AN INTRODUCTION TO PUMPING EQUIPMENT

Principle, Operation & Maintenance

WHAT IS THE PUMP?

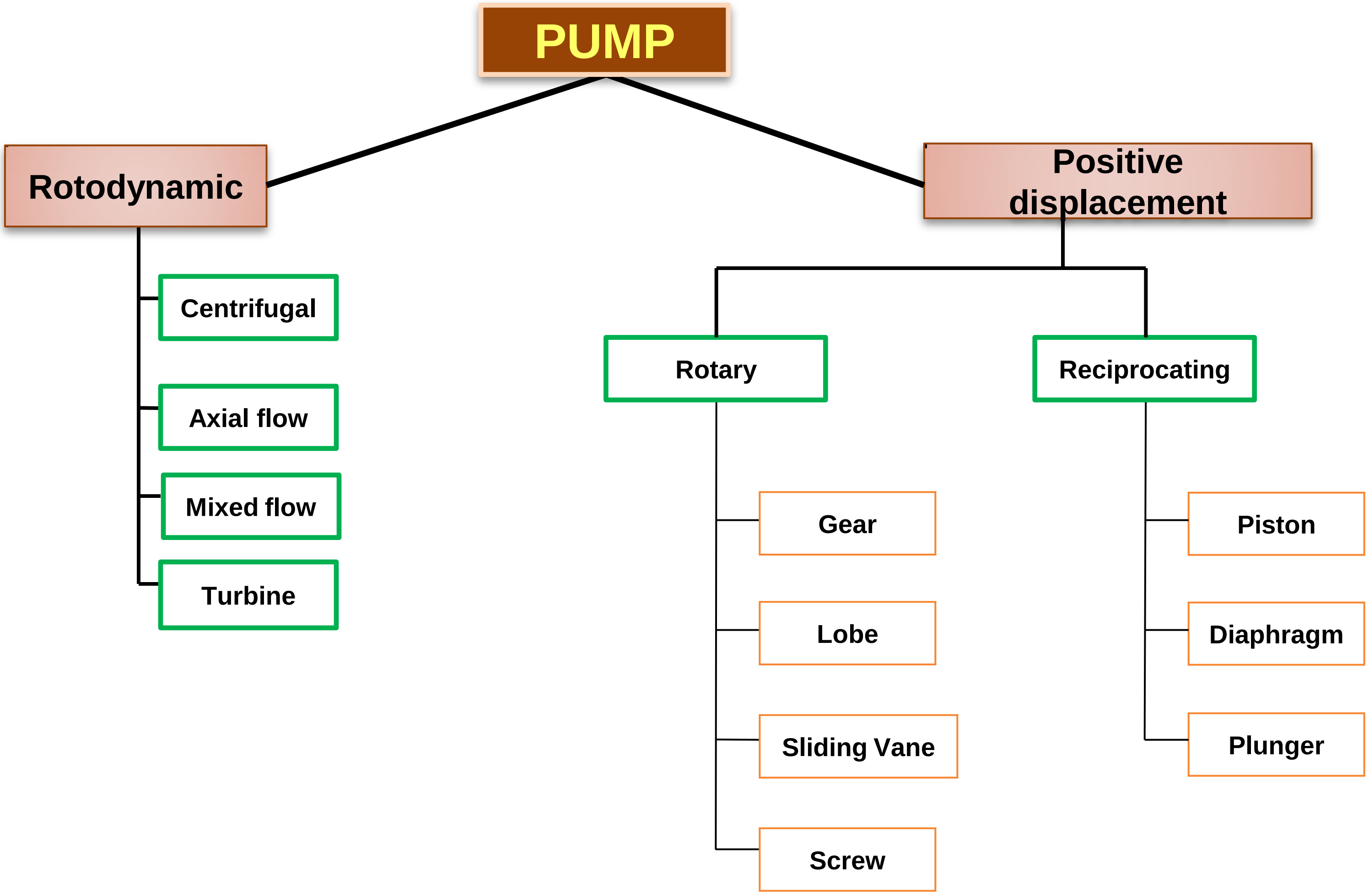
A hydrodynamic pump machine is a device for converting the energy held by mechanical energy into fluid

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:

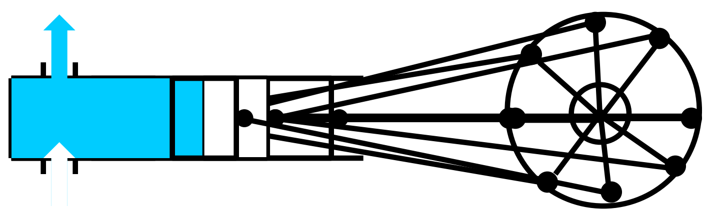
A variety of positive-displacement pumps are also available, generally consisting of a rotating member with a number of lobes that move in a close-fitting casing. The liquid is trapped in the spaces between the lobes and then discharged into a region of higher pressure. A common device of this type is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

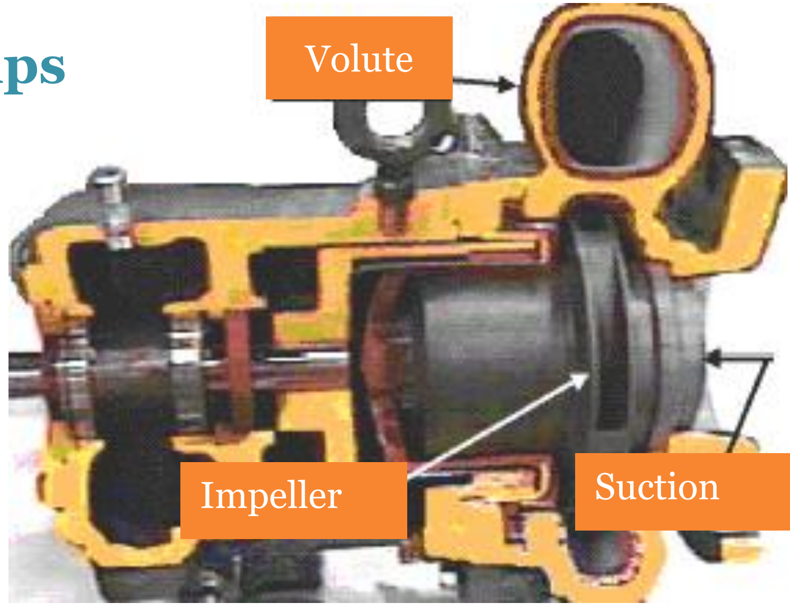
- **A positive displacement pump moves a fixed volume of fluid within the pump casing by applying a force to moveable boundaries containing the fluid volume.**



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
Optimum Flow and Pressure Applications	Medium/High Capacity, Low/Medium Pressure	Low Capacity, High Pressure	Low/Medium Capacity, Low/Medium Pressure
Maximum Flow Rate	100,000+ GPM	10,000+ GPM	10,000+ GPM
Low Flow Rate Capability	No	Yes	Yes
Maximum Pressure	6,000+ PSI	100,000+ PSI	4,000+ PSI
Requires Relief Valve	No	Yes	Yes
Smooth or Pulsating Flow	Smooth	Pulsating	Smooth
Variable or Constant Flow	Variable	Constant	Constant
Self-priming	No	Yes	Yes
Space Considerations	Requires Less Space	Requires More Space	Requires Less Space
Costs	Lower Initial Lower Maintenance Higher Power	Higher Initial Higher Maintenance Lower Power	Lower Initial Lower Maintenance Lower Power
Fluid Handling	Suitable for a wide range including clean, clear, non-abrasive fluids to fluids with abrasive, high-solid content. Not suitable for high viscosity fluids Lower tolerance for entrained gases	Suitable for clean, clear, non-abrasive fluids. Specially-fitted pumps suitable for abrasive-slurry service. Suitable for high viscosity fluids Higher tolerance for entrained gases	Requires clean, clear, non-abrasive fluid due to close tolerances Optimum performance with high viscosity fluids Higher tolerance for entrained gases

Construction of Centrifugal Pumps



1- Casing:-

Casing generally are two types:

I. Volute casings for a higher head.

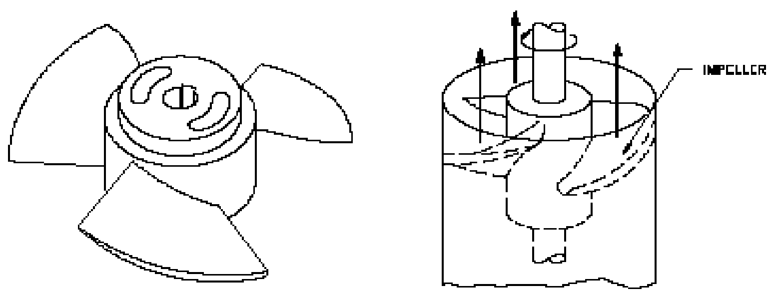
A *volute* is a curved funnel increasing in area to the discharge port.

II. Circular casings for low head and high capacity.

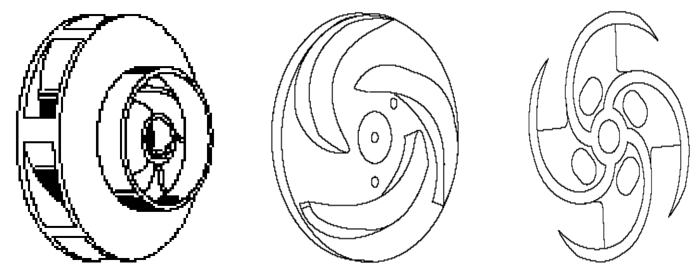
have stationary diffusion vanes surrounding the impeller periphery that convert velocity energy to pressure energy.

2-Impeller

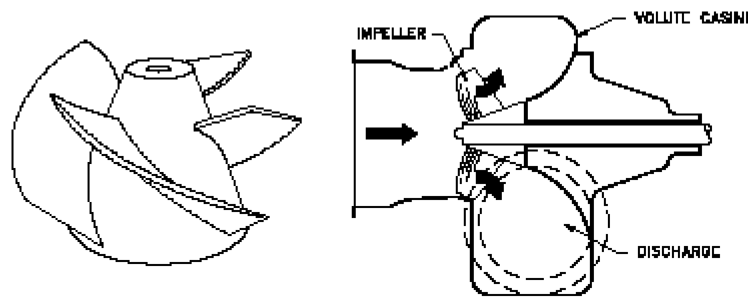
Three main categories of centrifugal pumps exist



Axial flow



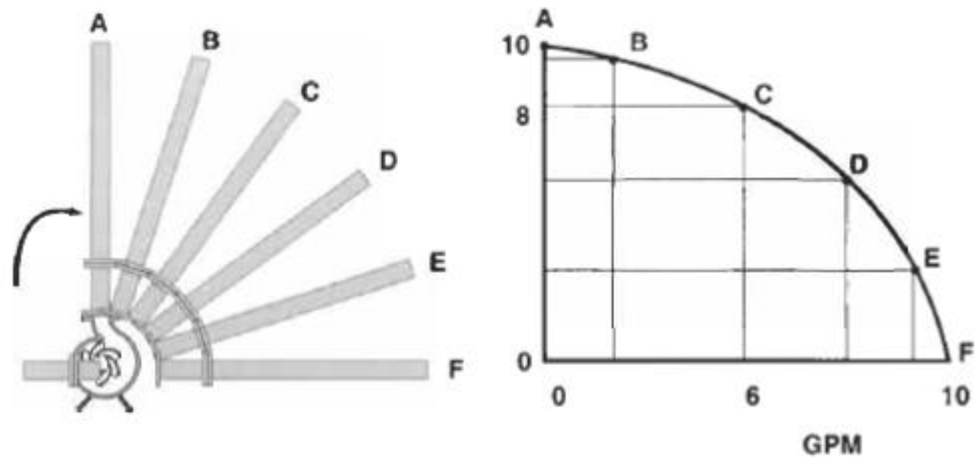
Radial flow

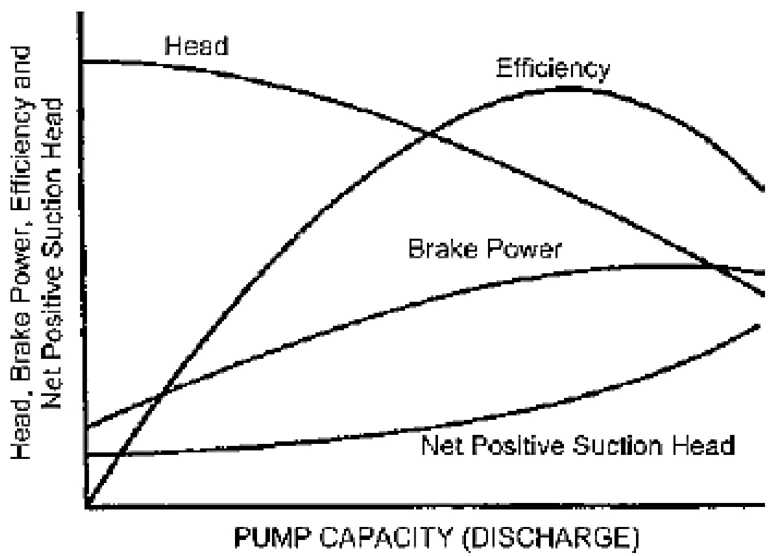


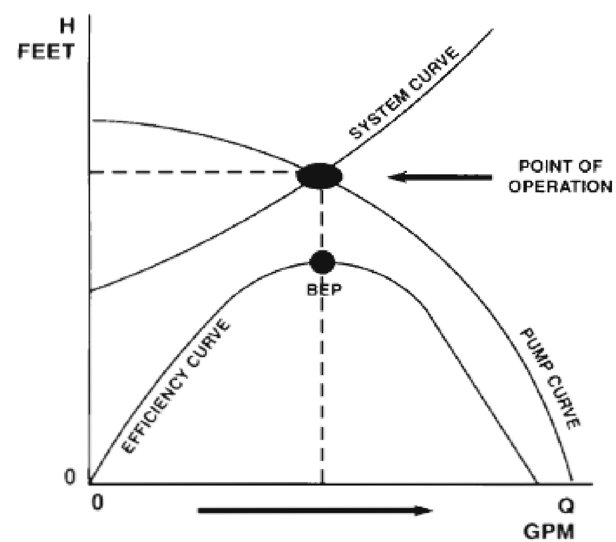
Mixed flow

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.

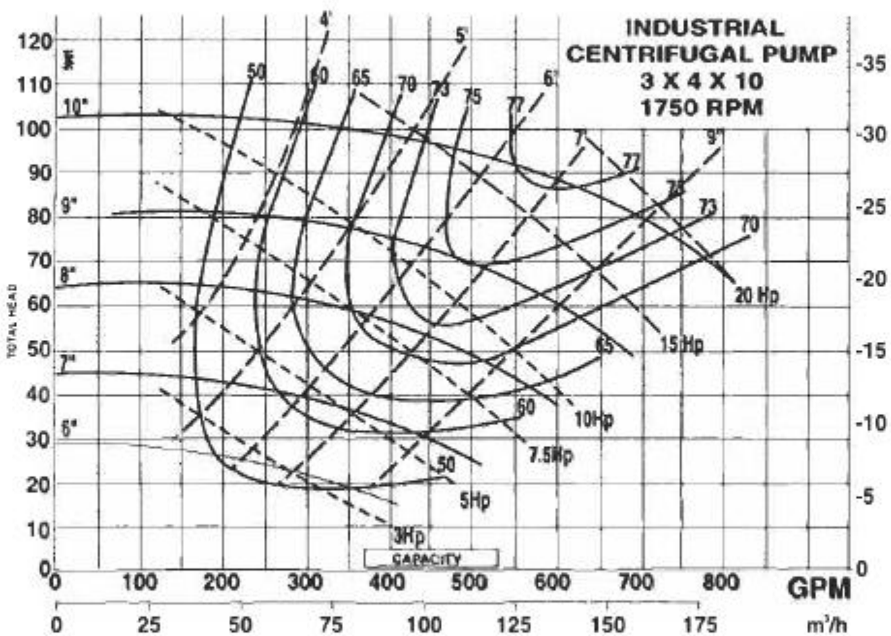


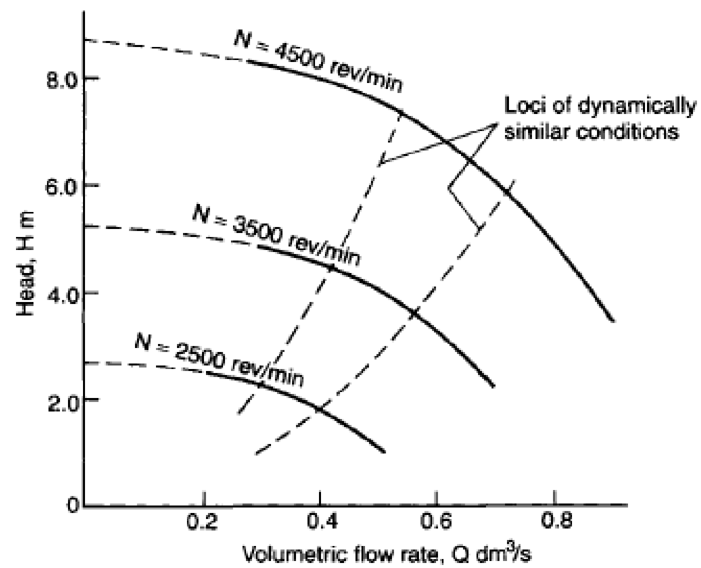




Family curves

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.

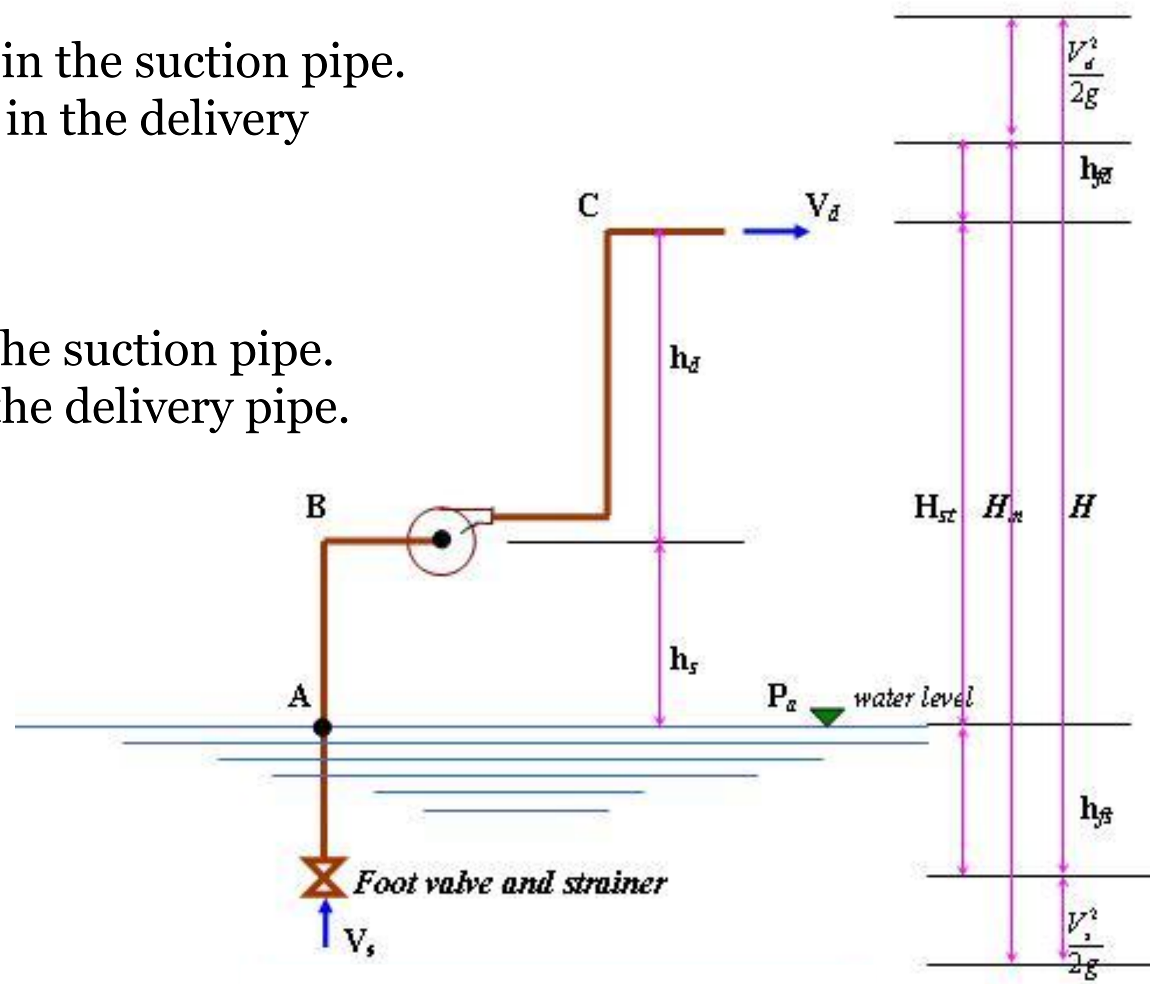
V_d = Velocity of fluid in the delivery pipe.

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)

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

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

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

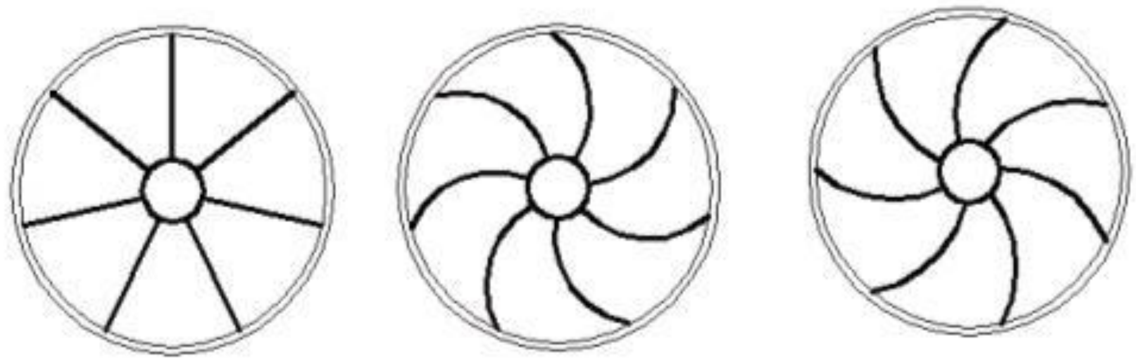
$$H_m = H + \frac{1}{2g}(V_s^2 - V_d^2)$$

When $V_s = V_d$
Hence $H_m = H$

Type of Impeller

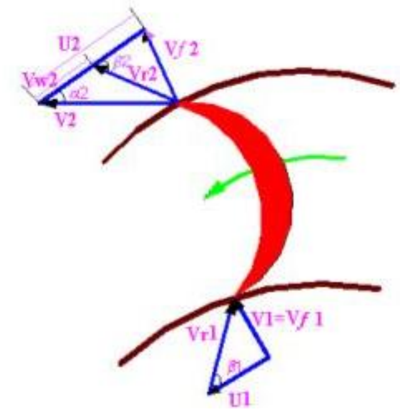
There are three main categories of impeller due type of impeller's vane, which are used in the centrifugal pumps as;

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

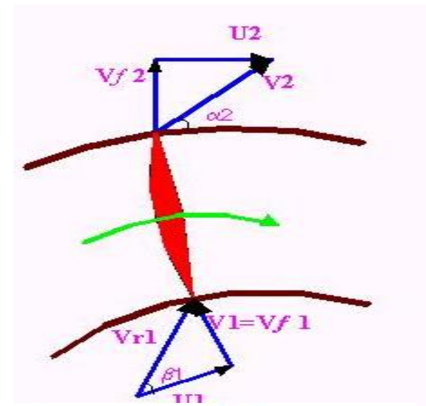


(a) (b) (c)

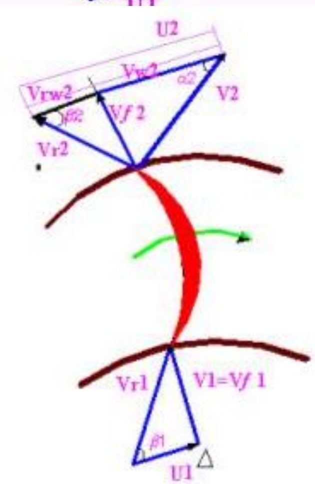
a) when $\beta_2 > 90^o$, the Forwards curved vanes of the impeller.



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 (2nd ed.)

3-Igor J. Karassik ,oseph P. Messina,Paul Cooper and Charles C. Heald,2001. Pump Handbook(3rd ed)