THERMAL AND HYDRAULIC MACHINES

UNIT 5

WHAT IS THE PUMP?

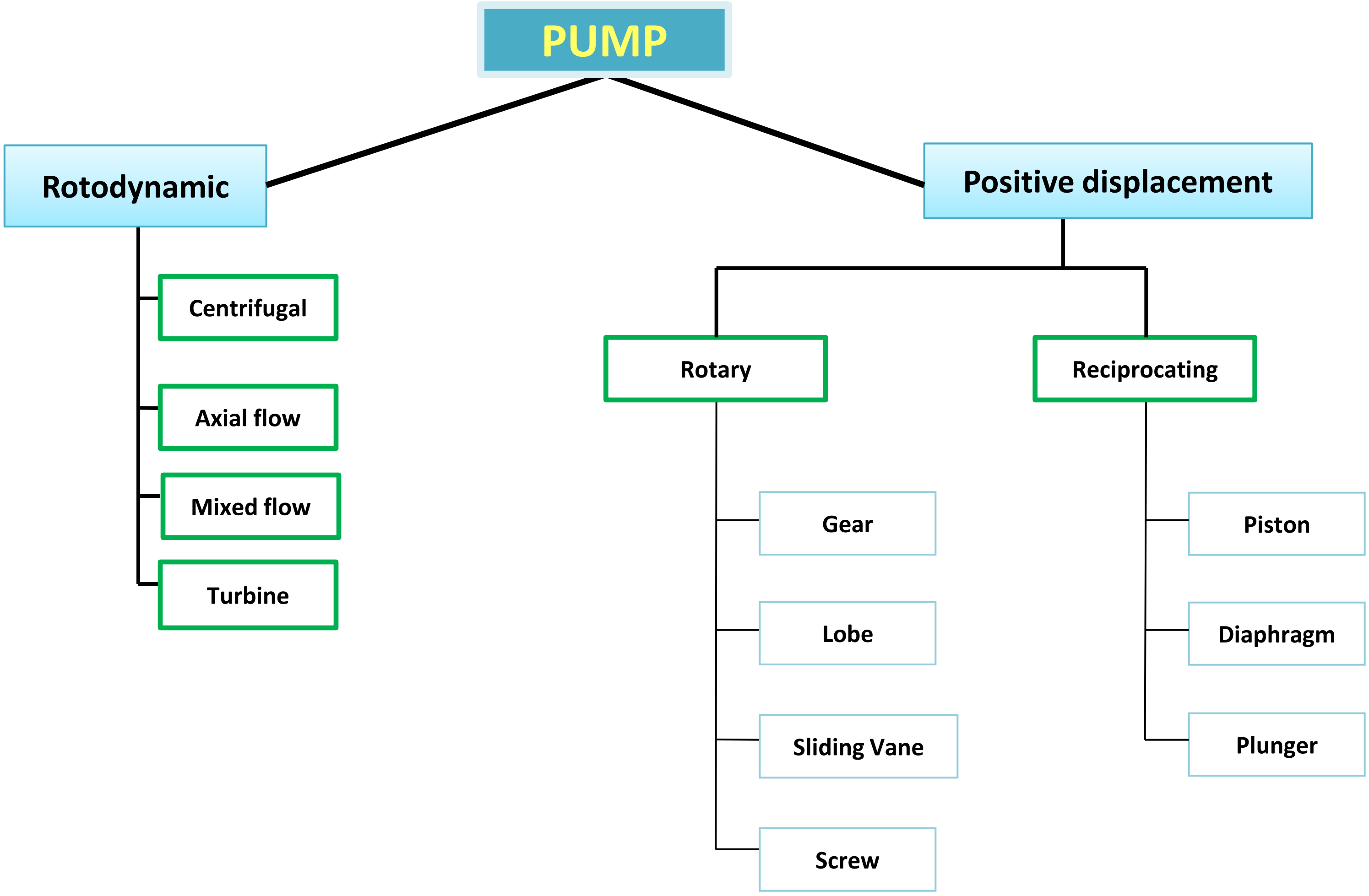
A hydrodynamic pump machine is a device for converting the energy held by mechanical energy into fluid

Pumps enable a liquid to:

1. **Flow from a region or low pressure to one of high pressure.**
2. **Flow from a low level to a higher level.**
3. **Flow at a faster rate.**

There are two main categories of pump:

- **Rotodynamic pumps.**
- **Positive displacement pumps.**



Centrifugal Pumps:

centrifugal pumps have a rotating impeller, also known as a blade, that is immersed in the liquid. Liquid enters the pump near the axis of the impeller, and the rotating impeller sweeps the liquid out toward the ends of the impeller blades at high pressure.

For low flows and high pressures, the action of the impeller is largely radial.

Positive-displacement Pumps:

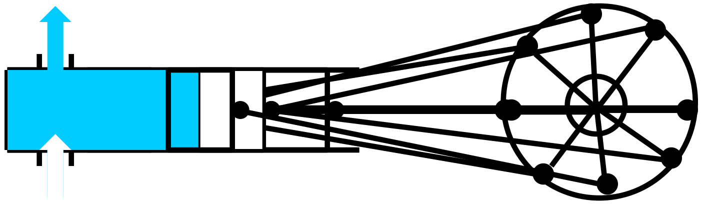
A variety of positive-displacement pumps are also available, generally consisting of a rotating member with a number of lobes that move in a close-fitting casing. The liquid is trapped in the spaces between the lobes and then discharged into a region of higher pressure. A common device of this type is the gear pump, which consists of a pair of meshing gears. The lobes in this case are the gear teeth

What is the main difference between kinetic and positive displacement pumps ?

The main difference between kinetic and positive displacement pumps lies in the method of fluid transfer.

- **A kinetic pump imparts velocity energy to the fluid, which is converted to pressure energy upon exiting the pump casing**

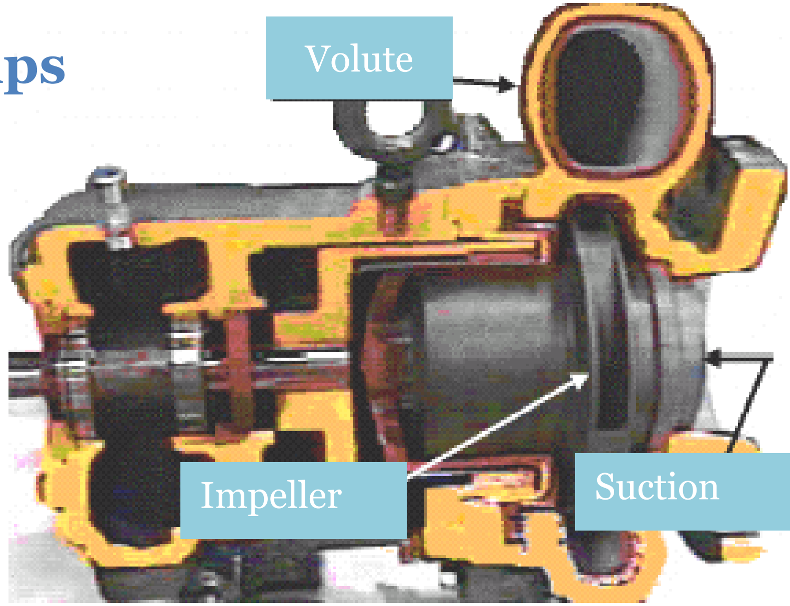
- **A positive displacement pump moves a fixed volume of fluid within the pump casing by applying a force to moveable boundaries containing the fluid volume.**



The Table below outlines some of the main differences between centrifugal pumps, reciprocating pumps and rotary pumps. Note that "centrifugal", "reciprocating" and "rotary" pumps are all relatively broad categories

Parameter	Centrifugal Pumps	Reciprocating Pumps	Rotary Pumps

Construction of Centrifugal Pumps



1- Casing:-

Casing generally are two types:

I. Volute casings for a higher head.

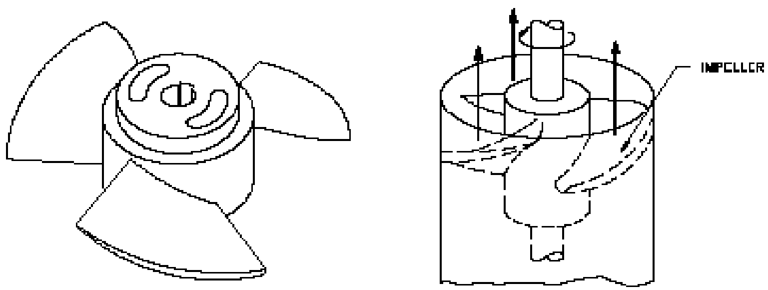
A *volute* is a curved funnel increasing in area to the discharge port.

II. Circular casings for low head and high capacity.

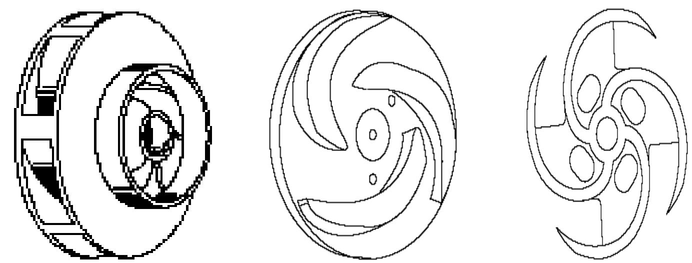
have stationary diffusion vanes surrounding the impeller periphery that convert velocity energy to pressure energy.

2-Impeller

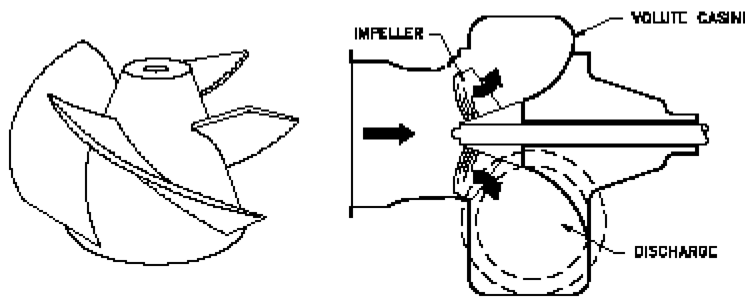
Three main categories of centrifugal pumps exist



Axial flow



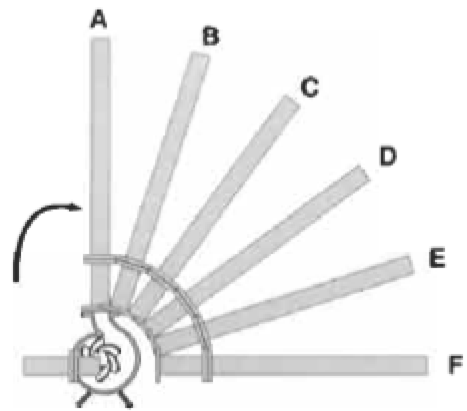
Radial flow

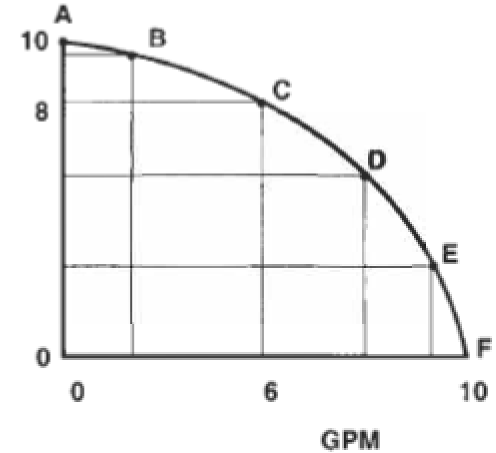


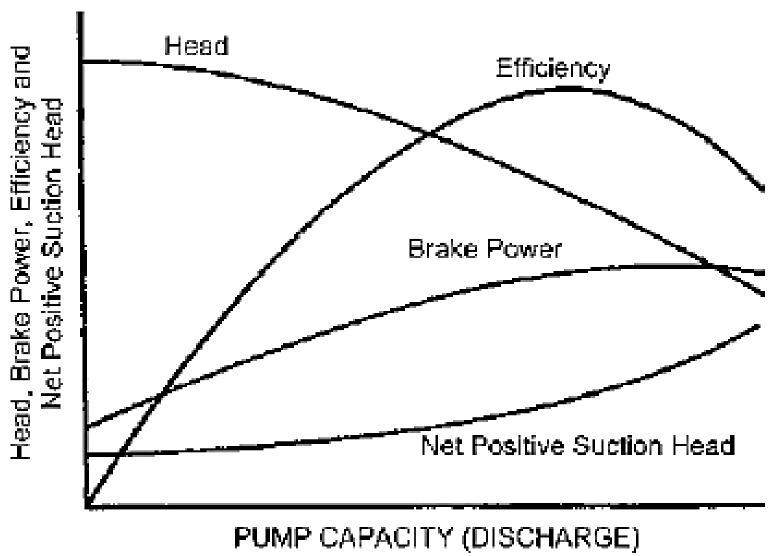
Mixed flow

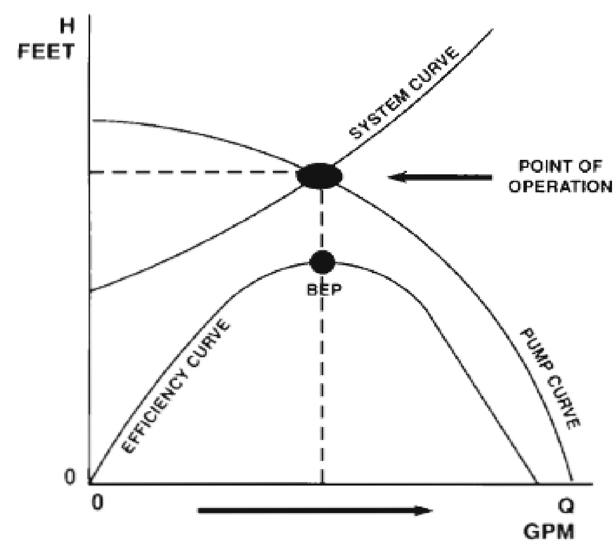
H-Q Carve

Once again, imagine starting a pump and raising the fluid in a vertical tube to the point of maximum elevation. On the curve this would be maximum head at zero flow. Now, rotate the running pump on its centerline *90°*, until the vertical tube is now in a horizontal position.



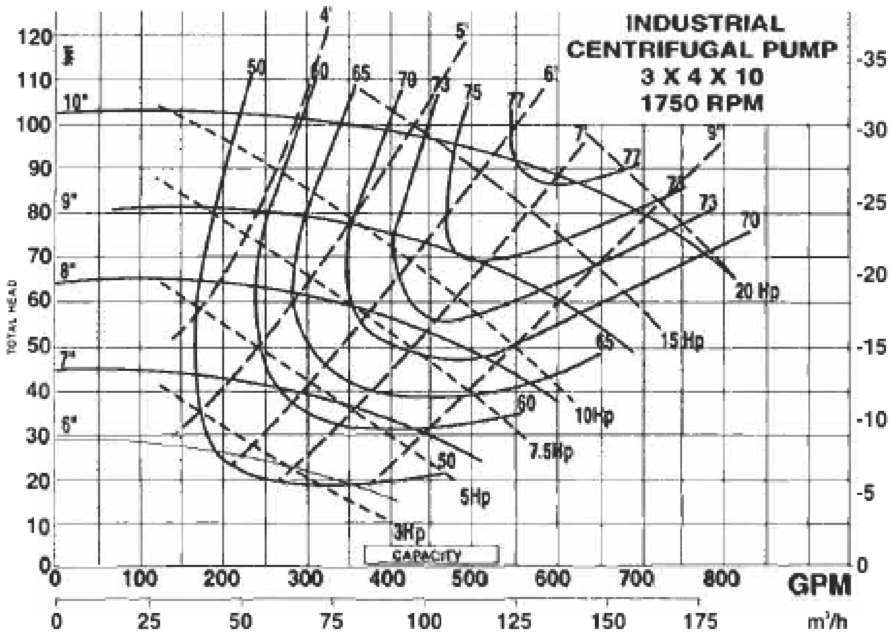


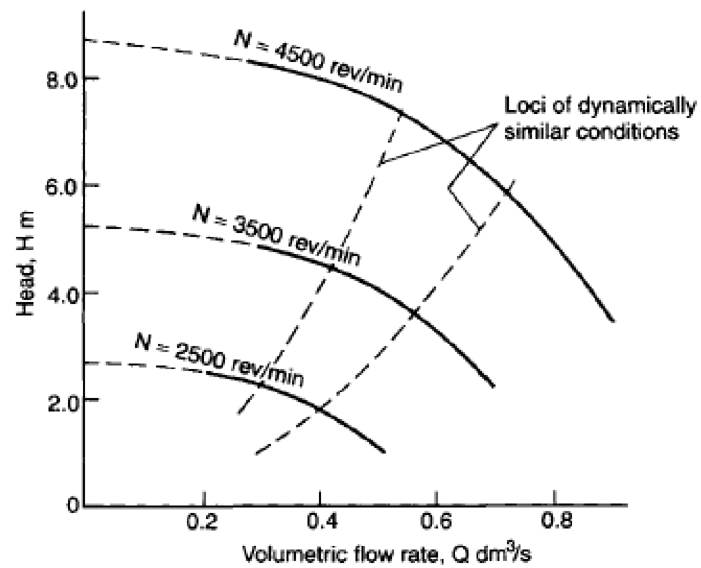




Family curves

At times you'll find that the information is the same, but the presentation of the curves is different. Almost all pump companies publish what are called the 'family of curves'. The pump family curves are probably the most useful for the maintenance engineer and mechanic, the design engineer and purchasing agent. The family curves present the entire performance picture of a pump.





Heads of Pump:

where :

V_s = Velocity of fluid in the suction pipe.

V_d = Velocity of fluid in the delivery pipe.

h_s = Suction head.

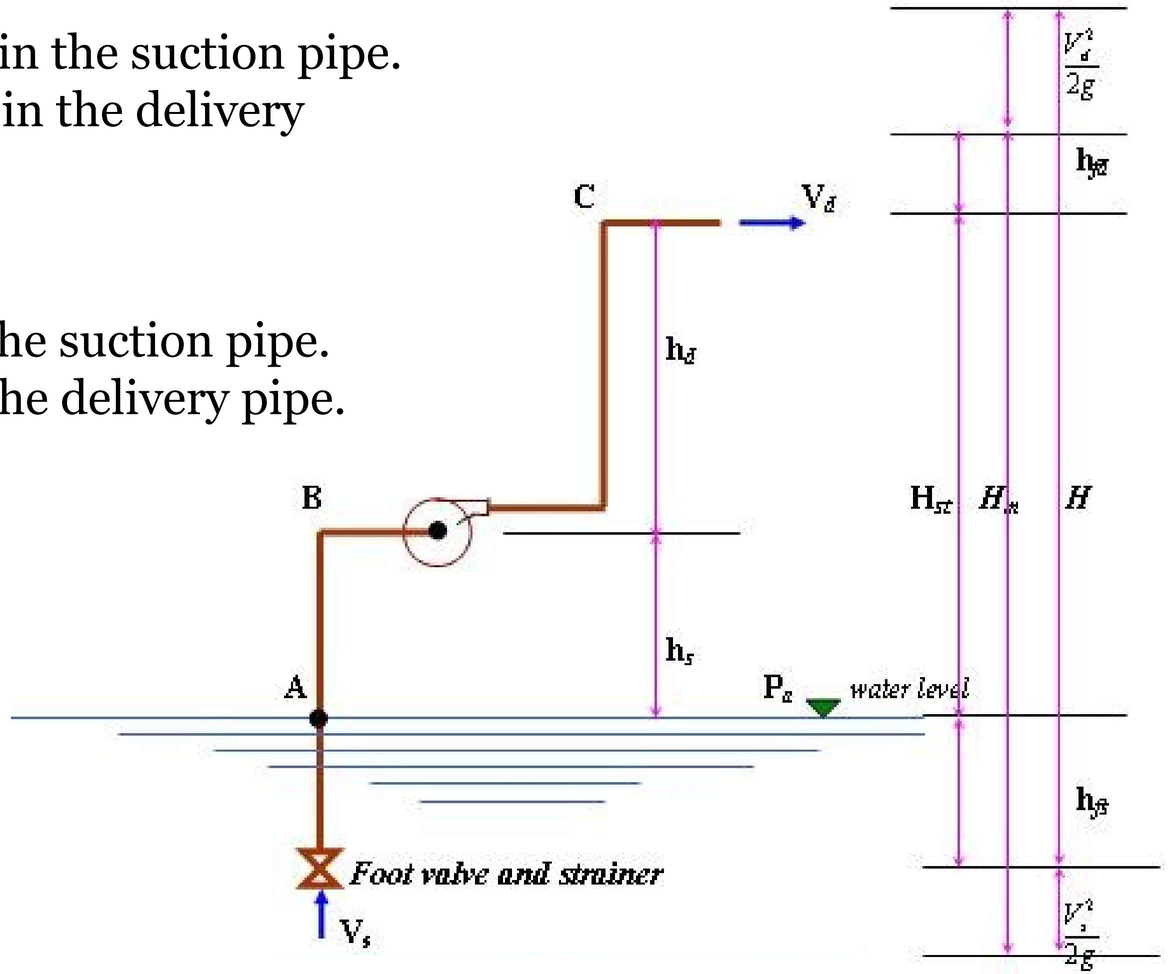
h_d = Delivery head.

h_{fs} = head losses in the suction pipe.

h_{fd} = head losses in the delivery pipe.

Static head (H_{st})

$$H_{st} = h_s + h_d$$



Manometric head (H_m) :

$$H_m = \frac{p_d - p_s}{\gamma} + (z_d - z_s)$$ but $$\frac{p_d}{\gamma} = h_d + h_{fd}$$ and $$\frac{p_s}{\gamma} = -(h_s + h_{fs})$$

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

$$= H_{st} + h_f + \frac{V_s^2}{2g}$$

(where $h_{fd} = f\frac{L}{D}(V_d^2/2g)$ **)**

where $h_f = h_{fs} + h_{fd}$

$$H_m = h' - H_L = \frac{V_{w2}U_2}{g} - H_L$$

(where H_L = impeller losses)

Total head (H)

$$H = \frac{p_d - p_s}{\gamma} + (z_d - z_s) + \frac{V_d^2 - V_s^2}{2g}$$

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

$$= H_{st} + h_f + \frac{V_d^2}{2g}$$

$$H_m = H + \frac{1}{2g}(V_s^2 - V_d^2)$$

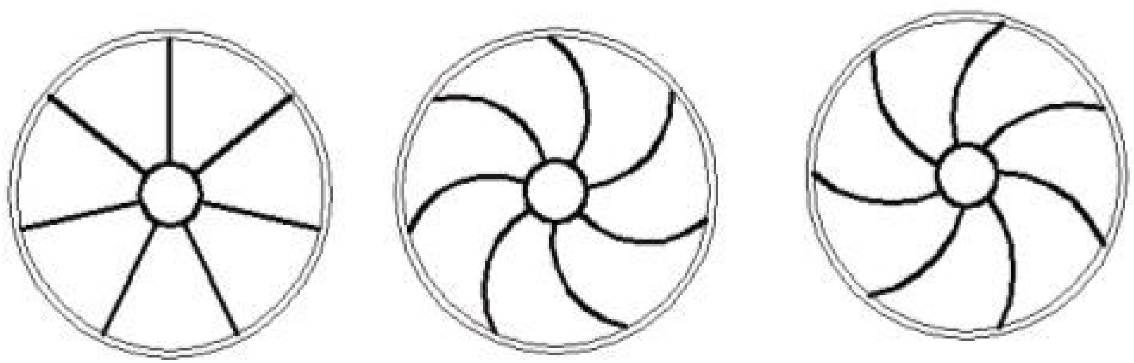
When $V_s = V_d$

Hence $H_m = H$

Type of Impeller

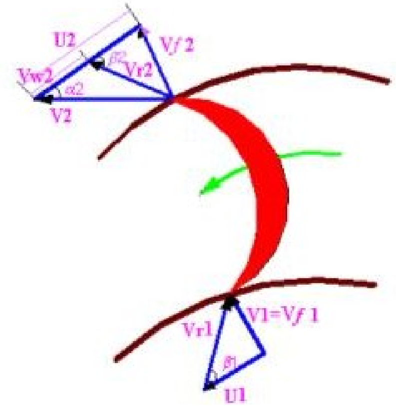
There are three main categories of impeller due type of impeller's vane, which are used in the centrifugal pumps as;

- **Radial vanes, Fig. (a).**
- **Backward vanes, Fig. (b).**
- **Forward vanes, Fig. (c).**

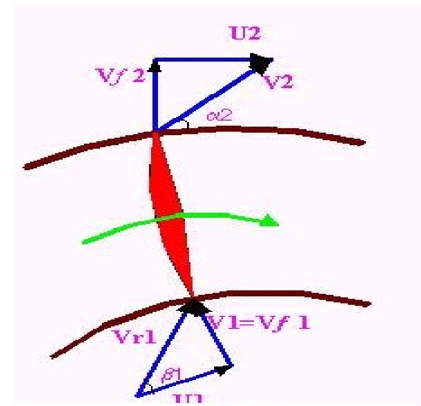


(a) (b) (c)

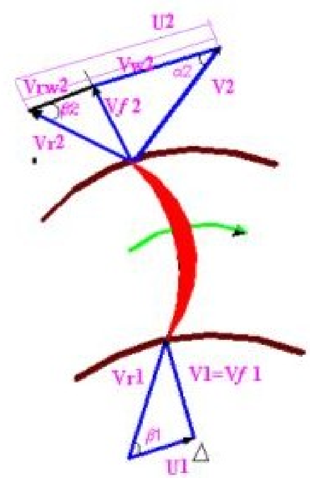
a) when $\beta_2 > 90^o$, the Forwards curved vanes of the impeller.



b) when $\beta_2 = 90^o$, the radial curved vanes of the impeller.



c) when $\beta_2 < 90^o$, the Backwards curved vanes of the impeller.



where :

V = absolute velocity of the water.

U = Tangential velocity of impeller (peripheral velocity).

V_r = relative velocity of water to the wheel.

V_f = velocity flow.

N = Speed of impeller in (rpm).

β = vane angle.

α = angle at which water leaves.

Pump Efficiencies

1- ***Hydraulic Efficiency*** (ζ_h)

$$\zeta_h = \frac{Pump's\ \ Total\ \ \ Head\ \ (H)}{Euler\ \ Head\ \ (H_e)}$$

$$\zeta_h = \frac{gH}{V_{w2}U_2}$$

The normal value varies between 60% - 90%

2- ***Manometric Efficiency***(ζ_m)

$$\zeta_m = \frac{Pump's\ \ Manometric\ \ \ Head\ \ (H_m)}{Euler\ \ Head\ \ (H_e)}$$

$$\zeta_m = \frac{gH_m}{V_{w2}U_2}$$

3 -***Volumetric Efficiency*** (ζ_v)

$$\zeta_v = \frac{Q}{Q + \Delta Q}$$

The normal value lies between 97% to 98%

4- *Mechanical Efficiency* (ζ)

It is due to losses in the shaft, coupling, and other operation losses as vibration

$$\zeta = \frac{Power \quad into\ the\ impeller}{Power \quad at\ the\ shaft}$$

$$\zeta = \frac{\rho\,(Q+\Delta Q\,)\,V_{w2}\,U_2}{Power \quad Shaft}$$

The normal value is 95% - 98%

5 - *Overall Efficiency* (ζ_o)

$$\zeta_o = \frac{P_{out}}{P_{in}} = \frac{\gamma QH}{T.\omega}$$

$$\zeta_o = \frac{P_{out}}{P_t} \times \frac{P_t}{P_{in}} = \frac{P_t}{P_{in}} \times \frac{\gamma QH}{\gamma (Q+Q_l)h'}$$

$$\zeta_o = \zeta_m \times \zeta_v \times \zeta_h$$

The normal value is 71% - 86%

Discharge of a Centrifugal Pump

$$Q = \pi D_1 b_1 V_{f1} = \pi D_2 b_2 V_{f2}$$

6- Power Required to Drive a Centrifugal Pump

$$P = \frac{\gamma Q H}{750\zeta_o} \quad (hp) \qquad\qquad P = \frac{\gamma Q V_{w1} U_1}{g750} \quad (hp)$$

7 -1 Cavitation

Cavitation is defined as the phenomenon of formation of vapor bubbles of flowing liquid in a region where the pressure of the liquid falls below its vapor pressure and the sudden collapsing of this vapor bubbles in a region of higher pressure. When the vapor bubbles collapse, a very high pressure is created. The formation and the collapse of a great number of bubbles on the surface produce intense local stresses that damage the surface by fatigue. It may occur at the entry to pumps or at the exit from hydraulic turbines in the vicinity of the moving blades

7 -2 Cavitation processes in centrifugal pump

The cavitation phenomenon develops in the impeller pump, when the pressure of liquid falls below the saturated vapor pressure at the prevailing temperature ($P_s < P_v$ of liquid), small vapor bubbles begin to form and the dissolved gases are evolved. The vapor bubbles are caught up by the following liquid and swept into a region of higher pressure, where they condense. Condensation takes place violently, accompanied by a tremendous increase in pressure, which has the character of water hammer blows. These impact follow each other in rapid succession, the vapor bubbles bursting both in the immediate vicinity of the surface attacked and in the pores causing cavitation pitting with many effecting.

8- The Affinity Law

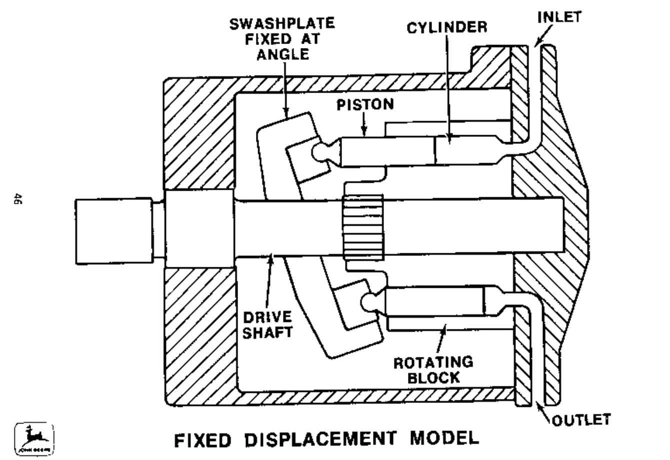
Formulas for Refiguring Pump Performance with Impeller Diameter or Speed Change		
Diameter Change Only	**Speed Change Only**	**Diameter and Speed Change**
$Q_2 = Q_1 \left(\frac{D_2}{D_1} \times \frac{N_2}{N_1}\right)$	$Q_2 = Q_1 \left(\frac{N_2}{N_1}\right)$	$Q_2 = Q_1 \left(\frac{D_2}{D_1}\right)$
$H_2 = H_1 \left(\frac{D_2}{D_1} \times \frac{N_2}{N_1}\right)^2$	$H_2 = H_1 \left(\frac{N_2}{N_1}\right)^2$	$H_2 = H_1 \left(\frac{D_2}{D_1}\right)^2$
$bhp_2 = bhp_1 \left(\frac{D_2}{D_1} \times \frac{N_2}{N_1}\right)^2$	$bhp_2 = bhp_1 \left(\frac{N_2}{N_1}\right)^2$	$bhp_2 = bhp_1 \left(\frac{D_2}{D_1}\right)^2$

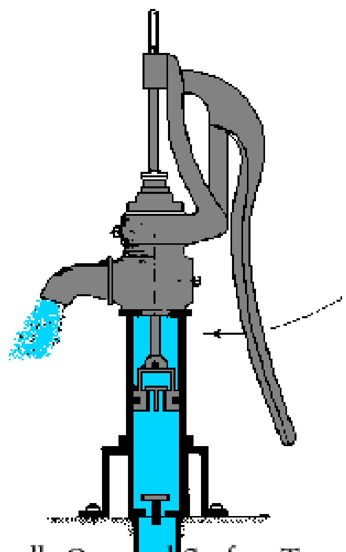
References:
1-Larry Bachus and Angel Custodio, (2003). Know and Understand Centrifugal Pumps.
2-Val S. Lobanoff Robert R. Ross, (1992). Centrifugal Pumps - Design and Application (2^{nd} ed.)
3-Igor J. Karassik ,oseph P. Messina,Paul Cooper and Charles C. Heald,2001. Pump Handbook(3^{rd} ed)

Positive Displacement Pumps: Reciprocating

- Piston/Plunger
- Diaphragm

INLINE AXIAL PISTON PUMP (3)





Manually Operated Surface-Type Piston Pump

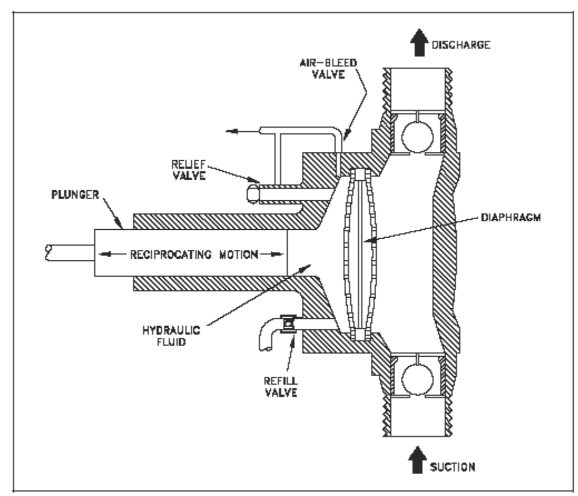
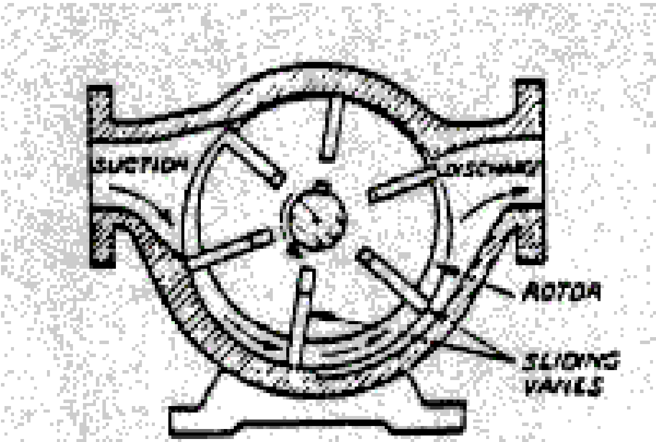


Figure 20 Diaphragm Pump

Positive Displacement Pumps: Rotary (Single Rotor)

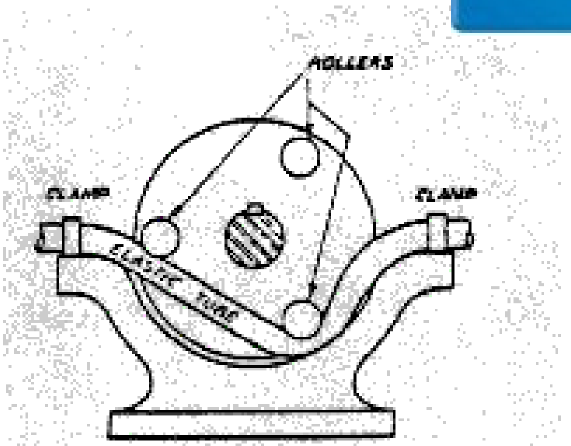
- Sliding Vane



Sliding vane pump

Positive Displacement Pumps: Rotary (Single Rotor)

- Flexible Tubing/ Peristaltic (Wave)

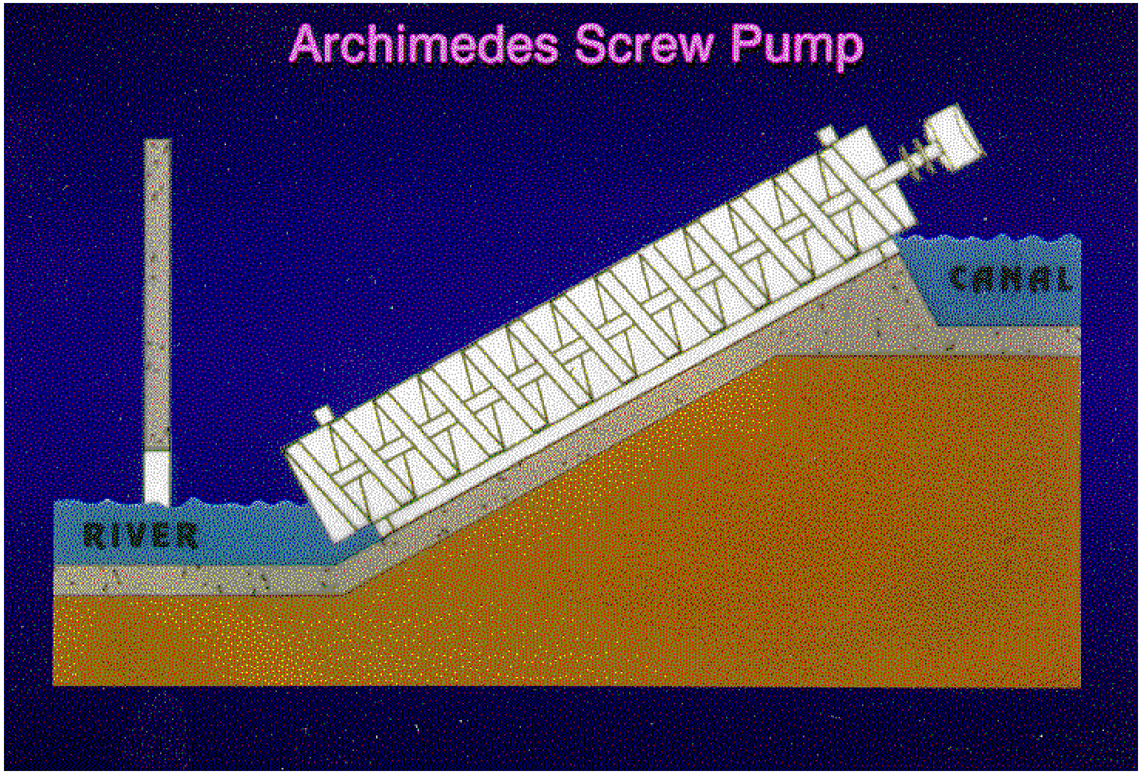


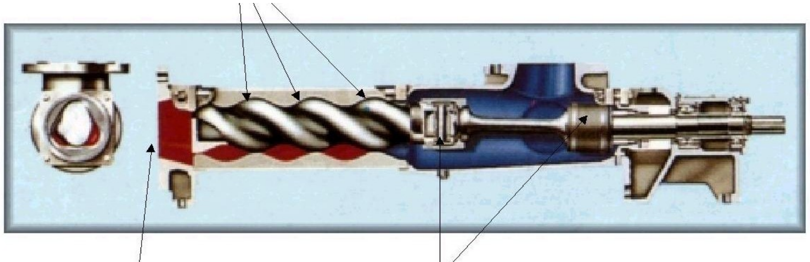
Peristaltic Pump

Positive Displacement Pumps: Rotary (Single Rotor)

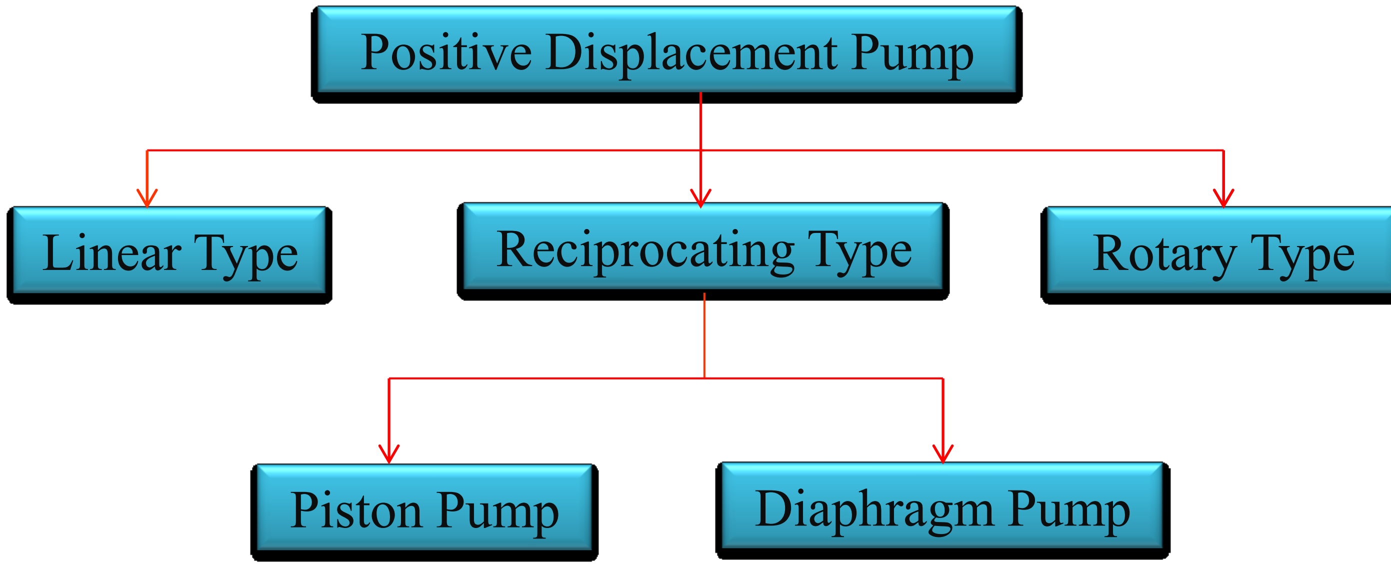
- Screw

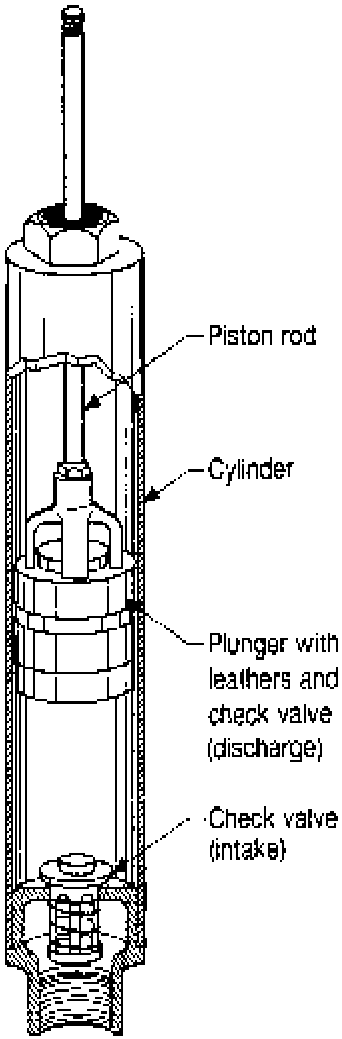
(1522 Woodcut)





FAMILY TREE

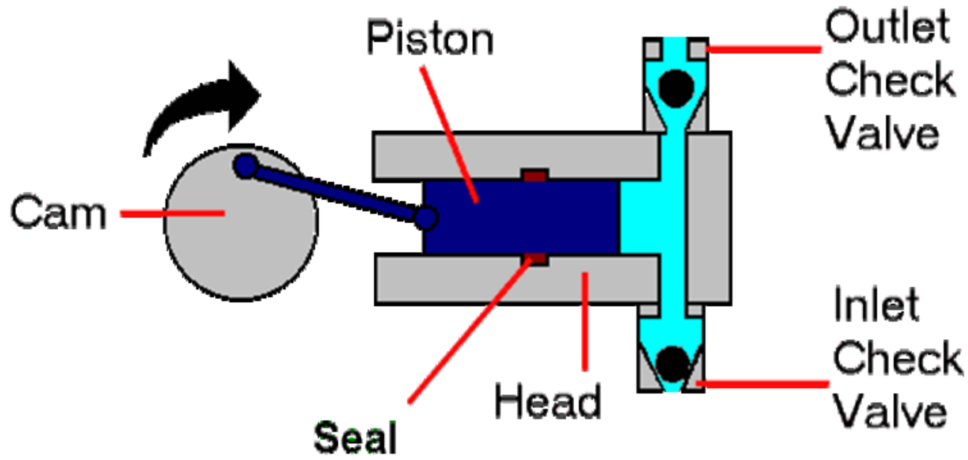




Causes a fluid to move by trapping a fixed amount of it and then forcing (displacing) that trapped volume into the discharge pipe.

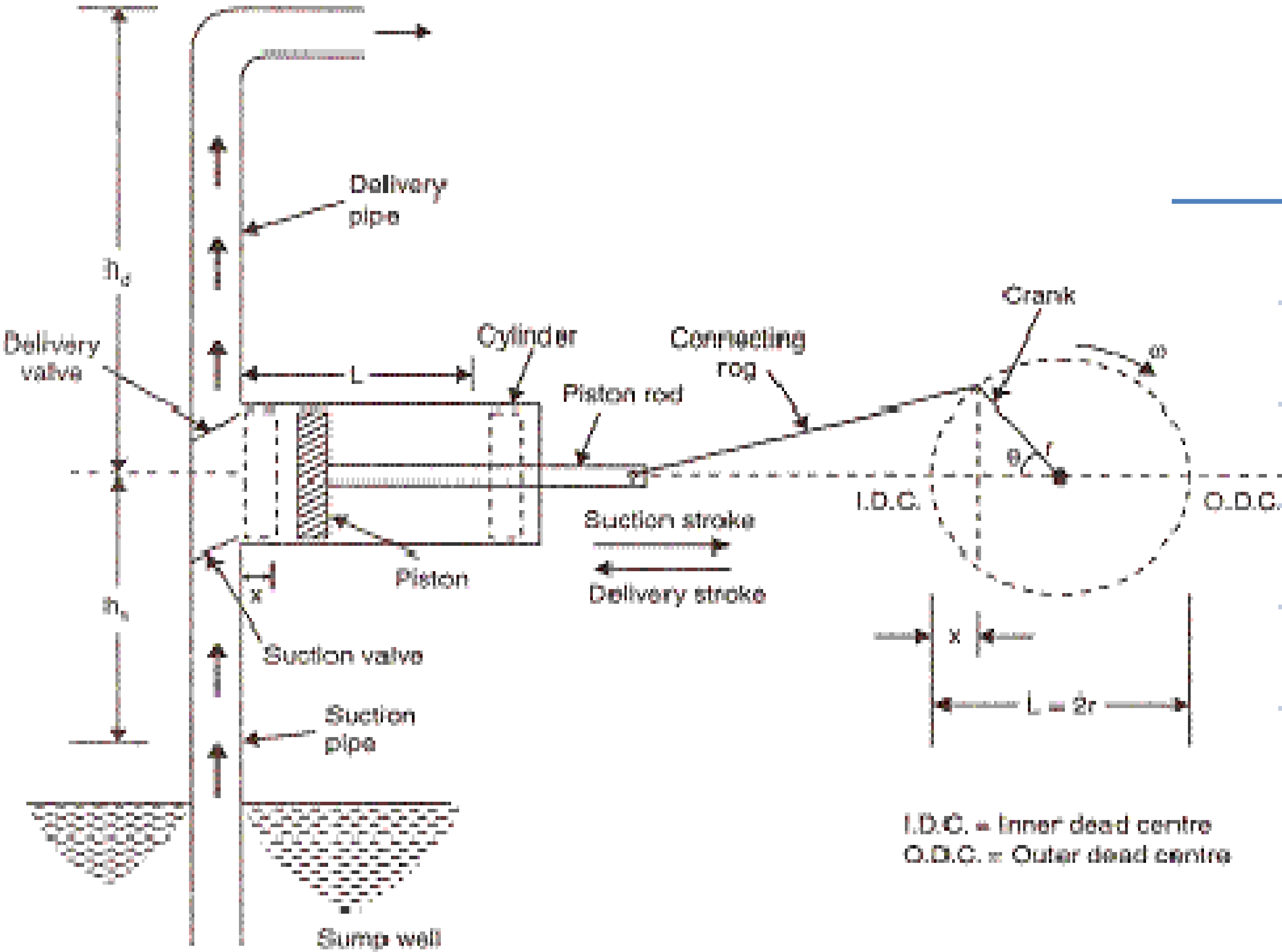
Also known as "Constant Flow Machines"

OPERATING PRINCIPLE



- …ciprocating 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.

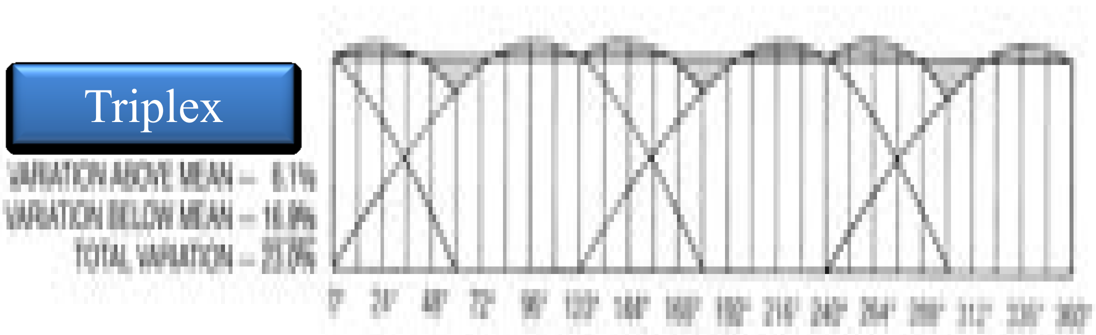
Delivery Pipe.

Suction valve.

Delivery Valve.

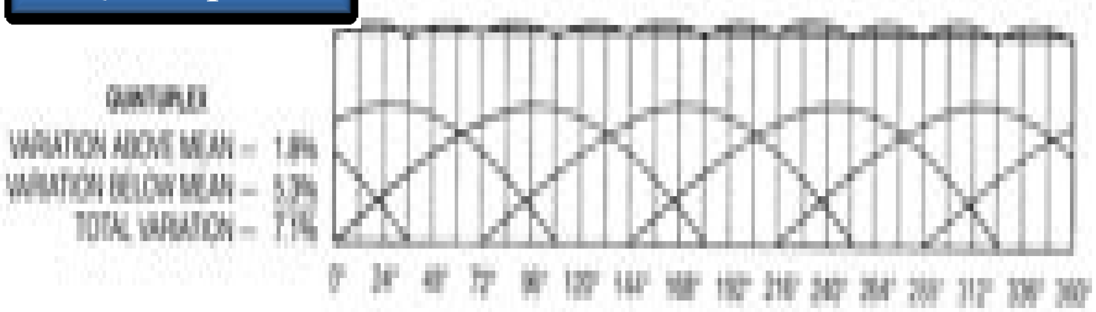
CHARACTERISTICS

Triplex



Crank-shaft Rotation

Quintuplex



Crank-shaft Rotation

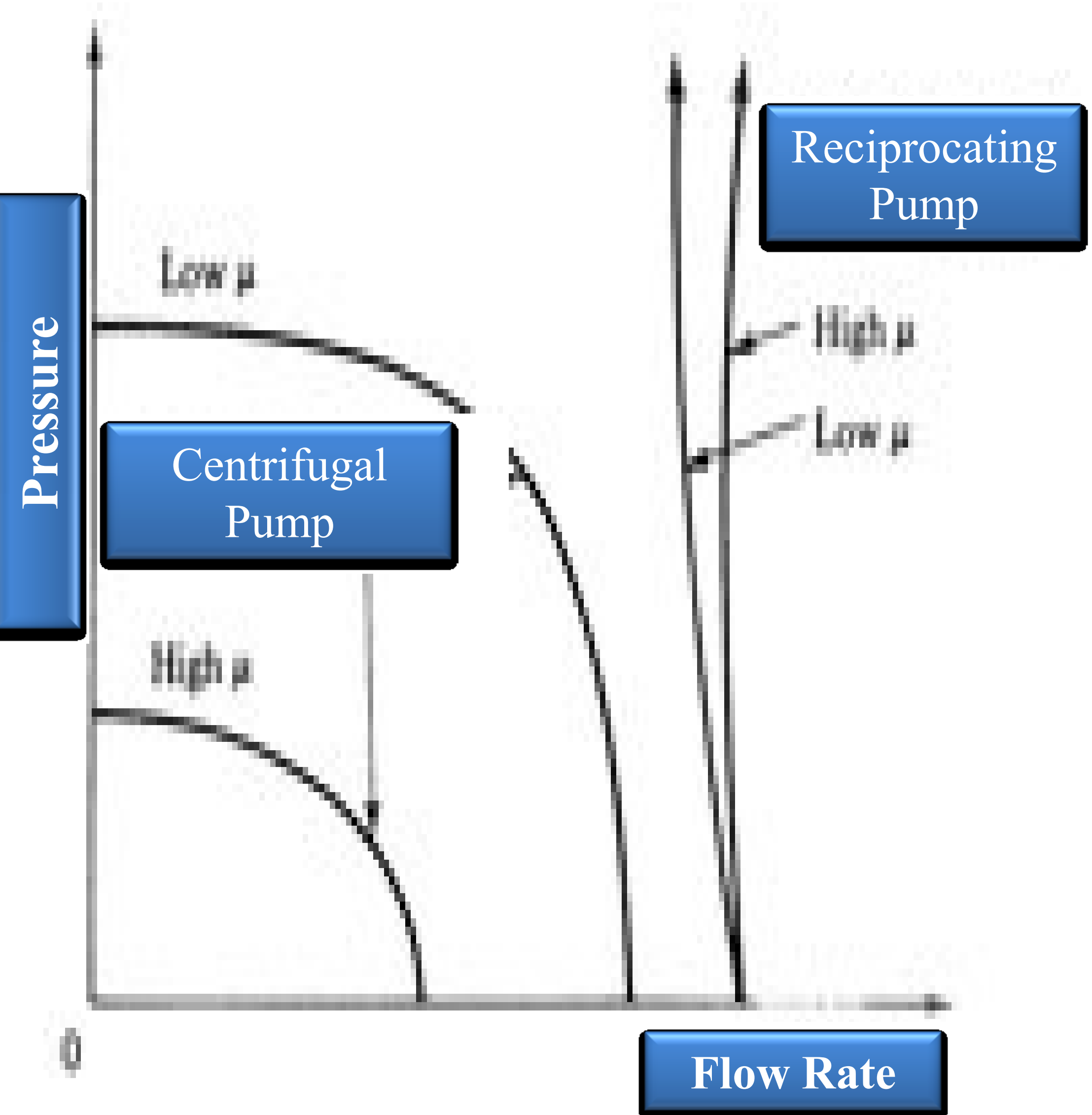
No generation of head.

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.

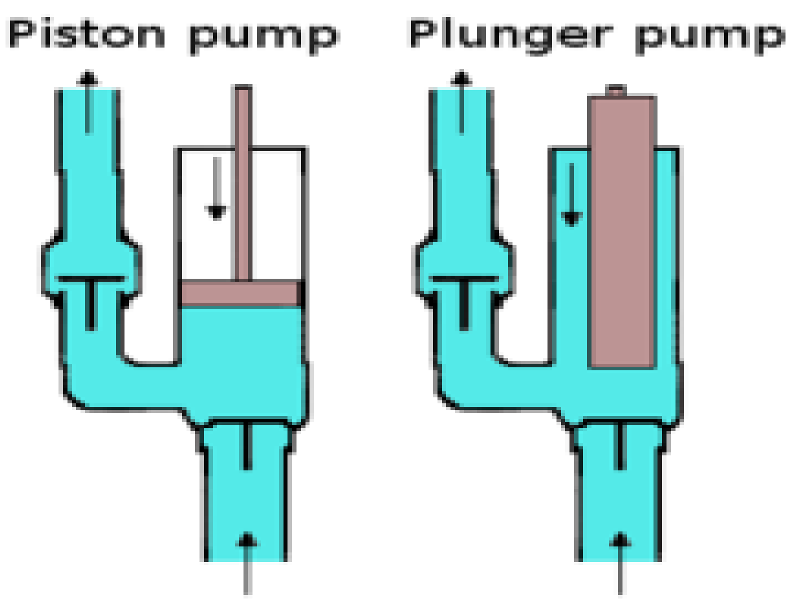
Fluid viscosity has little effect on the flow rate as the pressure increases.

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.

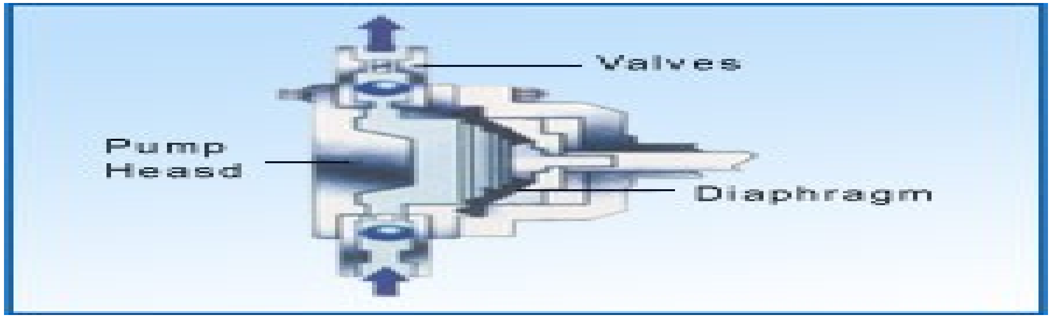
Other names are well service pumps, high pressure pumps, or high viscosity pumps.



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.

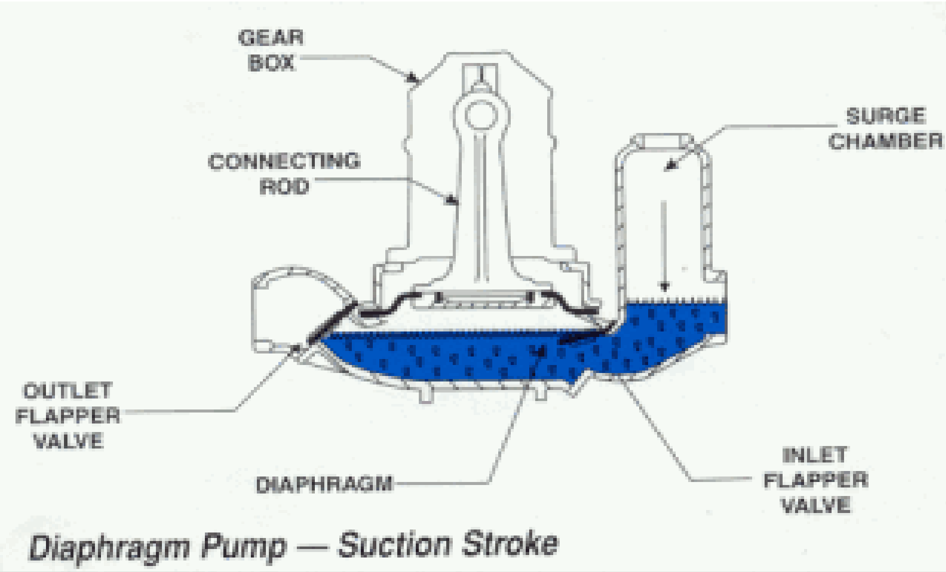
Are used to make air pumps for the filters on small fish tanks.

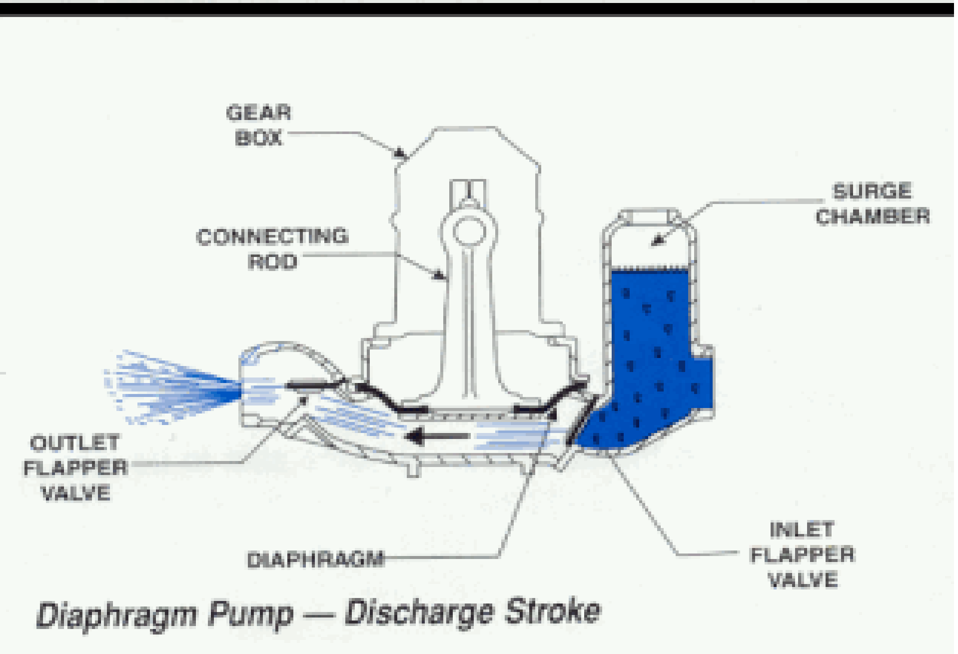
Can be up to 97% efficient.

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

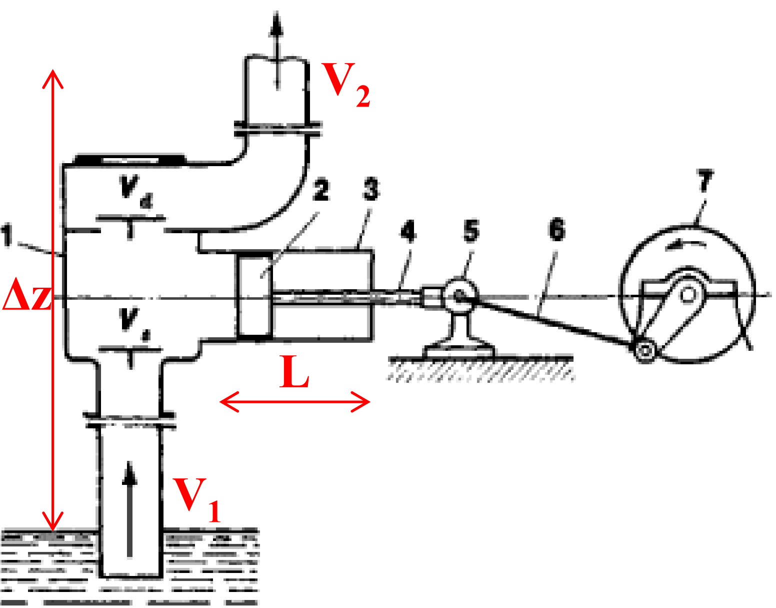
Power=(Δp*Q)/η

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.

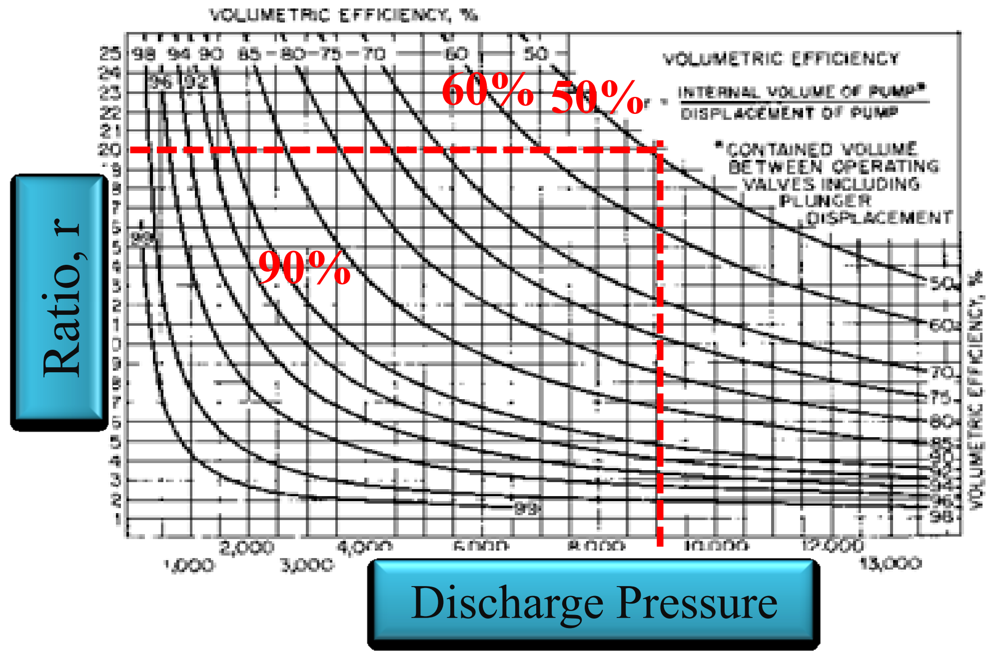
A: – Cross-section of piston or cylinder, m^2.

L: – length of stroke in meter, m.

N: – speed of crank, r.p.m.

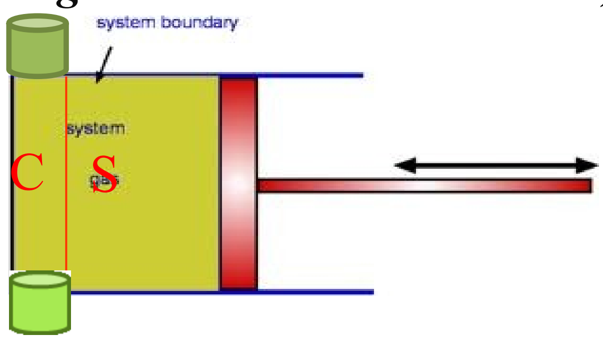
PUMP EFFICIENCY

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



<u>Volumetric efficiency</u> :

(Discharge volume / Suction volume)-slip



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

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

<u>Mechanical efficiency</u> : loss occurs while overcoming mechanical friction in bearing and speed reduction.

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

% 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.

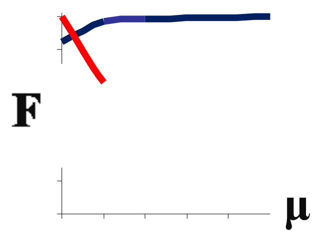
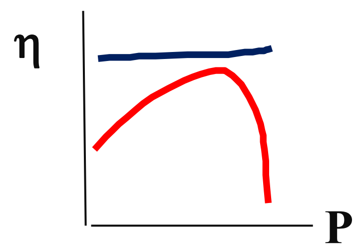
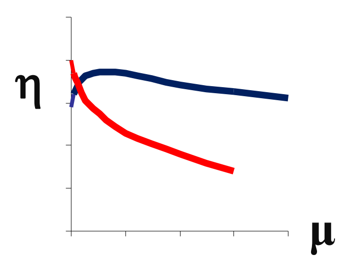
Oil and Gas.

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.*