# Unit-3 Centrifugal Pumps

The hydraulic machines which convert the mechanical energy into hydraulic energy are called pumps.
The hydraulic energy is in the form of pressure energy.
So, if the mechanical energy is converted into pressure energy by means of centrifugal force acting on the fluid, the hydraulic m/c is called centrifugal pump.

Centrifugal pump acts as a reverse of an inward radial flow reaction turbine. This means that the flow in centrifugal pumps is in the radial outward direction.

Centrifugal pump works on the principle of forced vortex flow which means that when a certain mass of liquid is rotated by an external torque, the rise in pressure head of rotating liquid takes place.

Rise in pr. head $\propto \frac{V^2}{2g} = \frac{r^2\omega^2}{2g}$

Thus at outlet of the impeller, where radius is more, rise in pr. head will be more and the liquid will be discharged at the outlet with a high pr. head. Due to this high pr. head, the liquid can be lifted to a high level.

## Classification of Pumps:-

Pumps can be classified according to the mechanical principle involved in transfer of energy. These are classified as:-

1) Positive displacement pumps. (Reciprocating pumps)
2) Rotodynamic pumps. (Centrifugal pumps)

In case of reciprocating pumps, the pressure energy of a fluid increased due to positive displacement of it's piston or plunger. These are used to handle low discharge rates at high pressures.

The rotary displacement pumps combines the advantage of reciprocating and centrifugal pumps. They are positive in action, compact, produce an even flow, have no valves and run at high speeds.

The centrifugal pumps are the most common of dynamic pump also called velocity pump. These are classified as rotodynamic pumps since the rotating impeller of pump impresses a centrifugal head or pressure on the liquid which leaves the impeller at a high velocity. This pressure enables the liquid to rise to a higher level. These pumps are suitable for large flow rates.

# Classification of Centrifugal pumps :-

Based on the design, constructional features and their application, the centrifugal pumps are classified as follows :-

1) Based on working head :-

- Low head pumps (upto a head of 15 m).
- Medium head pumps (15 m to 40 m).
- High head pumps (head > 40 m).

(These are multistage pumps since single impeller pump cannot build a pressure more than 40 m hea

2) Based on type of casing :-

The shape of casing is designed so as to reduce the loss of kinetic head to a minimum.

- Volute casing ~~pump (or constant velocity pump)~~ :-

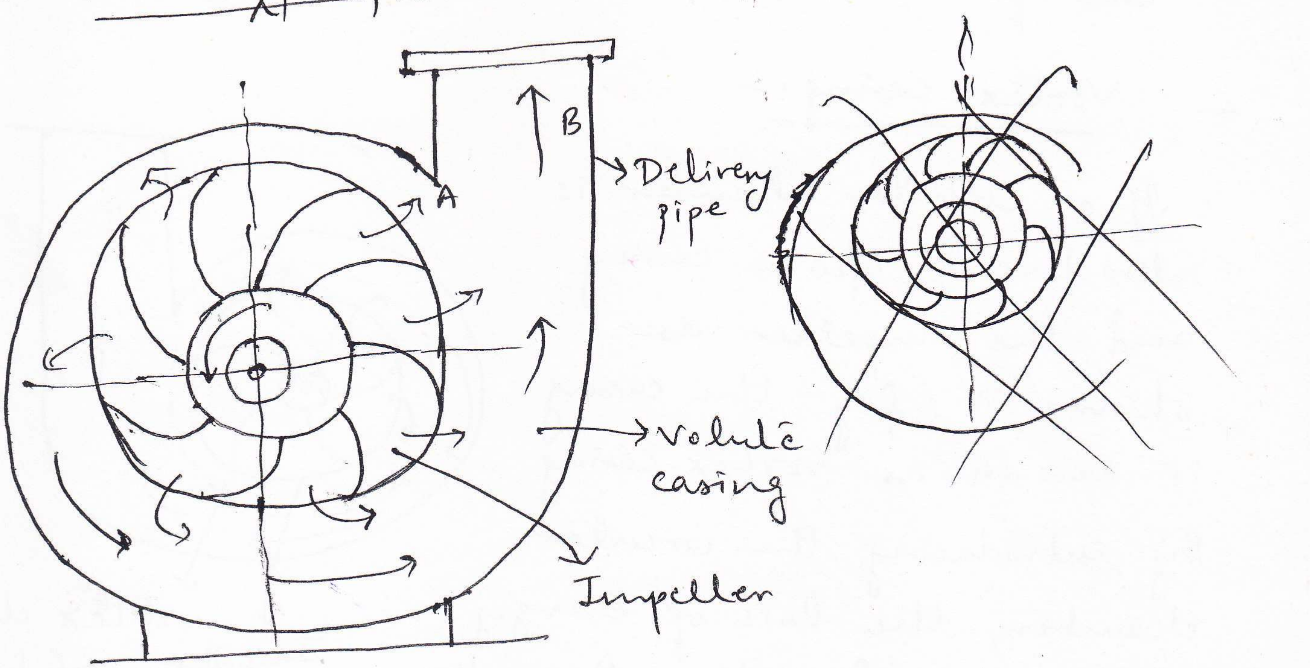


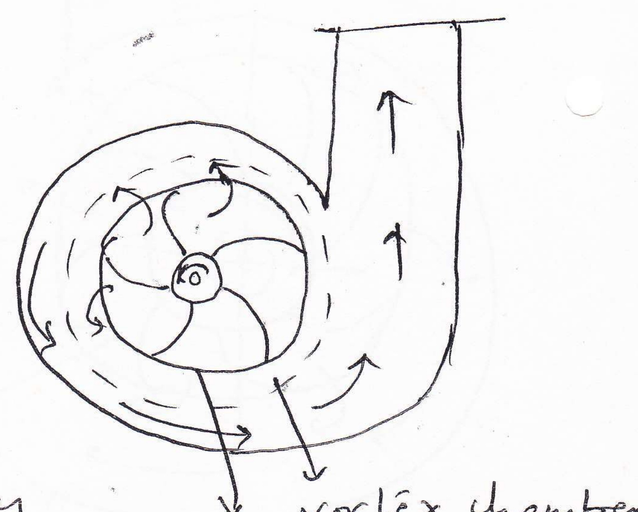

Fig. shows a centrifugal pump with a volute or collecting passage, round the impeller, of graduall increasing area.

The cross-section is so designed to give a constant velocity in the volute of spiral shape.
In such a volute casing the loss of energy is considerably reduce compared to a circular casing. However the conversion of kinetic energy into pr. energy is not possible. Due to this, the efficiency of pump only increases slightly.

The increase in area of flow decreases the velocity of flow. The decrease in velocity increases the pressure of the water flowing through the casing. It has been observed that in case of volute casing, the efficiency of the pump increases slightly as a large amount of energy is lost due to the formation of eddies in this type of casing.

## Vortex casing:-

If a circular chamber is introduced b/w a casing and the impeller as shown in fig. the casing is known as vortex casing. By introducing the circular chamber, the loss of energy due to the formation of eddies is reduced to a considerable extent. Thus the efficiency of pump is more in this case.




→ By Using vortex casing, the pump becomes bulky & expensive

Both volute & vortex casing pumps are single stage pumps with horizontal shaft.

– Casing with Guide blades :–

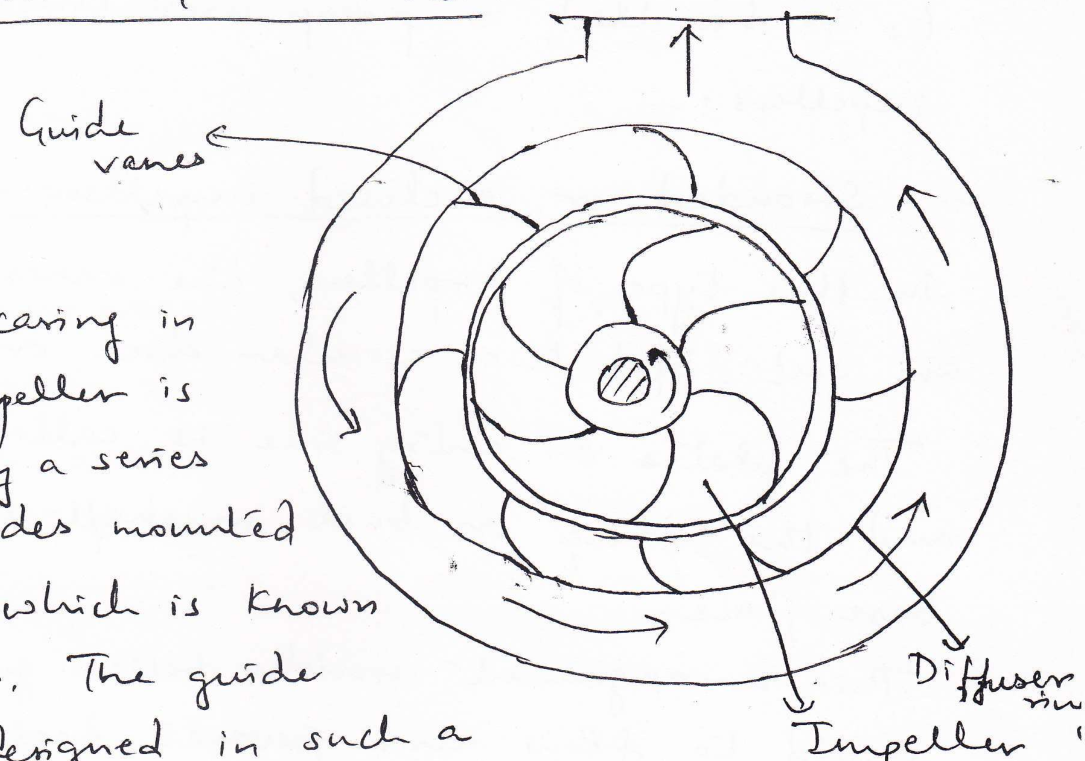



Fig. shows a casing in which the impeller is surrounded by a series of guide blades mounted on a ring which is known as diffuser. The guide vanes are designed in such a way that the water from the impeller enters the guide vanes without shock.

Also the area of the guide vanes increases, thus reducing the velocity of flow through guide vanes and consequently increasing the pressure of water. The water from guide vanes then passes through the surrounding casing which is in most of the cases concentric with the impeller.

In case of multistage pumps, the liquid from volute chamber flows into the impeller eye of next stage pump and final stage volute discharges into delivery pipe.

3) Based on liquid handled (or Types of impellers)

Depending upon the type and viscosity of liquid to be handled, a pump uses three types of impellers :-

- Shrouded or enclosed impellers :-

In this type of impellers, the vanes of impeller are cast b/w two circular disc or plates (shroudes

The plates on entry side is called crown plate and the plate on back or shaft side is calle' base plate.

This arrangement provides better guidance for liquid to flow and prevents leaking of liquid from blade tips from one passage to another passage with high efficiency.

These types of impeller pumps are mostly used for clear water or for other liquids of low viscosity free from dirt.

- Semi-open impellers :-

These impellers have only one plate on back side called base plate.

Such an arrangement helps in dealing with th liquids mixed with fibrous materials. Therefore these types of impellers can be used in sewage installation, sugar, and pulp industry, e with small amount of debris.

- <u>Open impellers:-</u>

These type of impellers do not have any cover plate on either side of the vanes. Therefore, the vanes of an open impeller are open from both sides.

Open impellers are not so efficient but they are useful to deal with liquids which may contain suspended solids such as sand, grit, clay, etc. since there pumps do not clog.

4) <u>Based on relative direction of flow through impeller:-</u>

- <u>Radial flow pumps:-</u>

In these type of pumps, the liquid enters at the centre of impeller and then it flows radially over impeller blades upto outer periphery.

- <u>Mixed flow pumps:-</u>

It is the modification of radial flow impeller in which the flow is the combination of axial and radial flow and the impeller resembles the propeller of a ship.

The mixed flow impellers have large discharge rates of liquid compared to radial flow impellers at low heads. Therefore, these type of pumps are suitable for irrigation applications.

- <u>Axial flow pumps:-</u>

The direction of flow of liquid through its impeller is in the axial direction only from inlet to exit.

These pumps are designed for very large discharge rates at low heads, hence these are ideally suited for irrigation purposes.

The pr. head developed in axial flow pump is not due to centrifugal action, rather it is due to flow of liquid on blades of aerofoil section similar to generation of lift force by the wings of an aeroplane.

These pumps have adjustable blades.

5) <u>Based on no. of entrances to impeller</u> :-

- <u>Single entry pump</u> :-

In this pump the liquid enters only from one side into the impeller from suction pipe.

These are also called single suction pump.

- <u>Double entry or double suction pump</u> :-

In these pumps, the entry to impeller is from both sides of impeller.

It is suitable for large discharge rates.

6) <u>Based on no. of impellers per shaft</u> :-

- <u>Single stage pump</u> :-

It has one impeller and it is suitable for heads upto 40 m.

- <u>Multistage pump</u> :-

These pumps uses two or more no. of impeller in series depending upon the head requirements. In these pumps, the discharge of one pump from casing enters into the eye of impeller of next pump in series.

7) Based on specific speed ($N_s$):-

$N_s$ is defined as the speed of a geometrically similar pump in all respect of actual pump, which delivers $1\ m^3/s$ of discharge under a head of 1 m.

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}}$$ (for single stage pump)

for multi-stage pumps,

$$H = \frac{\text{Total head}}{\text{No. of stages}} \quad \text{and} \quad Q = \frac{\text{Total Discharge}}{\text{No. of stages}}$$

Based on $N_s$ values, various types of pumps are:

| Pump | $N_s$ | |
|---|---|---|
| Radial flow | 10 – 30 | (slow) |
| | 30 – 50 | (Medium) |
| | 50 – 80 | (High) |
| Mixed flow | 80 – 160 | |
| Axial flow | 160 – 450 | |

8) Based on shaft position:-

— Horizontal shaft pump:-
Usually centrifugal pumps are with horizontal shaft.

— Vertical shaft pump:-
These pumps are designed for specific applications and to save space, e.g., the deep well & marine pum

# Main parts of a centrifugal pump:-

1) Impeller:-

The rotating part of a centrifugal pump is called impeller. It consists of a series of backward curved vanes. The impeller is mounted on a shaft which is connected to the shaft of an electric motor.

2) Casing:-

Casing of centrifugal pump is similar to the casing of a reaction turbine. It is an air-tight passage surrounding the impeller and is designed in such a way that the kinetic energy of water discharged at the outlet of impeller is converted into pr. energy before the water leaves the casing and enters the delivery pipe.

3) Suction pipe with a foot valve and strainer:

A pipe whose one end is connected to the inlet of the pump and other end dips into water in a sump is known as suction pipe. A foot valve which is a non-return valve or one-way type of valve is fitted at the lower end of suction pipe. The foot valve opens only in upward direct. A strainer is also fitted at the lower end of suction pipe.

4) Delivery pipe:-

A pipe whose one end is connected to the outlet of pump and other end delivers the water at a required height is known as delivery pipe.

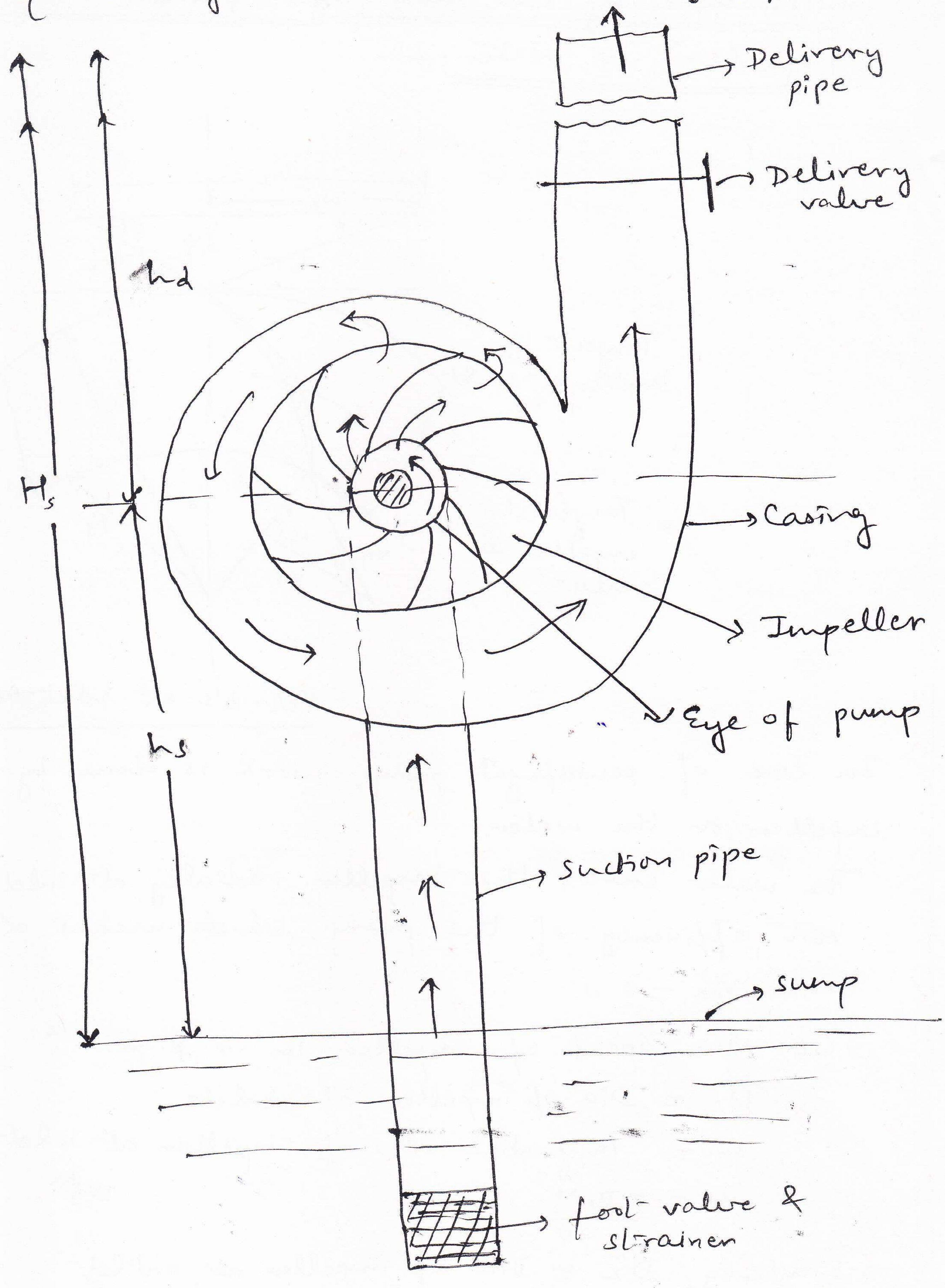
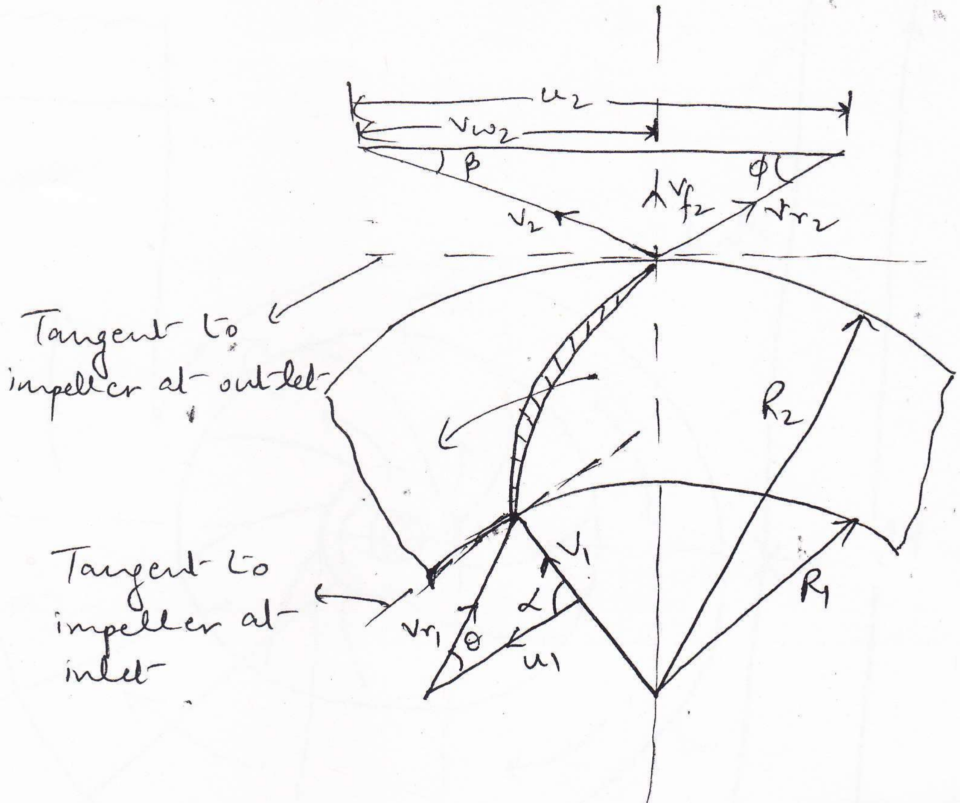



Fig:- Centrifugal Pump

## Work done by the centrifugal pump (or by impeller) on water:-




Vel. Δ's at inlet & outlet.

In case of centrifugal pump, work is done by the impeller on the water.

The water enters the impeller radially at inlet for best efficiency of the pump, which means $\alpha = 90^\circ$ and $V_{w_1} = 0$.

Let; $N$ = Speed of impeller in r.p.m.

$D_1$ = Dia of impeller at inlet

$u_1$ = Tangential vel. of impeller at inlet

$$u_1 = \frac{\pi D_1 N}{60}$$

Similarly, $D_2$ = Dia of impeller at outlet

$u_2$ = Tangential vel. of impeller at outlet

$$u_2 = \frac{\pi D_2 N}{60}$$

$V_1$ = Absolute vel. of water at inlet

$V_2$ = " " " " " outlet

$V_{r_1}$ = Rel. vel. of water at inlet

$V_{r_2}$ = " " " " " outlet

A centrifugal pump is the reverse of a radially inward flow reaction turbine.

But in case of a radially inward flow reaction turbine, W.D. by water on the runner per sec. per unit weight of water striking per sec.

$$= \frac{1}{g}\left[V_{w_1} \cdot u_1 - V_{w_2} \cdot u_2\right]$$

∴ Work done by the impeller on the water per sec. per unit weight of water striking per sec.

$$= -\,(\text{W.D. in case of turbine})$$

$$= -\frac{1}{g}\left[V_{w_1} \cdot u_1 - V_{w_2} \cdot u_2\right]$$

$$= \frac{1}{g}\left[V_{w_2} \cdot u_2 - V_{w_1} \cdot u_1\right]$$

But here, $V_{w_1} = 0$

$$\therefore \frac{\text{W.D./sec.}}{\text{wt./sec.}} = \frac{1}{g}\left[V_{w_2} \cdot u_2\right] \quad —(1)$$

W.D. by impeller on water per sec. $= \frac{W}{g}\left[V_{w_2} \cdot u_2\right]$

where, $W = \rho g Q$

where, $Q = \pi D_1 B_1 \cdot V_{f_1} = \pi D_2 B_2 \cdot V_{f_2}$

where, $B_1$ & $B_2$ are width of impeller at inlet & outlet and $V_{f_1}$ & $V_{f_2}$ are velocities of flow at inlet & outlet, Equⁿ (1) gives the head imparted to the water by the impeller or energy given by impeller.

## Definitions of heads and Efficiencies of Centrifugal Pump:-

1) **Suction head ($h_s$):-** (or suction lift) It is the vertical height of the centre line of the centrifugal pump above the water surface in the tank or pump from which water is to be lifted.

2) **Delivery head ($h_d$):-** The vertical distance b/w centre line of pump & the water surface in the tank to which water is delivered.

3) **Static head ($H_s$):-** The sum of suction head & delivery head is known as static head.

$$H_s = h_s + h_d$$

4) **Manometric head ($H_m$):-** It is defined as the head against which a centrifugal pump has to work.

a) $H_m$ = head imparted by the impeller to the water − loss of head in the pump

$$= \frac{V_{w_2} \cdot u_2}{g} - \text{loss of head in impeller \& casing}$$

b) $H_m$ = Total head at outlet of pump − Total head at inlet of pump

$$= \left(\frac{p_o}{\rho g} + \frac{V_o^2}{2g} + z_o\right) - \left(\frac{p_i}{\rho g} + \frac{V_i^2}{2g} + z_i\right)$$

$$= \left(h_d + \frac{V_d^2}{2g} + Z_d\right) - \left(h_s + \frac{V_s^2}{2g} + Z_s\right)$$

c) $$H_m = h_s + h_d + h_{fs} + h_{fd} + \frac{V_d^2}{2g}$$

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## Efficiencies of a Centrifugal pump:-

In case of a centrifugal pump, the power is transmitted from the shaft of electric motor to the shaft of the pump and then to the impeller. From the impeller, the power is given to the water. Thus power is decreasing from the shaft of the pump to the impeller and then to the water.

### a) Manometric Efficiency ($\eta_{man}$):-

The ratio of manometric head to the head imparted by the impeller to the water is known as manometric efficiency.

$$\eta_{man.} = \frac{\text{Man. head}}{\text{Head imparted by impeller to water}}$$

$$= \frac{H_m}{\left(\frac{V_{w_2} \cdot u_2}{g}\right)}$$

or

$$\eta_{man.} = \frac{\text{Power given to water at outlet of pump}}{\text{Power at the impeller}}$$

$$= \frac{\dot{w} \times H_m}{\dot{w} \times \left(\frac{V_{w_2} \cdot u_2}{g}\right)} = \frac{H_m}{\left(\frac{V_{w_2} \cdot u_2}{g}\right)}$$

### b) Mechanical Efficiency ($\eta_m$):-

$$\eta_m = \frac{\text{Power at the impeller}}{\text{Power at the shaft}} = \frac{\dot{w} \times \left(\frac{V_{w_2} \cdot u_2}{g}\right)}{S.P.}$$

c) Overall Efficiency ($\eta_o$) :-

$$\eta_o = \frac{\text{O/P Power of the pump}}{\text{I/P power to the pump}}$$

$$= \frac{W \times H_m}{S.P.}$$

or $$\boxed{\eta_o = \eta_{man.} \times \eta_m}$$

Prob. 19.1, 19.3, 19.4, 19.7, 19.~~8~~(A), 19.10.

# Minimum Speed for Starting a Centrifugal Pump:-

If the head due to pressure rise in the impeller is more than or equal to manometric head ($H_m$), the centrifugal pump will start delivering water. Otherwise, the pump will not discharge any water, though the impeller is rotating.

When impeller is rotating, the fluid (water) in contact with the impeller also rotates, which is the case of forced vortex flow.

For a forced vortex flow, the centrifugal head or head due to pressure rise in the impeller is given by,

$$= \frac{\omega^2 \cdot R_2^2}{2g} - \frac{\omega^2 R_1^2}{2g}$$

where, $\omega \cdot R_2 = u_2$ (tangential velocity of impeller at outlet)

$\omega \cdot R_1 = u_1$ (tangential velocity of impeller at inlet)

$\therefore$ Head due to pressure rise in impeller

$$= \frac{u_2^2}{2g} - \frac{u_1^2}{2g}$$

The pump starts delivering water if,

Head due to pr. rise in impeller $\geq H_m$

$$\Rightarrow \frac{u_2^2}{2g} - \frac{u_1^2}{2g} \geq H_m$$

Now for minimum speed,

$$\frac{u_2^2}{2g} - \frac{u_1^2}{2g} = H_m \qquad \text{--- (1)}$$

Also, $$\eta_{man.} = \frac{H_m}{\left(\frac{V_{w_2} \cdot u_2}{g}\right)}$$

$$H_m = \eta_{man.} \times \left(\frac{V_{w_2} \cdot u_2}{g}\right)$$

Putting the value of $H_m$ in eqn (1),

$$\frac{u_2^2}{2g} - \frac{u_1^2}{2g} = \eta_{man.} \times \frac{V_{w_2} \cdot u_2}{g}$$

Now, $u_2 = \frac{\pi D_2 N}{60}$ and $u_1 = \frac{\pi D_1 N}{60}$

$$\therefore \frac{1}{2g}\left(\frac{\pi D_2 N}{60}\right)^2 - \frac{1}{2g}\left(\frac{\pi D_1 N}{60}\right)^2 = \eta_{man.} \times \frac{V_{w_2} \cdot u_2}{g}$$

$$\frac{\pi^2 N^2}{(2g)(60)^2}\left[D_2^2 - D_1^2\right] = \eta_{man.} \times \frac{V_{w_2}}{g} \times \frac{\pi D_2 N}{60}$$

$$\Rightarrow \frac{\pi N}{120}\left[D_2^2 - D_1^2\right] = \eta_{man.} \times V_{w_2} \cdot D_2$$

$$\Rightarrow N = \frac{120 \times \eta_{man.} \times V_{w_2} \cdot D_2}{\pi\left[D_2^2 - D_1^2\right]} \qquad \text{--- (2)}$$

From eqn (2), the minimum speed for starting a centrifugal pump to deliver water can be obtained

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Prob. 19.14, 19.15.

# Multi-stage Centrifugal Pumps :-

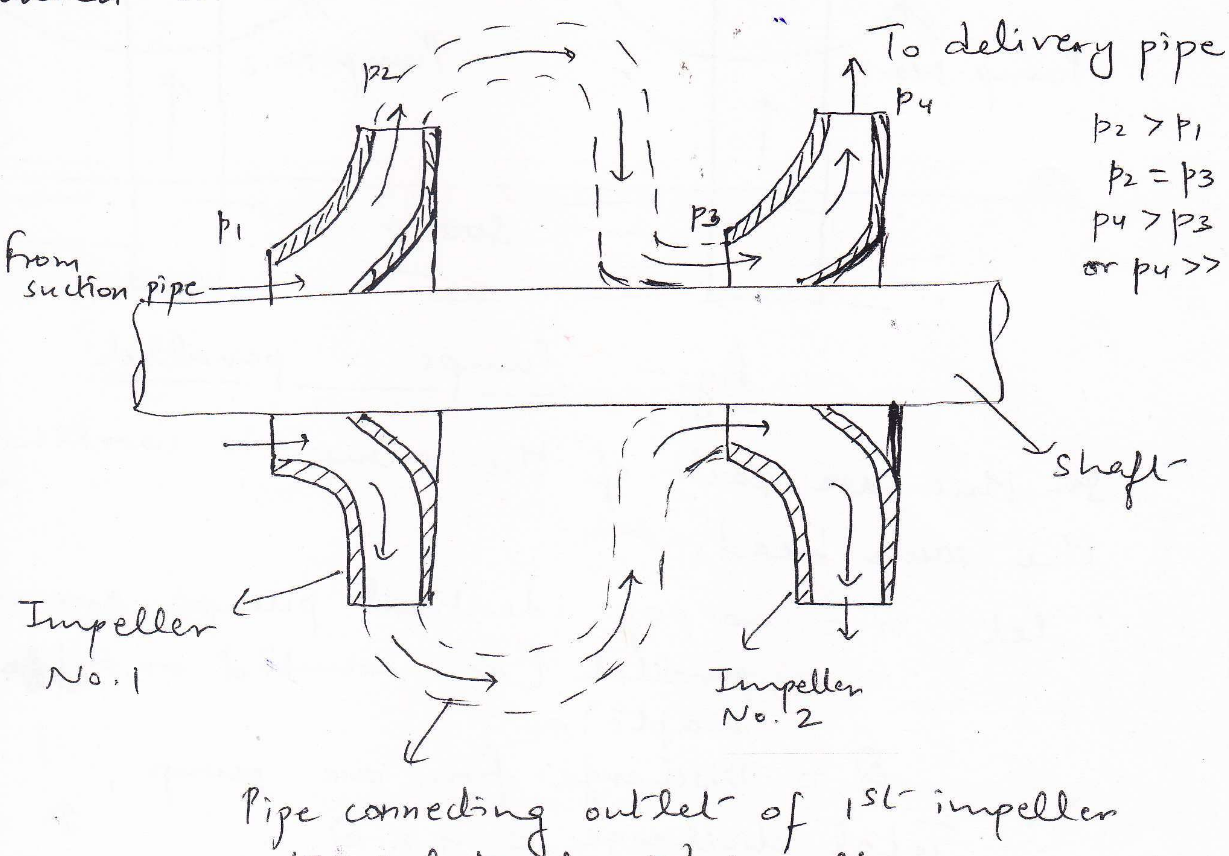
If a centrifugal pump consists of two or more impellers, the pump is called a multistage centrifugal pump. The impellers may be mounted on the same or on different shafts.

A multi-stage pump is having the following two important functions :-

1) To produce a high head. (series connection)
2) To discharge a large quantity of liquid. (parallel connection)

## 1) Multi-stage centrifugal pumps for High heads :-

For developing a high head, a no. of impellers are mounted in series on the same shaft.




$p_2 > p_1$
$p_2 = p_3$
$p_4 > p_3$
or $p_4 >> p$

Fig:- Two-stage pumps with impellers in series

Let, $n$ = no. of identical impellers mounted on the same shaft.

$H_m$ = Head developed by each impeller

Then total head developed $= n \times H_m$

The discharge passing through each impeller is same

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2) <u>Multi-stage Centrifugal Pumps for High discharge</u>

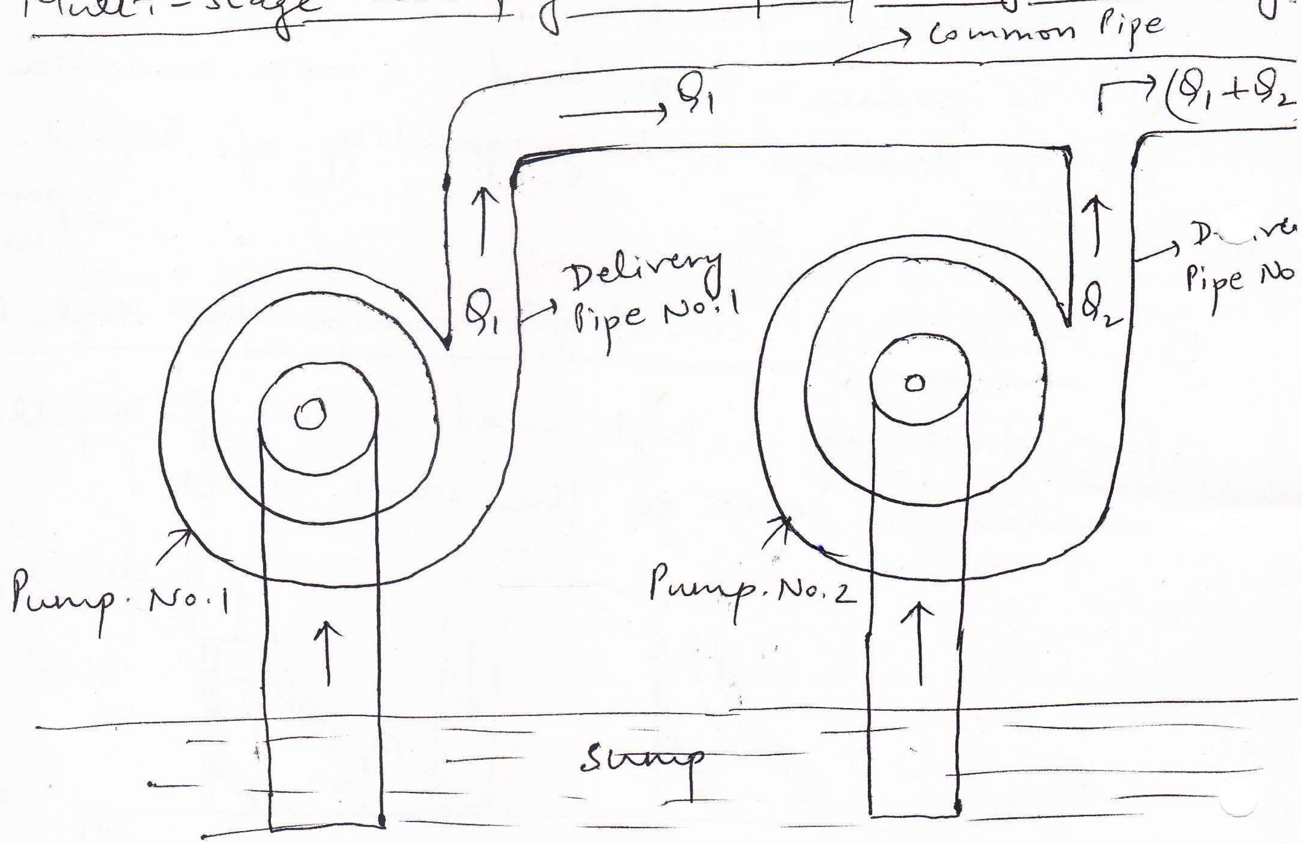


fig:- Pumps in parallel

In this case each of the pump is working against the same head.

Let, $n$ = no. of identical pumps arranged in parallel (or mounted on different parall shafts).

$Q$ = Discharge from one pump.

$\therefore$ Total discharge $= n \times Q$

or if the discharge is different (say $Q_1$ & $Q_2$),

$\therefore$ Total discharge $= Q_1 + Q_2$ (for a two-sta pump).

(Prob. 19.16)

## Specific Speed of a Centrifugal Pump ($N_s$) :-

It is defined as the speed of a geometrically similar pump which would deliver one cubic metre of liquid per sec against a head of 1 m.

### Expression for $N_s$ :-

We know, $Q = \text{Area} \times \text{vel. of flow}$

$$= \pi . D . B \times V_f$$

or $Q \propto D . B . V_f$

where, $D$ = Dia of impeller of pump

$B$ = width of impeller

But we know that, $B \propto D$

$$\therefore \quad Q \propto D^2 . V_f$$

Also, $u = \frac{\pi D N}{60}$

so, $u \propto DN$ —— ①

Also, $u \propto V_f \propto \sqrt{H_m}$ —— ②

From ① & ②,

$$\sqrt{H_m} \propto DN$$

$$\text{or } D \propto \frac{\sqrt{H_m}}{N}$$

$$\therefore \quad Q \propto \frac{H_m}{N^2} . \sqrt{H_m}$$

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

$$Q = K . \frac{H_m^{3/2}}{N^2}$$

If, $H_m = 1\ m$ and $Q = 1\ m^3/s$, then

$N = N_s$

$\therefore\ N_s^2 = K$

$$\Rightarrow\ Q = \frac{N_s^2 \cdot H_m^{3/2}}{N^2}$$

$$\text{or}\ N_s^2 = \frac{Q \cdot N^2}{H_m^{3/2}}$$

$$\text{or}\ \boxed{N_s = \frac{N\sqrt{Q}}{H_m^{3/4}}}$$

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## Model Testing of Centrifugal Pumps :-

Before manufacturing large size pumps, their model which are in complete similarity with the actual pumps (also called prototypes) are made.

Tests are conducted on models and performance of prototypes are predicted.

The complete similarity b/w model & actual pump (prototype) will exist if the following conditions are satisfied :-

1) $(N_s)_m = (N_s)_p \Rightarrow \left(\frac{N\sqrt{Q}}{H_m^{3/4}}\right)_m = \left(\frac{N\sqrt{Q}}{H_m^{3/4}}\right)$

2) $(K_H)_m = (K_H)_p \Rightarrow \left(\frac{H_m}{D^2N^2}\right)_m = \left(\frac{H_m}{D^2N^2}\right)_p$

3) $(K_Q)_m = (K_Q)_p \Rightarrow \left(\frac{Q}{D^3N}\right)_m = \left(\frac{Q}{D^3N}\right)_p$

4) $(K_P)_m = (K_P)_p \Rightarrow \left(\frac{P}{D^5N^3}\right)_m = \left(\frac{P}{D^5N^3}\right)$

→ Derivations of $K_H$, $K_Q$ and $K_P$ are done in reaction turbines.

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Q. 1 19.18 19.20 19.22.

## Priming of a Centrifugal Pump:-

It is defined as the operation in which the suction pipe, casing of pump and a portion of delivery pipe upto delivery valve is completely filled up from outside source with the liquid to be raised by the pump before starting the pump.

Thus the air from these parts of the pump is removed and these parts are filled with the liquid to be pumped.

We know, Head generated by the pump $= \dfrac{V_{w_2} \cdot u_2}{g}$

This is independent of density of liquid.
So if the pump is running in air, the head generated is in terms of metre of air. But if the pump is primed with water, the head generated is in metre of water. Therefore if the pump is not primed before, the water may not be sucked from the pump.

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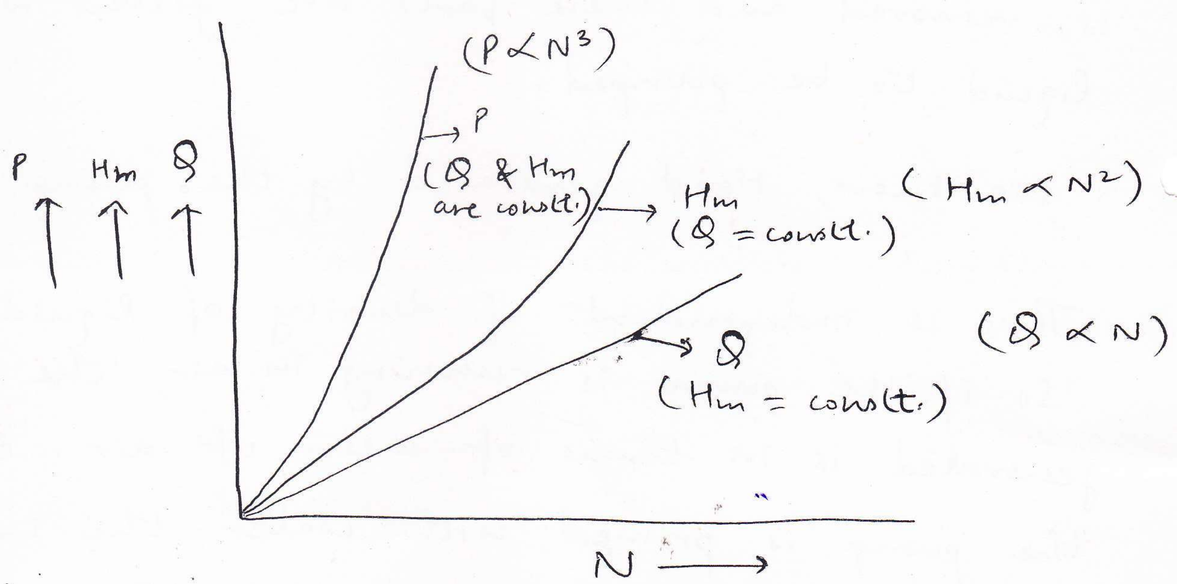
## Characteristic Curves of Centrifugal pumps:-

Characteristic curves of centrifugal pumps are defined as those curves which are plotted from the results of a number of tests on the centrifugal pump.
These curves are necessary to predict the behaviour and performance of the pump under different working conditions of flow rate, head and speed.

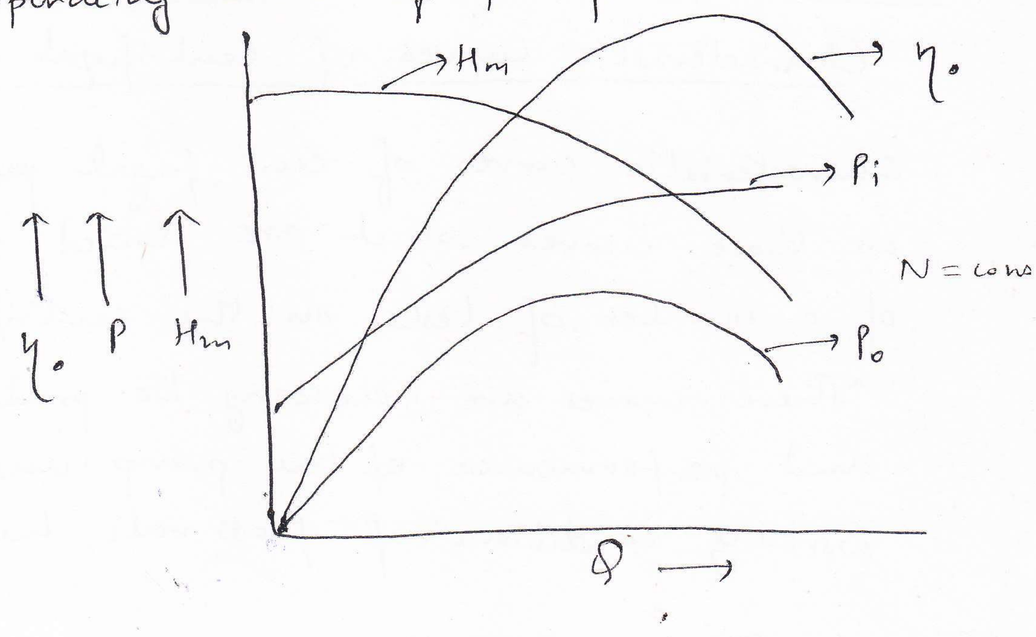
1) Main Characteristic Curves :- (C.C)

The main C.C. of a centrifugal pump consists of variation of $H_m$, $P$ and $Q$ w.r.t $N$. Also, for plotting $H_m$ Vs $N$, $Q$ is kept constant. For plotting $Q$ Vs $N$, $H_m$ is kept constant. And for plotting $P$ Vs $N$, $H_m$ and $Q$ are kept constant.




2) Operating C.C's :-

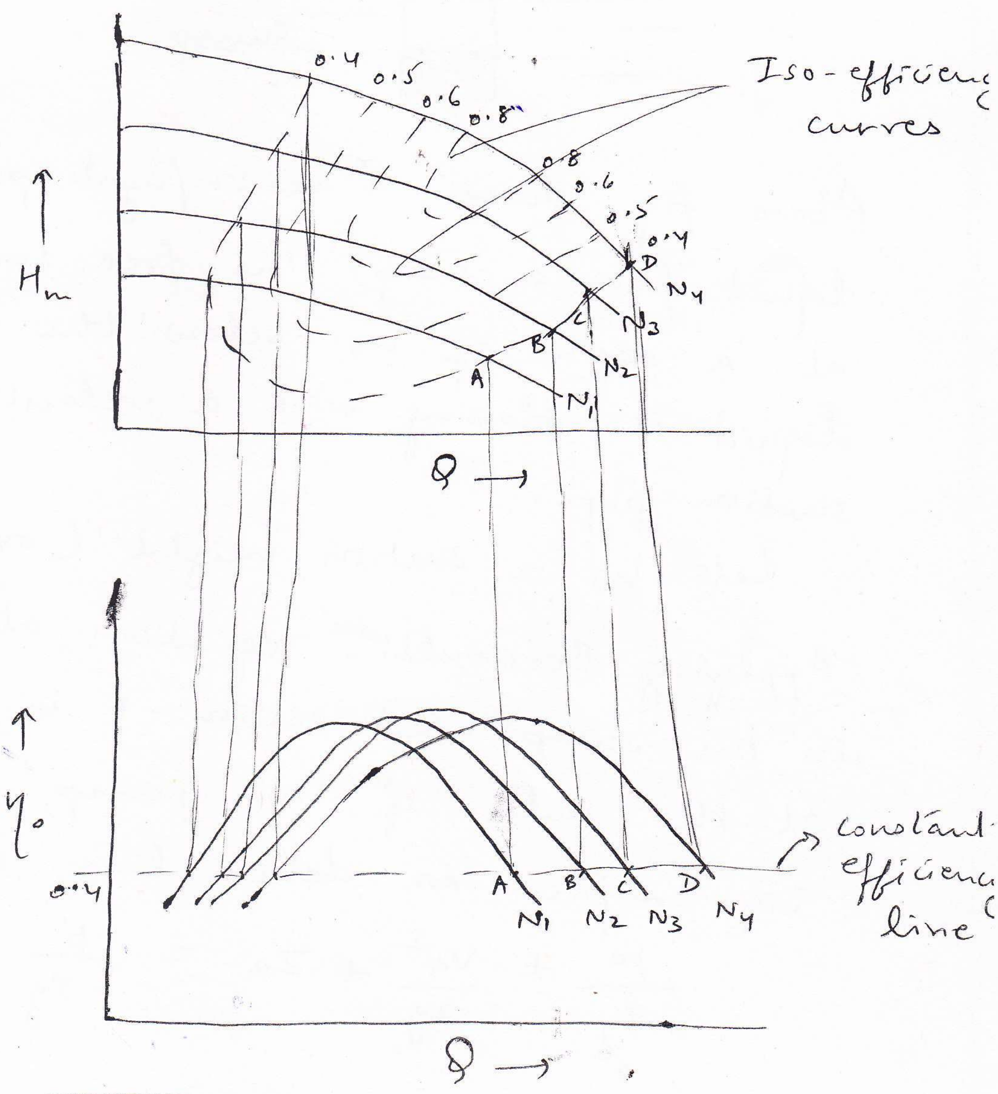
If the speed is kept constant, then $H_m$, $P$ and $\eta_o$ ... gives the operating C.C's of pump.



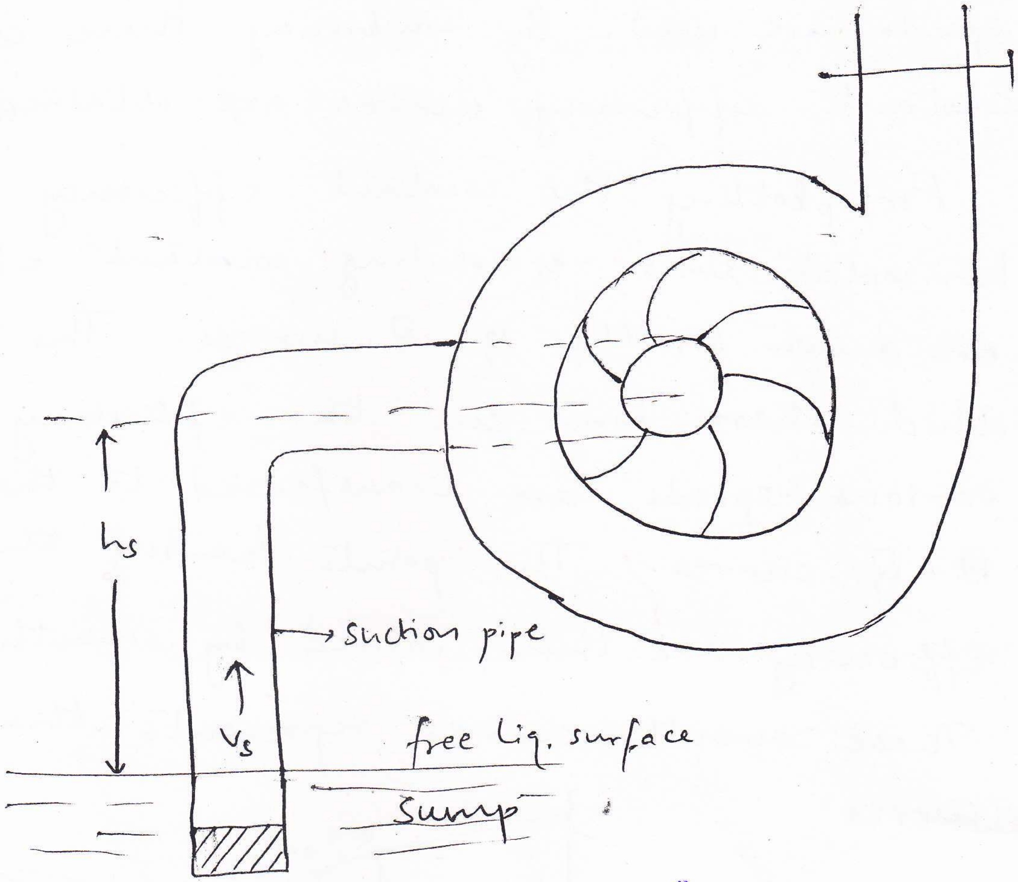
3) <u>Constant Efficiency Curves</u>:- (<u>or Iso - Efficiency Curves</u>)

$H_m$ Vs $Q$ and $\eta_o$ Vs $Q$ curves for different speeds are used. By combining these curves, constant efficiency curves are obtained.

For plotting the constant efficiency curves, horizontal lines representing constant efficiencies are drawn on the $\eta - Q$ curves. The points, at which these lines cut the efficiency curves at various speeds, are transferred to the corresponding H - Q curves. The points having the same efficiency are then joined by smooth curves. These smooth curves represents the iso-efficiency curves.



## Maximum Suction lift (or Suction height) :-




Above fig. shows a centrifugal pump that lifts a liquid from a sump. The free surface of liquid is at a depth of $h_s$ below the pump axis. The liquid is flowing with a velocity $V_s$ in the suction pipe.

Let $h_s$ = suction height (or lift)

Applying Bernoulli's equation at the free liq. surf in the sump and section-1 in the suction pipe at the inlet of the pump and taking free liq. surface as datum line, we get

$$\frac{p_a}{\rho g} + \frac{V_a^2}{2g} + Z_a = \frac{p_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 + h_L \quad \to (1)$$

where, $p_a$ → Atm. pr. on free liq. surface

$V_a$ → vel. of Liq. at the free surface of liq. $\simeq 0$.

$Z_a$ → Height of free surface from datum line $= 0$.

$p_1$ → Abs. pr. at inlet of pump

$V_1$ → vel. of liq. through suction pipe $= V_s$.

$Z_1$ → height of inlet of pump from datum line $= h_s$.

$h_L$ → Loss of head in foot valve, strainer and suction pipe $= h_{fs}$

∴ Equ$^n$ (1) becomes,

$$\frac{p_a}{\rho g} + 0 + 0 = \frac{p_1}{\rho g} + \frac{V_s^2}{2g} + h_s + h_{fs}$$

$$\Rightarrow \quad p_a/\rho g = p_1/\rho g + \frac{V_s^2}{2g} + h_s + h_{fs}$$

$$\text{or} \quad p_1/\rho g = p_a/\rho g - \left(\frac{V_s^2}{2g} + h_s + h_{fs}\right) \quad \to (2)$$

For finding the max. suction lift, the pr. at the inlet of the pump should not be less than the vapour pressure of liquid.

Hence, for limiting case,

$p_1 = p_v$ $\qquad$ $p_v$ → vap. pr. of liq. in absolute unit

$\therefore$ Equⁿ (2) becomes,

$$\frac{p_v}{\rho g} = \frac{p_a}{\rho g} - \left( \frac{V_s^2}{2g} + h_s + h_{fs} \right)$$

$\frac{p_a}{\rho g} \rightarrow$ Atm. pr. head $= H_a$ (m of liq.)

$\frac{p_v}{\rho g} \rightarrow$ Vapour pr. head $= H_v$ (m of liq.)

$$\therefore \quad H_v = H_a - \left( \frac{V_s^2}{2g} + h_s + h_{fs} \right)$$

$$\text{or} \quad h_s = H_a - H_v - \frac{V_s^2}{2g} - h_{fs} \qquad \text{--- (3)}$$

Equ$^n$ (3) gives the value of max. suction lift for a centrifugal pump. If suction height of pump is more as given by equ$^n$ (3), then vaporization of liq. at inlet of pump will take place and there will be a possibility of cavitation.

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# Net Positive Suction Head (NPSH) :-

NPSH is defined as the difference of absolute pr. head at the inlet of the pump and vapour pr. head (in absolute units) including the velocity head.

$\therefore$ NPSH = Abs. pr. head at inlet of pump − vapour pr. head (absolute units + velocity head

$$= \frac{p_1}{\rho g} - \frac{p_v}{\rho g} + \frac{V_s^2}{2g}$$

But $$\frac{p_1}{\rho g} = \frac{p_a}{\rho g} - \left(\frac{V_s^2}{2g} + h_s + h_{fs}\right)$$

$$\therefore \text{NPSH} = \left[\frac{p_a}{\rho g} - \left(\frac{V_s^2}{2g} + h_s + h_{fs}\right)\right] - \frac{p_v}{\rho g} + \frac{V_s^2}{2g}$$

$$= \frac{p_a}{\rho g} - \frac{p_v}{\rho g} - h_s - h_{fs}$$

$$= H_a - H_v - h_s - h_{fs}$$

$$\text{NPSH} = (H_a - h_s - h_{fs}) - H_v \quad \text{— (1)}$$

R.H.S. of eqn (1) is the total suction head. Hence, NPSH is equal to total suction head. Thus, NPSH may also be defined as the total head required to make the liquid flow through the suction pipe to the pump impeller.

For any pump installation, a distinction is made between the required NPSH and the available NPSH. The value of required NPSH is given by the pump manufacturer. This value can also be determined experimentally. For determining it's value, the pump is tested and minimum value of $h_s$ is obtained at which the pump gives max. efficiency without any objectional noise (i.e; cavitation free). The required NPSH varies with the pump design, speed of pump and capacity of pump.

When the pump is installed, the available NPSH is calculated from eqn (1).

In order to have cavitation free operation of centrifugal pump,

Available NPSH > Required NPSH.

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## Cavitation in Centrifugal Pumps :-

In centrifugal pumps, the cavitation may occur at the inlet of the impeller of the pump, or at the suction side of the pump, where the pressure is considerably reduced.

Hence, if the pressure at the suction side of the pump drops below the vapour pressure of the liquid then the cavitation may occur.

The cavitation in a pump can be noted by a sudden drop in efficiency and head.

In order to determine whether cavitation will occur in any portion of the suction side of the pump, the critical value of Thoma's cavitation factor ($\sigma$) is calculated.

## Thoma's Cavitation factor for Centrifugal Pumps:

$$\sigma = \frac{(H_b) - H_s - h_{Ls}}{H}$$

$$= \frac{(H_{atm} - H_v) - H_s - h_{Ls}}{H}$$

$$= \frac{(H_{atm} - H_v) - h_s - h_{fs}}{H_m} \quad \text{(for pumps)}$$

where, $H_{atm}$ → Atm. Pr. head in m of water or Abs. Pr. head at the liquid surface in pump

$H_v$ → Vapour Pr. head in m of water

$H_s$ → Suction pr. head in m of water

$h_{fs}$ → Head lost due to friction in suction pipe

H → Head developed by the pump

But, we know that,

$$NPSH = H_a - H_v - h_s - h_{fs}$$

$$\therefore \quad \sigma = \frac{NPSH}{H_m}$$

If the value of $\sigma$ is less than critical value $\sigma_c$, then cavitation will occur in the pumps.

The value of $\sigma_c$ depends upon $N_s$.

The following empirical relation is used to determine the value of $\sigma_c$,

$$\sigma_c = 0.103 \left(\frac{N_s}{1000}\right)^{4/3}$$

$$= \frac{0.103 N_s^{4/3}}{10^4} = 1.03 \times 10^{-5} N_s^{4/3}$$

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Prob. 19.23, 19.24.

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