Fluid Flow

Syllabus:
Types of flow, Reynold's number, Viscosity, concept of boundary layer, basic equations of fluid flow, valves, flow meters, manometers and measurement of flow and pressure.

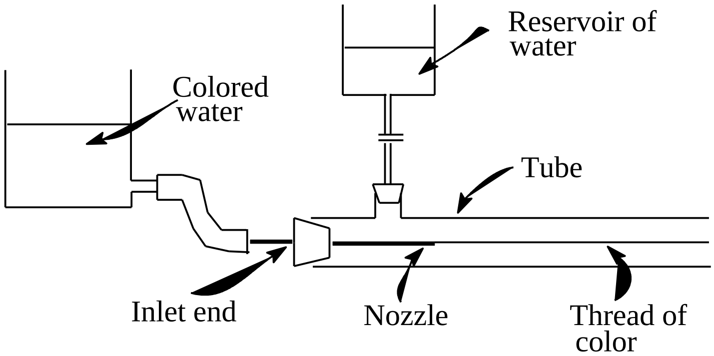
INTRODUCTION

Fluid includes both liquids and gases.

- Fluids may be defined as a substance that does not permanently resist distortion. An attempt to change the shape of a mass of fluid will result in layers of fluids sliding over one another until a new shape is attained. During the change of shape *shear stresses* will exist, the magnitude of which depends upon the viscosity of the fluid and the rate of sliding. But when a final shape is reached, all shear stresses will disappear. A fluid at equilibrium is free from shear stresses.
- The density of a fluid changes with temperature and pressure. In case of a liquid the density is not appreciably affected by moderate change of pressure. In case of gases, density is affected appreciably by both change of temperature and pressure.
- The science of fluid mechanics includes two branches:
  (i) fluid statics and (ii) fluid dynamics.
  Fluid statics deals with fluids at rest in equilibrium.
  Fluid dynamics deals with fluids under conditions where a portion is in motion relative to other portions.

TYPES OF FLOW

Reynolds' Experiment



This experiment was performed by Osborne Reynolds in 1883. In Reynolds experiment a glass tube was connected to a reservoir of water in such a way that the velocity of water flowing through the tube could be varied. At the inlet end of the tube a nozzle was fitted through which a fine stream of coloured water can be introduced.

After experimentation Reynolds found that when the velocity of the water was low the thread of color maintained itself through the tube. By putting one of these jets at different points in cross section, it can be shown that in no part of the tube there was mixing, and the fluid flowed in parallel straight lines.

As the velocity was increased, it was found that at a definite velocity the thread disappeared and the entire mass of liquid was uniformly colored. In other words the individual particles of liquid, instead of flowing in an orderly manner parallel to the long axes of the tube, were now flowing in an erratic manner so that there was complete mixing.

- When the fluid flowed in parallel straight lines the fluid motion is known as **Streamline flow** or **Viscous flow**. The particles of liquid flows along horizontal axis and there was no motion in the y-axis.
- When the fluid motion is erratic it is called **turbulent flow**. The particles of liquid flows along horizontal axis and at the same time they had motion in y-axis.

The velocity at which the flow changes from streamline or viscous flow to turbulent flow it is known as the **critical velocity**.

THE REYNOLDS NUMBER

From Reynolds' experiment it was found that critical velocity depends on

1. The internal diameter of the tube (D)
2. The average velocity of the fluid (u)
3. The density of the fluid (ρ) and
4. The viscosity of the fluid (μ)

   Further, Reynolds showed that these four factors must be combined in one and only one way namely $\left(\frac{DU\rho}{\mu}\right)$.

This function (Duρ / μ) is known as the Reynolds number. It is a **dimensionless group**.

It has been shown that for straight circular pipe, when the value of the Reynolds number is less than 2000 the flow will always be viscous.

i.e. $N_{Re} < 2000 \Rightarrow$ viscous flow or streamline flow

$N_{Re} > 4000 \Rightarrow$ turbulent flow

Dimensional analysis of Reynolds number

[D] = L (ft)

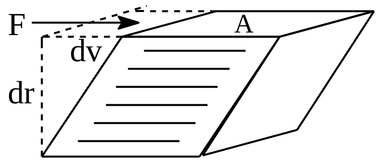
[u] = L/θ (ft / sec)

[ρ] = M / L^3 (lb/ft^3)

[μ] = M / (Lθ) {lb/(ft sec)}

$$\left[\frac{Du\rho}{\mu}\right] = \frac{(L)(L/\theta)(M/L^3)}{M/L\theta} = \frac{LLML\theta}{M\theta L^3} = 1 \Rightarrow \text{dimensionless group}$$

VISCOSITY



Let us consider a "block" of liquid consisting of parallel plates of molecules, similar to a deck of cards, as shown in the figure. The bottom layer is considered to be fixed in place. If the top plane of liquid is moved is moved at a constant velocity, each lower layer with move with a velocity directly proportional to its distance from the stationary bottom layer.

The infinitesimal change in velocity in between two adjacent layer = dv

The infinitesimal distance in between two adjacent layer = dr

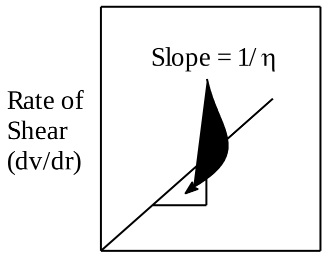
Velocity gradient or *Rate of Shear* = $\frac{dv}{dr}$

The force per unit area (F/A) required to bring about flow is called *shearing stress*.

∴ Shearing Stress = $\frac{F}{A}$

From experiment it was found that rate of shear is directly proportional to shearing stress.

i.e. $\frac{F}{A} \propto \frac{dv}{dr}$ or, $\frac{F}{A} = \eta \frac{dv}{dr}$ where η = *coefficient of viscosity*.



Unit of viscosity

The unit of viscosity is *poise*.

F is expressed in *dyne*

A is expressed in *cm^2*.

dr is expressed in cm and

dv is expressed in *cm/s*.

$$\therefore \eta = \frac{F\,dr}{A\,dv} = \frac{\text{dynes x cm}}{\text{cm}^2 \text{ x cm/sec}} = \frac{\text{dyne sec}}{\text{cm}^2} = \frac{\text{g x cm/sec}^2 \text{ x sec}}{\text{cm}^2} = \frac{\text{g}}{\text{cm sec}} = \text{poise}$$

A more convenient unit of work is the *centipoise (cp* plural *cps)*. 1 cp = $\frac{1}{100}$ *poise*

BERNOULLI'S THEOREM

When the principle of conservation of energy is applied to the flow of fluids, the resulting equation is called *Bernoullis theorem*.

Let us consider the system represented in the figure, and **assume** that the temperature is uniform through out the system. This figure represents a channel conveying a liquid from point A to point B The pump supplies the necessary energy to cause the flow. Let us consider a liquid mass **m** (lb) is entering at point A.

Let the pressure at A and b are P_A and P_B (lb-force/ft^2) respectively.

The average velocity of the liquid at A and B are u_A and u_B (ft/sec).

The specific volume of the liquid at A and B are V_A and V_B (ft^3/lb).

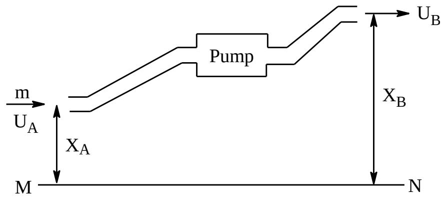


Fig. Bernoullis theorem

The height of point A and B from an arbitrary <u>datum plane</u> (MN) are X_A and X_B (ft) respectively.

Potential energy at point A, (W1)= mgX_A ft-poundal [absolute unit]

= $m (g/g_C)X_A$ ft-lb force = mX_A ft-lb force [gravitational unit]

Since the liquid is in motion

∴ Kinetic energy at point A, (W2) = $\frac{1}{2}.\ m\ u_A^2$ ft-poundal

= $(\frac{1}{2}.\ m\ u_A^2)/\ g_C$ pound-force

As the liquid **m** enters the pipe it enters against pressure of P_A lb-force/ft^2 and therefore.

Work against the pressure at point A, (W3) = mP_AV_A ft-lb$_f$.

N.B. Force at point A = P_A S [S = Cross-section area]

Work done against force P_A S = P_A (S h) = P_A V

∴ Total energy of liquid **m** entering the section at point a will be (E1) = W1 + W2 + W3

$$E1 = [\ mX_A + (\tfrac{1}{2}.\ m\ u_A^2)/\ g_C\ + mP_AV_A\ ]\ \text{ft-lb}_f.$$

After the system has reached the steady state when ever **m** (lb) of liquid enters at A another **m** (lb) pound of liquid is displaced at B according to the principle of the conservation of mass. This **m** (lb) leaving at B will have ab energy content of

$$E2 = [\ mX_B + (\tfrac{1}{2}.\ m\ u_B^2)/\ g_C\ + mP_BV_B\ ]\ \text{ft-lb}_f.$$

Energy is added by the pump. Let the pump is giving **w** ft-lb$_f$ / lb energy to the liquid

$$E3 = m\ w \quad \text{ft-lb}_f.$$

Some energy will be converted into heat by friction. It has been assumed that the system is at a constant temperature, hence, it must be assumed that the heat is lost by radiation or by other means. Let this loss due to friction be F ft-lb$_f$ / lb of liquid.

$$E4 = -\ mF \quad \text{ft-lb}_f \quad \text{[negative sign for loss]}$$

∴ The complete equation representing an energy balance across the system between points A and will therefore be

$$E1 + E3 + E4 = E2$$

or, $$mX_A + (\tfrac{1}{2}.\ m\ u_A^2)/\ g_C\ + mP_AV_A + m\ w\ -\ mF\ =\ mX_B + (\tfrac{1}{2}.\ m\ u_B^2)/\ g_C\ + mP_BV_B$$

Now, the unit of energy term is ft-lb$_f$ / lb

∴ The BERNOULLI'S THEOREM.

$$X_A + \frac{U_A^2}{2g_C} + P_AV_A + w - F = X_B + \frac{U_B^2}{2g_C} + P_BV_B$$

The density of the liquid ρ be expressed lb$_m$ / ft^3, then

$V_A = 1 / \rho_A$ and $V_B = 1 / \rho_B$ then Bernoulli's equation can be written in the form also

$$X_A + \frac{U_A^2}{2g_C} + \frac{P_A}{\rho_A} + w - F = X_B + \frac{U_B^2}{2g_C} + \frac{P_B}{\rho_B}$$

FLUID HEADS

All the terms in Bernoulli's theorem have unit of **ft-lb$_f$ / lb$_m$** which is numerically equal to '**ft**' only. That is each and every time terms can be expressed by height.

Dimensional Analysis

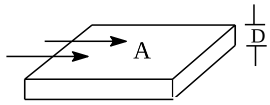
[ft]	=	L
[lb$_f$]	=	$(ML\theta^{-2}) / (L\theta^{-2}) = M$
[lb$_m$]	=	M
[ft-lb$_f$ / lb$_m$]	=	$L\not{M} / \not{M} = L$

That is every term has a dimension of length (or height) if the terms are expressed in gravitational unit. This height are termed as **heads** in the discussions of hydraulics. Each term has different names:

Potential heads	X_A , X_B.
Velocity heads	$U_A^2 / (2 g_C)$, $U_B^2 / (2 g_C)$
Pressure heads	$P_A V_A$, $P_A \rho_A$, $P_B V_B$, $P_B \rho_B$.
Friction head	F
Head added by the pump	w

FRICTION LOSSES

In Bernoulli's equation a term was included to represent the loss of energy due to friction in the system. The frictional loss of a fluid flowing through a pipe is a special case of general law of the resistance between a solid and fluid in relative motion.



Let us consider a solid body of any designed shape, immersed in a stream of fluid.

Let, the area of contact between the solid and f fluid = A

If the velocity of the fluid passing the body is small in comparison to the velocity of sound , it has been found experimentally that the resisting force depends only on the roughness, size and shape of the solid and on the velocity , density and viscosity of the fluid. Through a consideration of the dimensions of these quantities it can be shown that,

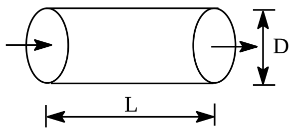
$$\frac{F}{A} = \frac{\rho u^2}{g_c}\,\phi\left[\frac{Du\rho}{\mu}\right]$$

where, F = total resisting force
A = area of solid surface in contact with fluid
u = velocity of the fluid passing the body
ρ = density of fluid
μ = viscosity of fluid
$g_c = 32.2$ (lb$_m$ ft)/ (lb$_f$ s^2)
ϕ = some friction whose precise form must be determined for each specific case.

The form of function ϕ depends upon the geometric shape of the solid and its roughness.

FRICTION IN PIPES

In a particular case of a fluid flowing through a circular pipe of length L, the total force resisting the flow must equal the product of the area of contact between the fluid and the pipe wall and F/A of the friction loss equation.



The pressure drop will be:

$$\Delta P_f = \frac{\text{Total force}}{\text{Cross sectional area}}$$

$$= \frac{(F / A)\,(L\pi D)}{\pi D^2/4}$$

$$= \frac{F}{A}\,\frac{L\pi D}{\pi D^2/4}$$

Since $\frac{F}{A} = \frac{\rho u^2}{g_c}\,\phi\left[\frac{Du\rho}{\mu}\right]$ Therefore $\Delta P_f = \frac{\rho u^2}{g_c}\,\phi\left[\frac{Du\rho}{\mu}\right]\left[\frac{4L\pi D}{\pi D^2}\right]$

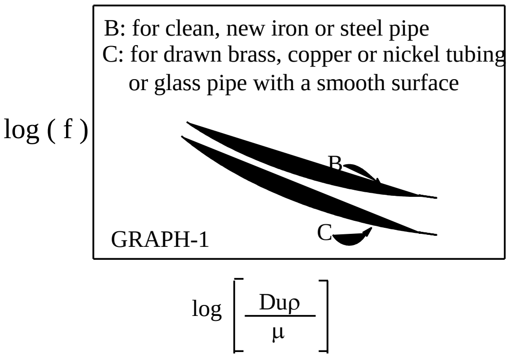
$$= \frac{4\,u^2\,L\,\rho}{g_c D}\,\phi\left[\frac{Du\rho}{\mu}\right] \quad \text{--------- eqn (1)}$$

where ΔP_f = pressure drop due to friction (lb/ft^2)
F / A = resisting force (ft-lb_f per ft^2 of contact area)
L = length of pipe (ft)
D = inside diameter of the pipe (ft)
ρ = density of fluid (lb_m / ft^3)
u = average velocity of fluid (ft / s)
μ = viscosity of fluid (lb_m / ft / s)
g_c = 32.2 (lb_m ft / lb_f s^2)

For many decades Fanning's equation was used:

$$\Delta P_f = \frac{2 f u^2 L \rho}{g_c D} \quad \text{----- eqn (2)}$$

In Fanning's equation the value of '**f** ' was taken from tables. This equation however has been widely used for so many years that most engineers still use the Fanning's equation, except that instead of taking values of 'f' from arbitrary tables a plot of the equation f = ($Du\rho / \mu$) is used.
The graph (graph 1) is not that much accurate : Error: ± 5 to 10 % may be expected for laminar flow



By combining Hagen Poiseulles equation a new simple form of equation can be obtained.

$$f = \frac{16}{\frac{Du\rho}{\mu}} = \frac{16}{\text{Reynolds No}}$$

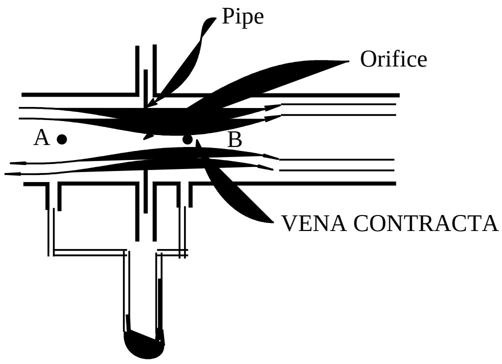
MEASUREMENT OF FLUID FLOW

Methods of measuring fluids may be classified as follows:-

1) *Hydrodynamic methods*
   (a) Orifice meter
   (b) Venturimeter
   (c) Pitot tube
   (d) Rotameter
   (e) Weirs
2) *Direct displacement*
   (a) Disc meters
   (b) Current meters
3) *Dilution method and*
4) *Direct weighing or measuring*

ORIFICE METER

Objective:
To measure the flow of fluids.
i) Velocity of fluid through a pipe (ft/sec)
ii) Volume of liquid passing per unit time (ft^3/sec, ft^3/min, ft^3/hr).



Description
An orifice meter is considered to be a thin plate containing an aperture through which a fluid issues. The plate may be placed at the side or bottom of a container or may be inserted into a pipe line.
A manometer is fitted outside the pipe. One end at point A and the other end at point B (see fig.). The pressure difference between A and B (i.e. before and after the orifice) is read, and the reading is then converted to fluid flow-rate.

Derivation
Bernoulli's equation is written between these two points, the following relationship holds

$$X_A + \frac{U_A^2}{2g_c} + \frac{P_A}{\rho_A} - F + w = X_B + \frac{U_B^2}{2g_c} + \frac{P_B}{\rho_B} \quad \text{......................(1)}$$

Conditions	**Equation (1) changes to:**
i) The pipe is horizontal $\therefore X^A = X_B$.	$\frac{U_A^2}{2g_c} + \frac{P_A}{\rho_A} - F + w = \frac{U_B^2}{2g_c} + \frac{P_B}{\rho_B}$
ii) If frictional losses are assumed to be inappreciable then F = 0	$\frac{U_A^2}{2g_c} + \frac{P_A}{\rho_A} + w = \frac{U_B^2}{2g_c} + \frac{P_B}{\rho_B}$
iii) If the fluid is a liquid then $\rho A \approx \rho B = \rho$ (let)	$\frac{U_A^2}{2g_c} + \frac{P_A}{\rho} + w = \frac{U_B^2}{2g_c} + \frac{P_B}{\rho}$
iv) Since no work is done on the liquid, or by the liquid between A and B. $\therefore$ w = 0	$\frac{U_A^2}{2g_c} + \frac{P_A}{\rho_A} = \frac{U_B^2}{2g_c} + \frac{P_B}{\rho_B}$ .... (2)

Equation (2) may be written as:

$$U_B^2 - U_A^2 = \frac{2g_C}{\rho}(P_A - P_B) \qquad \text{........................(3)}$$

Since, $P_A - P_B = \Delta P$, and since $\frac{\Delta P}{\rho} = \Delta H$

$\therefore$ equation (3) can be written as

$$\sqrt{U_B^2 - U_A^2} = \sqrt{2g_C\ \Delta H} \qquad \text{...(4)}$$

N.B. $P_A = H_A \rho g / g_c$
$P_B = H_B \rho g / g_c$
$P_A - P_B = (H_A - H_B)\rho g / g_c$
or, $\Delta P = \Delta H \rho g / g_c$.
Since, $g / g_c \approx 1.0$ hence, $\Delta H = \Delta P / \rho$
If the pipe to the right of the orifice plate were removed so that the liquid issued as a jet from the orifice, the minimum diameter of the stream would be less than the diameter of the orifice. This point of minimum cross-section is known a vena-contracta.

Point B was chosen at the vena-contracta. In practice the diameter of the stream at the vena-contracta is not known, but the orifice diameter is known. Hence equation (4) may be written in terms of the velocity through the orifice, as a result a constant (Co) has to be inserted in the equation (4) to correct the difference between this velocity and the velocity at the vena-contracta. There may be some loss by friction and this also may be included in the constant. Equation (4) then becomes:

$$\sqrt{U_0^2 - U_A^2} = C_0\sqrt{2g_C\ \Delta H} \qquad \text{............................(5)}$$

where U_0 = velocity through the orifice.
The pressure difference ΔP between A and B is read directly from the manometer.
In equation (5)

ΔH is measured from manometer ($\Delta P/\rho$)
g_c is constant
C_0 is constant and known for a particular orifice meter.
U_0 and U_A is unknown

So to solve both U_0 and U_A another equation is required. We can assume that the volume flow-rate at A and orifice are equal, we can thus deduce the following equation.

$$U_A \frac{\pi d_P^2}{4} = U_O \frac{\pi d_O^2}{4} \qquad \text{or,} \qquad \frac{U_A}{U_O} = \left(\frac{d_O}{d_P}\right)^2 \qquad \text{..................................(6)}$$

where, d_P = diameter of pipe
d_O = diameter of orifice
d_P and d_O are already known

Now we can solve equation (5) and (6) to get the value of both U_A and U_O.
U_A = velocity of fluid in the pipe

$U_A \times \frac{\pi d_P^2}{4}$ = volume flow rate of fluid in the pipe.

The constant Co depends on the

- ratio of the orifice diameter to the pipe diameter
- position of the orifice taps
- value of Reynolds number for the fluid flowing in the pipe.

*** For values of Reynolds number (based on orifice diameter i.e. $Re = \frac{d_O u_O \rho}{\mu}$ of 30,000 or above, the value of Co may be taken as 0.61.

Advantage

It is very simple device and can be easily installed i.e. cost of installation is less.

Fluids of various viscosity can be measured just by changing the orifice diameter.

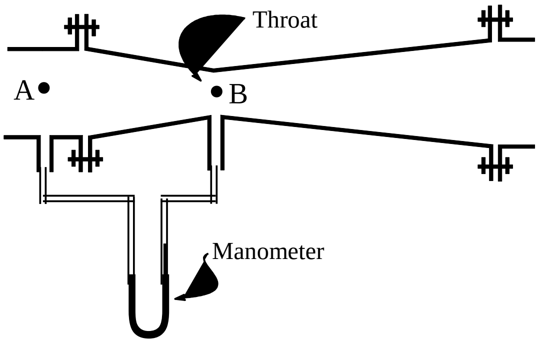
Disadvantage

The orifice always results in a permanent loss of pressure (head), which decreases as the ratio of orifice diameter to pipe, diameter increases i.e. cost of operation, particularly for long term, is considerable.

VENTURIMETER

Description

The venturimeter, as shown in the figure consists of two tapered sections inserted in the pipeline, with the tapers smooth and gradual enough so that there are no serious loss of energy. At point B the section of venturimeter has minimum diameter. This point is called the 'throat' of the venturimeter.



The venturimeter is fitted within a pipe. The pressure difference at A and B is measured by a manometer.

Derivation

If the Bernoulli's equation is written between these two points the following relationship holds.

$$X_A + \frac{U_A^2}{2g_c} + \frac{P_A}{\rho_A} - F + w = X_B + \frac{U_B^2}{2g_c} + \frac{P_B}{\rho_B} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Conditions	Equation (1) changes to:
i) The pipe is horizontal $\therefore X^A = X_B$.	$\frac{U_A^2}{2g_c} + \frac{P_A}{\rho_A} - F + w = \frac{U_B^2}{2g_c} + \frac{P_B}{\rho_B}$
ii) If frictional losses are assumed to be inappreciable then F = 0	$\frac{U_A^2}{2g_c} + \frac{P_A}{\rho_A} + w = \frac{U_B^2}{2g_c} + \frac{P_B}{\rho_B}$
iii) If the fluid is a liquid then $\rho A \approx \rho B = \rho$ (let)	$\frac{U_A^2}{2g_c} + \frac{P_A}{\rho} + w = \frac{U_B^2}{2g_c} + \frac{P_B}{\rho}$
iv) Since no work is done on the liquid, or by the liquid between A and B. i.e. w = 0	$\frac{U_A^2}{2g_c} + \frac{P_A}{\rho_A} = \frac{U_B^2}{2g_c} + \frac{P_B}{\rho_B}$ .... (2)

Equation (2) may be written as:

$$U_B^2 - U_A^2 = \frac{2g_C}{\rho}(P_A - P_B) \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Since, $P_A - P_B = \Delta P$, and since $\frac{\Delta P}{\rho} = \Delta H$

$\therefore$ equation (3) can be written as

$$\sqrt{U_B^2 - U_A^2} = \sqrt{2g_C \, \Delta H} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

N.B. $P_A = H_A \rho g / g_c$
$P_B = H_B \rho g / g_c$
$P_A - P_B = (H_A - H_B) \rho g / g_c$
or, $\Delta P = \Delta H \rho g / g_c$.
Since, $g / g_c \approx 1.0$ hence, $\Delta H = \Delta P / \rho$
If the pipe to the right of the orifice plate were removed so that the liquid issued as a jet from the orifice, the minimum diameter of the stream would be less than the diameter of the orifice. This point of minimum cross-section is known a vena-contracta.

Since there are practically no losses dude to eddies and since the cross-section of the high velocity part of the system is accurately defined hence equation (4) may be written as

$$\sqrt{U_B^2 - U_A^2} = C_V \sqrt{2g_C \ \Delta H} \ ....(5)$$

where U_B = velocity at the throat of the venturimeter
In case of venturimeter the value of coefficient $C_V = 0.98$.

Comparison between orificemeter and venturimeter:

Orifice meter	Venturimeter
1. Installation is cheap and easy. 2. The power loss is considerable in long run. 3. They are best used for testing purposes or other cases where the power loss is not a factor, as in steam lines. 4. Installing a new orifice plate with a different opening is a simple matter.	1. Installation is costly. It is less easier than orifice meter. (*Disadvantage*) 2. Power loss is less in long run even negligible (*Advantage*) 3. Venturimeters are used for permanent installation. 4. Installation of a different opening require replacement of the whole venturimeter. (*Disadvantage*)

PITOT TUBE

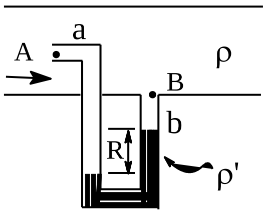


Fig 1

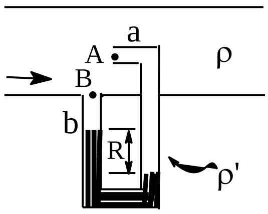


Fig 2

The pitot tube is a device to measure the local velocity along a streamline. The configurations of the device are shown in the figure. The manometer has two arms. One arm 'a' is placed at the center of the pipe and opposite to the direction of flow of fluid. The second arm 'b' is connected with the wall of the pipe. The difference of liquid in two arms of the manometer is the reading.

The tube in the 'a' hand measures the pressure head (X_A) and the velocity head $\left(\frac{U_A^2}{2g_C}\right)$. The 'b' hand measures only pressure head (X_B).

$$X_A + \frac{U_A^2}{2g_C} = X_B \qquad \text{or, } X_A - X_B = \frac{U_A^2}{2g_C} \qquad \text{or, } \Delta X = \frac{U_A^2}{2g_C} \ ....(i)$$

Here ΔX_B is the pressure head of the fluid whose flow is to be measured that corresponds to R. Since the manometer measures the pressure according to the following equation.

$$\Delta X = (\rho' - \rho) \ R g/g_C$$

or, $= (\rho' - \rho) \ R$ [Since $g/g_C \approx 1$]

where, ρ' = density of the liquid in the manometer
ρ = density of the fluid in the pipe.

Replacing ΔX in the equation (i) gives,

$$(\rho' - \rho)\,R = \frac{U_A^2}{2g_C} \qquad [U = U_A \text{ (let)}]$$

$$\therefore\; U = \sqrt{2(\rho' - \rho)\,g_C\,R} \qquad \text{(ii)}$$

The velocity measured is the maximum velocity inside the pipe.

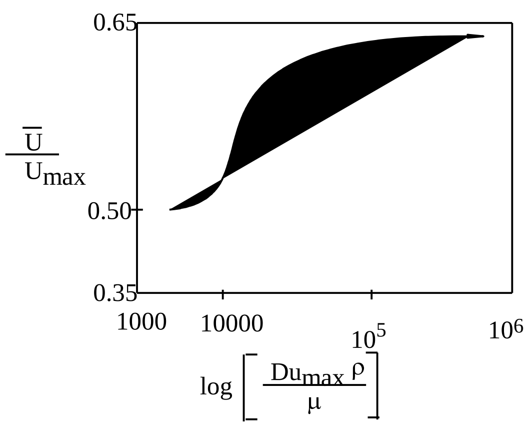
$$U_{max} = \sqrt{2\,g_C\,(\rho' - \rho)\,R}$$

By orifice meter or venturimeter average velocity of fluid is measured. With pitot tube velocity of only one point (i.e. at the center of the pipe) is measured. To convert U_{max} to average velocity $(\overline{U})$ the following relationship is taken into concern.

where, D = diameter of the pipe
U_{max} = maximum velocity of fluid
ρ = density of the fluid flowing
μ = viscosity of the fluid flowing
$\overline{U}$ = average velocity in the pipe

Disadvantage of pitot tube

1. It does not give the average velocity directly.
2. When velocity of gases are measured the reading are extremely small. In these cases some form of multiplying gauge like differential manometer and inclined manometers are used.



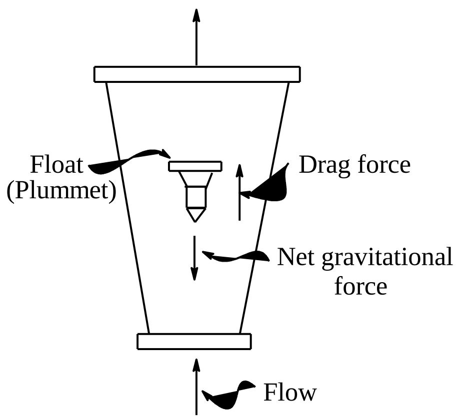
where D= diameter of the pipe
U_{max} = maximum velocity of fluid
ρ = density of the fluid flowing
μ = viscosity of the fluid flowing
U = average velocity in the pipe

ROTAMETER

Construction of rotameter:

It consists essentially of a gradually tapered glass tube mounted vertically in a frame with the large end up. The fluids flow upward through the tapered tube.

Inside the tapered tube a solid plummet or float having diameter smaller than that of the glass tube is placed. The plummet rises or falls depending on the velocity of the fluid.



Principles of rotameter:

For a given flow rate, the equilibrium portion of the float in the rotameter is established by a balance of three forces.

1. The weight of the float (w)
2. The buoyant force of the liquid on the float (B)
3. The drag force on the float (D)

'w' acts downward and B and D acts upward.

At equilibrium:

$W = B + D$

or, $D = W - B$

or, $F_D\,g_C = V_f\,\rho_f\,g - V_f\,\rho\,g$.

where, F_D = drag force
V_f = volume of float
ρ_f = density of float
ρ = density of fluid

The quantity of V_f can be replaced by $\frac{m_f}{\rho_f}$, where m_f is the mass of the float, and equation (i) becomes: $F_D\, g_C$ =

$$V_f(\rho_f - \rho)\, g = \frac{m_f}{\rho_f}(\rho_f - \rho)\, g = m_f\left(1 - \frac{\rho}{\rho_f}\right) g$$

For a given meter operating on a certain fluid, the right-hand side of equation- (ii) is constant and independent of the flow rate. Therefore F_D is also constant, when the *flow increases the position of the float must change to keep the drag force constant*.

$$F_D = K_1 \frac{U_{max} 2}{2g_c} \qquad \text{where, } K_1 = \text{constant}$$

If the tube is tapered, and difference between the diameters of float and tube are small then it can be shown that the height at which the plummet is floating is proportional to the rate of flow.

Advantages:

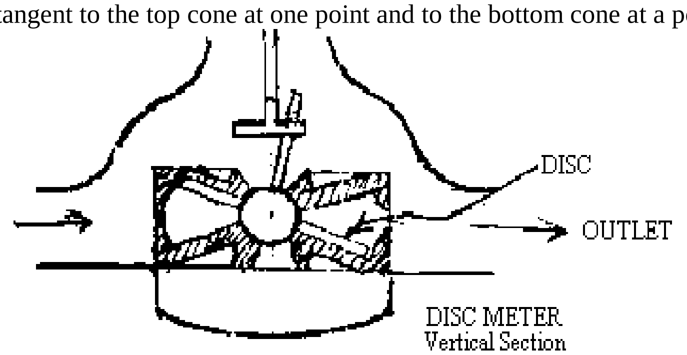
1. The flow rates can be measured directly.
2. Measured in linear scale and
3. Constant and small head loss.

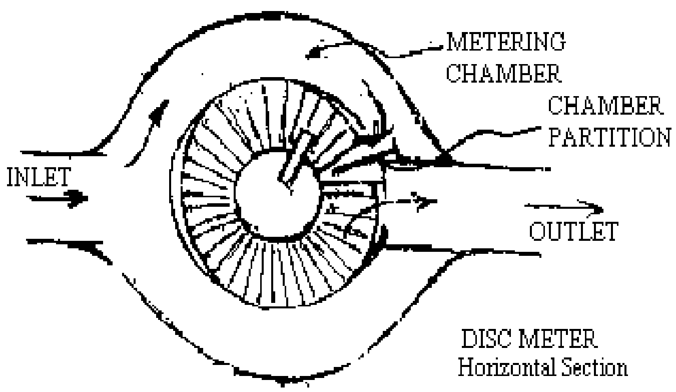
DISPLACEMENT METERS

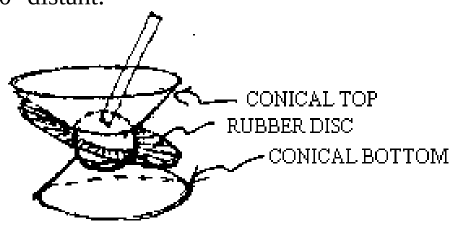
Displacement meters covers devices for measuring liquids based on the displacement of a moving member by a stream of liquid. These meters may be classified as *disc meters* and *current meters*.

DISCMETER

The figures share a typical discmeter. The displacement member in this apparatus is a hard-rubber disc. This disc is mounted in a measuring chamber which has a conical top and bottom. The disc is so mounted that it is always tangent to the top cone at one point and to the bottom cone at a point 180^0 distant.







The measuring chamber has a partition that extends half way across it, and the disc has a slot to take this partition.

The measuring chamber is set into the meter body in such a way that the liquids enters at one side of the partition, passes around through the measuring chamber, and out on the other side of the partition.

Whether the liquid enters above or below the disc, it moves the disc in order to pass, and this and this motion of the disc results in the axis moving as though, it were rotating around the surface of a cone whose apex is the center of the disc and whose axis is vertical. This motion of the axis of the disc is translated through a train of gears to the counting dial (not shown in the figure).

CURRENT METER

The displacement member is a turbine wheel which is delicately mounted so that it moves with the minimum of friction. The stream of water entering the meter strikes the buckets on the periphery of the wheel and makes it rotate at a speed proportional to the velocity of the water passing through the meter.

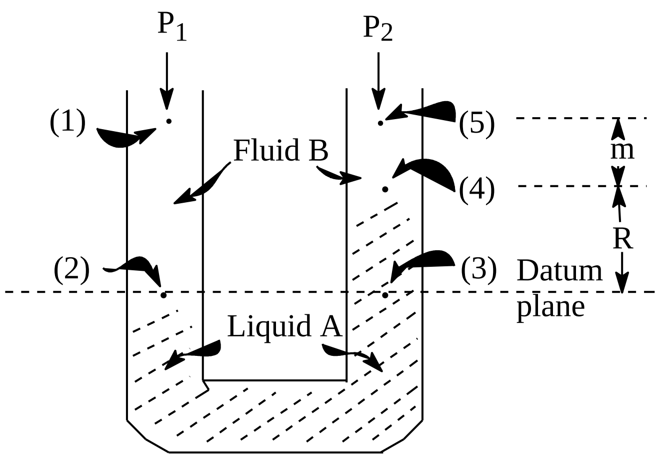
N.B. Both discmeter and current meter measures the total volume of liquid that has passed.

MANOMETERS

Simple manometer

Manometers are used to measure the pressure of any fluid.

A U-tube is filled with a liquid A of density ρ_A. The arms of the U-tube above liquid A are filled with fluid B which is <u>immiscible</u> with liquid A and has a density of ρ_B. A pressure of P1 is exerted in one arm of the U-tube, and a pressure P2 on the other. As a result of the difference in pressure ($P_1 - P_2$) the meniscus in one branch of the U-tube will be higher than the other branch.



The vertical distance between these two surfaces is R. *It is the purpose of the manometer to measure the difference in pressure ($P_1 - P_2$) by means of the reading R.*

At equilibrium the forces at the two points (2 and 3) on the datum plane will be equal.

Let the <u>cross sectional area</u> of the U-tube be S.

** All the forces are expressed in gravitational unit.

Total downward force at point (2) = Forces at point (1)
+ force due to column of fluid B in between points (1) and (2).
$= P_1S + (m + R)\,\rho_B\,(g / g_c)\,S$

Total downward force at point (3) = Force at point (5)
+ Force due to column of fluid B in between points (5) and (4)
+ Force due to column of liquid A in between points (4) and (3)
$= P_2S + m\,\rho_B\,(g/g_c)\,S + R\,\rho_A\,(g/g_c)\,S$

At equilibrium:

Force at point (2) = Force at point (3)

or, $P_1S + (m + R)\,\rho_B\,(g / g_c)\,S = P_2S + m\,\rho_B\,(g/g_c)\,S + R\,\rho_A\,(g/g_c)\,S$

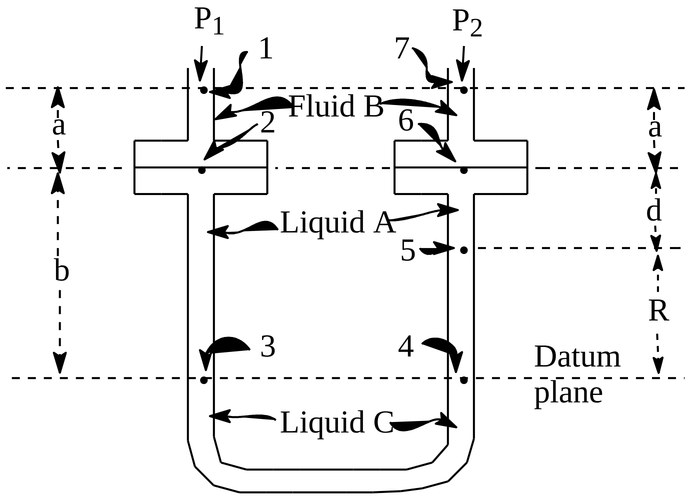
or, $P_1 - P_2 = R\,\rho_A\,(g/g_c) + m\,\rho_B\,(g/g_c) - m\,\rho_B\,(g/g_c) - R\,\rho_B\,(g/g_c)$

$= R\,(\rho_A - \rho_B)\,g/g_c.$

or, $$\Delta P = P_1 - P_2 = R\,(\rho_A - \rho_B)\,g/g_c.$$

It should be noted that this relationship is independent of the distance 'm' and cross sectional area 'S' of the U-tube, provided that P_1 and P_2 are measured from the same horizontal plane.

Differential Manometer



For the measurement of smaller pressure differences, differential manometer is used.
The manometer contains two liquids A and C which must be immiscible.
Enlarged chambers are inserted in the manometer so that the position of the meniscus 2 and 6 do not change appreciably with the changes in reading.

So the distance between (1) and (2) = Distance between (6) and (7)
Total downward force on point (3)
$F_{left} = P_1 S + a\rho_A g/g_c S + b\rho_A g/g_c S$
Total downward force on point (4)
$F_{right} = P_2 S + a\rho_B g/g_c S + d\rho_A g/g_c S + R\rho_C g/g_c S$
At equilibrium

$F_{left} = F_{right}$.

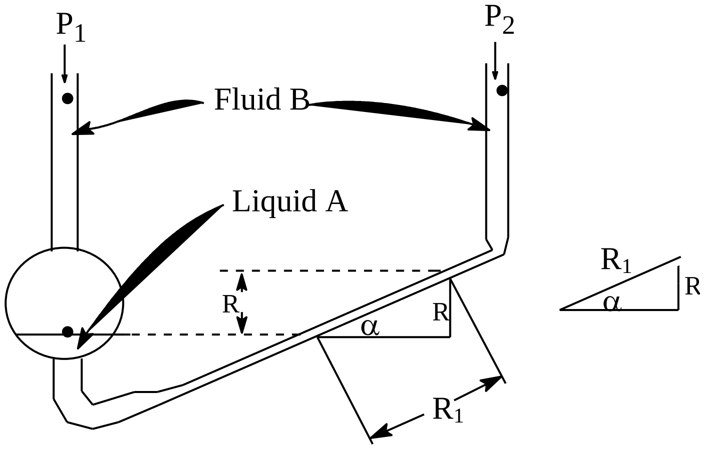
$\therefore \quad P_1 S + a\rho_A g/g_c S + b\rho_A g/g_c S = P_2 S + a\rho_B g/g_c S + d\rho_A g/g_c S + R\rho_C g/g_c S$

$P_1 - P_2 = (d - b)\rho_A g/g_c + R\rho_C g/g_c$
$= - R\rho_A g/g_c + R\rho_C g/g_c$.
$= R(\rho_C - \rho_A) g/g_c$

$$\Delta P = P_1 - P_2 = R(\rho_C - \rho_A) g/g_c$$

From this it follows that the smaller the differences $\rho_C - \rho_A$, the larger will be the reading R on the manometer for a given value of ΔP.

Inclined Manometer



For measuring small difference in pressure this type of manometer is used.
In this type of manometer the leg containing one meniscus must move a considerable distance along the tube. Here the actual reading R is magnified many folds by R_1, where

$R = R_1 \sin\alpha$

where α is the angle of inclination of the inclined leg with the horizontal plane.
In this case $\Delta P = P1 - P2$
$= R(\rho_A - \rho_B) g/g_c$.
In this type of gauge it is necessary to provide an enlargement in the vertical leg so that the movement of the meniscus in this enlargement is negligible within the range of the gauge.
By making α small the value of R is multiplied into a much larger distance R_1.

VALVES

Valves are used to control the rate of flow of fluids in a pipeline.

Normally valves are made of materials such as brass, iron, bronze, and cast iron, depending on the nature of the fluid that will come in contact with the valve.

Some of the design of valves:

(1) Plug cock valve (2) Globe valve (3) Gate valve
(4) Diaphragm valve (5) Quick opening valve (6) Check valve.

(1) Plug cock valve

Construction: It consists of a body casting, in which a conical plug is fitted. There is a cylindrical bore (passage) through the plug. Some packing materials are included around the stem to make is tight fitting.

Working: When the stem of the plug is rotated 90^0 the fluid passes through the cylindrical passage.

Application:
1. These valves are used when complete opening or complete closing is desirable.
2. They are used for handling compressed air or gas.

Disadvantages:
1. Pug cock valves are not suitable for steam because the grease will melt.
2. The plug becomes difficult to turn because it gets wedged firmly into the body. This problem is observed when the sides of the plug are nearly parallel.
3. If the plug sides are too much tapered then sometimes plug comes out of its seat.
4. It is difficult to regulate the flow.

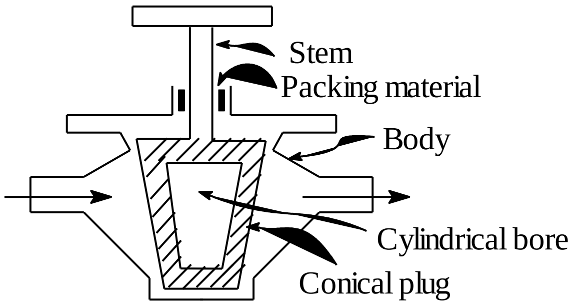


Fig. Plug cock valve

(2) Globe valves

Construction: A globe valve consists of a globular body with a horizontal internal partition. The passage of fluid is through a circular opening called *seat ring*, which can be opened or closed by inserting a *disc* in it. The disc can be rotated freely on the stem.

Working: When the stem is rotated the disc goes up and a passage is created in between the disc and seat through which liquid is passed.

Uses: They are mainly used in pipes with sizes not larger than 50mm. They can be fitted both in horizontal and vertical line.

Disadvantages:

Rust, scales or sludge prevent the opening of the valve.

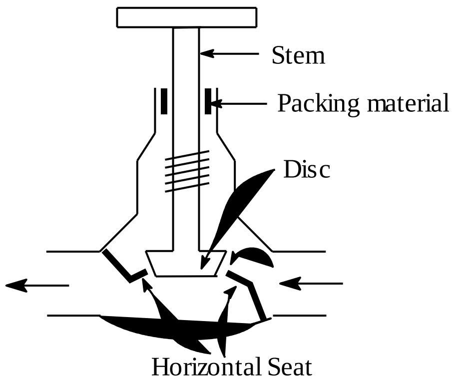


Fig. Globe valve

(3) Gate valves

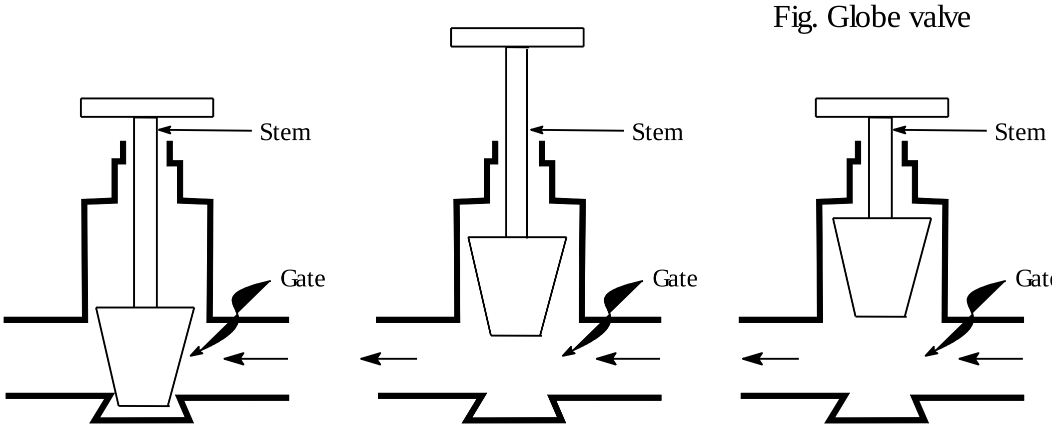


Fig. Gate valve (closed) Fig. Gate valve open [Rising type] Fig. Gate valve open [Non-rising type]

Construction: A wedge-shaped, inclined-seat type of gate is most commonly used. Two types of gate valves are available – (i) Rising stem gate valve and (ii) Non-rising type stem gate valve.

In rising stem type the gate can be raised by raising the stem.

(4) Diaphragm valves

By rotating the stem the flexible diaphragm is pressed against the bottom of the valve. The diaphragm may be made of
(i) reinforced fabric (cloth)
(ii) natural rubber / synthetic rubber faced with polytetrafluoroethylene (PTFE / Teflon)

Uses:
1. They are more suitable for fluids containing suspended solids.
2. PTFE (Teflon) - coated diaphragms are used in pipe lines those require repeated steam sterilization.

Advantages:
1. Diaphragm valves can be installed in any position.
2. Pressure drop is negligible.
3. Complete draining in horizontal lines is possible.
4. Simple construction.
5. Suspension type fluids can flow through it.
6. Replacement of diaphragm is easy. There is no need to remove the valve from the line.

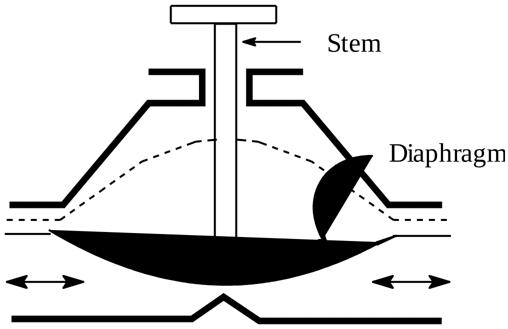


Fig. Construction of diaphragm valve

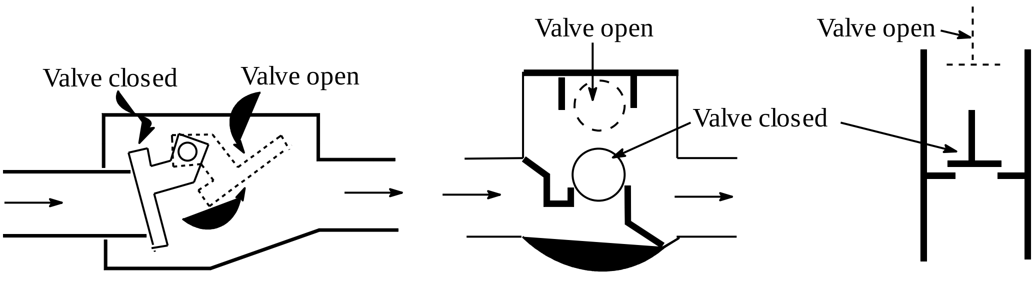
Disadvantages:
1. Diaphragm valves can work below 50 lb/sq.in. pressure.
2. These valves are expensive.

(5) Quick opening valve

Construction: The construction is similar to gate valve except that the stem is not threaded. In case of gate valve several turns are required to open or close the valve. Quick opening valves have smooth stems and are opened or closed by lever handle in a simple operation.
Disadvantages: Water hammering may occur during closing. When a liquid flows through a pipe it has kinetic energy. When the flow is suddenly stopped by closing the quick-opening valve, suddenly the velocity is destroyed. The kinetic energy appears as intense shock due to inertia of motion. This is called water hammering.

(6) Check valves

These valves are used when unidirectional flow is desirable. Protective mechanism is included to prevent the reversal flow. These are automatically opened, when flow of fluid builds up the pressure. There are three types of check valves:
(a) Swing check, (b) Ball check, (c) Lift check, vertical.



Uses:
This types of valves are used for unidirectional flow of fluid.

Basic Engineering (Theory questions)

Chapter-1: Flow of fluids

Q1. What is Reynold's number? Determine the unit of Reynold's number. What is the significance of Reynold's number (or How will you interpret the value of Reynold's number of a fluid flowing through a pipe)? [1+1+1]

Q2. Define viscosity and give the unit of viscosity. [1+1]

Q3. Derive Bernouli's theorem. [6]

Q4. Write short note on the following flow-meters:

(a) Orifice meter, (b) Venturimeter, (c) Pitot tube, (d) Rotameter, (e) Discmeter, (f) Current meter

Q5. Write short note on the following manometers:

(a) Simple manometer, (b) Differential manometer (c) Inclined manometer

Q6. Write short note on the following valves:

(a) Plug-cock valve, (b) Gate valves, (c) Diaphragm valve, (d) Quick opening valve, (e) Check valve.