

Module - V

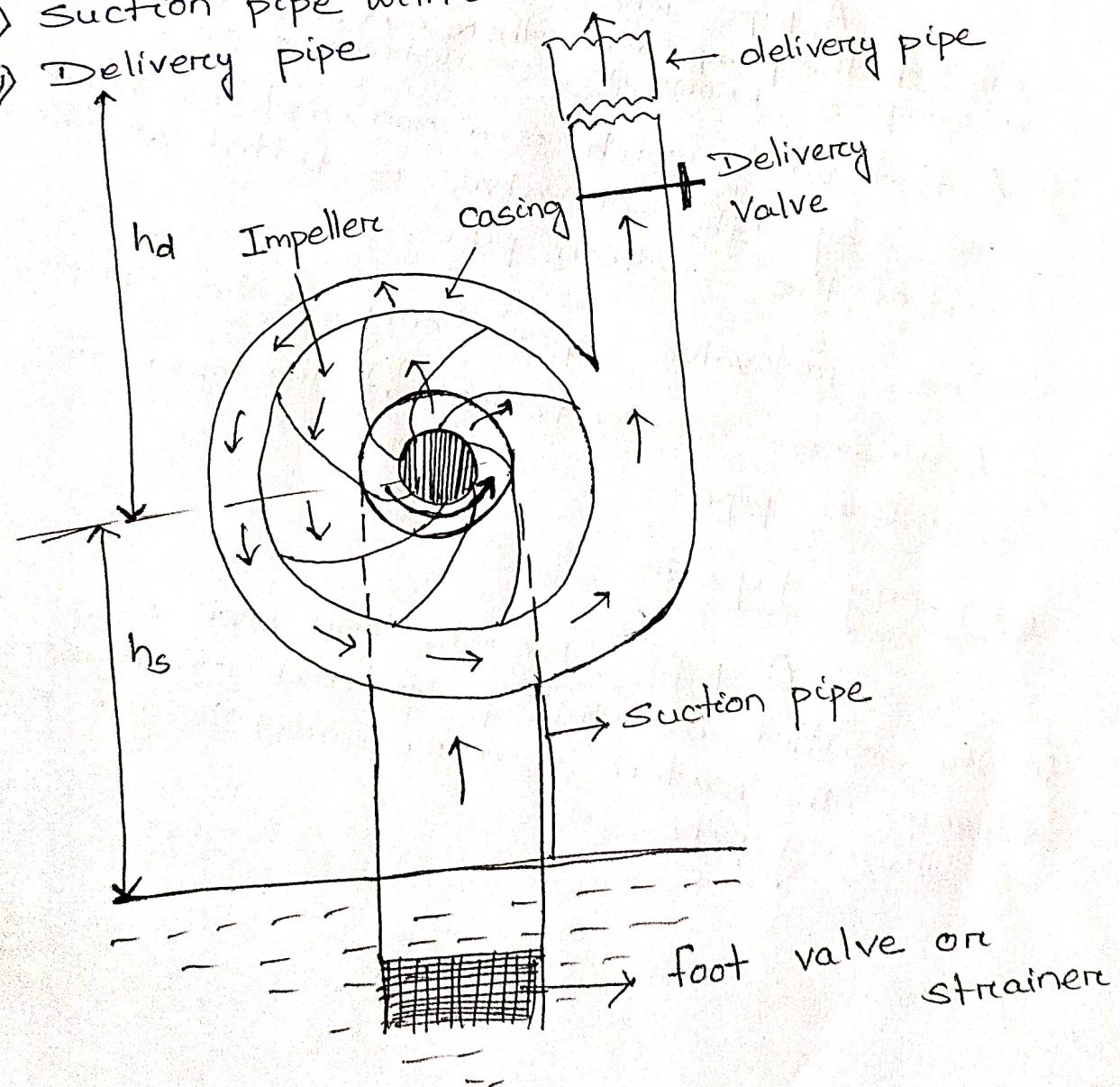
Centrifugal Pump

- A hydraulic machines which convert the mechanical energy into hydraulic energy are called pumps.
- If the mechanical energy is converted into pressure energy by means of centrifugal force acting on the fluid, the hydraulic machine is called centrifugal pump.

Main parts of a centrifugal pump

The following are the main parts of a centrifugal pump.

- i) Impeller
- ii) Casing
- iii) Suction pipe with a foot valve and a strainer.
- iv) Delivery pipe



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 :-
The casing of a 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 it converts KE to PE.

3) Suction Pipe with a foot valve and a 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 a suction pipe.

⇒ A foot valve which is a non-return valve or one way type of valve is fitted at the lower end of the suction pipe.
⇒ The foot valve opens only in the upward direction.
⇒ A strainer is also fitted at the lower end of the suction pipe.

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

Q) The internal and external diameters of the impeller of a centrifugal pump are 200 mm and 400 mm respectively. The pump is running at 1200 rpm. The vane angles of the impeller at inlet and outlet are 20° and 30° respectively. The water enters the impeller radially and velocity of flow is const. Determine the workdone by the impeller per unit wt. of water.

Given,

$$\text{Internal dia, } D_1 = 200 \text{ mm}$$

$$\text{External dia, } D_2 = 400 \text{ mm}$$

$$\text{Speed, } N = 1200 \text{ rpm}$$

$$\text{Vane angle, } \theta = 20^\circ \text{ (inlet)}$$

$$\text{Outlet, } \phi = 30^\circ$$

$$\alpha = 90^\circ$$

$$v_{w1} = 0$$

$$u_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.2 \times 1200}{60} = 12.56 \text{ m/s}$$

$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.4 \times 1200}{60} = 25.13 \text{ m/s}$$

$$\text{Inlet velocity triangle, } \tan \theta = \frac{v_{f1}}{u_1} = \frac{v_{f1}}{12.56}$$

$$\begin{aligned} v_{f1} &= 12.56 \tan 20^\circ \\ &= 12.56 \times \tan 20^\circ \\ &= 4.57 \text{ m/s} \end{aligned}$$

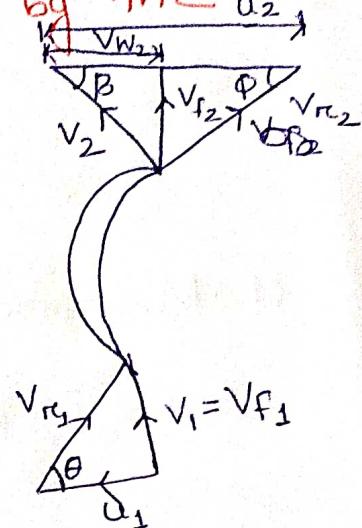
$$\text{From outlet velocity triangle, } \tan \phi = \frac{v_{f2}}{u_2 - v_{w2}}$$

$$= \frac{4.57}{25.13 - v_{w2}}$$

$$\Rightarrow 25.13 - v_{w2} = \frac{4.57}{\tan 30^\circ}$$

$$\Rightarrow v_{w2} = 25.13 - 7.915 = 17.215 \text{ m/s}$$

Workdone by impeller per kg of water per second is given by $\eta = \frac{1}{g} v_{w2} u_2 = \frac{17.215 \times 25.13}{9.81} = 44.1 \text{ Nm/N}$



Efficiencies of a centrifugal Pump :-

(a) Manometric efficiency (η_{man}) =
$$\frac{\text{Manometric head}}{\text{Head imparted by impeller to water}} = \frac{H_m}{V_w u_2} = \frac{g H_m}{V_w u_2}$$

(b) Mechanical efficiency (η_m): -

$$\begin{aligned}\eta_m &= \frac{\text{Power at the impeller}}{\text{Power at the shaft}} \\ &= \frac{W}{g} \times \left(\frac{V_w u_2}{1000} \right) \\ &\quad \text{S.P.}\end{aligned}$$

(c) Overall Efficiency (η_o): -

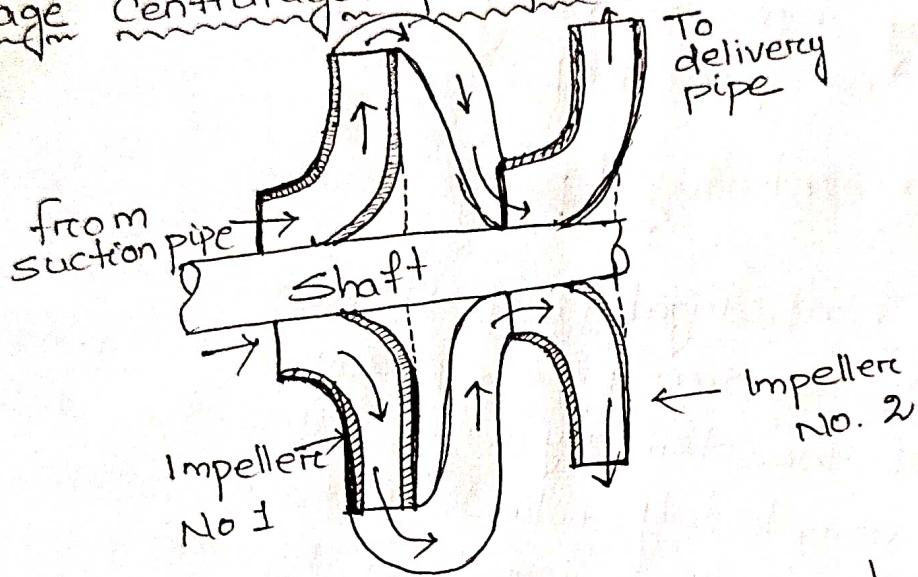
$$\begin{aligned}\eta_o &= \frac{\text{Power input}}{\text{Power output}} \\ \text{Power input} &= \frac{\text{Weight of water lifted} \times H_m}{1000} \\ \eta_o &= \frac{W H_m}{1000} \\ &\quad \text{S.P.}\end{aligned}$$

$$\boxed{\eta_o = \eta_{\text{man}} \times \eta_m}$$

Multistage Centrifugal Pump :-

- If a centrifugal pump consists of two or more impellers, the pump is called multistage centrifugal pump.
- A multistage pump is having the following two important functions.
 - To produce a high head
 - To discharge a large quantity of liquid.

Multistage Centrifugal Pumps for high heads :-



The water from the suction pipe enters the 1st impeller at inlet and is discharged at outlet with increased pressure.

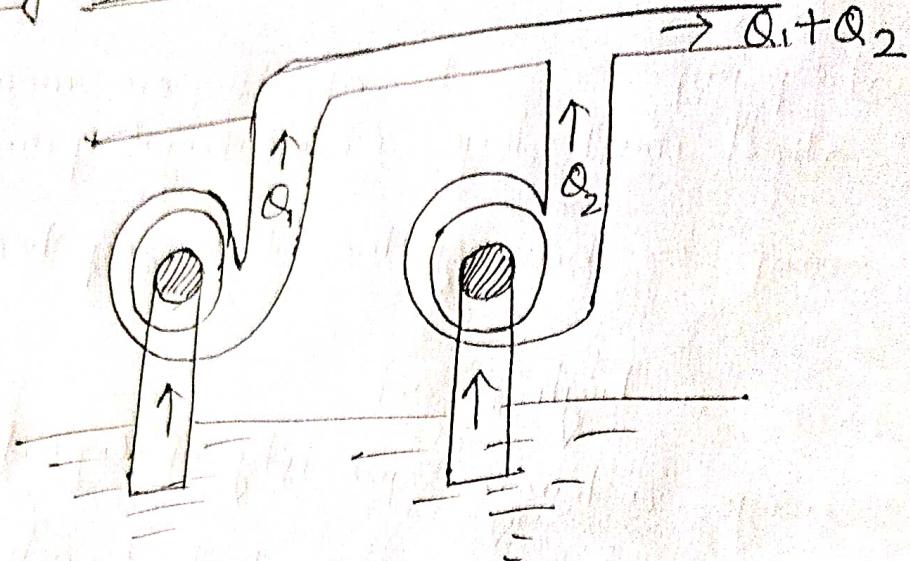
The water with increased pressure from the outlet of the 1st impeller is taken to the inlet of 2nd impeller with the help of a connecting pipe.

Thus if more impellers are mounted on the same shaft, the pressure at the outlet will be increased further.

$$\text{Total head developed} = n \times H_m$$

$n \rightarrow$ no of impellers
 $H_m \rightarrow$ Head developed by each impeller.

Multistage centrifugal pump for high discharge



For obtaining high discharge, pump should be connected in parallel.

Priming of a centrifugal pump

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

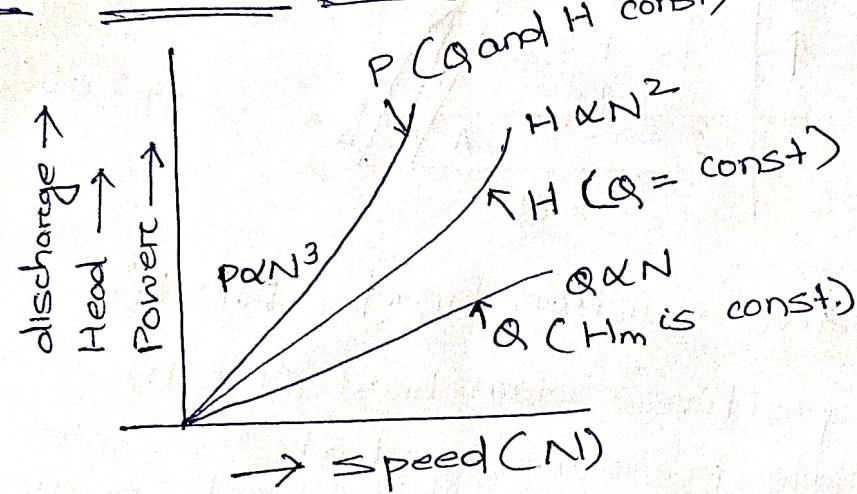
Thus the air from these parts of the pump is removed and these parts are filled with the liquid to be pumped.

Characteristic curves of centrifugal pumps :-

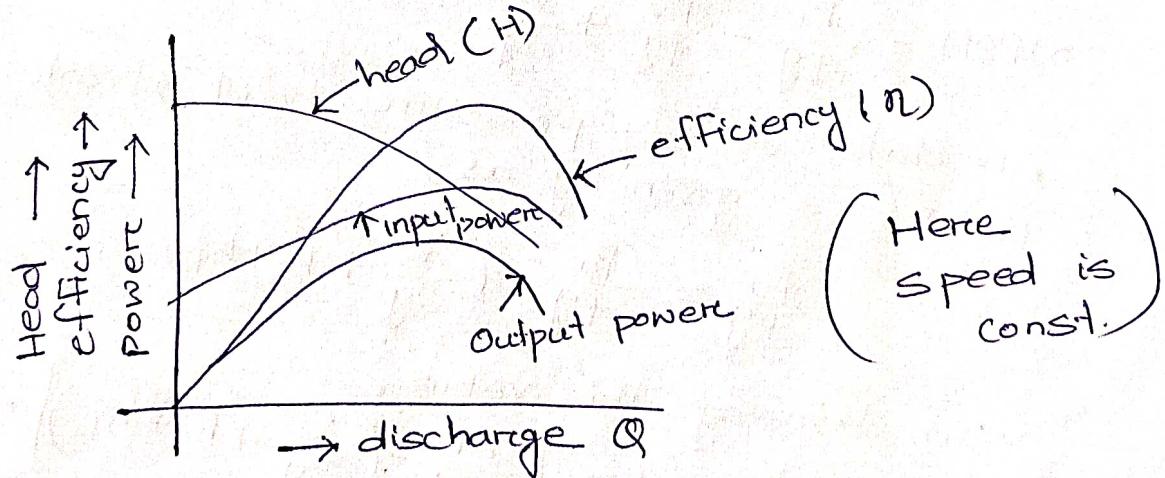
Characteristic curve of the pump are drawn by considering the property of pump like, different flow rate, head and speed.

The following are the important characteristic curves for pumps.

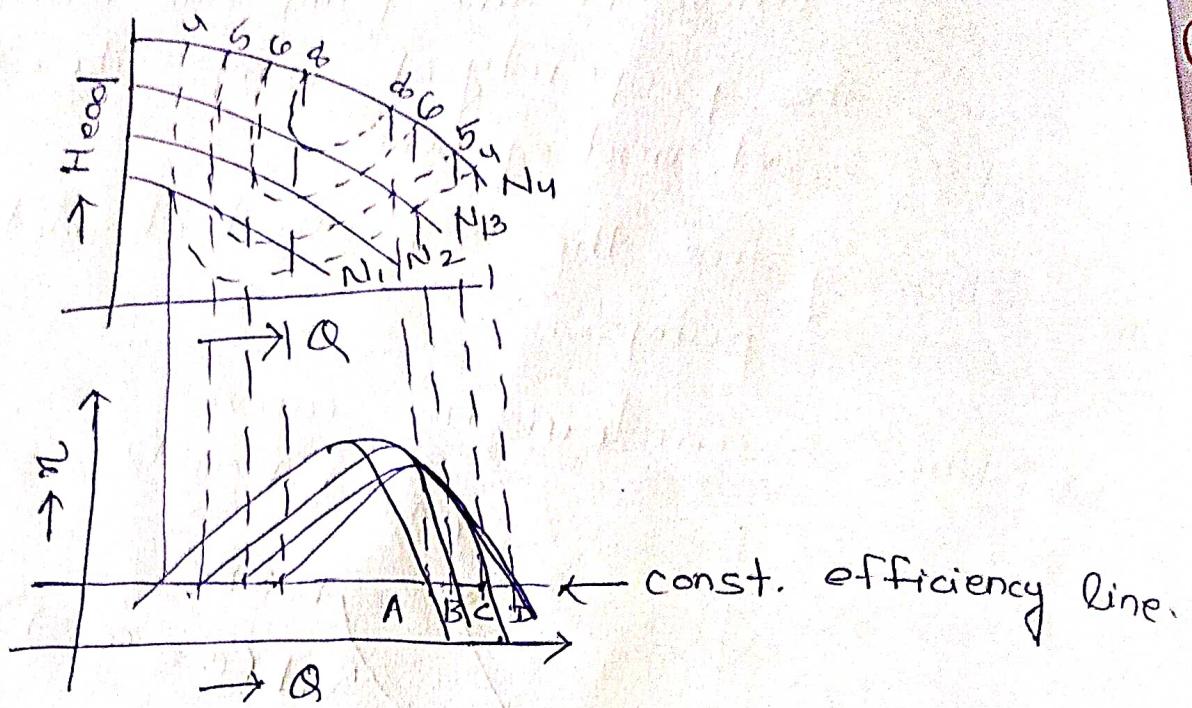
1) Main characteristic curve



2) Operating characteristic curve



3) Constant efficiency curve



Net positive suction head (NPSH)

The net positive suction head (NPSH) is defined as the absolute pressure head at the inlet to the pump minus the vapour pressure head (in absolute units) plus the velocity head.

$$NPSH = \frac{P_1}{\rho g} - \frac{P_v}{\rho g} + \frac{V_s^2}{2g}$$

Absolute velocity pressure head at inlet of the pump is given by as,

$$\frac{P_1}{\rho g} = \frac{P_a}{\rho g} - \left(\frac{V_s^2}{2g} + h_s + h_{fs} \right)$$

Substituting this value,

$$NPSH = \left[\frac{P_a}{\rho g} - \left(\frac{V_s^2}{2g} + h_s + h_{fs} \right) \right] - \frac{P_v}{\rho g} + \frac{V_s^2}{2g}$$

$$= \frac{P_a}{\rho g} - \frac{P_v}{\rho g} - h_s - h_f$$

$$= H_a - H_v - h_s - h_f$$

Cavitation in centrifugal pump :-

In centrifugal pumps the cavitation may occur at inlet of the impellers 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 the cavitation Thomas's cavitation factor is calculated.

$$\sigma = \frac{H_b - H_s - h_{fs}}{H}$$
$$= \frac{(H_{atm} - H_v) - H_s - h_{fs}}{H}$$

H_{atm} = Atm. pressure head

H_v = Vapour pressure head

H_s = Suction pressure head

h_{fs} = head lost due to friction head. on suction pipe

H = head developed by the pump.

Reciprocating Pump

Define reciprocating pump and explain its working principle.

If the mechanical energy is converted into hydraulic energy by sucking the liquid into a cylinder in which a piston is reciprocating (moving backward and forward), which exerts the thrusts on the liquid and increases its hydraulic energy, the pump is known as reciprocating pump.

reciprocating

Parts of the reciprocating pump is,

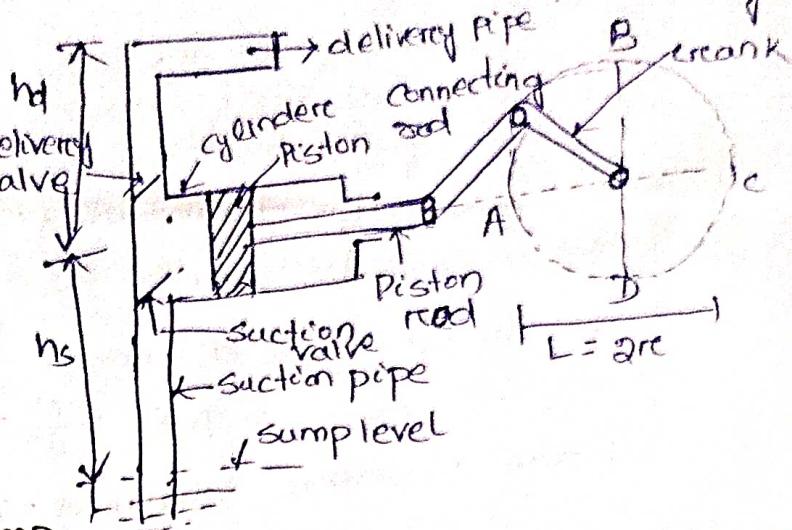
(1) cylinder with a piston, piston rod and crank

(2) suction pipe

(3) delivery pipe

(4) suction valve

(5) delivery valve



Working of a reciprocating pump

It is a single acting reciprocating pump which consists of a reciprocating pump piston which moves forwards and backwards in a close fitting cylinder. The movement of the piston is obtained by connecting the piston rod to the crank by means of a connecting rod. The crank is rotated by means of an electric motor. Suction and delivery pipes with suction valve and delivery valve are connected to the cylinder. The suction and delivery valve are one way valve, which allow the water to flow in one direction only. Suction valve allows water from the suction pipe to the cylinder and delivery valve allows the water from cylinder to delivery pipe only.

When crank starts rotating, the piston moves to and fro in the cylinder. When crank is at A, the piston is at the extreme left position in the cylinder. As the crank is rotating from A to C ($\theta=0^\circ$ to $\theta=180^\circ$), the piston is moving toward right in the cylinder.

The movement of the piston towards right creates a partial vacuum in the cylinder. But on the surface of the liquid in the sump atmospheric pressure is acting, which is more than the pressure inside the cylinder. Thus the liquid is forced in the suction pipe from the sump.

When the crank is rotating from C to A ($\theta=180^\circ$ to 360°), the piston from its extreme point right to starts moving towards left.

The movement of the piston towards left increases the pressure of the liquid inside the cylinder more than atm. pressure. Hence suction valve closes and delivery valve opens. The liquid is forced into the delivery pipe & is raised to a required height.

Discharge through a reciprocating pump :-

Consider a single acting reciprocating pump,

Let D = dia of the cylinder

A = c/s area " arc portion

$$= \frac{\pi}{4} D^2$$

r = radius of crank

N = rpm of the crank

L = Length of the stroke = $2\pi r$

$$\text{Vol. of water delivered in one revolution} = \text{Area} \times \text{length}$$

$$\text{No of revolution/sec} = \frac{N}{60}$$

$$= A L$$

$$\text{Discharge } Q = \text{discharge in one revolution} \times \text{no. of revolution/sec}$$

$$= A L \times \frac{N}{60} = \frac{ALN}{60}$$

$$\text{Weight of water delivered} = W = \rho g Q = \frac{\rho g ALN}{60}$$

Workdone by reciprocating pump:-

Workdone = Weight of water lifted/sec \times Total height

$$= W \times (h_s + h_d)$$

$$\boxed{W.D = \frac{\rho g ALN}{60} (h_s + h_d)}$$

$$\text{Power required} = P = \frac{\text{Workdone/sec}}{1000} = \frac{\rho g ALN}{60} \times \frac{(h_s + h_d)}{1000}$$

$$\boxed{P = \frac{\rho g ALN (h_s + h_d)}{60,000} \text{ KW}}$$

Q) What do u mean by SLIP of a reciprocating pump?

→ Slip of a pump is defined as the difference between the theoretical discharge and actual discharge of the pump. The ^{actual} discharge of a pump is always less than the theoretical discharge due to leakage.

→ The difference of the theoretical discharge and actual discharge is known as slip of the pump. Hence,

$$\text{Slip} = Q_{th} - Q_{act}$$

$$\text{Percentage slip} = \frac{Q_{th} - Q_{act}}{Q_{th}} \times 100 = \left(1 - \frac{Q_{act}}{Q_{th}} \right) \times 100 = (1 - c_d) \times 100$$

$$c_d = \frac{Q_{act}}{Q_{th}} = \text{co-eff. of discharge.}$$

Q) Define negative slip:- If actual discharge is more than the theoretical discharge, the slip of the pump will become -ve. In that case slip of the pump becomes -ve. It occurs when delivery pipe is short and suction pipe is long and pump is running at high speed.

Indicators Diagram

It is the graph bet' the pressure head in the cylinders and the distance travelled by piston from inner dead centre for the complete revolution of the crank.

Ideal indicators diagram

→ If the indicators diagram is under ideal cond' then it is known as ideal indicators diagram.

→ In this diagram line EF is known as atm. pressure head = 10.3 m of water.

$$\text{Let } H_{\text{atm}} = \text{atm press head}$$

$$L = \text{length of stroke}$$

$$h_s = \text{suction head}$$

$$h_d = \text{delivery head}$$

→ During suction stroke, the pressure head in the cylinders is const. and ~~equals~~ equal to suction head(h_s) which is below the line EF.

→ During delivery stroke, the pressure head in the cylinder = delivery head(h_d). which is above ~~is~~ line EF.

→ Thus for one complete revolution of the crank, the pressure head in the cylinders is represented by the diagram A-B-C-D-A, known as ideal indicators diagram

Workdone by the pump per second,

$$= \frac{\rho g A L N}{60} \times (h_s + h_d)$$

$$= K \times L (h_s + h_d) \propto L \times (h_s + h_d)$$

$$\text{Area of diagram} = AB \times BC = AB \times (BF + CF)$$

$$= L \times (h_s + h_d)$$

Workdone by the pump \propto area of the indicators dia.

(2) Effect of acc' in suction and delivery pipes on indicators dia.

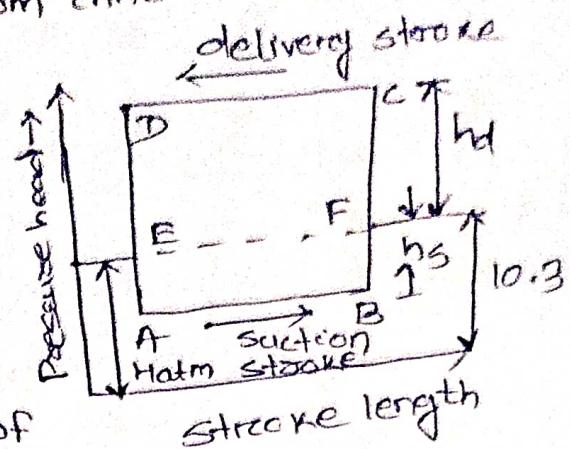
The pressure head due to acc' in the suction pipe is given by

$$h_{as} = \frac{l_s}{g} \times \frac{A}{a_s} \times \omega^2 r \cos \theta$$

$$\text{When } \theta = 0^\circ \quad \cos \theta = 1, \quad h_{as} = \frac{l_s}{g} \times \frac{A}{a_s} \omega^2 r$$

$$\theta = 90^\circ \quad \cos \theta = 0, \quad h_{as} = 0$$

$$\theta = 180^\circ \quad \cos \theta = -1, \quad h_{as} = - \frac{l_s}{g} \times \frac{A}{a_s} \omega^2 r$$



- The pressure head inside the cylinder during suction stroke will not be equal to h_s . It is equal to the sum of h_s and h_{as} .
- At the beginning of suction stroke $\theta=0^\circ$, h_{as} is +ve and hence the pressure head in the cylinder is $(h_s + h_{as})$.
- At the middle $\theta=90^\circ$, $h_{as}=0$ Pressure head will be h_s
- At the end, $\theta=180^\circ$, $h_{as}=-ve$ Pressure head = $h_s - h_{as}$
- For suction stroke, the indicator dia will be $A'G'B'$.
- Also area of $A'AG_1 = \text{Area of } BGB'$
- Similarly in case of delivery stroke,
at the beginning delivery stroke = had
 $\text{Press. head} = had + had$
- Area of $CC'H = \text{Area of } DD'H$
- Area of $ABCD = \text{Area of } A'B'C'D'$.

