Pumps

Pumps are devices for supplying energy or head to a flowing liquid in order to overcome friction and also if necessary to raise the liquid to a higher level or to flow against a higher pressure. Pumps transform mechanical energy (or other forms of energy) into fluid energy.

If a pump is placed between two points in a piping system, then Bernoulli's equation is

$$\underbrace{\left(Z_2 + \frac{P_2}{\rho g} + \frac{V_2^2}{2g}\right) - \left(Z_1 + \frac{P_1}{\rho g} + \frac{V_1^2}{2g}\right)}_{\text{Useful work}} = \underbrace{+\Delta h}_{\text{Head developed by pump}} - \underbrace{h_f}_{\text{Head loss in system}}$$

Therefore

$$\boxed{\text{Total work} = \text{Useful work} + \text{useless work}}$$

Pumps are associated with liquids; while fans, blowers and compressors are associated with gases depending on the amount of gas to be moved and the pressure rise to be achieved.

Classification of pumps:

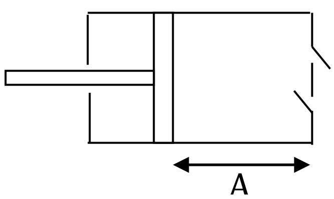
Two basic types:

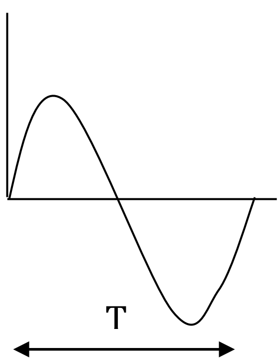
- Positive displacement pumps (static)
- Kinetic or dynamic (centrifugal)

Positive displacement pumps:

- Reciprocating pumps – Piston and cylinder $Q \propto f x A$

  f=Frequency $=1/T$; T = period of a cycle ; A=Amplitude





- Rotary pumps – Gear pumps, screw pumps

  Q ∝ rotational speed

Characteristics:

- Suitable for high viscosity liquids, dilatant liquids
- Difficult and expensive to maintain
- Cannot be operated against closed discharge
- Suitable for high head delivery
- High initial cost
- Can be used as metering pumps

Centrifugal pumps:

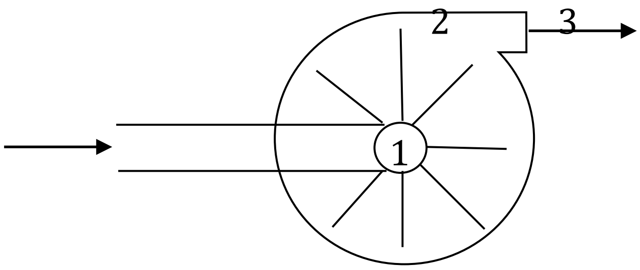
Energy or head is achieved by centrifugal action. Depending on the shape of he impeller we have:

Radial Pumps – Liquid is thrown radially (most common)
Axial Pumps – Liquid is thrown axially

Principle of operation:

Pump (Mech. Energy) →High KE →Injection work →High pressure at outlet

Theory:



BE between 1 & 2 (assuming friction is negligible)

$P_2 \cong P_1$ $(P_2 is\ slightly > P_1$

$V_1 \ll V_2$ $(fluid\ is\ accelerated\ from\ 1\ to\ 2)$

and $\frac{\Delta P}{\rho} \ll \frac{\Delta V^2}{2}$

$$\therefore \frac{\Delta V^2}{2} \cong + \frac{dW_{ao}}{dm} = \widehat{W}$$

Work → KE

Tangential velocity = r x angular velocity
= r (2 π rpm)   rpm=rounds per minute

- Tangential velocity is greater for great radius
- P does not change significantly

Now, BE between 2 & 3 (diffuser section: KE is diffused into injection work)

(Assuming friction is negligible, no work done, $V_3 \ll V_2$)

$$\frac{P_3 - P_2}{\rho} \cong \frac{V_2^2}{2} \cong \frac{P_3 - P_1}{\rho}$$

It can be seen that a centrifugal pump consists of two stages:

- Increase in KE at approximately constant P
- Conversion of KE into P in the diffuser section

For a given pump:

$$\frac{\Delta \mathrm{P}_{\text{across pump}}}{\rho} \cong \text{Constant}$$

$$\Delta P = \rho \ \frac{V^2}{2} = \rho \ \frac{(r\omega)^2}{2}$$

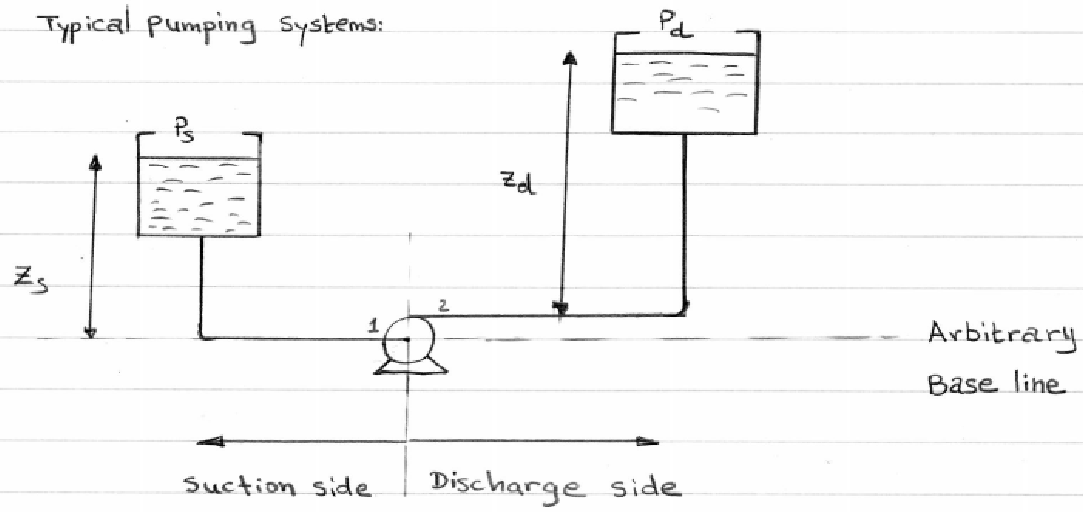
$$= \frac{\rho}{2}\left(\frac{D}{2}\ 2\pi\ rpm\right)^2$$

$$= \frac{\rho}{2}(\ \pi\ D\ rpm)^2$$

$$= \text{constant}$$

System Heads:

Typical pumping systems:



Important heads to be considered in a pumping system:

- Suction head
- Discharge head
- Total system head
- Available NPSH

Suction side

BE between supply Tank and 1

$$\left(\frac{P_1}{\rho g} + z_1 + \frac{V_1^2}{2g}\right) = \left(\frac{P_s}{\rho g} + z_s\right) - h_{fs}$$

Suction head:

$$h_s = \left(\frac{P_s}{\rho g} + z_s\right) - h_{fs}$$

Notes: - $z_s < 0$ if liquid level is below Base line

- h_{fs} reduces h_s

Discharge Side

BE between receiving Tank and 2

$$\left(\frac{P_2}{\rho g} + z_2 + \frac{V_2^2}{2g}\right) = \left(\frac{P_d}{\rho g} + z_d\right) + h_{fd}$$

Discharge Head:

$$h_d = \left(\frac{P_d}{\rho g} + z_d\right) + h_{fd}$$

Note: - h_{fd} increases h_d.

System Head:

BE Between supply and receiving Tanks: $\left(\frac{P_d}{\rho g} + z_d\right) - \left(\frac{P_s + z_s}{\rho g}\right) = +\Delta h - h_{fT}$

$$+\Delta h = \left(\frac{P_d}{\rho g} + z_d\right) - \left(\frac{P_s}{\rho g} + z_s\right) + h_{fT} \Rightarrow h_{fT} = h_{fd} + h_{fs}$$

$$\boxed{+\Delta h = h_d - h_s}$$

Note: $+\Delta h$ increases with Q since $(h_{fs} + h_{fd})$ increase with Q.

This is the total head which should be imparted by the pump to the fluid for a certain flow rate. It is called the **System Head.** It is the work required to be done by the pump for a certain system at a certain flow rate.

For the pump:

BE across the pump (between entrance and exit i.e. 1 and 2):

$$\Delta h = \left(\frac{P_2 - P_1}{\rho g}\right)$$

Note:

The system head equation can be written as:

$$\Delta h = \underbrace{(Z_d - Z_s)}_{1} + \underbrace{\left(\frac{P_d - P_s}{\rho g}\right)}_{2} + \underbrace{(h_{fd} + h_{fs})}_{3}$$

$$h_{fs} = 4f \frac{\sum L_{es}}{d_s} \frac{V_s^2}{2} + [h_{entry}]$$

$$h_{fd} = 4f \frac{\sum L_{ed}}{d_d} \frac{V_d^2}{2} + [h_{exit}]$$

- In many cases $[h_{entry}]$ and $[h_{exit}]$ are negligible
- For a given system, the terms 1 and 2 are fixed. Therefore, the system head varies as function of 3 which is function of Q (the volume flow rate)
- For turbulent flow$\Delta h\ vs\ Q\ is\ a\ curve$; while for laminar flow it is a straight line.