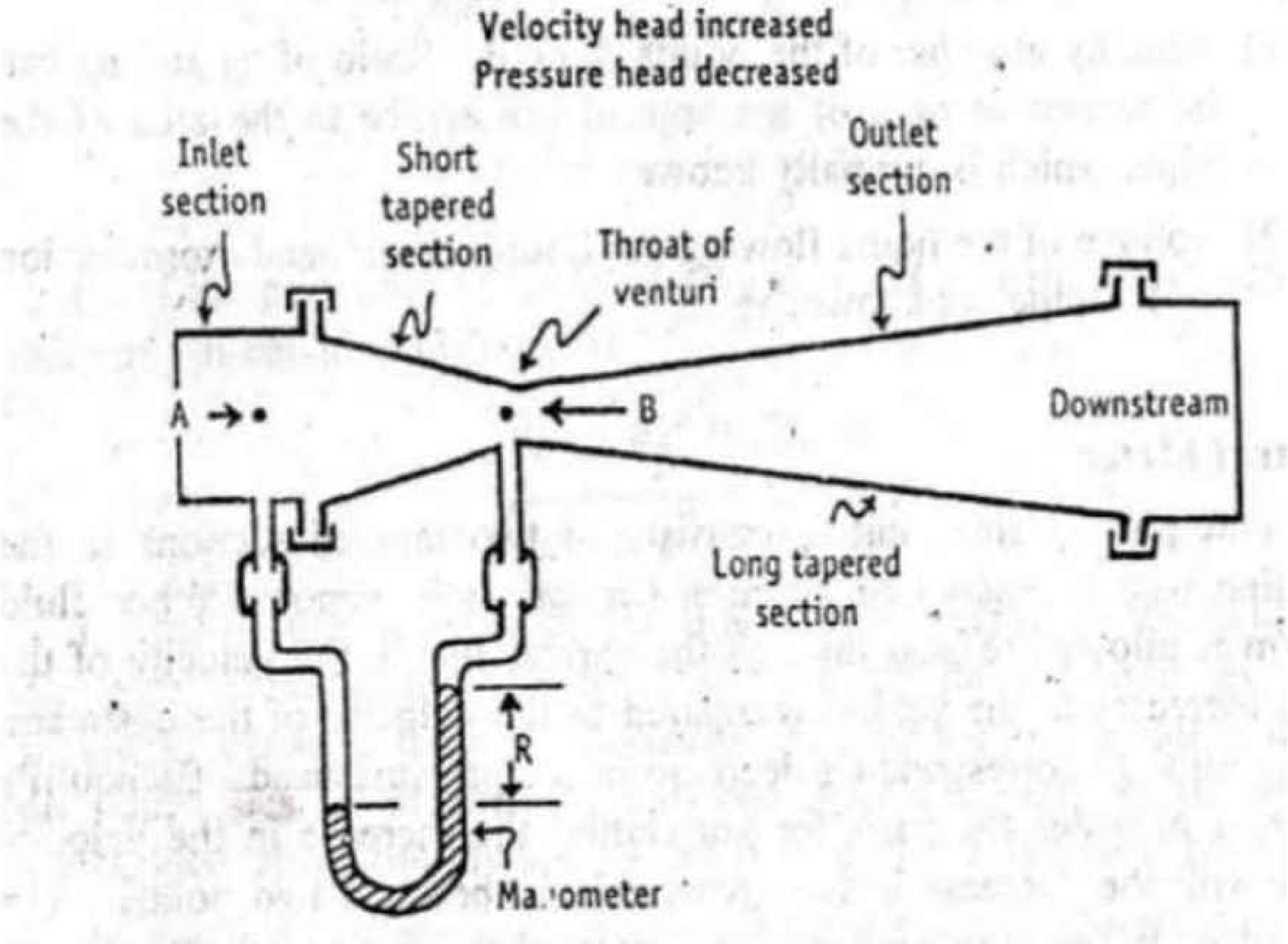


Figure 2-9. Construction of a venturi meter.

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**Working :** Venturi meter is referred to as *variable head meter*, i.e., it measures the variable differential pressure across a fixed constriction placed in the path of flow consisting of a constant area. In a venturi meter, the velocity of the fluid is increased at the throat, due to the constriction. This results in decreased pressure in the up-stream cone. The pressure drop in the upstream cone is utilised to measure the rate of flow using a manometer. Venturi meter nearly confirms the theoretical equations obtained for an orifice meter. On similar lines of equation (30), an equation for venturi meter may be written as:

$$\sqrt{u_v^2 - u_A^2} = C_v\sqrt{2g.\Delta H} \qquad (35)$$

where $u_v$ = velocity at the throat of the venturi, m/s
$u_A$ = velocity at point A (venturi throat), m/s
$C_v$ = coefficient (= 0.98)

If the diameter of the smaller section is one-fifth of the pipe diameter or less, $u_A^2$ is considered to be small compared to $u_v^2$. Therefore, $u_A^2$ term may be disregarded. A simplified form of equation (35) is:

$$u_v = C_v\sqrt{2g.\Delta H} \qquad (34)$$

**Disadvantages**

- Expensive
- Need technical expert
- Not flexible
- Occupies more space

**Advantages**

- Power loss is less
- Head loss is negligible

**Applications:**

- It is commonly used for liquids, specially for water.
- It can also be used for the measurement of gases.

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# PITOT TUBE

- Principle:

✓ Pitot tube consists of sensing element with a small constriction compared to the size of the flow channel.

✓ When the sensing element is inserted at the center of the stream, the velocity of flow is increased.

✓ This results in decrease in pressure head.

$$\Delta H_p = u^2 /2g$$

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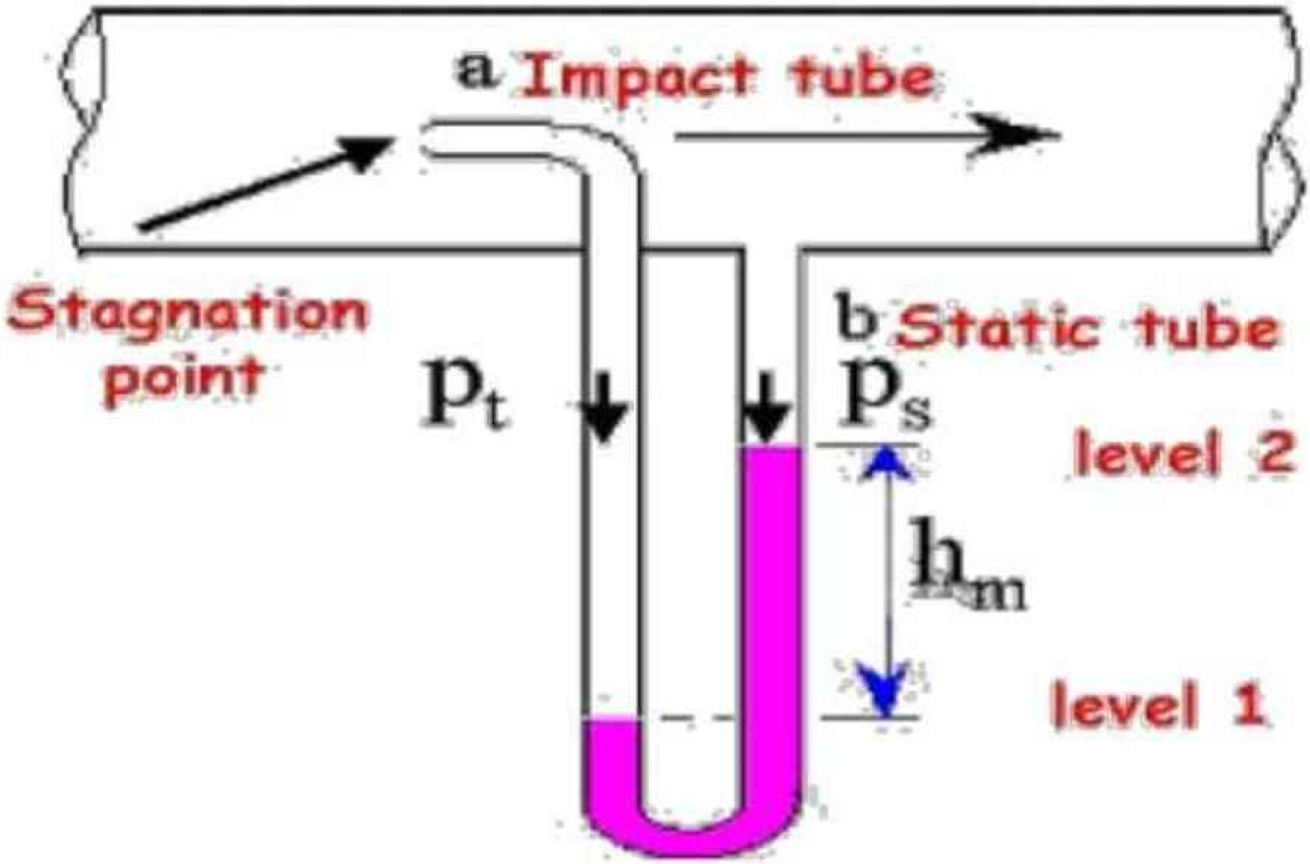
PITOT TUBE

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## Construction

- It is also known as  insertion meter or insertion tube
- The size of the sensing element is small compared to the flow channel
- The point of measurement may be at the center of the channel
- One tube is perpendicular to the flow direction and the other is parallel to the flow
- Two tubes are connected to the manometer

## Working

- Tube are inserted in the flow shown is the figure.
- Pitot tube is used to measure the velocity head of the flow.
- In this tube velocity of fluid is increased at the narrow constriction which results in decreased pressure.

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- Tube at right angles to the flow measures pressure head only while the tube that points upstream measures pressure head and velocity head.

$$\mu^2 = C_v \sqrt{2g \, \Delta H}$$

- $C_v$ coefficient of Pitot tube

**Advantage** : Pitot tube measures the velocity at one point only.

**Disadvantages** : (1) The pitot tubes themselves cause more disturbance. Eddies within the pressure tube disturb the readings.

(2) They do not give average velocity directly.

(3) For gases, the reading is extremely small. For gases working on low pressure, some form of multiplying gauges must be used.

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## ROTAMETER

Principle:

- ✓ Rotameter is known as area meter as it measures area of flow.
- ✓ It consist of a vertical, tapered and transparent tube in which plummet is placed.
- ✓ During the fluid flow through the tube the plummet rises and falls because of variation of flow.

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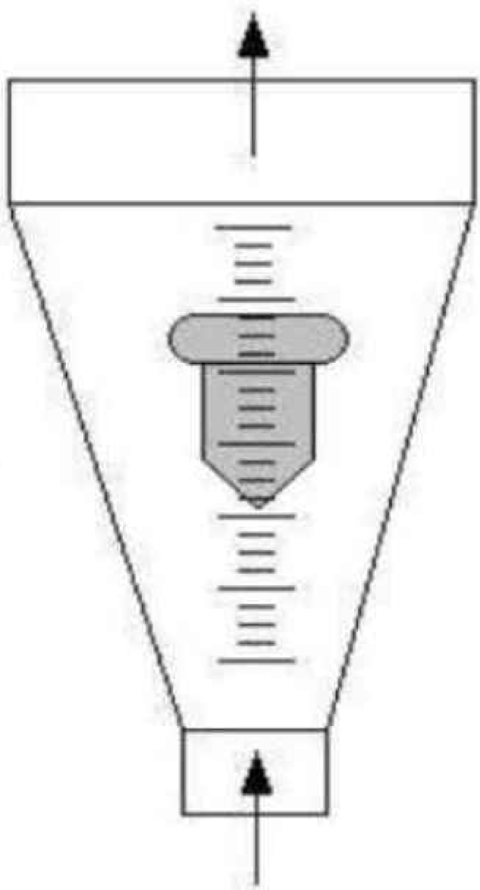

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## Construction

- It consists of vertically tapered and transparent tube with narrow end down, in which a plummet is placed.
- A solid plummet is placed in the tube. The diameter of the plummet is smaller than the narrowest part of the tube.
- Floats/plummet is made up of glass, aluminium or plastic.
- The tube is usually made of glass on which linear scale is given.
- During the flow the plummet rise due to variation in flow
- The upper edge of the plummet is used as an index to note the reading

**Working :** As the flow is upward through a tapered tube, the flow of fluid varies. The plummet, which is surrounded by the fluid, rises and falls depending on the rate of flow. The greater the flow rate, the higher the plummet rises in the tube. In rotameters, the pressure drop is constant or nearly constant.

Uses : Rotameters are extensively used in chemical industries, such as bulk drugs. In the fermenters, the supply of air is controlled through rotameters. Rotameters are satistactory both for gases and for liquids at high and low pressures.

Advantages : (1) Operator has a direct visual index of flow reading. It is satisfactory for manual control of processes for experimental work.

(2) It does not require the condition that straight pipes should run before and after the meter.

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