UNIT -6
RECIPROCATING PUMPS

Course Objectives:

CO5:Identify and understand pressure variations, acceleration effects in suction, delivery and work done against friction in a reciprocating pump.

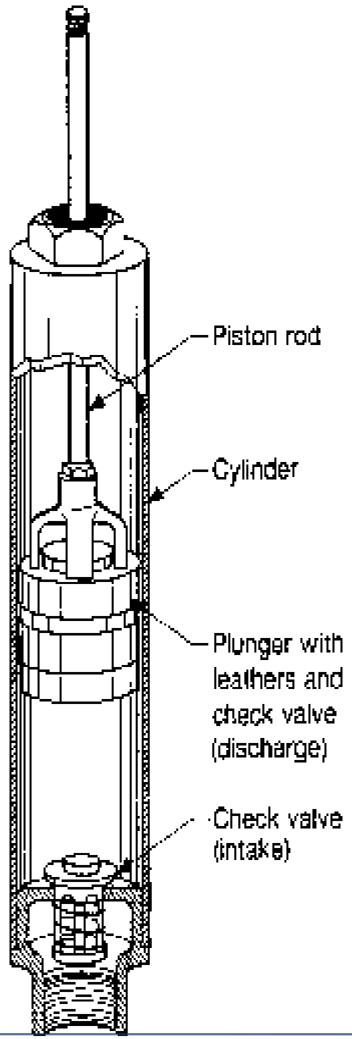
Topics

1. Reciprocating Pumps- Family Tree, Operating Principle and Working
2. Characteristics
3. Applications
4. Difference between Centrifugal and Reciprocating Pump
5. Discharge Through a Reciprocating Pump
6. Workdone by a Reciprocating Pump
7. Discharge, Work done and power required to drive a double acting pump
8. Slip of a Reciprocating Pump
9. Negative Slip of a Reciprocating Pump
10. Air vessels

RECIPROCATING PUMPS

Family Tree

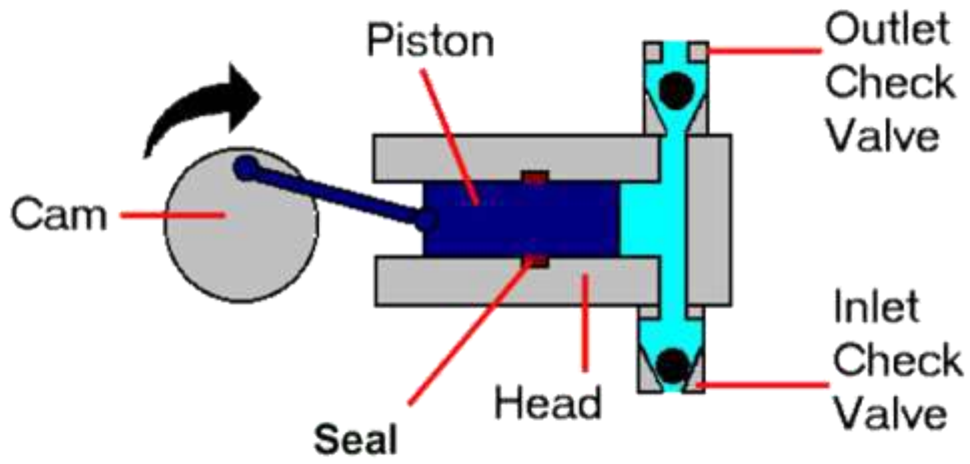
- Positive Displacement Pump
  - Linear Type
  - Reciprocating Type
    - Piston Pump
    - Diaphragm Pump
  - Rotary Type



Causes a fluid to move by trapping a fixed amount of it and then forcing (displacing) that trapped volume into the discharge pipe.

Also known as "Constant Flow Machines"

OPERATING PRINCIPLE



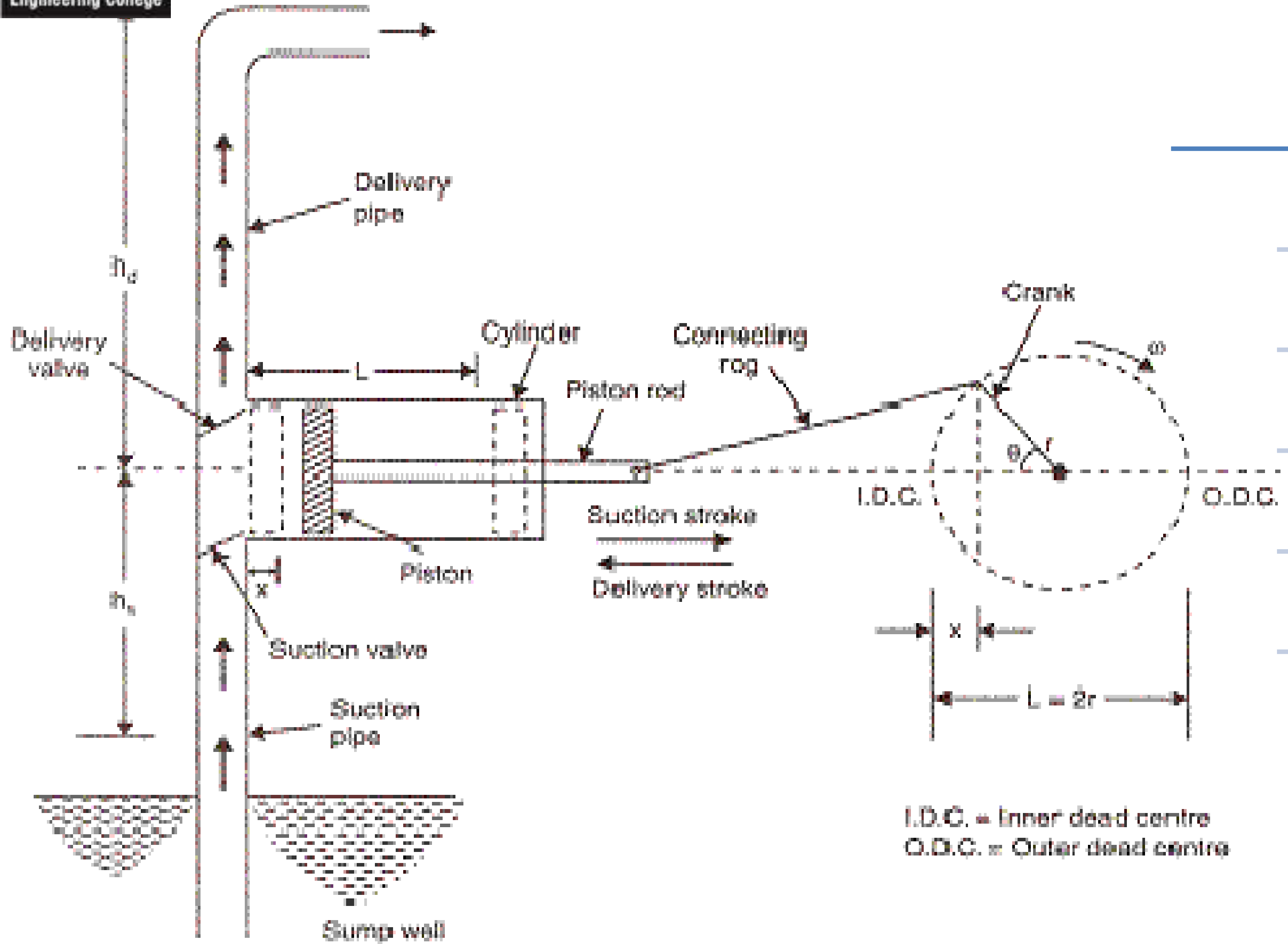
Pushing of liquid by a piston that executes a reciprocating motion in a closed fitting cylinder.

Crankshaft-connecting rod mechanism.

Conversion of rotary to reciprocating motion.

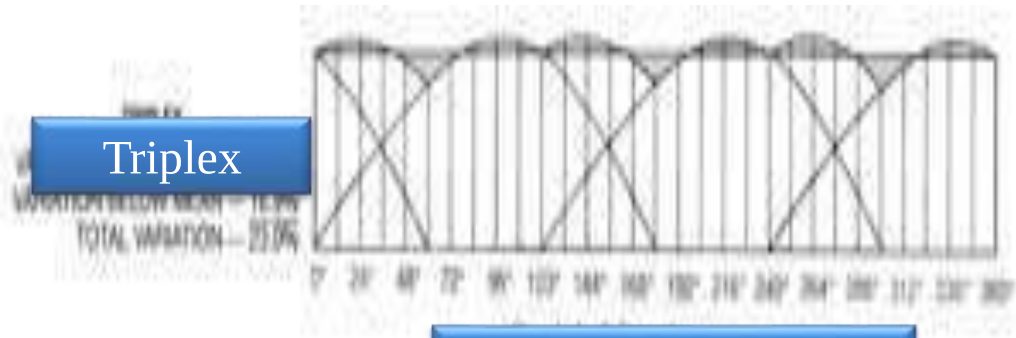
Entry and exit of fluid.

WORKING



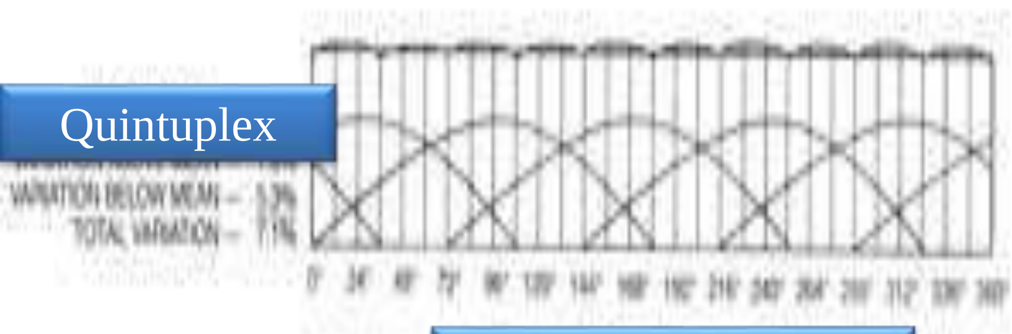
- *Cylinder.*
- *Suction Pipe.*
- *Delivery Pipe.*
- *Suction valve.*
- *Delivery Valve.*

CHARACTERISTICS



Triplex

Crank-shaft Rotation



Quintuplex

Crank-shaft Rotation

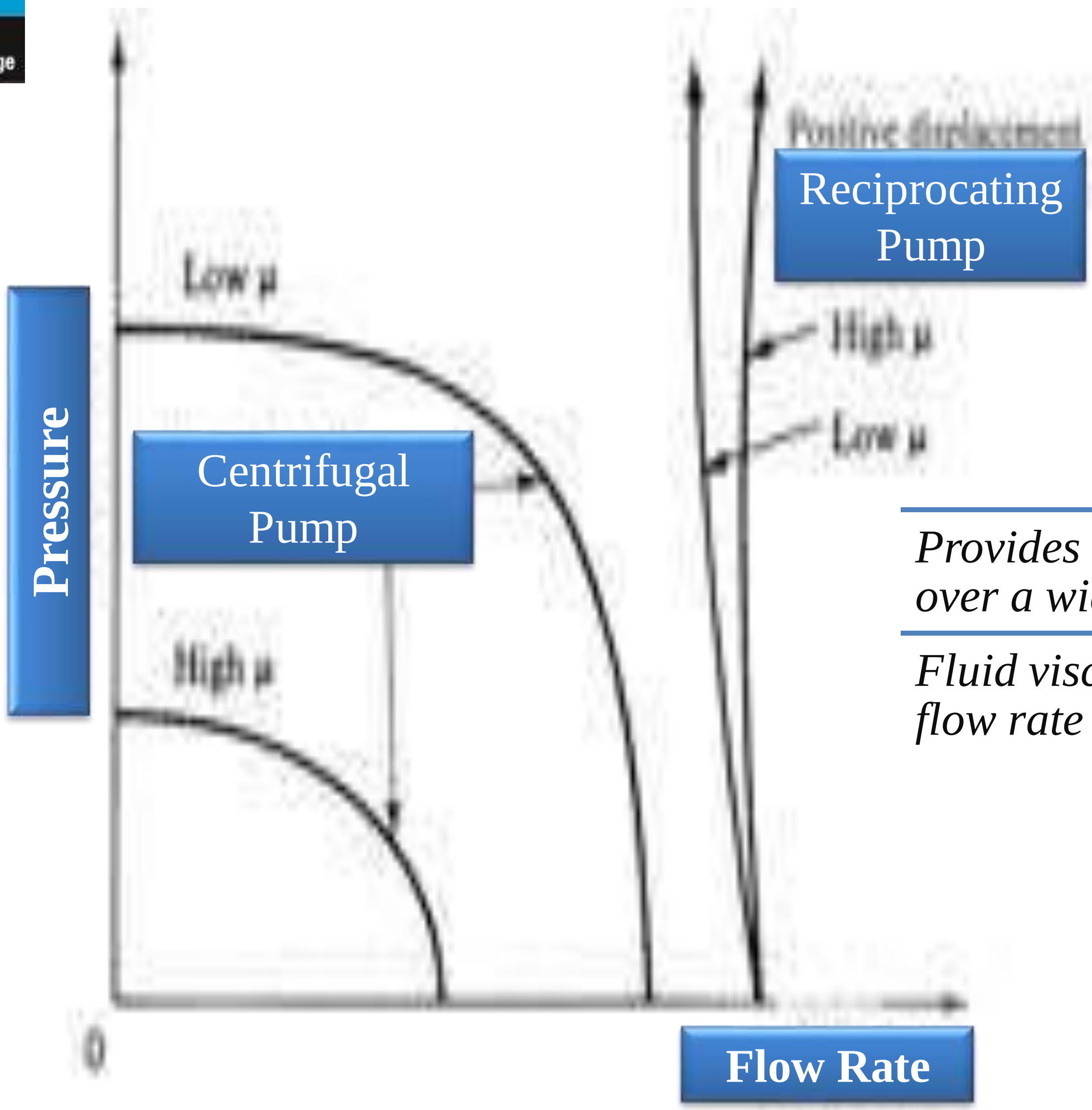
No generation of head.

Because of the conversion of rotation to linear motion, flow varies within each pump revolution.

Flow variation for the triplex reciprocating is 23%.

Flow variation for the quintuplex pump is 7.1%.

EFFECT OF VISCOSITY



Provides a nearly constant flow rate over a wider range of pressure.

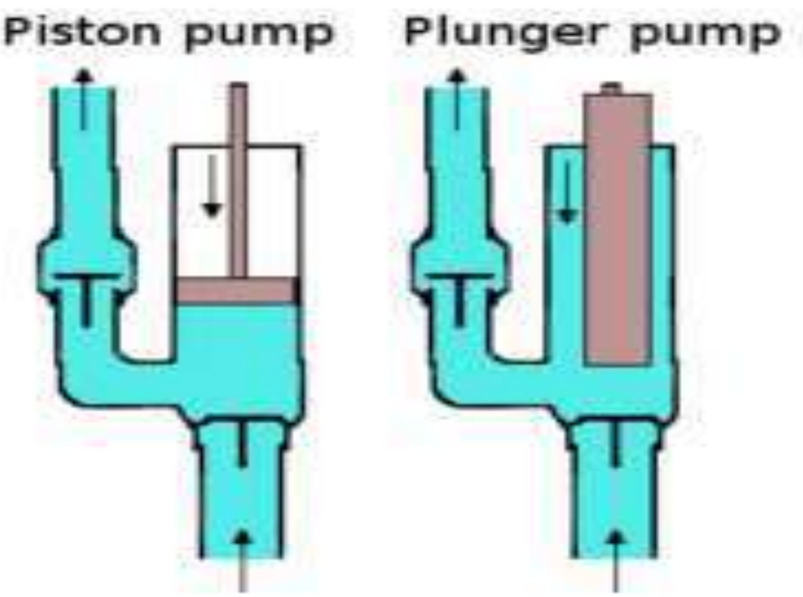
Fluid viscosity has little effect on the flow rate as the pressure increases.

PISTON/PLUNGER PUMP

They are reciprocating pumps that use a plunger or piston to move media through a cylindrical chamber.

It is actuated by a steam powered, pneumatic, hydraulic, or electric drive.

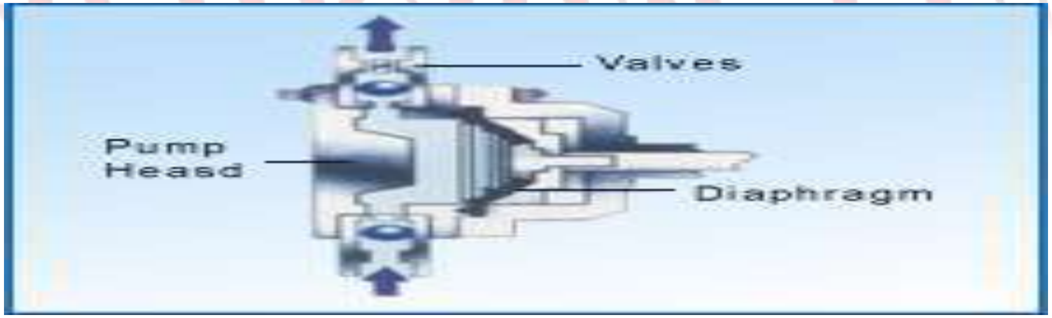
Other names are well service pumps, high pressure pumps, or high viscosity pumps.



Cylindrical mechanism to create a reciprocating motion along an axis, which then builds pressure in a cylinder or working barrel to force gas or fluid through the pump. The pressure in the chamber actuates the valves at both the suction and discharge points.

The volume of the fluid discharged is equal to the area of the plunger or piston, multiplied by its stroke length.

DIAPHRAGM PUMP



*A **diaphragm pump** is a pump that uses a combination of the reciprocating action of a rubber, thermoplastic or teflon diaphragm and suitable non-return check valves to pump a fluid.*

Has been developed for handling corrosive liquids and those containing suspensions of abrasive solids.

In one section a piston or plunger operates in a cylinder in which a non-corrosive fluid is displaced..

The movement of the fluid is transmitted by means of flexible diaphragm to the liquid to be pumped. The only moving parts of the pump that are in contact with the liquid are the valves, and these can be specially designed to handle the material.

In some cases the movement of the diaphragm is produced by direct mechanical action, or the diaphragm may be air actuated.

CHARACTERISTICS OF DIAPHRAGM PUMP

Suitable for discharge pressure up to 1,200 bar have .

Good dry running characteristics.

Are low-shear pumps.

Can be used to make artificial hearts.

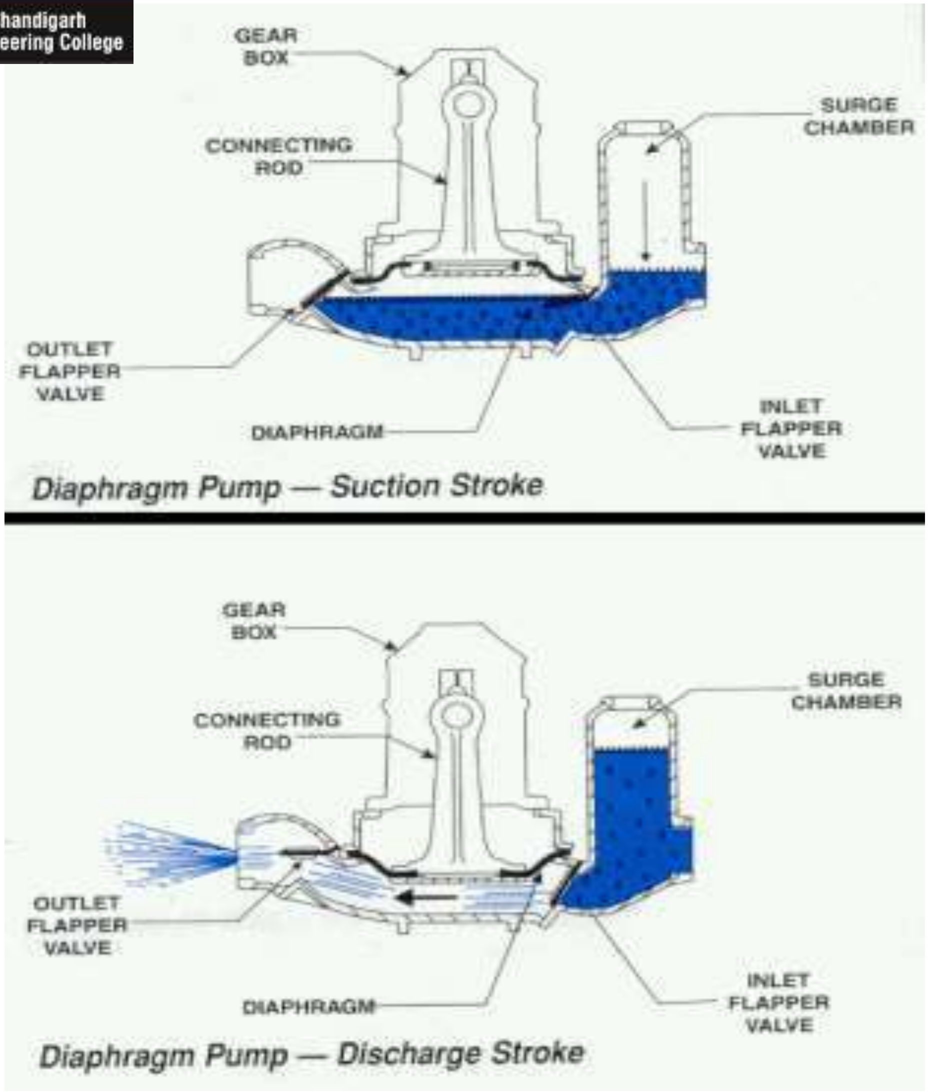
Are used to make air pumps for the filters on small fish tanks.

Can be up to 97% efficient.

Can handle highly viscous liquids.

Are available for industrial, chemical and hygienic applications.

WORKING OF DIAPHRAGM PUMP



A vacuum is created inside the pump casing each time the diaphragm is raised.

This opens the inlet valve and seals the discharge valve allowing water and air to enter the pump.

When the diaphragm is lowered the resulting pressure seals the inlet and opens the outlet valve purging the pump housing of water and air.

Unlike centrifugal designs the water inside the casing is *positively displaced* and no recirculation occurs.

PUMPING POWER

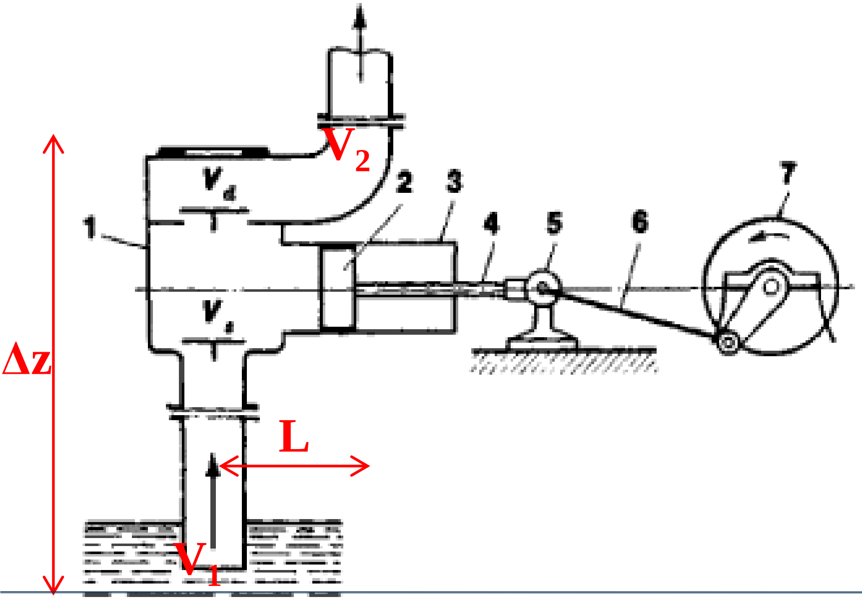
Power=(Δp*Q)/η

ΔP: Change in total pressure between the inlet and outlet.

$$\Delta P = \frac{(v_2^2 - v_1^2)}{2} + \Delta z g + \frac{\Delta p_{\text{static}}}{\rho}$$

Q: Discharge of the pump.

η: Efficiency.



Q=(ALN)/60.

Q: – Discharge of the pump, m^3/sec.

A: – Cross-section of piston or cylinder, m^2.

L: – length of stroke in meter, m.

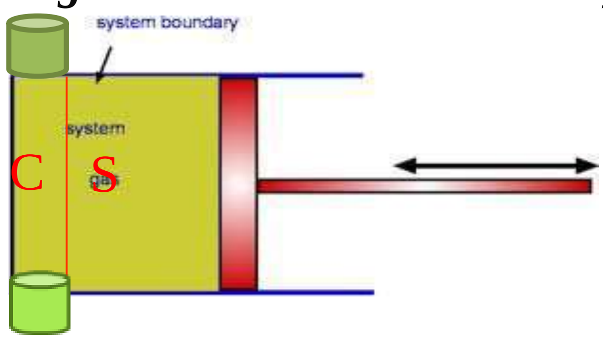
N: – speed of crank, r.p.m.

PUMP EFFICIENCY

The ratio of the power imparted on the fluid by the pump in relation to the power supplied to drive the pump.

Volumetric efficiency :

(Discharge volume / Suction volume)-slip

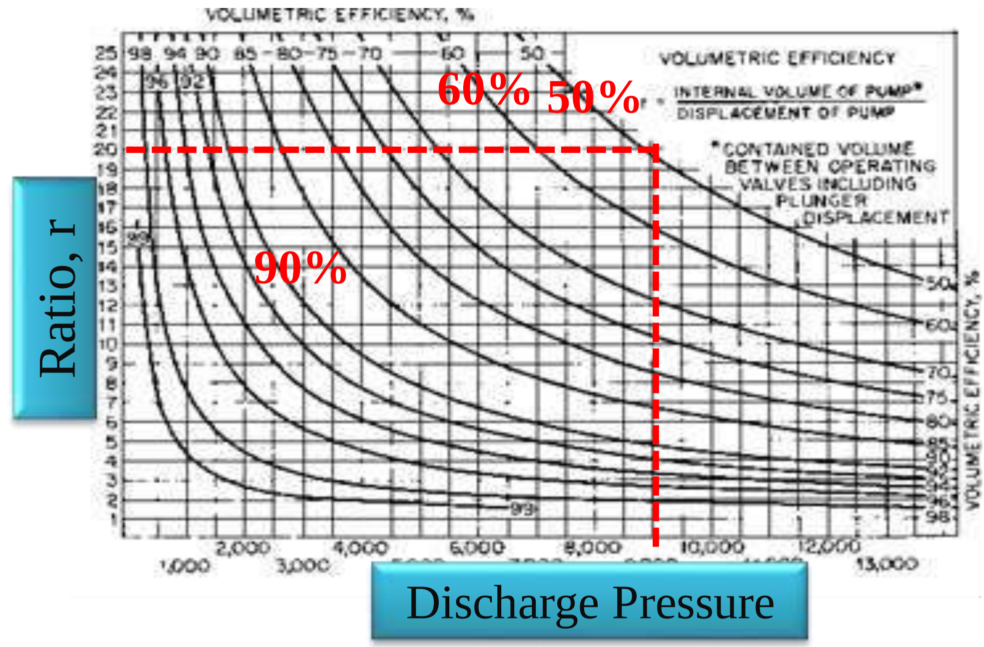


$$r = (V_C+V_S)/V_S = 1+(V_C/V_S)$$

Mechanical efficiency : loss occurs while overcoming mechanical friction in bearing and speed reduction.

Speed of piston= (stroke)(rpm)/(30000).*

(mm)



% of full speed	44	50	73	100
M.E, %	93.3	92.5	92.5	92.5

% of full-load developed pressure	20	40	60	80	100
M.E,%	82	88	90	92	92

APPLICATION

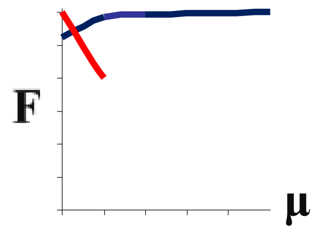
- *Agriculture.*
- *Chemical.*
- *Desalination.*
- *Horizontal Drilling.*
- *General Industries.*
- *Mining.*
- *Oil and Gas.*
- *Pulp and Paper.*
- *Sewer Cleaning.*
- *Steel.*

COMPARISON

CENTRIFUGAL(—)

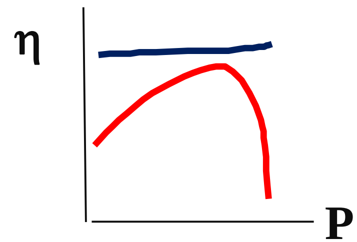
RECIPROCATING(—)

Loses flow as the viscosity goes up.



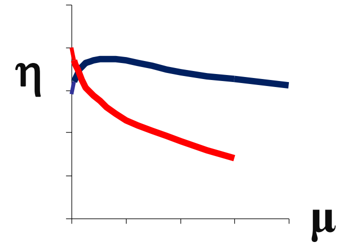
Increases flow due to thickening of the flow.

Changes in pressure has a dramatic effect on efficiency.



Changes in pressure has little effect on efficiency.

Very inefficient at even modest viscosity.



Very efficient with high viscosity.

Discharge Through a Reciprocating Pump

Chandigarh Engineering College

20.3.1 Discharge Through a Reciprocating Pump. Consider a single* acting reciprocating pump as shown in Fig. 20.1.

Let D = Diameter of the cylinder

A = Cross-sectional area of the piston or cylinder

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

r = Radius of crank

N = r.p.m. of the crank

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

h_s = Height of the axis of the cylinder from water surface in sump.

h_d = Height of delivery outlet above the cylinder axis (also called delivery head)

Volume of water delivered in one revolution or discharge of water in one revolution

= Area × Length of stroke = $A \times L$

Number of revolution per second, $= \dfrac{N}{60}$

∴ Discharge of the pump per second,

Q = Discharge in one revolution × No. of revolution per second

$$= A \times L \times \frac{N}{60} = \frac{ALN}{60} \quad ...(20.1)$$

Weight of water delivered per second,

$$W = \rho \times g \times Q = \frac{\rho g ALN}{60}. \quad ...(20.2)$$

Workdone by a Reciprocating Pump

Chandigarh Engineering College

20.3.2 Work done by Reciprocating Pump. Work done by the reciprocating pump per second is given by the reaction as

Work done per second = Weight of water lifted per second × Total height through which water is lifted

$$= W \times (h_s + h_d) \quad ...(i)$$

where $(h_s + h_d)$ = Total height through which water is lifted.

From equation (20.2), Weight, W, is given by

$$W = \frac{\rho g \times ALN}{60}.$$

Substituting the value of W in equation (i), we get

$$\text{Work done per second} = \frac{\rho g \times ALN}{60} \times (h_s + h_d) \quad ...(20.3)$$

∴ Power required to drive the pump, in kW

$$P = \frac{\text{Work done per second}}{1000} = \frac{\rho g \times ALN \times (h_s + h_d)}{60 \times 1000}$$

$$= \frac{\rho g \times ALN \times (h_s + h_d)}{60{,}000} \text{ kW} \quad ...(20.4)$$

Discharge, Work done and power required to drive a double acting pump

20.3.3 Discharge, Work done and Power Required to Drive a Double-acting Pump. In case of double-acting pump, the water is acting on both sides of the piston as shown in Fig. 20.2. Thus, we require two suction pipes and two delivery pipes for double-acting pump. When there is a suction stroke on one side of the piston, there is at the same time a delivery stroke on the other side of the piston. Thus for one complete revolution of the crank there are two delivery strokes and water is delivered to the pipes by the pump during these two delivery strokes.

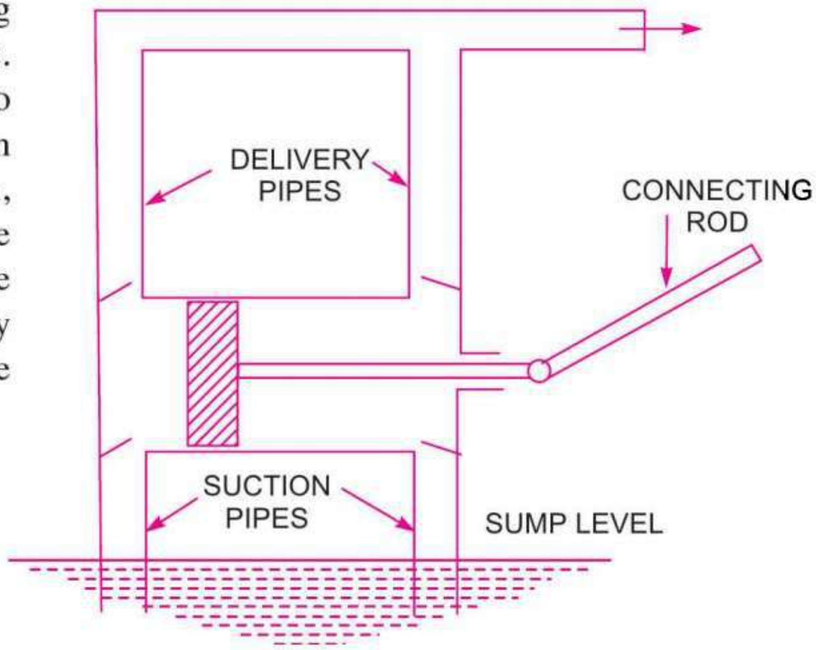


Fig. 20.2

Let D = Diameter of the piston,

d = Diameter of the piston rod

∴ Area on one side of the piston,

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

Area on the other side of the piston, where piston rod is connected to the piston,

$$A_1 = \frac{\pi}{4} D^2 - \frac{\pi}{4} d^2 = \frac{\pi}{4} (D^2 - d^2).$$

$\therefore$ Volume of water delivered in one revolution of crank

$$= A \times \text{Length of stroke} + A_1 \times \text{Length of stroke}$$

$$= AL + A_1L = (A + A_1)L = \left[\frac{\pi}{4}D^2 + \frac{\pi}{4}\left(D^2 - d^2\right)\right] \times L$$

$\therefore$ Discharge of pump per second

$$= \text{Volume of water delivered in one revolution} \times \text{No. of revolution per second}$$

$$= \left[\frac{\pi}{4}D^2 + \frac{\pi}{4}\left(D^2 - d^2\right)\right] \times L \times \frac{N}{60}$$

If 'd' the diameter of the piston rod is very small as compared to the diameter of the piston, then it can be neglected and discharge of pump per second,

$$Q = \left(\frac{\pi}{4}D^2 + \frac{\pi}{4}D^2\right) \times \frac{L \times N}{60} = 2 \times \frac{\pi}{4}D^2 \times \frac{L \times N}{60} = \frac{2ALN}{60} \quad ...(20.5)$$

Equation (20.5) gives the discharge of a double-acting reciprocating pump. This discharge is two times the discharge of a single-acting pump.

Work done by double-acting reciprocating pump

Work done per second = Weight of water delivered × Total height

$$= \rho g \times \text{Discharge per second} \times \text{Total height}$$

$$= \rho g \times \frac{2ALN}{60} \times (h_s + h_d) = 2\rho g \times \frac{ALN}{60} \times (h_s + h_d) \quad ...(20.6)$$

$\therefore$ Power required to drive the double-acting pump in kW,

$$P = \frac{\text{Work done per second}}{1000} = 2\rho g \times \frac{ALN}{60} \times \frac{\left(h_s + h_d\right)}{1000}$$

$$= \frac{2\rho g \times ALN \times \left(h_s + h_d\right)}{60{,}000} \quad ...(20.7)$$

Slip of a Reciprocating Pump

▶ 20.4 SLIP OF RECIPROCATING PUMP

Slip of a pump is defined as the difference between the theoretical discharge and actual discharge of the pump. The discharge of a single-acting pump given by equation (20.1) and of a double-acting pump given by equation (20.5) are theoretical discharge. The actual discharge of a pump is 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, mathematically.

$$\text{Slip} = Q_{th} - Q_{act} \qquad \text{...(20.8)}$$

But slip is mostly expressed as percentage slip which is given by,

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

$$= (1 - C_d) \times 100 \qquad \left(\because \frac{Q_{act}}{Q_{th}} = C_d\right) \qquad \text{...(20.9)}$$

where C_d = Co-efficient of discharge.

Negative Slip

20.4.1 Negative Slip of the Reciprocating Pump. Slip is equal to the difference of theoretical discharge and actual discharge. If actual discharge is more than the theoretical discharge, the slip of the pump will become –ve. In that case, the slip of the pump is known as negative slip.

Negative slip occurs when delivery pipe is short, suction pipe is long and pump is running at high speed.

▶ 20.5 CLASSIFICATION OF RECIPROCATING PUMPS

The reciprocating pumps may be classified as :

1. According to the water being in contact with one side or both sides of the piston, and
2. According to the number of cylinders provided.

If the water is in contact with one side of the piston, the pump is known as single-acting. On the other hand, if the water is in contact with both sides of the piston, the pump is called double-acting. Hence, classification according to the contact of water is :

(*i*) Single-acting pump, and (*ii*) Double-acting pump.

According to the number of cylinder provided, the pumps are classified as :

(*i*) Single cylinder pump, (*ii*) Double cylinder pump, and

(*iii*) Triple cylinder pump.

AIR VESSEL

- An air vessel is a closed chamber containing compressed air in the top portion and liquid in the bottom of the chamber.
- At the base of the vessel there is a opening where the liquid can flow in and out of the vessel.
- Air vessel is fitted for the following reasons

  (a) To obtain continuous supply of fluid at a uniform rate

  (b) To save a considerable amount of work in overcoming the frictional resistance in the suction and delivery pipe.

  (c) To run the pump at a high speed without separation

References

- **A Textbook of Fluid Mechanics and Hydraulic Machines**
Dr. R. K. Bansal, Laxmi Publications

- **NPTEL VIDEO LECTURES**