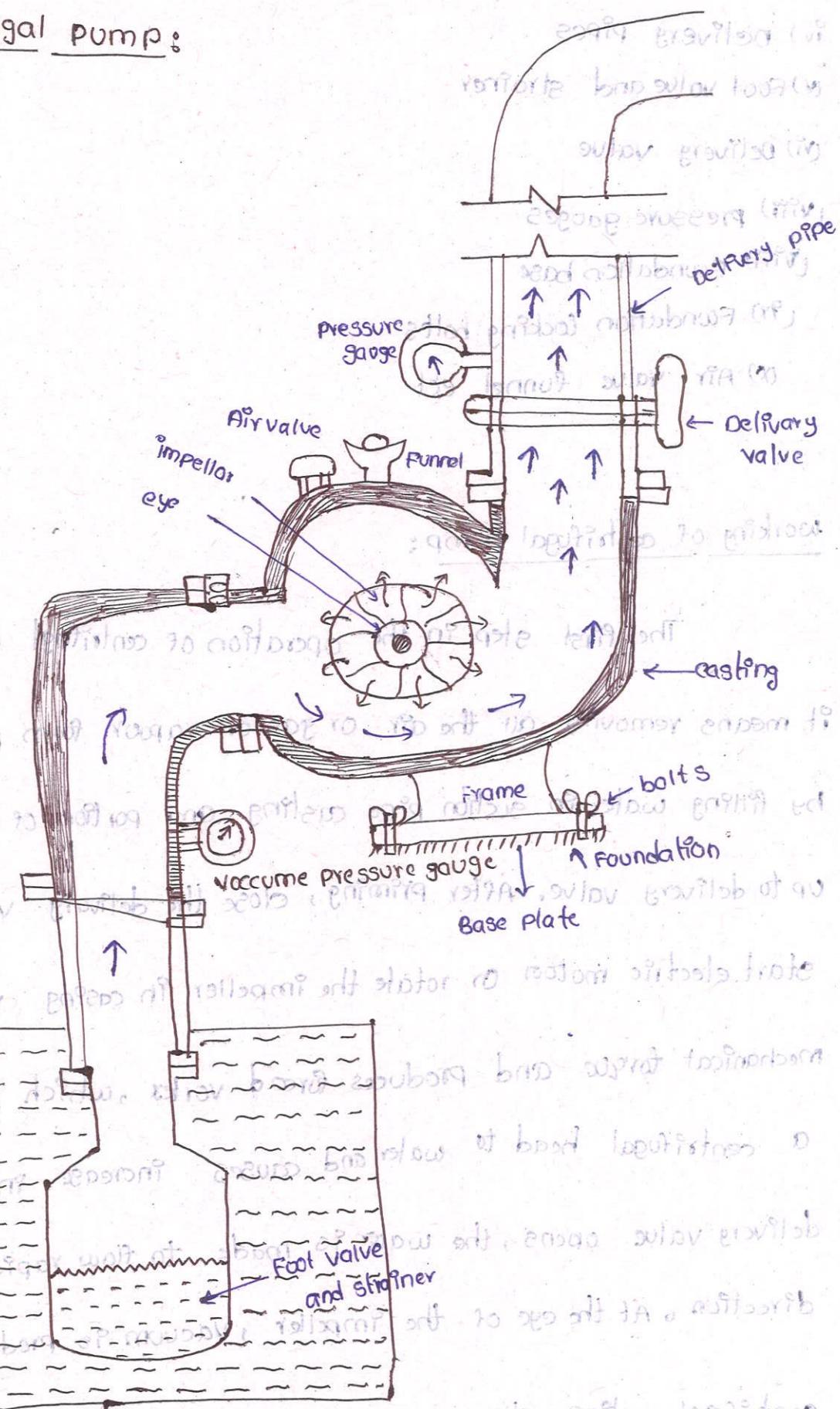


## \*5. CENTRIFUGAL AND RECIPROCATING PUMPS \*

centrifugal pump:



basically centrifugal pump is a pump which rotates about a horizontal axis.

The main components of a centrifugal pump are as follows

- i) Impeller
- ii) Casting
- iii) Suction pipes
- iv) Delivery pipes
- v) Foot valve and strainer
- vi) Delivery valve

vii) Pressure gauges

viii) Foundation base

ix) Foundation locking bolts

x) Air valve funnel etc

provided  
water

outlet  
valve

bottom

### Working of centrifugal pump:

The first step in the operation of centrifugal pump is priming

It means removing all the air or gas or vapour from pump portion

by filling water in suction pipe casting, and portion of delivery pipe

up to delivery valve. After priming, close the delivery valve and

start electric motor or rotate the impeller in casing receives

mechanical torque and produces forced vortex, which imparts

a centrifugal head to water and causes increase in pressure, when

delivery valve opens, the water is made to flow rapidly in outward direction. At the eye of the impeller, vacuum is produced due to

centrifugal action, this helps to suck the water from sump through

suction pipe, the higher pressure water leaves the impeller and flows

through delivery pipe to required height.

## Multistage centrifugal pump:

The pumps which possess two or more impellers mounted on the same shaft or on the different shafts to increase either the head or discharge.

The discharge of the liquid is known as multistage centrifugal pumps.

The pumps with single impeller gives a maximum head of 100m. when liquid is to be pumped against larger heads two or more impellers are mounted on the same shaft i.e. are connected in series in which

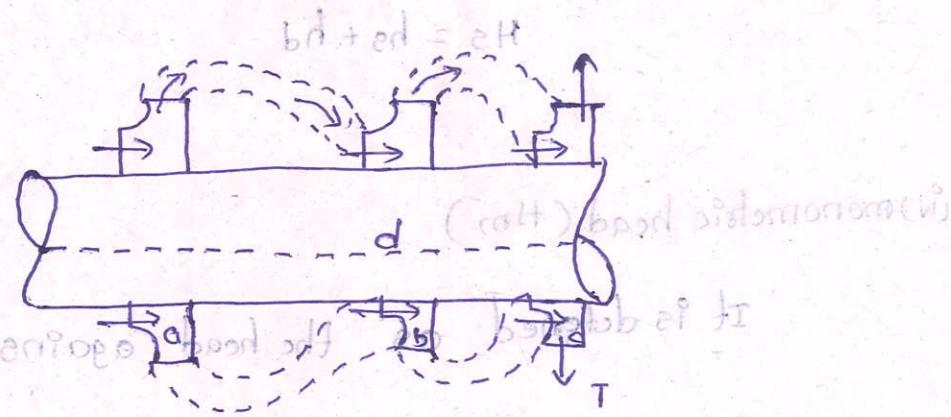
a way that the liquid after passing through the first impellers

are mounted on the same shaft i.e. are connected. This passes

process continuous till the last impeller from where the liquid

passes into the delivery valve. The total head development using

n impellers, which are identical is given by the product of number of impellers and the head ( $H_m$ ).



impellers; a, b, c

Guidance passages; e, f, g, h

Three stage centrifugal pump.

different heads for a centrifugal pump:

For a centrifugal pump there are four types of heads, they are

(i) suction head ( $h_s$ ):

It is the vertical height from the surface of the water which is to be lifted to the center of the pump. The lift of water is known as suction lift.

(ii) Delivery head:

It is the vertical height to which the water is to be supplied from the center of the pump.

(iii) static head:

It is a vertical distance between the surface of water below the pump and the height at which the water is to be delivered i.e.

It is the sum of suction head. mathematically it is written as

$$H_s = h_g + h_d$$

(iv) monometric head ( $H_m$ )

It is defined as the head against which a centrifugal pump has to work. It is given as follows.

$$H_m = \text{Head imparted by the impeller to water} - \text{loss of head in pump}$$

## Advantages of centrifugal pumps:

- 1) Initial cost for installation of centrifugal pump is low
- 2) Installation and main feature of centrifugal pump is easier and economical as it has small number of components.
- 3) It is very compact and requires less space.
- 4) It is a high speed pump and can be directly coupled to electric or oil engine.
- 5) Discharging capacity of centrifugal pump is higher than reciprocating pump.
- 6) Discharge through the centrifugal pump is uniform.
- 7) Performance of centrifugal pump at low heads is quite high.

## Expression for work done by impeller on water:

Expression can be obtained by drawing the velocity triangles

at inlet and outlet of blade, water enters the impeller radially

at inlet, absolute velocity makes an angle  $90^\circ$  with direction of motion of impeller, Thus, no whirl component at inlet ( $V_{wi} = 0$ )

let speed of impeller be  $N$  rpm

$D$  - diameter of impeller at inlet

$U$  - tangential velocity of impeller at inlet

$$W = \frac{\pi D N}{60}$$

( $W = \text{work done per second}$ )

unit -  $J/s$ , pg - 4/14

$v_1$  = Absolute velocity at inlet

$v_{r2}$  - Relative velocity inlet

$\omega$  - Angle between  $v_1$  and  $v_{r2}$

$\theta$  - Angle between  $u_1$  and  $v_{r2}$

$v_{r2}, \omega, \theta$  are values at outlet

Workdone on impeller per second per unit weight of water striking per second is given by  $\frac{1}{g} (v_{w1} u_1 - v_{w2} u_2)$

Workdone by Impeller on water = -(Workdone on Impell)

$$\text{Workdone by Impeller on water} = -\left(\frac{1}{g} (v_{w2} u_2 - v_{w1} u_1)\right)$$

$$\text{Workdone by Impeller on water/sec} = \frac{w}{g} (v_{w2} u_2 - v_{w1} u_1)$$

$$\text{But } v_{w1} = 0 \quad (\because \alpha = 90^\circ)$$

$$\text{Workdone for sec} = \frac{w}{g} (v_{w2} u_2)$$

where

$$w - \text{Weight of water} = \rho g Q$$

$Q$  - Area  $\times$  Velocity

$$Q = \pi D_1 B_1 \times V_f_1$$

$$= \pi D_2 B_2 \times V_f_2$$

$$= \pi D^2 B^2 \times V_f$$

$$\therefore \text{Workdone by Impeller on water} = \frac{w}{g} (v_{w2} u_2)$$

## efficiencies of centrifugal pumps:

The centrifugal pump has three types of efficiencies they are

1) manometric efficiency  $\eta_{mano}$

2) mechanical efficiency  $\eta_m$

3) overall efficiency,  $\eta_o$

1) manometric efficiency ( $\eta_{mano}$ )  
It is the ratio of manometric head ( $H_m$ ) to the head imparted by impeller to water. It is written as.

$$\eta_{mano} = \frac{\text{Manometric head}}{\text{Head imparted by impeller to water}}$$

The power given by the impeller to water at the outlet of the pump

The power given to the water at outlet of pump.

$$= \frac{W H_m}{1000} \text{ kw}$$

The power at the impeller per

$$= \frac{\text{Workdone by impeller per second}}{1000} \text{ kw}$$

$$= \frac{\frac{W}{g} \times \frac{V_w U_2}{1000}}{1000} \text{ kw}$$

$$= \frac{\frac{W \times H_m}{1000}}{\frac{W}{g} \times \frac{V_w U_2}{1000}}$$

$$= \frac{g \times H_m}{V_w^2 \times U_2}$$

incapabilities to V<sub>w2</sub> and don't eat among losses off

## Q) mechanical efficiency:

It is the ratio of power available at the impeller to the power available at the shaft of the pump.

to the power available at the shaft of the pump; the power at impeller

is less than the power at the shaft due to the mechanical properties

losses during the transmission of power from shaft to the impeller.

mathematically it is written as

$$\eta_m = \frac{\text{power at the impeller}}{\text{power at the shaft}}$$

$$= \frac{w}{g} \left[ \frac{V_w^2 U_2}{1000} \right]$$

S.P.

where

S.P. - shaft power

## Overall efficiency:

$$= \frac{w \times mH \times w}{1000}$$

It is defined as the ratio of power output of the pump to the power input to the pump; mathematically it is written as

$$\eta_o = \frac{\text{Power Input}}{\text{Power Output}}$$

$$= \frac{mH \times w}{1000}$$

$$= \frac{mH \times w}{1000} \times \frac{w}{B}$$

The output power

= weight of water lifted  $\times \text{Hm}$

$$1000 \times 0.04 \times 1000 \times \frac{\text{Hm}}{1000} = \text{S.P}$$

Input power, shaft power = S.P

$$\therefore \eta = \left[ \frac{w \text{Hm}}{1000 \times \text{S.P}} \right]^{0.5} = V$$

And also  $\eta_o = \eta_{\text{mano}} \times \eta_m$

problem:

calculate the rate of flow of water through a pipe of diameter of 300 mm, when the difference of pressure head between the two ends of a pipe 400 m apart is 5 m of water. Take the value of  $f=0.009$  in the formula  $h_f = \frac{4fLV^2}{d \times 2g}$

Ans: ~~rate of flow~~ ~~to be converted into discharge~~

given that

Diameter of pipe  $d = 300 \text{ mm} = 0.3 \text{ m}$

difference of pressure head  $h_f = 5 \text{ m}$

length of pipe  $L = 400 \text{ m}$

Friction factor  $f = 0.009$

using the following formula, velocity of flow can be

obtained.

unit - 5, Pg - 7/4

$$h_f = 4 \rho L v^2$$

$$\frac{2g}{d}$$

unit  $\text{m}^2/\text{s}^2$  converted to  $\text{m}^3/\text{s}$  =

$$S = \frac{4 \times 0.009 \times 400 v^2}{0.3 \times 2 \times 9.81}$$

$$\frac{\text{m}^3/\text{s}}{0.001}$$

$$0.4 \times 0.009 \times 400 \times v^2 = 5 \times 0.3 \times 2 \times 9.81$$

$$v = \sqrt{\frac{5 \times 0.3 \times 2 \times 9.81}{4 \times 0.009 \times 400}}$$

$$v = 1.430 \text{ m/s}$$

discharge

$$Q = \text{Area} \times \text{velocity}$$

$$Q = \frac{\pi}{4} (d)^2 \times v$$

$$Q = \frac{\pi}{4} \times (0.3)^2 \times 1.430$$

$$\therefore Q = 0.101 \text{ m}^3/\text{sec} \quad (0.101 \text{ lit/sec})$$

Expression for specific speed of a centrifugal pump:

Specific speed:

specific speed of a centrifugal pump is the speed in

revolutions per minute of a geometrically similar pump to the

actual pump, in given conditions, it develops unit power working

against unit head. It is denoted by  $N_s$ .

Expression for specific speed of pump.

The discharge of a centrifugal pump is

$$Q = \text{Area} \times \text{velocity of flow}$$

$$Q = \pi D^2 \times V_f$$

$$Q \propto D^2 \times V_f$$

But  $D \propto N$  (from eqn 1)  $\therefore Q \propto N^2 \times V_f$

$$\therefore Q \propto D^2 \times V_f$$

Using the relation

$$V_f = \frac{\pi D N}{60}$$

$$V_f \propto D N$$

$\therefore Q \propto D^3 N$   $\therefore Q = H g q N$

Tangential velocity ( $v_t$ ) and velocity of flow ( $V_f$ ) are related to manometric head as.

$$v_t \propto V_f \propto \sqrt{H_m}$$

On substituting the value of  $v_t$  in equation (a)

$$v_t \propto D N \quad (\because v_t \propto D N)$$

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

On substituting value of  $D$  in (a) we get

$$\therefore Q \propto \left[ \frac{\sqrt{H_m}}{N} \right]^2 \times V_f$$

$$Q \propto \left[ \frac{H_m}{N^2} \right] \times V_f \quad (\because V_f \propto \sqrt{H_m})$$

$$Q \propto \left( \frac{H_m^{3/2}}{N^2} \right)$$

$$V_f = (e_{ad} - e_d - \Delta H) = \Delta H g N$$

$$\boxed{\therefore Q = k \cdot \frac{H_m^{3/2}}{N^2}}$$

$$\text{Crossing of bridge} \quad \Delta H = \frac{H_f - H_i}{B_2}$$

in terms of time

unit  $m^3$ , pg - 9/14

NPSH :

$$qV \times \rho g = 0$$

"net positive suction Head". This term is used in centrifugal pumps. It is related to suction conditions of centrifugal pump.

Definition:

It is the absolute pressure head at the inlet to the pump, minus the vapour pressure head plus the velocity head

$NPSH = \text{Absolute pressure head at inlet} - \text{vapour pressure head}$

+ Velocity head

$$NPSH = \frac{P_1}{\rho g} - \frac{P_v}{\rho g} + \frac{V_1^2}{2g}$$

where

$$\frac{P_1}{\rho g} = \frac{P_A}{\rho g} - \frac{V_1^2}{2g} - h_s - h_{fs}$$

Substitute equation (2) in equation (1) if it is true no

$$\therefore NPSH = \left[ \frac{P_A}{\rho g} - \frac{V_1^2}{2g} - h_s - h_{fs} \right] - \frac{P_v}{\rho g} + \frac{V_1^2}{2g}$$

$$= \frac{P_A}{\rho g} - \frac{P_v}{\rho g} - h_s - h_{fs}$$

$$NPSH = (H_A - h_s - h_{fs}) - H_v$$

$$NPSH = \text{total suction head}$$

where  $\frac{P_A}{\rho g} = H_A$  (Atmospheric pressure)

## Reciprocating pumps:

separate provides

velocity diagram of noting to action broad off on prout

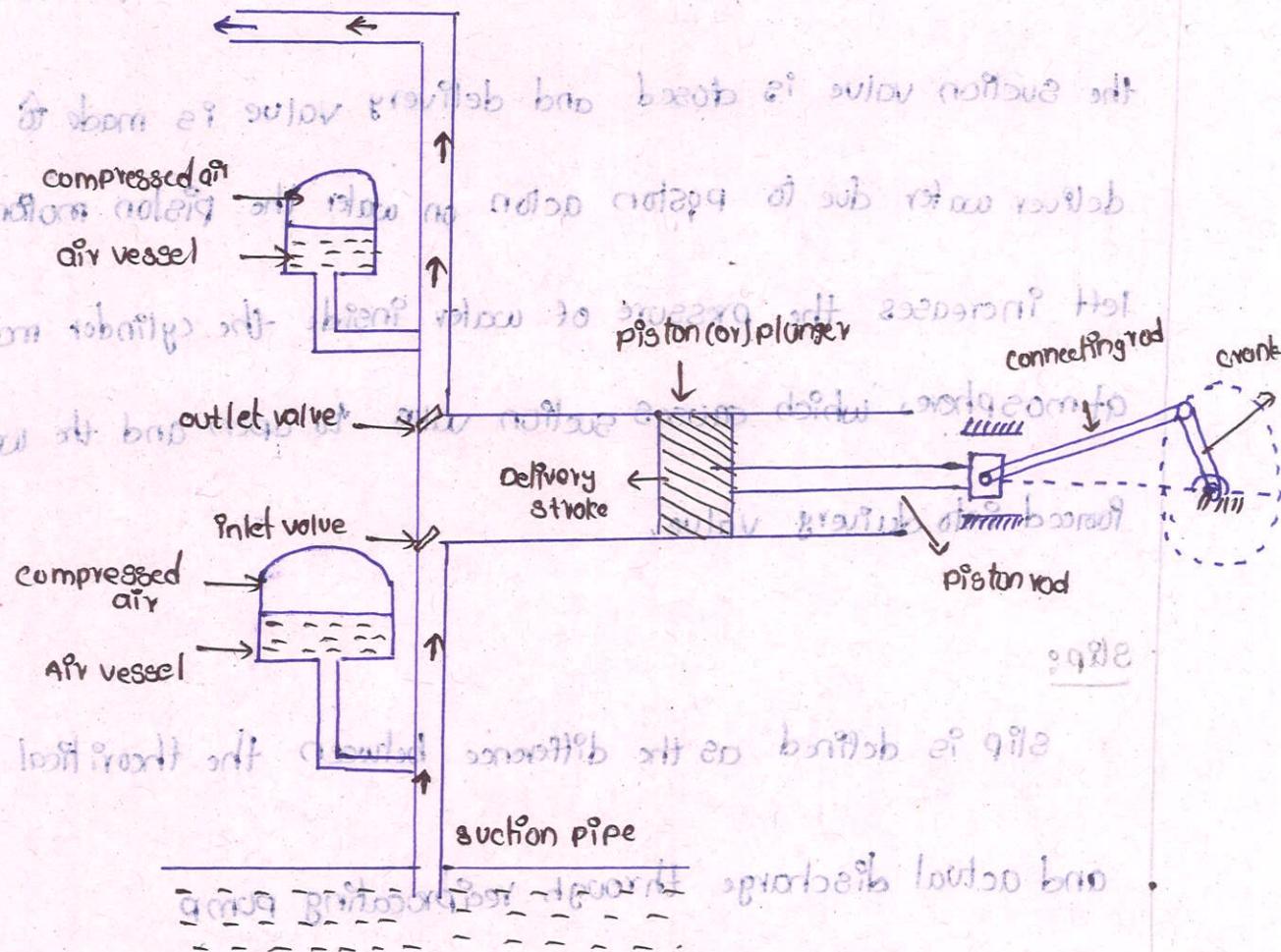


fig: Reciprocating pump.

show two time notes to actionless of sub broad of T

### i) Suction strokes:

The moment to piston is obtained from connecting rod

$$001x \frac{10A^2 - m^2}{10} = 912 \text{ N}$$

through rod through rotation of crank is driven by any prime mover

(electric motor or mechanical means). During backward motion of

piston, i.e. away from values, the delivery valve is closed and

suction valve opens due to suction, which develops pressure

inside the water inside the cylinder is lower than atmosphere during

to atmospheric pressure is equal to blade area  $30 \text{ ft}^2$   
suction.

## Delivery strokes

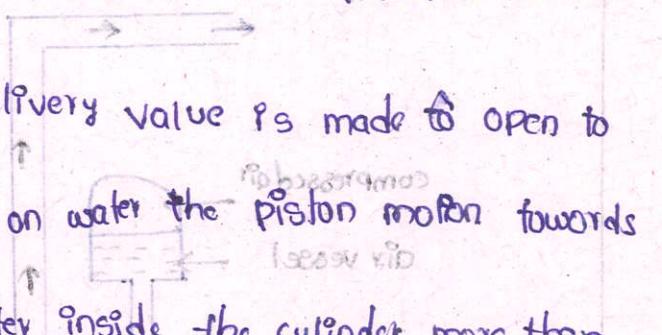
: 89 mud 89 mud 89 mud

(B)

during the forward motion of piston, i.e. towards valves,

the suction valve is closed and delivery valve is made to open to

deliver water due to piston action on water the piston motion towards



left increases the pressure of water inside the cylinder more than atmosphere, which causes suction valve to open and the water is

pumped into delivery valve.

## Slip:

slip is defined as the difference between the theoretical discharge and actual discharge through reciprocating pump

$$\text{Slip, } S = Q_{th} - Q_{Act}$$

It is caused due to acceleration of piston without water delivered.

$$\% \text{ slip} = \frac{Q_{th} - Q_{Act}}{Q_{th}} \times 100$$

or slip is due to ratio of actual discharge to theoretical discharge

$$= \frac{Q_{Act}}{Q_{th}} \times 100$$

ratio of actual discharge to theoretical discharge

where  $C_d$  = coefficient of discharge

coefficient of discharge = ratio of actual discharge to theoretical discharge

% of slip should be less. By proper maintenance of pump

proper sealing and tightness of piston with cylinder slip can be reduced.

## Functions of air vessels in a reciprocating system:

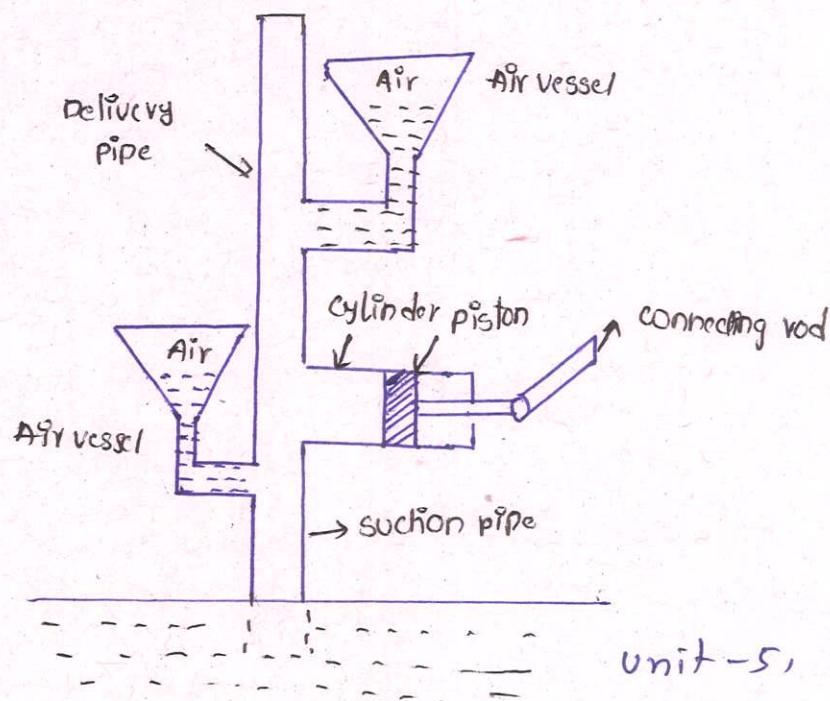
### Air vessels:

Air vessels are closed chambers attached to the suction and delivery pipes of reciprocating pumps. These are located closed to the cylinder of the pump. The air vessels are filled with liquid being pumped up to some level and remaining volume is occupied by air, which is present over the surface of the liquid. The main functions of air vessels are

- 1) To supply uniform and continuous rate of supply of the fluid.
- 2) To save the power required to run the pump.
- 3) To run the pump at high speed without any danger of separation of liquid in the pump.

### Working of Reciprocating pump attached with Air vessels:

Consider a single acting reciprocating pump with air vessels attached to its suction and delivery pipes is shown in figure below.



(B)

→ In the delivery stroke, the delivery valve is open and suction valve is closed. The liquid in the cylinder is pushed into the delivery pipe. Some of the liquid in the delivery pipe enters the air vessel and due to this air get compressed. During this stroke the water valve, the delivery valve is closed

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