NILASAILA INSTITUTE OF SCIENCE & TECHNOLOGY
SERGARH-756060, BALASORE (ODISHA)
(Approved by AICTE & Affiliated to SCTE&VT, Odisha)

SUBJECT–

HYDRAULICS & PNEUMATIC CONTROL

4TH SEMESTER

AUTOMOBILE ENGINEERING

NIST POLYTECHNIC BALASORE

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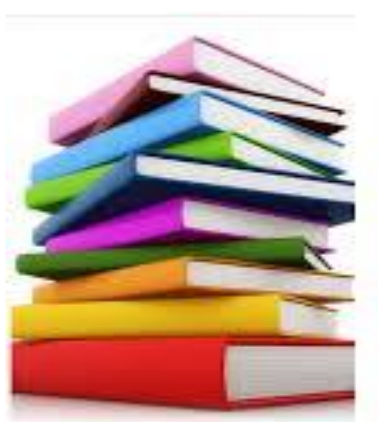

HYDRAULICS AND PNEUMATICS

BASED ON THE HYDRAULIC AND PNEUMATIC SUBJECT THIS CONTAINS MODEL QUESTIONS AND ANSWERS FROM PREVIOUS EXAMS

Fluid Properties

Fluid Properties is an important topic that has a good weightage of the questions to be asked in all mechanical engineering exams.

Ideal Fluid

Characteristics of Ideal Fluid

- Ideal fluid should be having zero viscosity and zero surface tension.
- Ideal fluid is incompressible.
- There is no ideal fluid that posses all the properties but air and water are considered an ideal fluid.

Properties of Fluid

Properties of fluid are as follows:

(1). Intensive properties:

- Intensive properties are those properties which do not dependent on mass.

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- Example: Temperature, pressure, density, Boiling and Melting point, refractive index, etc.

(2). Extensive properties

- Extensive properties are those properties that are dependent on mass.
- Example – mass, Energy, Volume, Momentum, etc.

Mass Density (ρ):

- It is the mass of fluid per unit volume at a given temperature and pressure.
- Mass density is a function of Temperature and Pressure.
- Mass density for gases is inversely proportional to temperature & directly proportional to pressure.
  Since for an ideal gas:
  $P = \rho RT$
- $$\text{Since}: \rho = \frac{m}{V} \ (kg/m^3)$$
  $$\text{Mass density } (\rho) = \frac{\text{Mass of fluid (kg)}}{\text{Volume of fluid } (m^3)}$$
  Unit: kg/m^3 or g/cc
- At 4°C and 1 atm pressure: $\rho_{water} = 1000\ kg/m^3 = 1$ g/cc

Specific Weight or Weight Density [w or r]

- Specific density is also known as weight density is defined as the ratio of the weight of the fluid to its volume.

  $$\text{Weight density (w)} = \frac{\text{Weight (N)}}{\text{Volume of fluid } (m^3)} = \frac{\text{mass}(m) \times g}{V}$$
  $$\text{Since}: \rho = \frac{m}{V} \ (kg/m^3)$$
  Thus, $w = \rho g = N/m^3$
  Where: g → acceleration due to gravity.
- w for water at 4°C and 1 atm = $1000 \times 9.8\ N/m^3 = 9.8\ kN/m^3$

Specific Volume

- Specific volume is the Reciprocal of specific mass.
- The volume of fluid per unit mass

- Unit of specific volume: $\left(\frac{m^3}{kg}\right)$

Specific Gravity or Relative Density

- Specific gravity is the ratio of the specific weight of the fluid to the specific weight of the standard fluid.

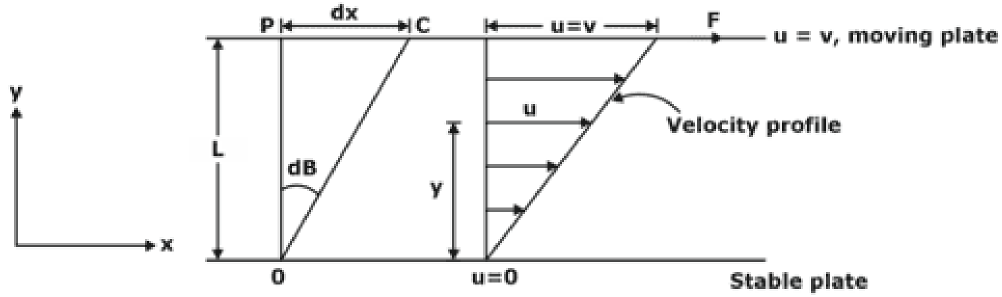
$$\text{Specific gravity} = \frac{\text{Specific weight of substance (fluid)}}{\text{Specific weight of standard fluid}}$$

- Standard fluid
  - Liquid – water at 4ºC
  - Gas – Hydrogen or Air
- Specific gravity is a dimensionless quantity.
- Relative density is the ratio of the density of a fluid to the density of another fluid (not necessarily water).
- Whereas specific gravity is the ratio of the density of a fluid to the density of the standard fluid (i.e., water at 4ºC).
- For taking water as standard fluid: $\text{Specific gravity} = \text{relative density} = \frac{\rho_f}{\rho_{water}}$

Viscosity

- Viscosity tells about the internal resistance of a fluid to its own flow.
- Viscosity is a measure of the resistance offered by a fluid layer to an adjacent layer of fluid at motion.
- Viscosity is due to the internal friction force caused by cohesive force between fluid molecules (dominant in fluid) and molecular momentum transfer between particles due to collision (dominant in gases).

Assume a system having fluid between two plates.



Note:

- Assume linear variation of velocity
- dβ = Angle of deformation during 'dt'

- Velocity at distance y from the bottom plate $u(y) = \left(\frac{y}{L}\right).V$

  $$\frac{u}{y} = \frac{V}{L}$$

- If consider infinite small element then velocity gradient= $\frac{du}{dy} = \frac{V}{L}$ ....(a)
- Displacement of fluid element at p to c during small time interval dt :
  dx = Vdt .... (b)

  $$\tan(d\beta) \approx d\beta = \frac{dx}{L}$$

  Put the value of dx from equation (b):

  $$d\beta = v\frac{dt}{L}$$

  Now replace V from equation (a):

$$d\beta = \frac{du}{dy} \times dt$$

$$\frac{d\beta}{dt} = \frac{du}{dy} \quad ....(1)$$

- Angular deformation rate is equal to the velocity gradient.

According to Newton

- Rate of deformation is proportional to shear stress, so:

$$\tau \propto \frac{d\beta}{dt}$$

Now, from equation (1):

$$\tau \propto \frac{du}{dy}$$

$$\tau = \mu \frac{du}{dy}$$

- μ → Absolute viscosity or Dynamic viscosity or Coefficient of viscosity.
- **Unit:**

$$\tau\left(\frac{N}{m^2}\right) = \mu \frac{du\left(\frac{m}{s}\right)}{dy\,(m)}$$

$$\mu = \frac{\tau\left(\frac{N}{m^2}\right) \times dy(m)}{du\left(\frac{m}{s}\right)} = \frac{N-s}{m^2}$$

Resultant Unit: $\frac{N-s}{m^2}$ or $\frac{kg}{m-s}$

Note: Viscosity of water at 20°C = **1 centipoise**

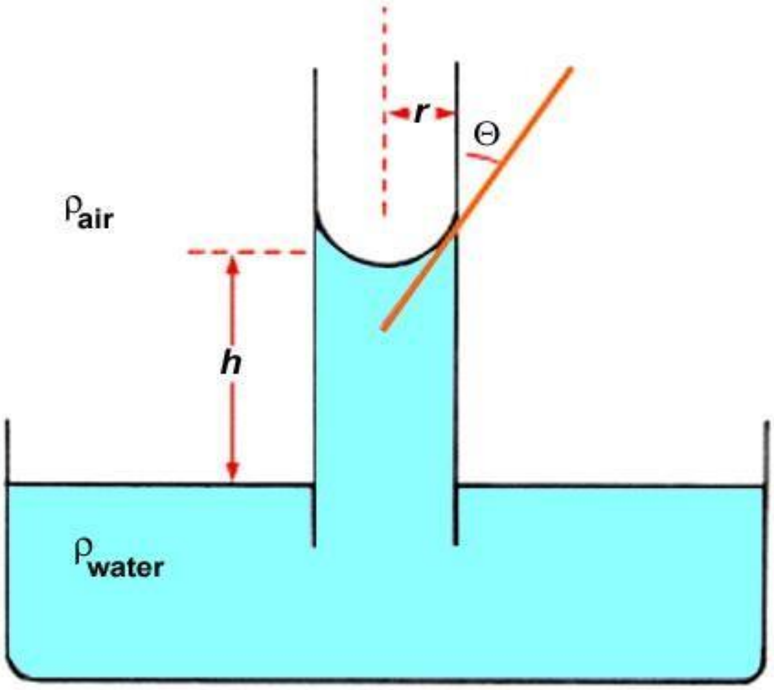
- Poise is a CGS unit: poise = Dyne-s/cm^2

$$1\,\text{poise} = \frac{1}{10}\left(\frac{N-s}{m^2} \text{ or } \frac{kg}{m-s}\right)$$

CAPILLARITY

- Capillarity is defined as a phenomenon of rise or fall of a liquid surface in small tube relative to the adjacent general level of liquid when the tube is held vertically in the liquid. The rise ofliquid surface is known as capillary rise while the fall of liquid surface is known as capillary depression. It is expressed in terms of cm or mm of liquid. Its value depends upon thespecific weight of the liquid, diameter of the tube and surface tension of the liquid

Basically the fluids are classified into 5 types and these are



1. Ideal fluid
2. Real fluid
3. Newtonian fluid
4. Non-Newtonian fluid, and
5. Ideal plastic fluid

1. Ideal Fluid:

A fluid which can not be compressed and have no viscosity falls in the category of ideal fluid. Ideal fluid is not found in actual practice but it is an imaginary fluid because all the fluid that exist in the environment have some viscosity. There is in no ideal fluid in reality.

2.Real Fluid:

A fluid which has at least some viscosity is called real fluid. Actually all the fluids existing orpresent in the environment are called real fluids. for example water.

3.Newtonian Fluid:

If a real fluid obeys the Newton's law of viscosity (i.e the shear stress is directly proportionalto the shear strain) then it is known as the Newtonian fluid.

If real fluid does not obeys the Newton's law of viscosity then it is called Non-Newtonianfluid.

4.Ideal Plastic Fluid:

A fluid having the value of shear stress more than the yield value and shear stress isproportional to the shear strain (velocity gradient) is known as ideal plastic fluid

Non-Newtonian Fluid

Measurement of pressure

MANOMETER

A manometer is an instrument that uses a column of liquid to measure pressure, although the term is currently often used to mean any pressure instrument.

Two types of manometer, such as

1. Simple manometer
2. Differential manometer

The U type manometer, which is considered as a primary pressure standard, derives pressure utilizing the following equation:

$P = P2 - P1 = h\omega \rho g$ Where:

P = Differential pressure

P1 = Pressure applied to the low pressure connection P2 = Pressure applied to the high pressure connection

$h\omega$ = is the height differential of the liquid columns between the two legs of the manometer ρ = mass density of the fluid within the columns

g = acceleration of gravity

SIMPLE MANOMETER

A simple manometer consists of a glass tube having one of its ends connected to a point where pressure is to be measured and other end remains open to atmosphere. Common types of simple manometers are:

1.Piezometer

2.U tube manometer 3.Single Column manometer

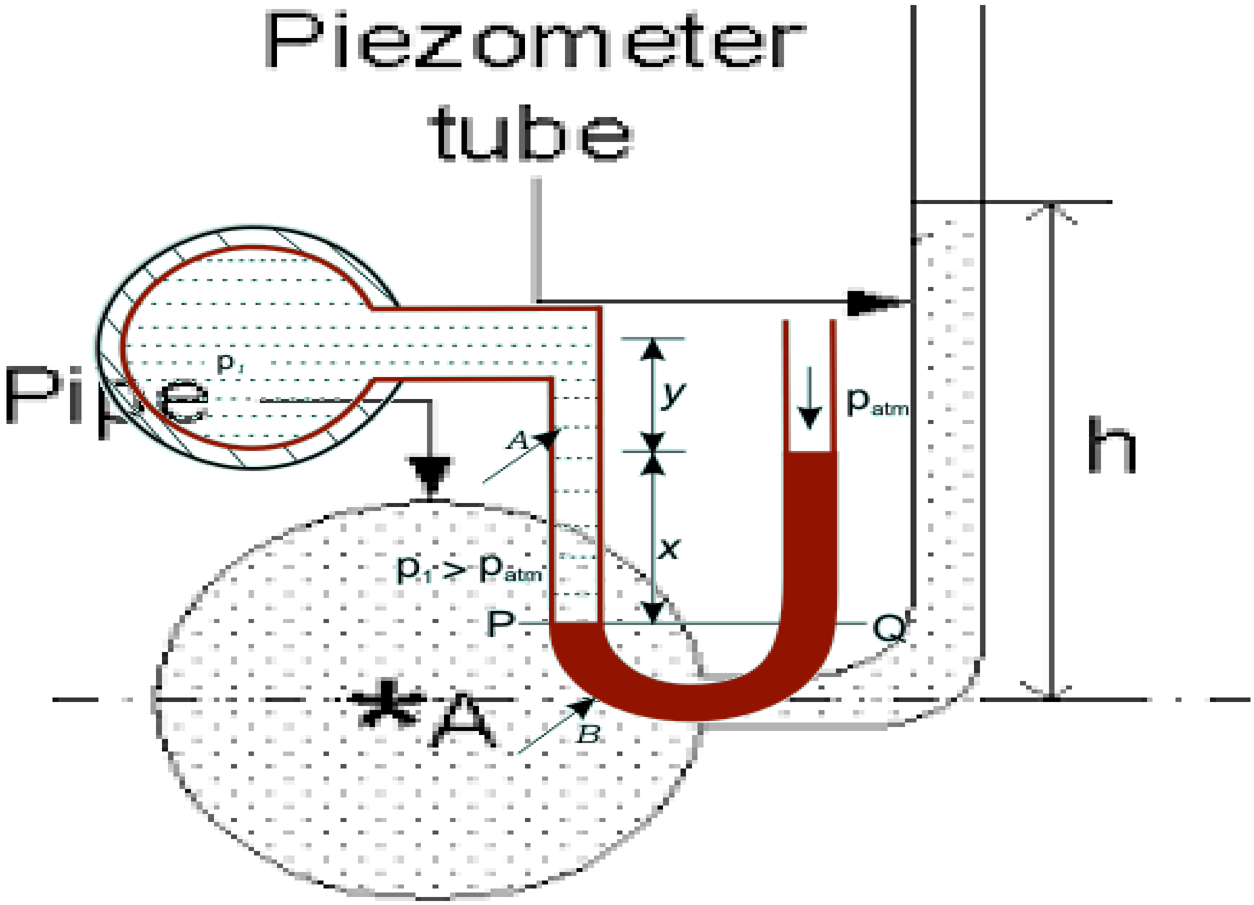
PIEZOMETER

A piezometer is either a device used to measure liquid pressure in a system by measuring the height to which a column of the liquid rises against gravity, or a device which measures the pressure (more precisely, the piezometric head) of groundwater at a specific point. A

piezometer is designed to measure static pressures, and thus differs from a pitot tube by not being pointed into the fluid flow.

U TUBE MANOMETER

Manometers are devices in which columns of a suitable liquid are used to measure the difference in pressure between two points or between a certain point and the atmosphere.



Manometer is needed for measuring large gauge pressures. It is basically the modified form of the piezometric tube. A common type manometer is like a transparent "U-tube" as shown in Fig.

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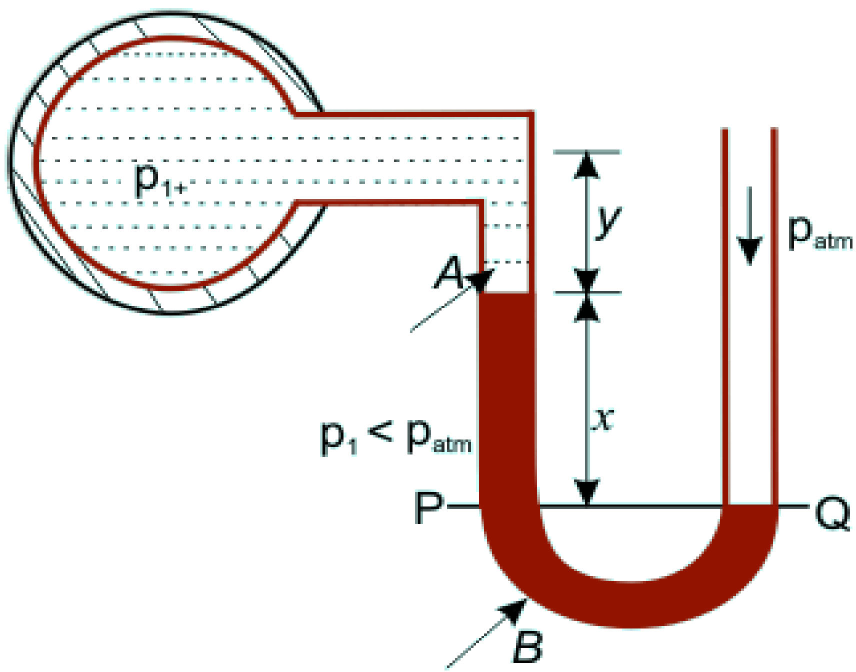


DIFFERENTIAL MANOMETER

Differential Manometers are devices used for measuring the difference of pressure between two points in a pipe or in two different pipes . A differential manometer consists of a U-tube, containing a heavy liquid, whose two ends are connected to the points, which difference of pressure is to be measure.

Most commonly types of differential manometers are:

1- U-tube differential manometer.

2- Inverted U-tube differential manometer

U-tube differential manometer For two pipes are at same levels:- PA-PB=h.g(pg-p1)

Where:

P1=density of liquid at A=density of liquid at B. For two pipes are in different level:-

PA- PB= h.g (pg-p1) + p2 gy- p1 gx

Where:

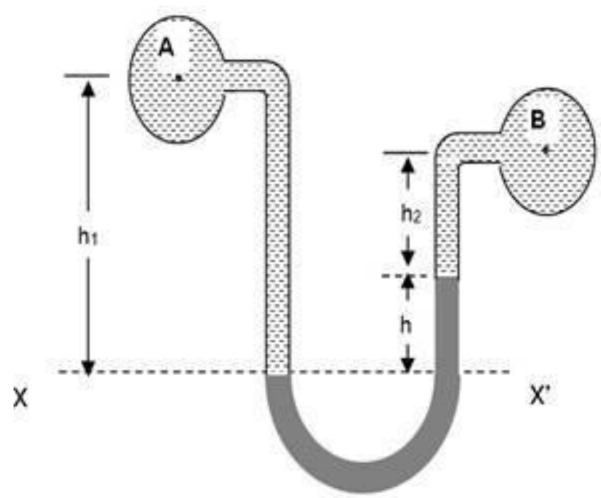
h = difference in mercury level in the U-tube

y = distance of the centre of B, from the mercury level in the right limb.

x = distance of the centre of A, from the mercury level in the left limb. P1=density of liquid at A.

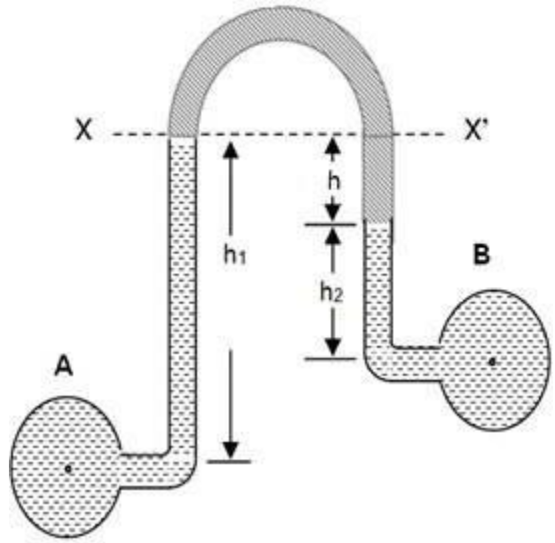
p2=density of liquid at B.

pg=density of mercury (heavy liquid)



Inverted U-tube differential manometer

It consists of inverted U-tube, containing a light liquid. The two ends of the tube are connected to the points whose difference of pressure is to be measured. It is used for measuring differences of low pressures



PA –PB =ρ1*g*h1 - ρ2 *g*h2 -ρs*g*h Where;

h1 = height of liquid in left limb below the datum line h2 = height of liquid in right limb

h=difference of light liquid

ρ1 =density of liquid at A

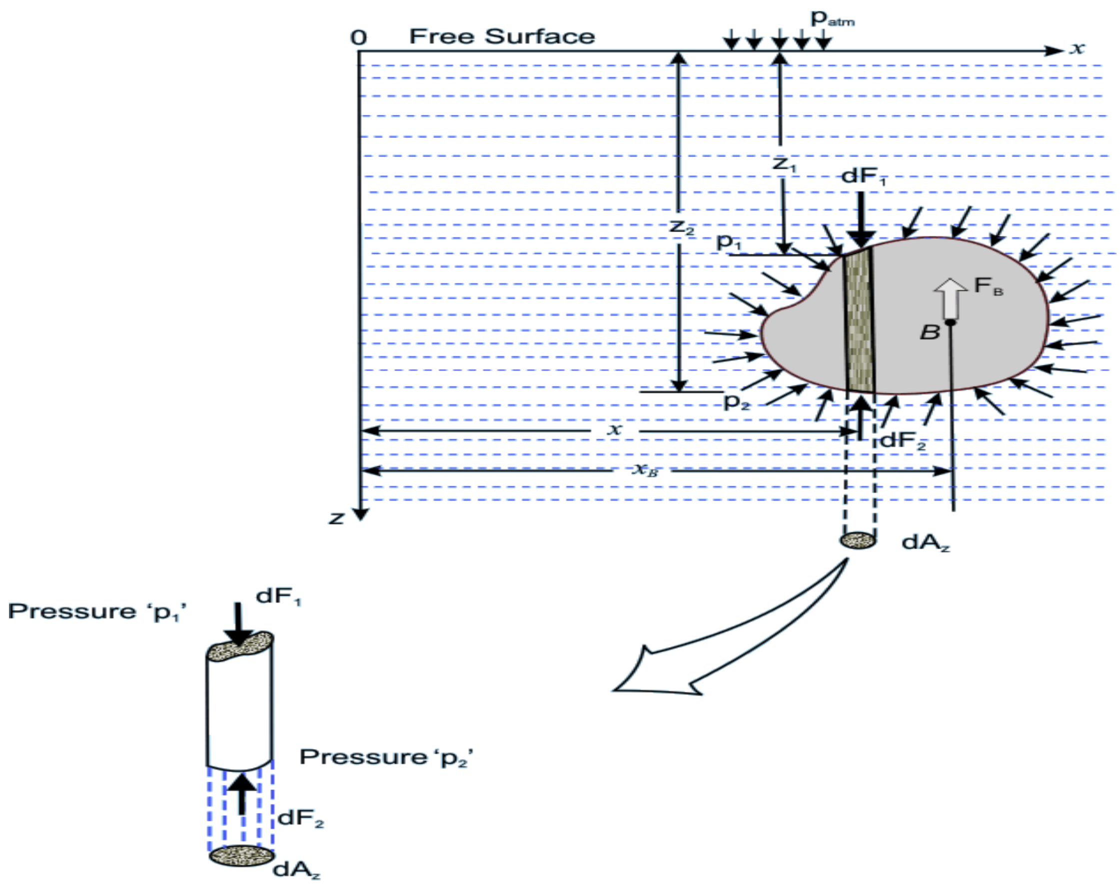
ρ2 =density of liquid at B

ρs =density of light liquid PA =pressure at A

Buoyancy

- When a body is either wholly or partially immersed in a fluid, a lift is generated due to the net vertical component of hydrostatic pressure forces experienced by the body.
- This lift is called the buoyant force and the phenomenon is called buoyancy

Consider a solid body of arbitrary shape completely submerged in a homogeneous liquid as



shown in Fig. Hydrostatic pressure forces act on the entire surface of the body.

Stability of Floating Bodies in Fluid

When the body undergoes an angular displacement about a horizontal axis, the shape of the immersed volume changes and so the centre of buoyancy moves relative to the body.

As a result of above observation stable equilibrium can be achieved, under certain condition, even when G is above B. Fig illustrates a floating body -a boat, for example, in its equilibrium position

Important points to note here are

a. The force of buoyancy FB is equal to the weight of the body W

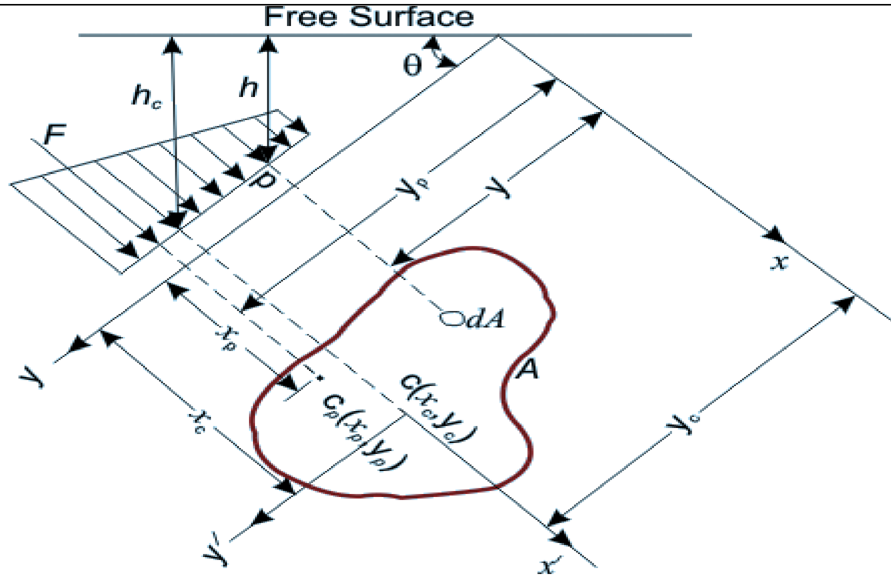
b. Centre of gravity G is above the centre of buoyancy in the same vertical line.

c. Figure b shows the situation after the body has undergone a small angular displacement q with respect to the vertical axis.

d. The centre of gravity G remains unchanged relative to the body (This is not always true for ships where some of the cargo may shift during an angular displacement).

e. During the movement, the volume immersed on the right hand side increases while that on the left hand side decreases. Therefore the centre of buoyancy moves towards the right to its new position B'.

Let the new line of action of the buoyant force (which is always vertical) through B' intersects the axis BG (the old vertical line containing the centre of gravity G and the old centre of buoyancy B) at M. For small values of q the point Impractically constant in position and is known as metacentre. For the body shown in Fig. M is above G, and the couple acting on the body in its displaced position is a restoring couple which tends to turn the body to its original position. If M were below G, the couple would be an overturning couple and the original equilibrium would have been unstable. When M coincides with G, the body will assume its new position without any further movement and thus will be in neutral equilibrium. Therefore, for a floating body, the stability is determined not simply by the relative position of B and G,ratherby the relative position of M and G. The distance of



Let p denotes the gauge pressure on an elemental area dA. The resultant force F on the area A is therefore

Where h is the vertical depth of the elemental area dA from the free surface and the distance y is measured from the x-axis, the line of intersection between the extension of the inclined plane and the free surface (Fig.). The ordinate of the centre of area of the plane surface A is defined as

we get

where is the vertical depth (from free surface) of centre c of area .

Hydrodynamics

Bernoulli's law

Up to now the focus has been fluids at rest. This section deals with fluids that are in motion in a steady fashion such that the fluid velocity at each given point in space is not changing with time. Any flow pattern that is steady in this sense may be seen in terms of a set of streamlines, the trajectories of imaginary particles suspended in the fluid and carried along with it. In steady flow, the fluid is in motion but the streamlines are fixed. Where the streamlines crowd together, the fluid velocity is relatively high; where they open out, the fluid becomes relatively stagnant.

When Euler and Bernoulli were laying the foundations of hydrodynamics, they treated the fluid as an idealized inviscid substance in which, as in a fluid at rest in equilibrium, the shear stresses associated with viscosity are zero and the pressure p is isotropic. They arrived at a simple law relating the variation of p along a streamline to the variation of v (the principle is credited to Bernoulli, but Euler seems to have arrived at it first), which serves to explain many of the phenomena that real fluids in steady motion display. To the inevitable question of when and why it is justifiable to neglect viscosity, there is no single answer. Some answers will be provided later in this article, but other matters will be taken up first. Consider a small element of fluid of mass m, which—apart from the force on it due to gravity—is acted on only by a pressure p. The latter is isotropic and does not vary with time but may vary from point to point in space. It is a well-known consequence of Newton's laws of motion that, when a particle of mass m moves under the influence of its weight mg and an additional force F from a point P where its speed is vP and its height is zP to a point Q where its speed is vQ and its height is zQ, the work done by the additional force is equal to the increase in kinetic and potential energy of the particle—i.e., that

Equation.

In the case of the fluid element under consideration, F may be related in a simple fashion to the gradient of the pressure, and one finds

Equation.

Continuity Equation Derivation

Continuity equation represents that the product of cross-sectional area of the pipe and the fluid speed at any point along the pipe is always constant. This product is equal to the volume flow per second or simply the flow rate. The continuity equation is given as:

$R = A v = \text{constant}$

Where,

R is the volume flow rate

A is the flow area

v is the flow velocity

Assumption of Continuity Equation

Following are the assumptions of continuity equation:

The tube is having a single entry and single exit

The fluid flowing in the tube is non-viscous

The flow is incompressible

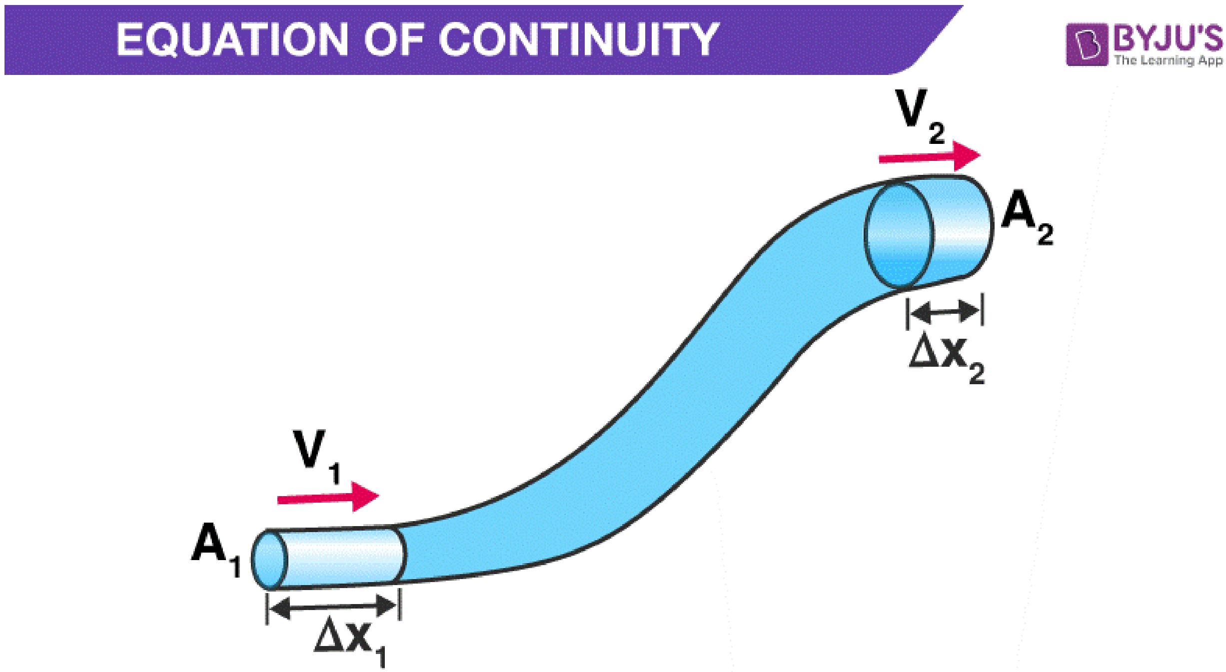
The fluid flow is steady

Related Article:

Bernoulli's Principle

Derivation

Consider the following diagram:



Now, consider the fluid flows for a short interval of time in the tube. So, assume that short interval of time as Δt. In this time, the fluid will cover a distance of Δx1 with a velocity v1 at the lower end of the pipe.

At this time, the distance covered by the fluid will be:

$\Delta x1 = v1\Delta t$

Now, at the lower end of the pipe, the volume of the fluid that will flow into the pipe will be:

$V = A1\ \Delta x1 = A1\ v1\ \Delta t$

It is known that mass (m) = Density (ρ) × Volume (V). So, the mass of the fluid in Δx1 region will be:

$\Delta m1$= Density × Volume

=> $\Delta m1 = \rho 1A1v1\Delta t$ ——–(Equation 1)

Now, the mass flux has to be calculated at the lower end. Mass flux is simply defined as the mass of the fluid per unit time passing through any cross-sectional area. For the lower end with cross-sectional area A1, mass flux will be:

$\Delta m1/\Delta t = \rho 1A1v1$ ——–(Equation 2)

Similarly, the mass flux at the upper end will be:

$\Delta m2/\Delta t = \rho 2A2v2$ ——–(Equation 3)

Here, v2 is the velocity of the fluid through the upper end of the pipe i.e. through $\Delta x2$, in Δt time and A2, is the cross-sectional area of the upper end.

In this, the density of the fluid between the lower end of the pipe and the upper end of the pipe remains the same with time as the flow is steady. So, the mass flux at the lower end of the pipe is equal to the mass flux at the upper end of the pipe i.e. Equation 2 = Equation 3.

Thus,

$\rho 1A1v1 = \rho 2A2v2$ ——–(Equation 4)

This can be written in a more general form as:

$\rho A v$ = constant

The equation proves the law of conservation of mass in fluid dynamics. Also, if the fluid is incompressible, the density will remain constant for steady flow. So, $\rho_1 = \rho_2$.

Thus, Equation 4 can be now written as:

Bernoulli's Principle

Bernoulli's principle states that

The total mechanical energy of the moving fluid comprising the gravitational potential energy of elevation, the energy associated with the fluid pressure and the kinetic energy of the fluid motion, remains constant. Bernoulli's principle can be derived from the principle of conservation of energy.

Bernoulli's Principle Formula

Bernoulli's equation formula is a relation between pressure, kinetic energy, and gravitational potential energy of a fluid in a container.

The formula for Bernoulli's principle is given as:

p +

$\rho v2 + \rho gh$ =consta

Where,

p is the pressure exerted by the fluid

v is the velocity of the fluid

ρ is the density of the fluid

h is the height of the container

Bernoulli’s equation gives great insight into the balance between pressure, velocity and elevation.

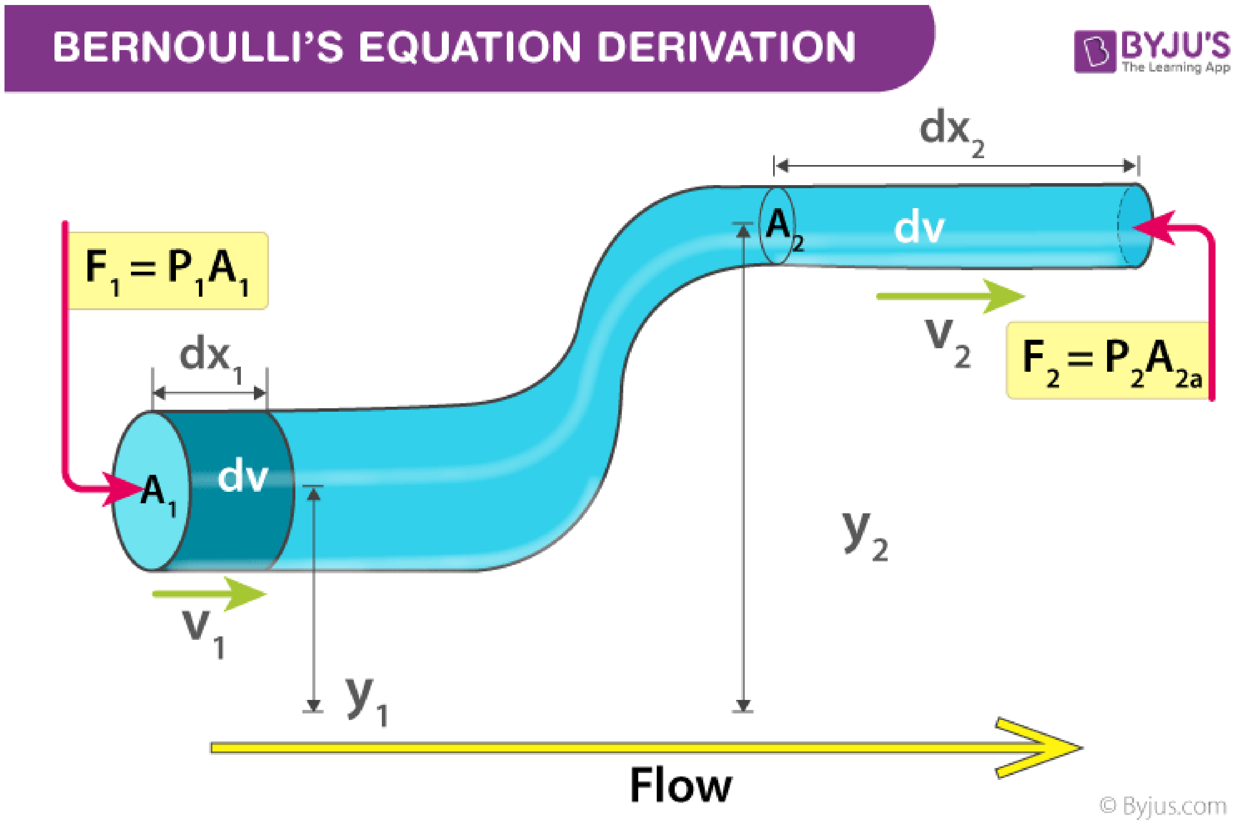
Related Articles:

Fluid Dynamics

Continuity Equation

Bernoulli’s Equation Derivation

Consider a pipe with varying diameter and height through which an incompressible fluid is flowing. The relationship between the areas of cross-sections A, the flow speed v, height from the ground y, and pressure p at two different points 1 and 2 is given in the figure below.



Consider the fluid initially lying between B and D. In an infinitesimal timeinterval Δt, this fluid would have moved.

Suppose v1= speed at B and v2= speedat D, initial distance moved by fluid from to C=v1Δt.

In the same interval Δtfluid distance moved by D to E = v2Δt.

P1= Pressureat A1, P2=Pressure at A2.

Work done on the fluid atleft end (BC) W1 = P1A1(v1Δt).

Work done by the fluid at the other end (DE)W2 = P2A2(v2Δt)

Net work done on the fluid is W1 – W2 = (P1A1v1Δt– P2A2v2Δt)

By the Equation of continuity Av=constant.

P1A1 v1Δt - P2A2v2Δt where A1v1Δt =P1ΔV and A2v2Δt = P2ΔV.

Therefore Work done = (P1– P2) ΔVequation (a)

Part of this work goes in changing Kinetic energy, ΔK = (½)m (v22 – v12) and part in gravitational potential energy,ΔU =mg (h2 – h1).

The total change in energy $\Delta E = \Delta K + \Delta U = (½)\ m\ (v22 – v12) + mg\ (h2 − h1)$. (i)

Density of the fluid $\rho = m/V$ or $m = \rho V$

Therefore in small interval of time Δt, small change in mass Δm

$\Delta m = \rho \Delta V$ (ii)

Putting the value from equation (ii) to (i)

$\Delta E = 1/2\ \rho \Delta V\ (v22 – v12) + \rho g \Delta V\ (h2 − h1)$ equation(b)

By using work-energy theorem: $W = \Delta E$

From (a) and (b)

$(P1-P2)\ \Delta V = (1/2)\ \rho \Delta V\ (v22 – v12) + \rho g \Delta V\ (h2 − h1)$

$P1-P2 = 1/2\rho v22 - 1/2\rho v12 + \rho gh2 - \rho gh1$(By cancelling ΔV from both the sides).

After rearranging we get,$P1 + (1/2)\ \rho\ v12 + \rho g\ h1 = (1/2)\ \rho\ v22 + \rho g\ h2$

$P + (1/2)\ \rho v2 + \rho g\ h$ = constant.

Bernoulli's equation: Special Cases

When a fluid is at rest. This means $v1 = v2 = 0$.

From Bernoulli's equation $P1 + (1/2)\ \rho\ v12 + \rho g\ h1 = (1/2)\ \rho\ v22 + \rho g\ h2$

By putting$v1 = v2 = 0$ in the above equation changes to

$P1-P2 = \rho g(h2-h1)$. This equation is same as when the fluids are at rest.

When the pipe is horizontal.$h1 = h2$.This means there is no Potential energy by the virtue of height.

Therefore from Bernoulli's equation($P1 + (1/2)\ \rho\ v12 + \rho g\ h1 = (1/2)\ \rho\ v22 + \rho g\ h2$)

By simplifying,$P + (1/2)\ \rho\ v2$ = constant.

Problem:-

Water flows through a horizontal pipeline of varying cross-section.If the pressure of waterequals 6cm of mercury at a point where the velocity of flow is 30cm/s, what is the pressure at the another point where the velocity of flow is 50m/s?

Answer:-

At R1:- v_1 = 30cm/s =0.3m/s

$P_1=\rho g\ h=6x10^{-2}x13600x9.8=7997N/m^2$

At R2:- v_2=50cm/s=0.5m/s

From Bernoulli's equation: - $P+ (1/2)\ \rho\ v^2+\rho g\ h=constant$

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

$7997+1/2x\ 1000x\ (0.3)^2 = P_2+1/2x\ 1000x\ (0.5)^2$

$P_2=7917N/m^2$

$=\rho g\ h_2 = h_2x13600x9.8$

h_2 = 5.9cmHg.

A centrifugal pump acts as a reversed turbine except that in this device special modifications are made to increase the efficiency. Centrifugal pumps are all of the outward flow type, where the radial velocity of water is increased by centrifugal action caused by the rotating vanes. It is necessary that the pump has to be full of water when starting it and hence, it should not be left to drain. External power is used to turn the vanes which gives a centrifugal head to the water collected in the pump.

This water is forced to leave the moving vanes at the outer periphery at a high velocity and pressure. This creates a partial vacuum in the centre of the pump and accordingly, the water from the suction pipe flows into it. It is the high pressure of the water leaving the vanes, which is utilized to overcome the delivery head of the pump. In the pumps made in the earlier years, the kinetic energy of the water leaving the vanes was not utilized and there used to be considerable loss of energy in the formation of eddies in the surrounding circular chamber.

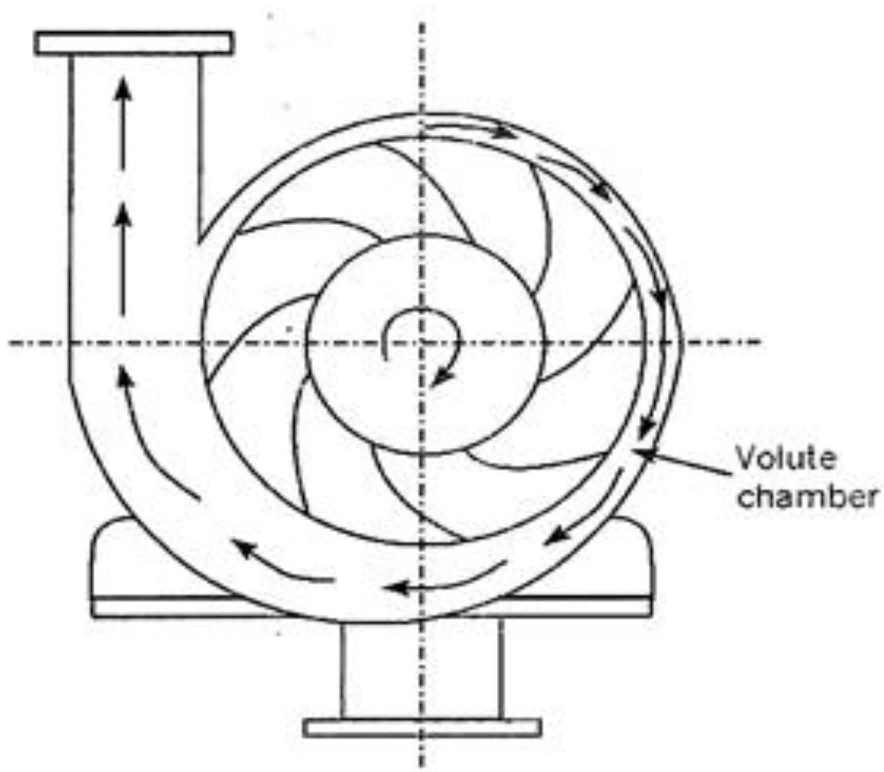


Fig. 24.1. Centrifugal pump with volute chamber.

In the later models, this defect has been rectified by converting the kinetic energy into pressure energy by making the water leaving the vanes, flow through a passage of gradually increasing area. The increase in the pressure head brought about in this manner is utilized in increasing the delivery head to the pump, thereby the efficiency of the pump is increased.

Generally, centrifugal pumps are made of the radial flow type only. But there are also axial flow or propeller pumps which are particularly adopted for low heads

The following are the methods used to convert the kinetic energy of the water leaving the vanes into pressure energy:

(i) The Volute Chamber:

The volute chamber is a spiral casing surrounding the wheel which is also called the impeller. The water which leaves the vanes is directed to move in the volute chamber circumferentially. The area of the volute chamber increases gradually and hence, the velocity gets decreased accompanied by corresponding increase of pressure.

As the water reaches the delivery pipe, a considerable part of kinetic energy is converted into pressure energy. Observations however have shown that in this arrangement the efficiency of the pump is increased only slightly. This means eddies are not completely avoided and some loss of energy takes place in the eddies due to the continually increasing quantity of water passing through the volute chamber.

(ii) Vortex or Whirlpool Chamber:

This is an improvement over the ordinary volute chamber. In this case, the impeller is surrounded by a chamber by combining a circular chamber and a spiral chamber. See Fig. 24.2. In this arrangement the efficiency is increased considerably

These are fixed vanes which receive the water leaving the moving vanes. The guide vanes provide a gradually increasing area of flow leading to decrease of kinetic energy and increase of pressure energy. A pump with such receiving guide vanes is called a turbine pump. The angles of the guide vanes at their receiving tips are such that the water enters the guides without shock. The guides are fixed over a circular ring. The ring with the guide blades is called a diffuser. The pump is also provided with a volute chamber which directs the water to the delivery pip

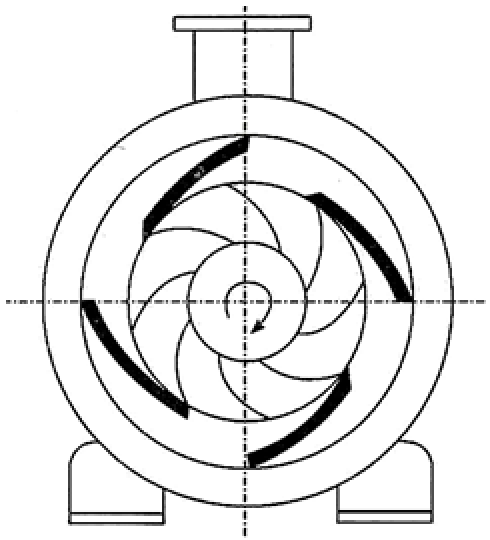
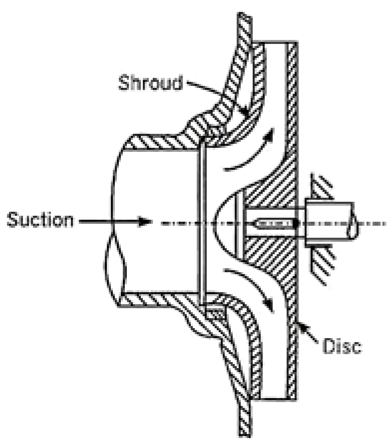


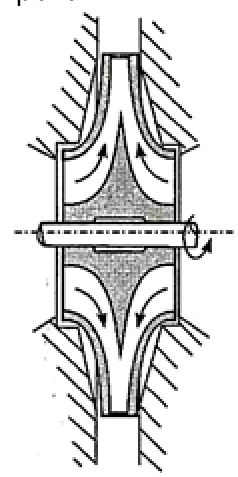
Fig. 24.3. Centrifugal pump with guide blades.

Single Suction and Double Suction Impellers:

Impellers may be single suction impellers or double suction impeller



(a) Single suction Impeller.



(b) Double suction Impeller.

Fig. 24.4.

In a single suction impeller water enters at one side of the casing only. But in a double suction impeller, water enters the impeller on both sides of the casing. This type of impeller can accommodate a large rate of flow. While in the case of a single suction impeller, due to entry of water on one side of the casing only, a lateral thrust is transmitted to the impeller. But in a double suction impeller, the thrusts act on both sides of the impeller and are balanced.

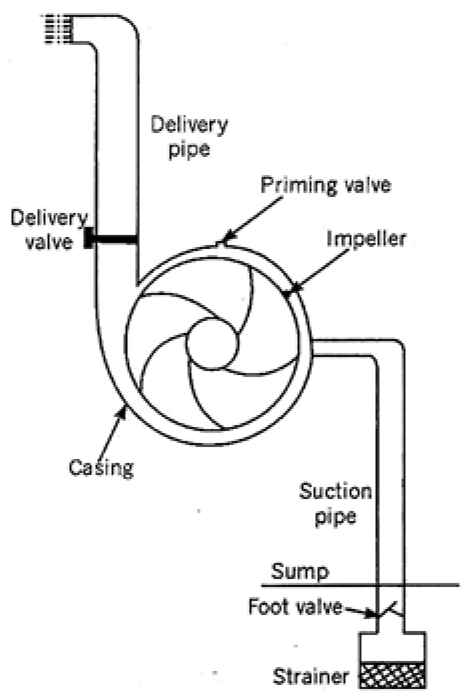
i. The Suction Pipe:

This is a pipe connecting the pump and the inlet of the pump. A non-return valve is provided at the lower end of this pipe. This valve does not allow the water to drain out of the pipe, when the pump is not running. By containing the water in the suction pipe, it assists in priming.
Generally, the lower end of the pipe is also provided with a strainer which allows only clear water into the pipe. The upper end of this pipe is connected to the inlet of the impeller and this section is called the eye of the pump. This pipe is called the suction pipe since the pressure in this pipe is below the atmospheric pressure.

To avoid cavitation the negative pressure at the pump inlet is maintained within limits. Obviously, from this consideration, the height of the suction pipe above the sump water level is kept as small as possible. Again, from this consideration the diameter of the suction pipe is made large. To prevent pressure drops bends should be avoided in the suction pipe. Due to larger diameter provided, the velocity in the suction pipe is lowered and accordingly, the loss of head due to friction in the pipe is minimized.

ii. The Delivery Pipe:

This is a pipe connecting the pump outlet to the delivery end or delivery reservoir. A delivery valve is provided with strainer near the outlet of the pump, in order to regulate the flow into the delivery pipe



iii. The Foot Value:

Fig. 24.5. The Centrifugal pump.

This is a one way valve allowing the liquid to flow only from the sump to the suction pipe. This valve is fitted at the lower end of the suction pipe and is permanently positioned well below the lowest sump water level. As this valve does not allow backward flow, it retains the water in the suction pipe when the pump is not in operation.

Strainer:

A strainer or screen is provided to the foot valve to prevent any suspended solid material from entering the suction pipe.

Priming of the Pump:

The centrifugal head generated in the pump is proportional to the specific weight of the fluid which fills the passage. If the impeller contains only air, the rotation of the-air mass can produce only a small centrifugal head. Hence, in order to operate the pump it is necessary that the pump should be filled with the liquid to be pumped. After the pump is filled with the liquid, the impeller should be rotated.

This process is called priming of the pump. Generally, priming is done by introducing the liquid into the impeller through a funnel provided. As the liquid fills the impeller, the air present in it will escape through the airvent valve. After all the air in the impeller and the casing is removed, the airvent valve is closed and the pump can be run.

The Analysis of the Pump:

The analysis of the pump is made similar to that of a radial flow turbine. The inlet and outlet diagrams are drawn as usual.

(*i*) *The vector diagrams* : Fig. 24.7 shows the inlet and outlet diagrams. The shape of the vanes is usually such that the flow at inlet is entirely radial, *i.e.*, the whirl component of the velocity at inlet is zero. Note the nomenclature for the inlet angle θ which is taken as the interior angle in the inlet diagram. Since the flow at inlet is entirely radial it follows $V_w = 0$ and $V = V_f$

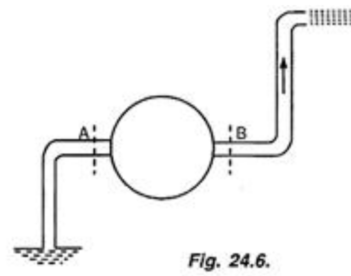


Fig. 24.6.

In all the cases, the outlet diagram is such that whirl component of the velocity at outlet is in the direction of motion of the vanes.

The velocity of whirl at outlet

$$= V_{w1} = v_1 - V_{f1} \cot \phi$$

where v_1 = peripheral velocity at outlet.

(*ii*) *Work done per second by the impeller* : In the case of the pump work is done by the impeller on the water. Since there is no whirl component at inlet, the work done per second by the impeller per *N* of water $\frac{V_{w1} v_1}{g}$. This is also the energy head generated by the impeller.

(*iii*) *The Manometric Head H_m.* This is the head against which the pump has to work.

The Manometric head = Static lift + Delivery head + Kinetic heads in the pipes + Losses of head in the pipes

$$H_m = H_s + H_d + \frac{v_s^2}{2g} + \frac{v_d^2}{2g} + h_{fs} + h_{fd}$$

The kinetic heads $\frac{v_s^2}{2g}$ and $\frac{v_d^2}{2g}$ in the suction and delivery pipes are very small and can be ignored in the above relation.

Hence, practically $\quad H_m = H_S + H_d + h_{fS} + h_{fd}$

The manometric head is ultimately the head developed by the pump. The manometric head is slightly less than the head generated by the impeller due to some losses in the pump.

$$\therefore \quad H_m = \frac{V_{w1} v_1}{g} - \text{Impeller losses.}$$

The manometric head may also be visualized as the increase of energy head at outlet of the pump over the energy head at inlet to the pump.

If *A* is a section of the suction pipe close to the pump and *B* is a section of the delivery pipe close to the pump then manometric head

$$= H_m = [\text{Energy head at } B] - [\text{Energy head at } A].$$

$$\therefore \quad H_m = \left[Z_b + \frac{p_b}{w} + \frac{v_d^2}{2g}\right] - \left[Z_a + \frac{p_a}{w} + \frac{v_s^2}{2g}\right]$$

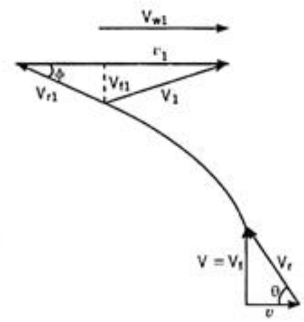


Fig. 24.7.

(*iv*) *The manometric efficiency* η_{man}

This is the ratio of the manometric head to the head actually generated by the impeller.

Applying Bernoulli's equation to sump water level and inlet to the pump,

$$\frac{p_{at}}{w} = \frac{p_s}{w} + H_s + h_{f_s} + \frac{v_s^2}{2g} \quad ...(i)$$

Where H_s = suction lift, h_{f_s} = friction loss in the suction pipe

v_s = velocity in the suction pipe.

Manufacturers of pumps prescribe a certain net positive suction head denoted by NPSH as a permissible value of the inlet pressure p_s relative to the vapour pressure

$$NPSH = \frac{p_s - p_{vap}}{w} \quad or \quad \frac{p_s}{w} = NPSH + \frac{p_{vap}}{w}$$

From equation (*i*)

$$H_s + h_{f_s} + \frac{v_s^2}{2g} = \frac{p_{at}}{w} - \frac{p_s}{w} = \frac{p_{at}}{w} - \left(NPSH + \frac{p_{vap}}{w}\right)$$

$$\therefore \quad H_s + h_{f_s} + \frac{v_s^2}{2g} = \frac{p_{at} - p_{vap}}{w} - NPSH$$

Thus the limiting condition for the suction head is

$$H_s + h_{f_s} + \frac{v_s^2}{2g} \le \frac{p_{at} - P_{vap}}{w} - NPSH$$

Minimum Speed to Start the Pump:

While starting a centrifugal pump, it should be realized that no flow will occur through the wheel until the difference of pressure head in the impeller is sufficiently large to overcome the total lif

Suppose, when the impeller is rotating and there is no flow, the pressure head generated by centrifugal action will be $\left(\frac{v_1^2}{2g} - \frac{v^2}{2g}\right)$. Hence, flow can occur only when this quantity exceeds the total lift H, since v_d the velocity in the delivery pipe is zero when flow just commences.

Since $$H = \frac{V_{w1} v_1}{g}$$

the minimum theoretical speed for the flow to commence will prevail when

$$\frac{v_1^2}{2g} - \frac{v^2}{2g} = \frac{V_{w1} v_1}{g}$$

In the actual case, the flow will commence, when

$$\frac{v_1^2}{2g} - \frac{v^2}{2g} = \eta_{man} \frac{V_{w1} v_1}{g} = H_m.$$

Putting $v = \frac{\pi d N}{60}$ and $v_1 = \frac{\pi d_1 N}{60}$ in the above equation,

$$\left(\frac{\pi N}{60}\right)^2 \left(\frac{d_1^2 - d^2}{2g}\right) = \eta_{man} \cdot \frac{V_{w_1} v_1}{g} = H_m$$

Loss of Head in a Centrifugal Pump due to Reduced or Increased Flow:

A centrifugal pump will exhibit its maximum efficiency only when it is running and discharging at the speeds for which it was originally designed. When there is an increase or decrease in the discharge from the normal discharge, a loss of head occurs at entry due to shock.

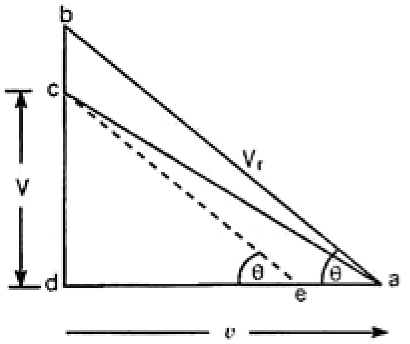


Fig. 24.14.

In Fig. 24.14, abd represents the inlet velocity triangle when the pump is running at its normal speed. The velocity of flow at this stage is represented by db. Suppose the velocity of flow is reduced to the value dc, while the pump continues to run at the same speed. In this condition the velocity triangle is represented by acd. Now the relative velocity is represented by ac. But the blade angle θ at inlet cannot change. This means the relative velocity will no longer be parallel to the blade and this results in shock at entry.
Since the velocity of flow has a certain definite value in the new condition, and since the flow of water has to take place along the vane, it therefore, follows that the velocity diagram will be the triangle ecd, the side ec of the triangle being parallel to ab. Thus, a sudden change ae will take place in the tangential velocity and due to this shock, a loss of head will occur

The loss of head due to the sudden change of velocity

$$= \frac{(\text{change in velocity})^2}{2g}$$

∴ Head lost at inlet $= \dfrac{(ae)^2}{2g} = \dfrac{(v - V\cot\theta)^2}{2g}$

where V = Velocity of flow *dc* through the pump.

Multistage Centrifugal Pumps:

A centrifugal pump with a single impeller can develop a head up to nearly 40 metres. In order to develop greater heads or to discharge a high rate, a multistage pump is used. A multistage pump is a pump with more than one impeller.

There are two ways of arranging the impellers in a multistage pump as explained below:

(i) Impellers in Series:

In this case, a number of impellers are mounted over a common shaft. The discharge from the first impeller is guided into the inlet of the second impeller. The discharge from the second impeller is guided into the inlet of the third impeller and so on and finally, the discharge from the last impeller is directed to the delivery pipe.

As the liquid flows through each impeller, the head H_m is impressed on it. Suppose there are n impellers. The total head developed = H_t = n H_m. The same discharge Q passes through all the impellers and is finally delivered to the delivery pip

(ii) Impellers in Parallel:

This arrangement is meant for discharging a high rate of flow at a given small head H_m. The impellers in this case are mounted on separate shafts. The discharges from the various delivery pipes are collected in a collecting pipe which communicates to the final delivery pipe.

If Q = discharge from one impeller,

Total discharge $= Q_t = nQ$

where n = number of impellers.

But the total head developed = Head developed by each impeller = H_m.

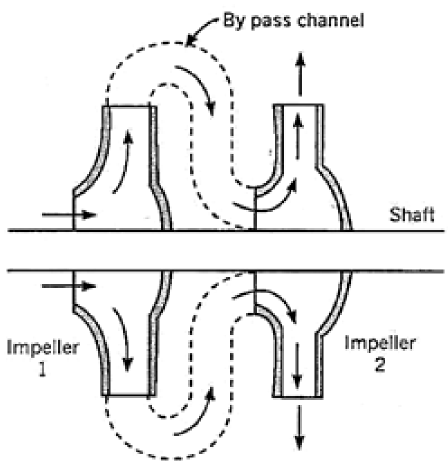


Fig. 24.15. Impellers in series.

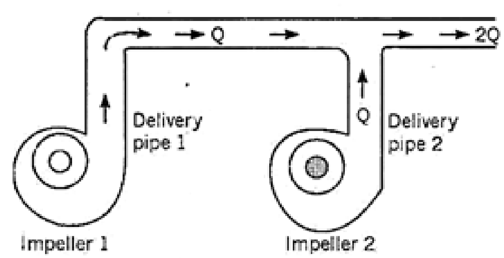


Fig. 24.16. Impellers in parallel.

Water Pressure in Centrifugal Pumps:

We can determine the pressure of water at any section of the stream in the pump by using Bernoulli's equation. Fig. 24.17 shows a centrifugal pump with its suction and delivery pipes. Let A and B be points at inlet and outlet edges of the impeller at the level of the centre of the pump.

Let C be a point on the water surface of the sump. Let D a point just at the outlet of the delivery pipe.

Let H_s = Suction lift
H_d = Delivery head
p_a = Absolute pressure in Pa at A
p_b = Absolute pressure in Pa at B.

Total energy head at A = Total energy head at C

$$H_s + \frac{V^2}{2g} + \frac{p_a}{w} + h_{f_s} = H_{at} = 10.3\ m$$

We can determine p_a from the above equation.

Total energy head at A = Total energy head at B – work done by the impeller

$$\therefore \frac{V^2}{2g} + \frac{p_a}{w} = \frac{V_1^2}{2g} + \frac{p_b}{w} - \left(\frac{V_{w_1} v_1}{g} \times efficiency\right)$$

We can determine p_b from the above equation.

Again, total energy head at B = Total energy head at D + losses

$$\therefore \frac{V_1^2}{2g} + \frac{p_b}{w} = H_{at} + h_d + \frac{v_d^2}{2g} + \text{loss in diffuser} + h_{f_d}$$

We can determine the loss of head in the diffuser from the above equation.

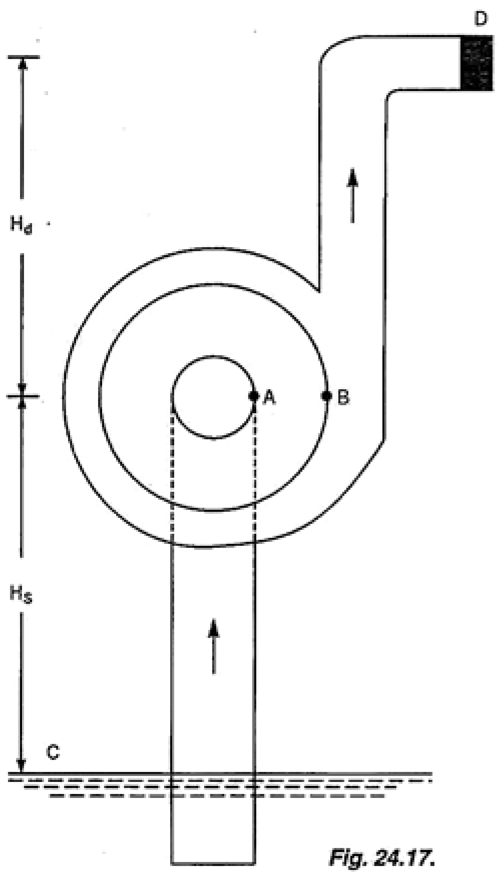


Fig. 24.17.

Specific Speed of a Centrifugal Pump:

The specific speed of a centrifugal pump is the speed at which the pump would deliver one cube metre per second under a head of 1 metre. All geometrically similar pumps have the same specific speed. The discharge of the pump is given by

$$Q = \pi d b V_f \text{ (with the usual notations).}$$

We know (*i*) $V_f \propto \sqrt{H}$

(*ii*) $$v = \frac{\pi d N}{60} \propto \sqrt{H}$$

$\therefore$ $$d \propto \frac{\sqrt{H}}{N}$$

(*iii*) $$b \propto d$$

$\therefore$ $$b \propto \frac{\sqrt{H}}{N}$$

$\therefore$ $$Q \propto \frac{\sqrt{H}}{N} \cdot \frac{\sqrt{H}}{N} \cdot \sqrt{H}$$

$\therefore$ $$Q \propto \frac{H^{3/2}}{N^2}$$

$\therefore$ $$N^2 \propto \frac{H^{3/2}}{Q}$$

$\therefore$ $$N \propto \frac{H^{3/4}}{\sqrt{Q}}$$

Let $$N = N_s \frac{H^{3/4}}{\sqrt{Q}}$$

where N_s = a constant of proportionality.

When $H = 1$ and $Q = 1$, we find

$$N = N_s$$

Hence, N_S represents the speed under a head of 1 *metre* while delivering a discharge of 1 m^3/sec. Hence, N_S represents the specific speed of the pump.

$\therefore$ $$N_s = \frac{N\sqrt{Q}}{H^{3/4}}$$

Principle of Similarity Applied to Centrifugal Pumps:

By the application of principle of similarity, it is possible to predict the performance of a prototype pump from tests on a geometrically similar model

RECIPROCATING PUMPS

Reciprocating pump is a device which converts the mechanical energy into hydraulic energy by sucking the liquid into a cylinder. In this pump, a piston is reciprocating, which uses thrust on the liquid and increases its hydraulic energyReciprocating pump is also known a called a positive displacement pump. Because it discharges a definite quantity of liquid. It is often used where a small quantity of liquid is to handled and where delivery pressure is quite large

Parts of Reciprocating Pump

The following are the main parts of the reciprocating pump.

Cylinder

Suction Pipe

Delivery Pipe

Suction valve

Delivery valve

Air vessels

Cylinder

A cylinder, in which piston is moving to and fro. The moment of the piston obtains by a connecting rod, which connects the piston and crank.

Suction Pipe

In which the source of water connects the cylinder together. The suction pipe allows the water to flow in the cylinder.

Delivery Pipe

After the process, the source of water leaves the cylinder and discharge through the delivery pipe.

Suction Valve

In this valve, the flow of water enters from the suction pipe into the cylinder.

Delivery Valve

In this valve, the flow of water discharge from the cylinder into the delivery pip

Air Vessels

It is a closed chamber made up cast iron. Having to two ends one ends is open at its base through which the water flows into the vessel cylinder. The air vessels fitted to the suction pipe and delivery pipe of this pump to get a uniform discharge

Functions of Air Vessels

The air vessels use to get the continuous flow of water at a uniform rate.

To reduce the amount of work in overcoming the frictional resistance in the suction pipe and delivery pipe.

To run the pump at high speed with separation.

Types of Reciprocating Pump

The following are the types of reciprocating pump according to the source of work and mechanism.

Simple hand-operated reciprocating pump

Power-operated deep well reciprocating pump

Single-acting reciprocating pump

Double-acting reciprocating pump

Triple-acting reciprocating pump

Pump with air vessels

Pump without air vessels

Working Principle of Reciprocating Pump

Following are the two different working principles:

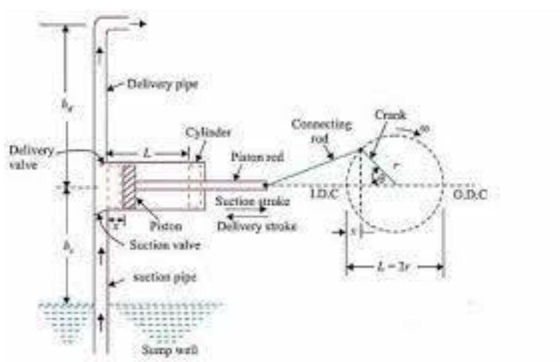
Single-acting reciprocating pump and

A double-acting reciprocating pump.

1. Single Acting Reciprocating Pump

In this pump, A cylinder, in which a piston moves forward and backward. The piston is reciprocating by means of the connecting rod. The connecting rod connects the piston and the rotating crank. The crank is rotating by means of an electric motor.

The suction and delivery pipes with suction and delivery valve are arranged to the cylinder.



The suction valve allows the water to the cylinder and

The delivery valve leaves the water from the cylinder.

As the crank rotates, during the first stroke of the piston (called suction stroke), the water enters into the cylinder. In a suction stroke, the crank is rotating from A to C (from 0° to 180°) the piston is moving towards the right side of the cylinder. Due to this, the vacuum creates in the cylinder. This vacuum causes the suction valve to open and the water enters the cylinder.

In the next stroke called delivery stroke, the water leaves the cylinder. In the delivery stroke, the crank is rotating from C to A (from 180° to 360°) the piston is moving to the left side of the cylinder. Due to this, the pressure of the liquid increases inside the cylinder. This pressure causes the suction valve to close and delivery valve to open. Then the water is forced into the delivery pipe and raised to a required height.