FLOW AND TRANSPORTATION OF FLUID AND HEAT

Syllabus:

1. Flow of fluids: Fluid statics, Manometers, Reynolds number, Bernoulli's theorem, fluid heads, Friction losses, Measurement of fluid flow meters – Orifice meter, Venturimeter, Pitot tube, Rotameter and Displacemeter.
2. Transportation of fluids, pipe, joints, valves, reciprocating piston, duplex, diaphragm, rotary, centrifugal and turbine pumps.

Questions:

Flow of fluids:

1. Bernoulli's theorem. (91, 95) [8]
2. State and explain the significance of Bernoulli's equation and Reynolds number with regards to flow of fluids. (92, 96) [8 + 8]
3. Fluid head and friction losses - short notes. (93, 94, 95) [8]
4. Derive Bernoulli's equation to prove the conservation of energy during the flow of fluids. (94) [8]

Measurement of fluid flow meters:

Short notes on

1. Displacemeter (91) [8]
2. Pitot tube (92, 93, 95) [4]
3. Venturimeter (93, 95) [8]
4. Fluid flow meters / displacemeters. (94) [8]
5. Manometer (93) [8]
6. Measurement of fluid flow by Orifice meter, Venturimeter and Rotameter.

Transportation of fluids

1. Rotary centrifugal and Turbine pumps. (91, 93) [8]
2. Turbine pumps (92) [4]
3. Pumps (94) [8]
4. Centrifugal (volute) pump (94`) [4]
5. Diaphragm pump (94`) [4]
6. Rotary (gear) pump (94`) [4]
7. Reciprocating piston and Duplex pump (95) [16]
8. Describe briefly the different pumps and for transportation of fluids (93, 96) [16]

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.

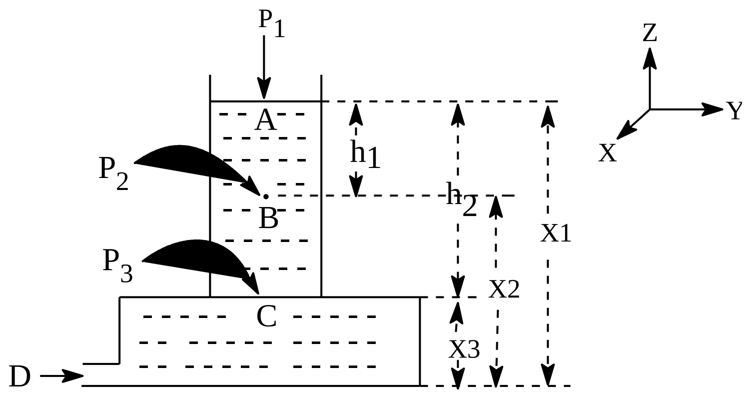
- The science of fluid mechanics includes two branches:

(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.

FLUID STATICS



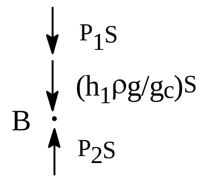
Hydrostatic pressure

In a stationary column of static fluid the pressure at any one point is the same in all directions. The pressure will also remain constant in any cross-section parallel to the earth's surface, but will vary from height to height.

Let us consider, that the column of fluid in the figure is remaining at equilibrium. If the orifice D is open then the fluid will try to flow away. So either D is closed or a pressure is applied such that the liquid column stand at any desired height. The cross-section of the column is S (let). Now, say the pressure at the height $X_2 = P_2$ (in gravitational unit). At equilibrium all the forces acting on point B will be the same.

i.e. *Upward force* $= P_2S$

Downward forces:



Force given by atmosphere $= P_1S$

Force given by fluid column of height $h_1 = (h_1\rho\, g/g_c)S$

Where, ρ is the density of the fluid.

At equilibrium upward and downward forces are equal at point B.

$\therefore \quad P_2S = P_1S + h_1\, \rho\, S\, g/g_c$ eqn. (1)

where, each term of force is expressed in gravitational units i.e. lb_f, gm-wt, kg-wt etc.

$g/g_c \approx 1.0$ so equation (1) can be written as

$P_2S = P_1S + h_1\, \rho\, S$

$P_2 = P_1 + h_1\, \rho$ eqn. (2)

Similarly, $P_3 = P_2 + (h_2 - h_1)\, \rho$

$= P_1 + h_1\, \rho + h_2\, \rho - h_1\, \rho$

$= P_1 + h_2\, \rho$

$= P_1 + (X_1 - X_3)\, \rho$ [since $h_2 = X_1 - X_3$]

We can thus generalize for any point in the fluid, the pressure will be

$P_n = P_1 + \rho\, \Delta X$ where $\Delta X = X_1 - X_m$.

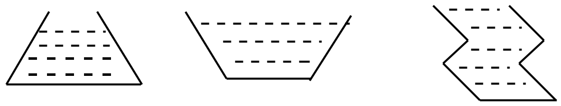
or, $P_n - P_1 = \rho\, \Delta X$

or, $\Delta P_n = \rho\, \Delta X$ eqn. (3)

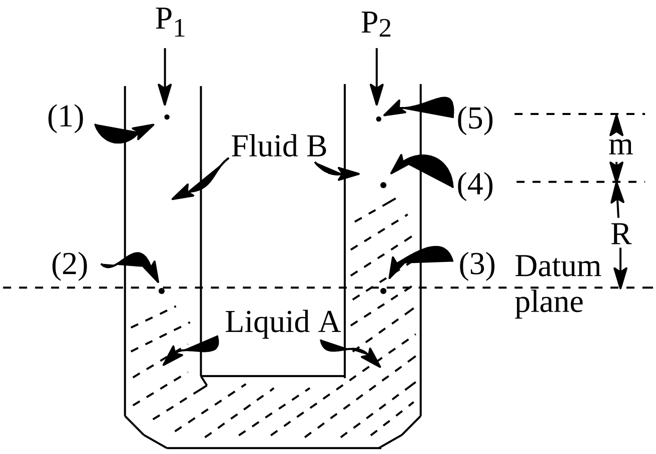
i.e. the pressure difference (ΔP_n) between any two points can be measured by the vertical distance between those two points, multiplied by the density of the fluid.

Since in equation (3) there is no term involving the cross-sectional area (S), it is not necessary that the vertical column be of uniform cross-section.

i.e. the shape may be any of the following types:



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 immiscible 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 cross sectional area 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, $\boxed{\Delta P = P_1 - P_2 = R\, (\rho_A - \rho_B)\, g/g_c.}$

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

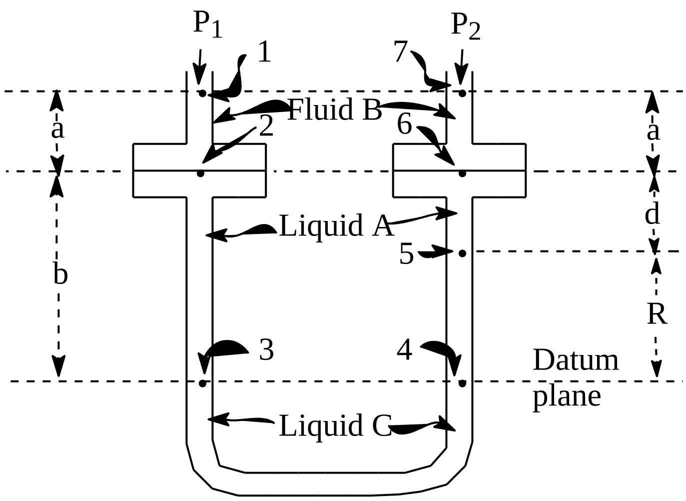


Fig. Differential manometer

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)

$F_{left} = P_1S + a\, \rho_A\, g/g_c\, S + b\, \rho_A\, g/g_c\, S$

Total downward force on point (4)

$F_{right} = P_2S + a\, \rho_B\, g/g_c\, S + d\, \rho_A\, g/g_c\, S + R\rho_C\, g/g_c\, S$

At equilibrium

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

$\therefore \quad P_1S + a\, \rho_A\, g/g_c\, S + b\, \rho_A\, g/g_c\, S = P_2S + a\, \rho_B\, g/g_c\, S + d\, \rho_A\, g/g_c\, S + R\rho_C\, g/g_c\, S$

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

$= - R\, \rho_A\, g/g_c + R\rho_C\, g/g_c$.

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

$$\boxed{\Delta P = P_1 - P_2 \quad = R\, (\rho_C - \rho_A)\, g/g_c}$$

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

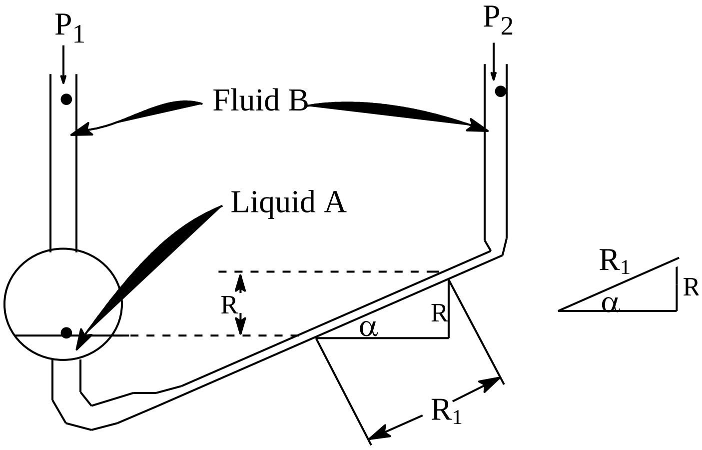


Fig. Inclined manometer

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 $\Delta P = P1 - P2$

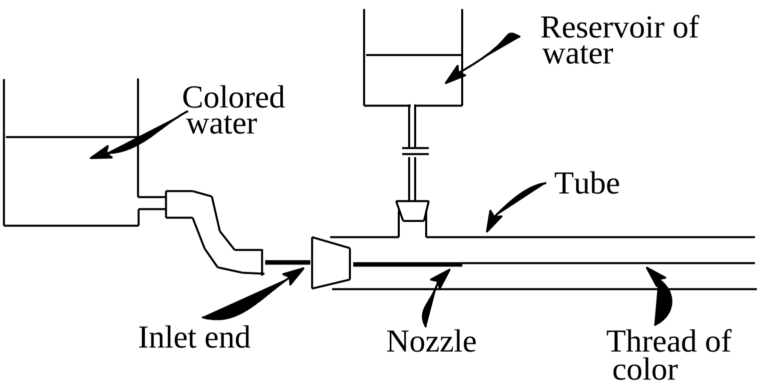
$= R\,(\rho_A - \rho_B)\, g/g_c.$

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.

FLUID DYNAMICS

Reynolds' Experiment



This experiment was performed by Osborne Reynolds in 1883. I 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**.

When the fluid motion is erratic it is called turbulent flow. 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 ($Du\rho / \mu$) . This function ($Du\rho / \mu$) 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. NRe < 2000 ⇒ viscous flow or streamline flow

NRe > 4000 ⇒ turbulent flow

Dimensional analysis of Reynolds number

$[D] = L$ (ft)

$[u] = L/\theta$ (ft / sec)

$[\rho] = M / L^3$ (lb/ft^3)

$[\mu] = M / (L\theta)$ {lb/(ft sec)}

$$\left[\frac{Du\rho}{\mu}\right] = \frac{(L)\,(L/\theta)\,(M/L^3)}{\dfrac{M}{L\theta}} = \frac{L\,L\,M\,L\,\theta}{M\,\theta\,L^3}$$

$= 1 \Rightarrow$ dimensionless group

BERNOULLI'S THEOREM

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

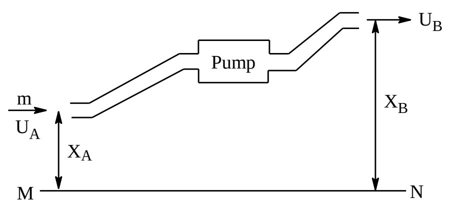


Fig. Bernoullis theorem

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).

The height of point A and B from an arbitrary datum plane (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

$$E1 = [\ mX_A + (^1/_2.\ m\ u_A^2)/\ g_C + mP_AV_A\ ]\ \text{ft-lb}_f.$$

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

$$E2 = [\ mX_B + (^1/_2.\ m\ u_B^2)/\ g_C + mP_BV_B\ ]\ \text{ft-lb}_f.$$

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, $$mX_A + (^1/_2.\ m\ u_A^2)/\ g_C + mP_AV_A + m\ w - mF = mX_B + (^1/_2.\ m\ u_B^2)/\ g_C + mP_BV_B$$

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

∴ The BERNOULLI’S THEOREM.

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

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

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

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

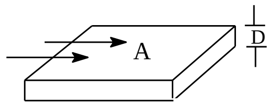
[ft]	=	L
[lb$_f$]	=	$(ML\theta^{-2}) / (L\theta^{-2}) = M$
[lb$_m$]	=	M
[ft-lb$_f$ / lb$_m$]	=	$L\cancel{M} / \cancel{M} = L$

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

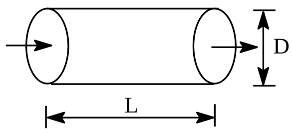
$g_c = 32.2$ $(lb_m\ ft)/(lb_f\ s^2)$

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

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

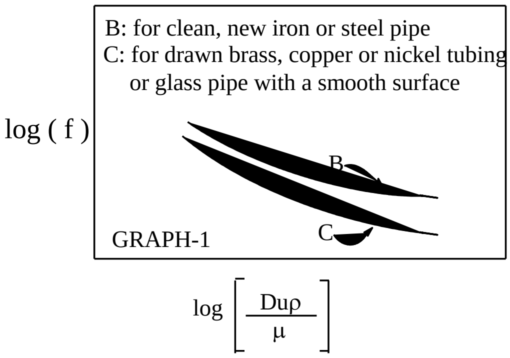
where ΔP_f = pressure drop due to friction (lb/ft^2)
F / A = resisting force ($ft\text{-}lb_f$ per ft^2 of contact area)
L = length of pipe (ft)
D = inside diameter of the pipe (ft)
ρ = density of fluid (lb_m / ft^3)
u = average velocity of fluid (ft / s)
μ = viscosity of fluid (lb_m / ft / s)
g_c =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

The graph (graph 1) is not that much accurate : Error: ± 5 to 10 % may be expected for <u>laminar flow</u>



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

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

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*

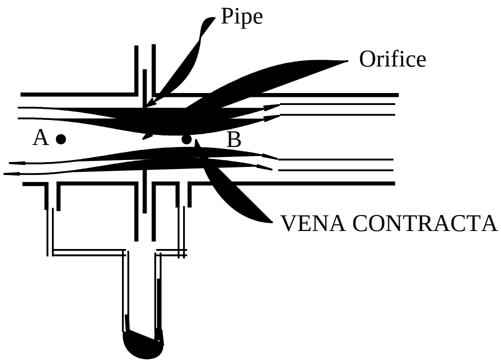
ORIFICE METER

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

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

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. $\therefore$ 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:

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

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

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

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

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.

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:

$$\sqrt{U_0^2 - U_A^2} = C_0\sqrt{2g_C\ \Delta H} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

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.

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

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

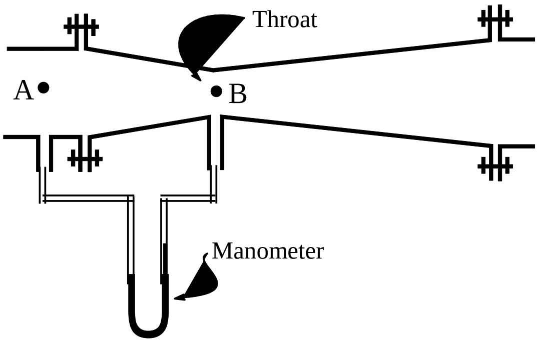
The orifice always results in a permanent loss of pressure (head), which decreases as the ratio of orifice diameter to pipe, diameter increases i.e. cost of operation, particularly for long term, is considerable.

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.

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

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) iv) Since no work is done on the liquid, or by the liquid between A and B. i.e. w = 0	$\frac{U_A^2}{2g_c} + \frac{P_A}{\rho} + w = \frac{U_B^2}{2g_c} + \frac{P_B}{\rho}$ $\frac{U_A^2}{2g_c} + \frac{P_A}{\rho_A} = \frac{U_B^2}{2g_c} + \frac{P_B}{\rho_B}$ .... (2)

Equation (2) may be written as:

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

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

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

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

> 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

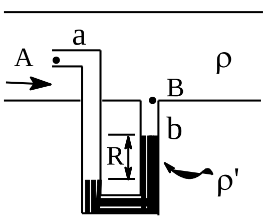


Fig 1

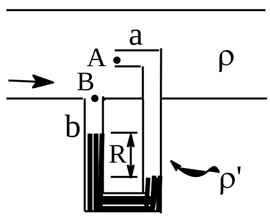


Fig 2

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).

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

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.

$$\Delta X = (\rho' - \rho)\, Rg/g_C$$

or, $\quad = (\rho' - \rho)\, R \qquad$ [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,

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

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

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

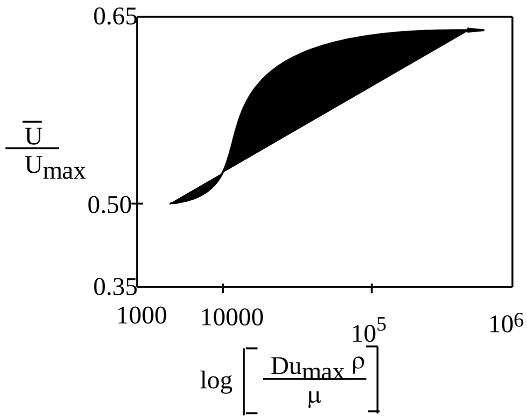
ρ = density of the fluid flowing

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.



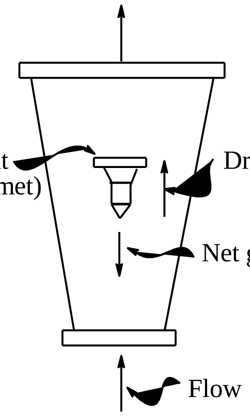
where D= diameter of the pipe
U_{max} = maximum velocity of fluid
ρ = density of the fluid flowing
μ = viscosity of the fluid flowing
U = average velocity in the pipe

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:

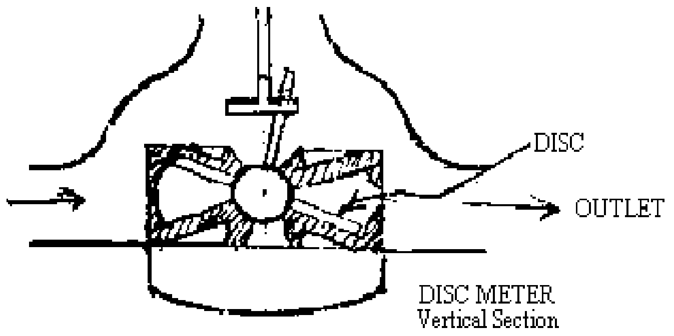
1. The flow rates can be measured directly.
2. Measured in linear scale and
3. Constant and small head loss.

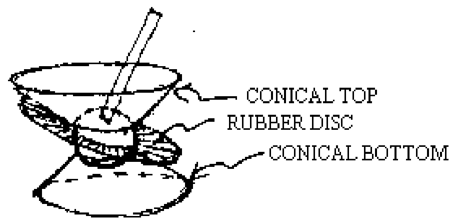
DISPLACEMENT METERS

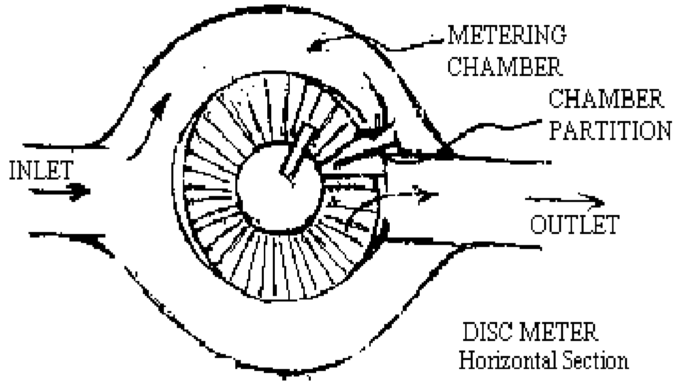
Displacement meters covers devices for measuring liquids based on the displacement of a moving member by a stream of liquid. These meters may be classified as *disc meters* and *current meters*.

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.





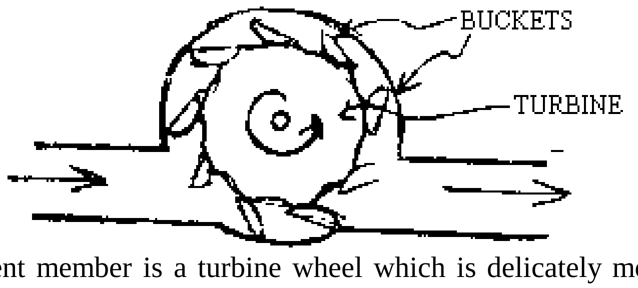


The measuring chamber has a partition that extends half way across it, and the disc has a slot to take this partition.

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.

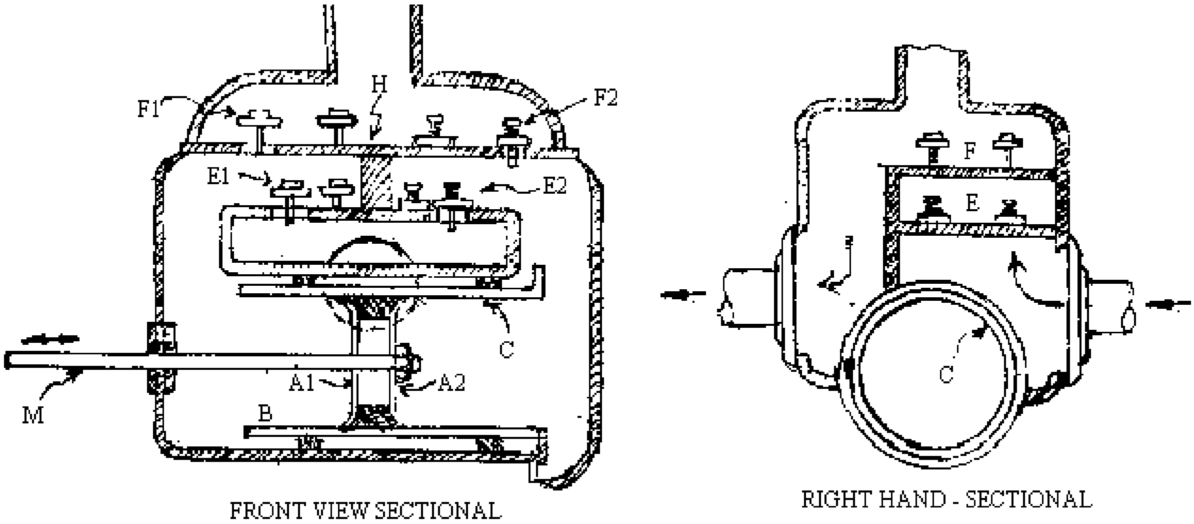
PUMPS

Reciprocating pumps: Piston, Duplex, Diaphragm
Rotary pumps: Centrifugal, Volute, Turbine, Gear

Pump is the device that moves the fluid through a pipe.
Minimum configuration of a pump: Cylinder,
piston or plunger,
power to drive the piston and
valves.

RECIPROCATING PUMPS

1. PISTON TYPE



A_1, A_2 : Piston, B: Piston packing, C: Cylinder liner, E_1, E_2: Suction valves, F_1,F_2: Discharge valves, H: Valve decks, M: Piston rod.

Construction

The pump in the figure has single water cylinder – hence called simplex pump. The pump consists:

(i) A piston consisting essentially of two discs A_1 and A_2 with rings of packing B between them. The piston operates within a removable bornze liner, C.

(ii) The lower row of valves, E_1 and E_2 are suction valves, in the upper row F_1 and F_2 are discharge valves.

(iii) The overall assembly is packed within an air-tight casing.

Operation

(i) If the piston is moving from left to right, it will create a suction on the left hand side which will open the left hand suction valves E_1 and close the left hand discharge valves F_1.

(ii) At the same time a pressure is develop on the right hand side which will close the E_2 suction valves and open F_2 discharge valves.

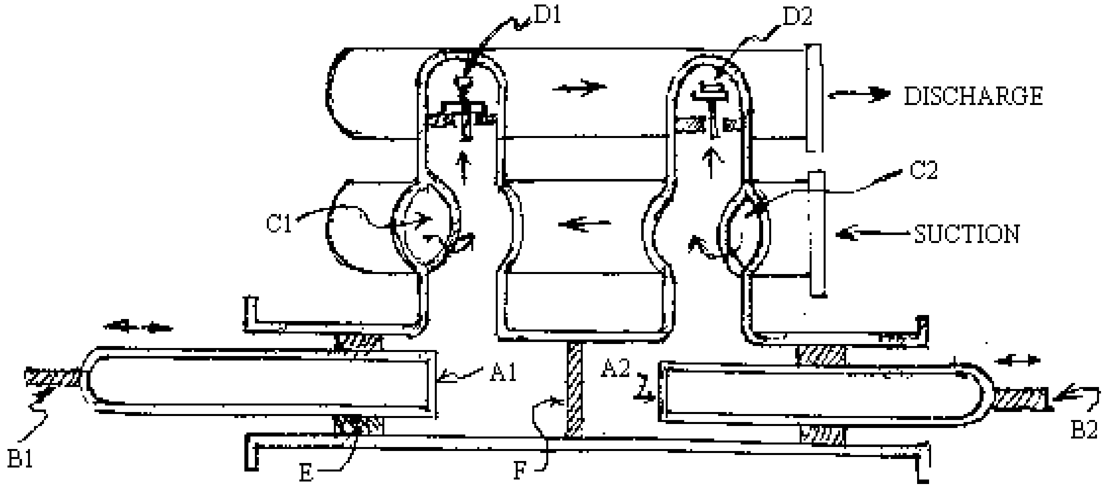
This pump is double acting , because it displaces water on both halves of the cycle.

The pump requires minimum 4 valves.

Uses

- This type of pump is suitable for pressure heads upto 150 to 200 ft and for any liquids that are not viscous, corrosive or abrasive.
- The valve type is deck valves, hence it cannot withstand very high pressure.

RECIPROCATING DUPLEX PUMP



Duplex plunger pump–longitudinal section

A_1, A_2: Water plungers, B_1,B_2: Piston rod, C_1, C_2: Suction valves, D_1, D_2: Discharge valves, E: Packing ring, F: Partition.

Construction

The pump in the figure consists of two water cylinders, hence called duplex pump. The pump consists:

(i) Two plungers are packed inside the cylinders. Two stationary packing ring in between the plungers and the cylinders.

(ii) Two suction valves, C_1,C_2 and two discharge valves D_1, D_2 are provided.

(iii) the cylinder is divided into two parts by a partition F.

Operation

(i) Both the plungers act synchronously. When left plunger A_1, is producing suction, right plunger A_2 increases the pressure.

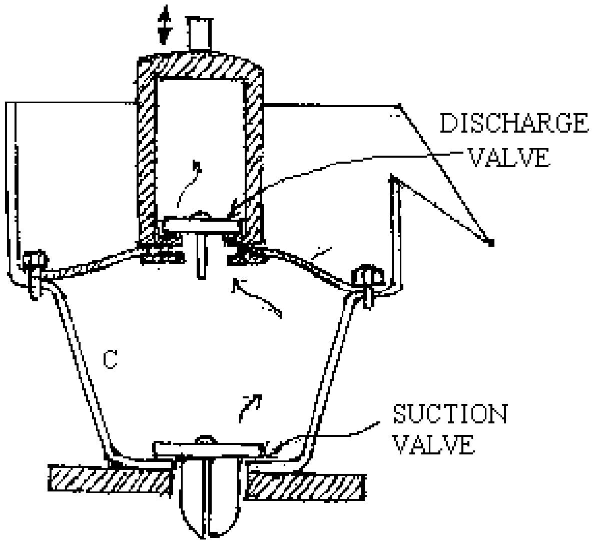
(ii) When plunger A_1 produce suction pressure, suction valve C_1 opens and discharge valve D_1 remains closed. At the same time plunger A_2 produce pressure so discharge valve D_2 opens while suction valve C_2 remains closed.

Use

(i) When pump liquids contains suspended matter that may abrade the packing so that replacement are more frequent then this type of pump is useful.

(ii) Since the valves are of pot-valve type hence can be used under high pressure.

RECIPROCATING DIAPHRAGM PUMP



Construction

In the figure of diaphragm pump instead of a piston or plunger it employs a flexible diaphragm with a discharge valve attached to the shaft the discharge valve is flap type]. it also has a suction valve.

Operation

When the shaft is moved upward the chamber C experiences partial vacuum and suction valve is opened and liquid comes in. When the shaft goes down the discharge valve opens and suction valve closes – the liquid comes out of the pump.

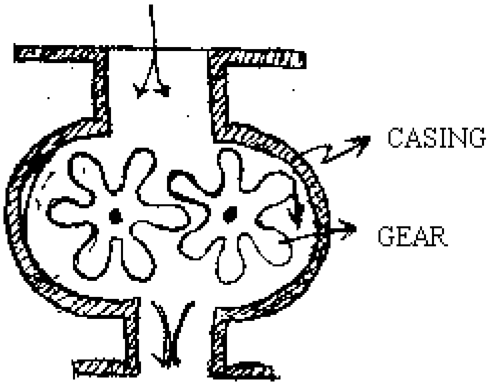
Uses / Advantages

(i) Since it has no moving parts except the flexible diaphragm and the valve, since its construction is rugged and simple and repairs are easily made, it is suited for the most severe services.
(ii) It is the most satisfactory pump available for handling liquids with large amounts of solids in suspension under low pressure.
(iii) By adjusting the diaphragm the stroke may be varied and the discharge controlled within accurate limits.

ROTARY PUMP

(i) Rotary positive displacement pump
(ii) Centrifugal pump

ROTARY POSITIVE DISPLACEMENT PUMP



Construction

The pump consists of essential two gears, which match with each other and which run in close contact with the casing. The number of teeth of the gears varies from two or more in each wheel.

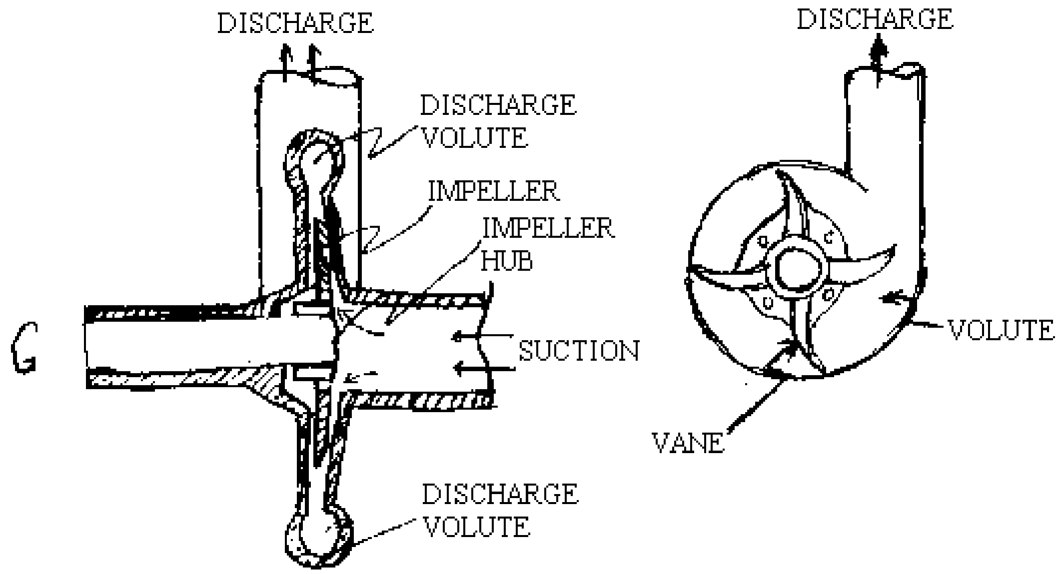
Operation

Slugs of liquids are cut between the gear teeth and the casing, carried around next to the casing and forced out through the discharge pipe.

Use

(i) Such a pump handles viscous or heavy liquids.
(ii) Since the performance of positive displacement rotary pump depends on maintaining a running fit between the rotating member and the casing it is not desirable to use this pumps on liquids that carry solids in suspension.
(iii) They are used to handle quite stiff pastes, semifluid waxes and similar material can be handled with those pumps when the speed is not too high.

CENTRIFUGAL PUMP



The main principle of these pumps is that the liquid is sucked from the centre of an impeller and thrown centrifugally upwards to the periphery from where liquid is discharged.

Centrifugal pumps are of two distinct types, *Volute type* and *Turbine type*.

Construction

The simplest form of the centrifugal pump is the single-stage single suction, open runner volute. The most important member of the centrifugal pump is the impeller or runner. This consist essentially of a series of curved vanes extending from a hub. This is maintained in the casing of the pumps in such a way that the two halves of the casing are as near by as possible in contact with the surface of these vanes.

Operations

Water entering at the suction connection is thrown outward by the rotation of the vanes. As the liquid leaves the vanes and enters the volute of the casing , the velocity is increased according to Bernoulli's theorem therefore, its pressure must be correspondingly increased and this increase in pressure is the source of the head developed by the pump.

Disadvantages

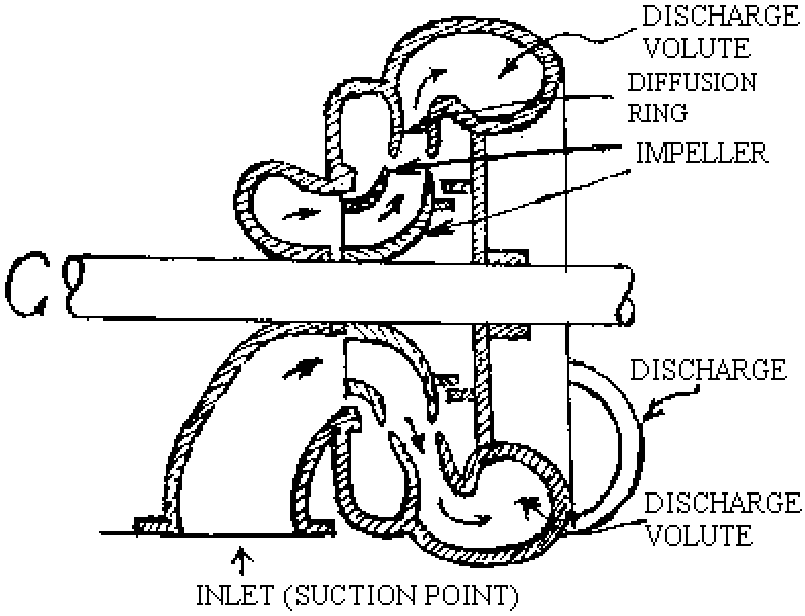
In case of open impeller system there are two main power losses:

(i) The water which was thrown out radically by the vanes must suddenly change its direction as it enters the volute. Any such sudden change in direction involves turbulence which consumes power in the form of friction.

(ii) These are cheap pumps and therefore not accurately finished. This fit between the impeller and the casing is usually poor and therefore there is leakage from the discharge side back to the suction side.

To prevent this loss by leakage from the discharge side to the suction side, the closed impeller system has bee developed. In this case the vanes of the impeller are enclosed between two rings.

TURBINE CENTRIFUGAL PUMP



Construction

Turbine pumps consists of an impeller with vanes, a diffusion ring – they are fitted in a casing. The diffusion ring is stationary. The liquid is discharged in a volute.

Operation

In case of volute pumps the principal energy loss was due to turbulence that occurs at the point where the liquid changes its path from radial flow (due to the action of the impeller) to tangential flow in the discharge volute. The diffusion ring in a turbine pump cause the liquid to make this change in direction smoothly and without shocks or eddies. The liquid issuing from the tip of the impeller is caught in these passages and turned gradually and smoothly into the discharge volute.

Use

Turbine pumps is reserved for clear, non-viscous and non-corrosive liquids.