SHROFF S. R. ROTARY INSTITUTE OF CHEMICAL TECHNOLOGY
ANKLESHWAR

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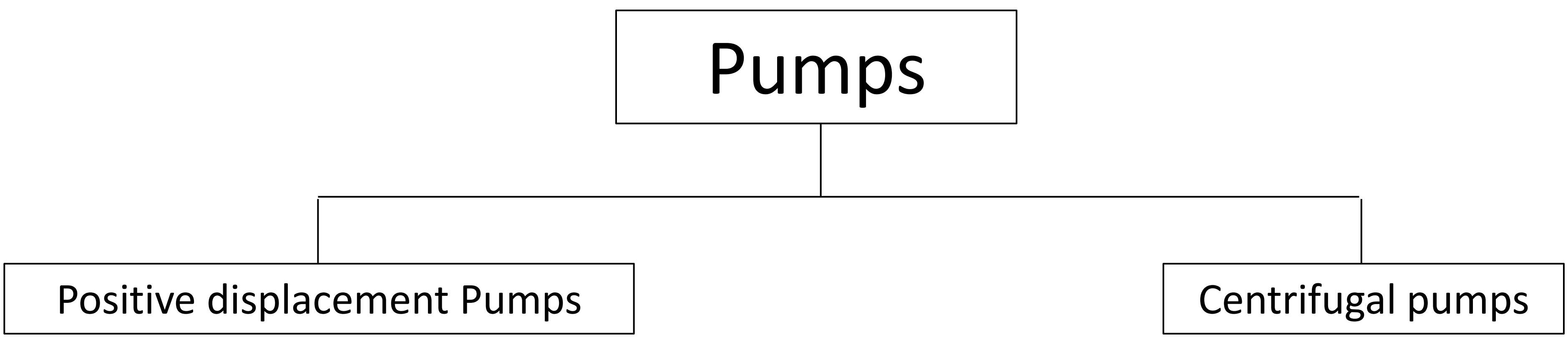
PUMP,FANS & COMPRESSORS

Pumps

- Transportation of liquids is facilitated through pipes either by gravity or by pumps.
- Pump is a device which increases mechanical energy of the liquid increasing either its velocity, pressure or elevation.



``	**Positive displacement pumps**	**Centrifugal pumps**
1	They apply pressure directly on to liquid by a piston rotating in an cylinder which alternatively filled and emptied by liquid.	They generate high rotational velocities converting resulting kinetic energy of liquid into pressure energy.
2	Closing the delivery valve results in serious after effects.	Closing the delivery valve results in no suction and discharge. The mechanical energy is wasted in the form of heat energy
3	Reciprocating pump, Gear Pump, Lobe pump, vane pump, screw pump are examples	Centrifugal pump is an example of non-positive displacement pump.
4	Used for high pressure and low discharge	Used for low pressure and high discharge

Centrifugal Pump

Main part of centrifugal pump

The following are the main part of centrifugal pump

- 1. Impeller
- 2. Casing
- 3. Suction pipe with a foot valve and strainer
- 4. Delivery pipe

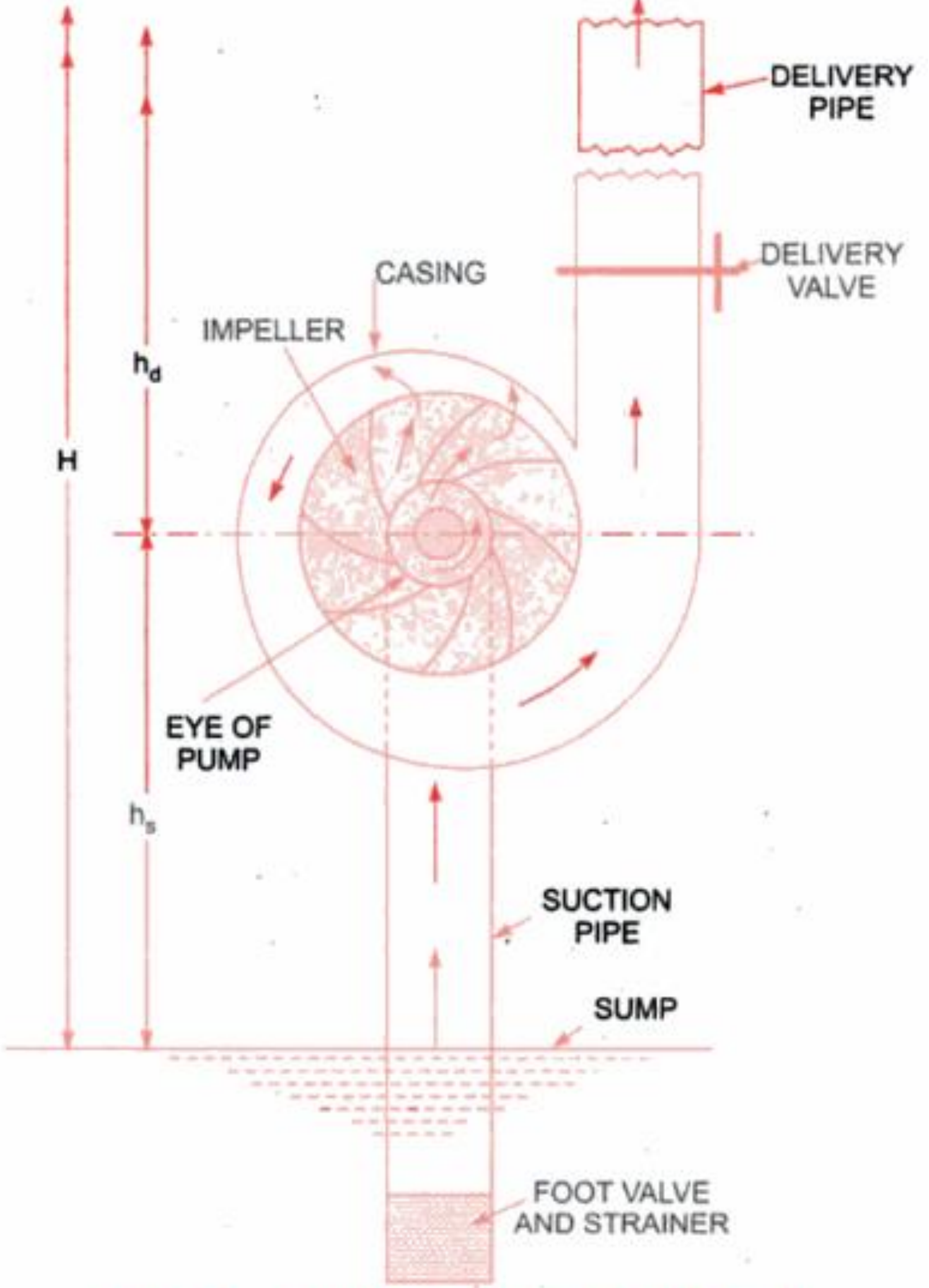


Fig. 19.1 *Main parts of a centrifugal pump.*

Components of centrifugal Pump

1. Impeller

The rotating part of a centrifugal pump is called impeller. It is consists of a series of backward curved vanes. The impeller is mounted on the a shaft which is connected to the shaft of an electric motor

2. Casing:

The casing of a centrifugal pump is similar to reaction turbine. It is an air tight passage surrounding the impeller and is designed in such a way that the kinetic energy of water discharged at the outlet of the impeller is converted in to pressure energy before water leaves the casing and enters the delivery pipe.

Components of centrifugal Pump

3. Suction pipe with foot valve and a strainer

A pipe whose one end is connected to the inlet of the pump and other end dips into water sump is known as suction pipe. A foot valve which is a non return valve or one way type valve is fitted at the lower end of the suction pipe. The foot valve is opened only in upward direction. A strainer is also fitted at the lower end of the suction pipe.

4. Delivery pipe

A pipe whose one end is connected to the outlet of the pump and other end delivers the water at a required height is known as delivery pipe.

Heads in a pump

1. Suction head
2. Delivery head
3. Static head
4. Manometric Head

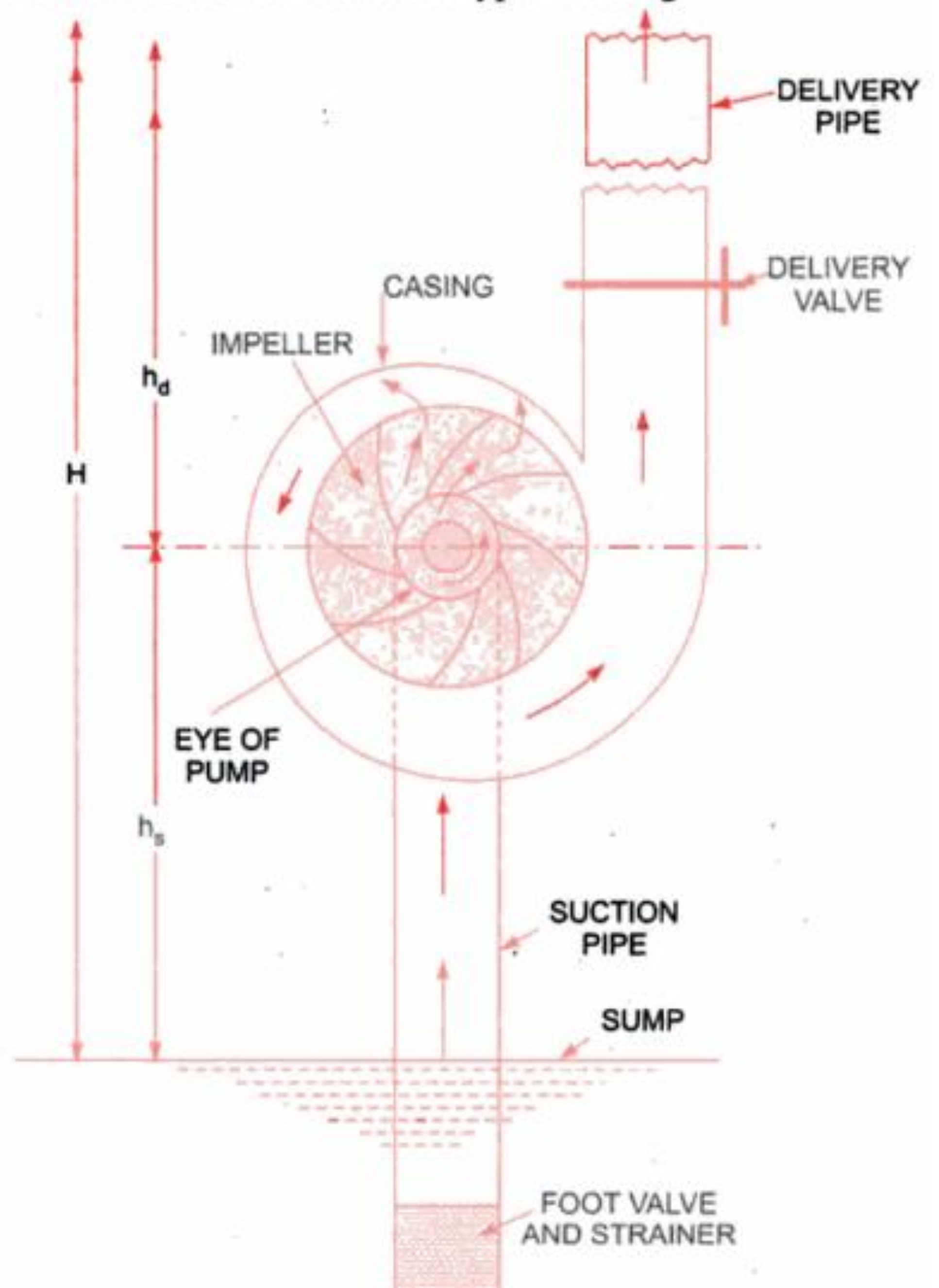


Fig. 19.1 *Main parts of a centrifugal pump.*

Suction head: It is the vertical distance between the liquid level in the reservoir and eye line of the pump. It is denote by h_s.

Delivery head: It is the vertical height of liquid surface in overhead tank to which liquid is to be delivered above the centerline of the pump.

Static head: It is the vertical distance between liquid levels in the reservoir and overhead tank. Or it is the sum of suction head and delivery head.
It is denote by H, then,

$$H = hs + hd$$

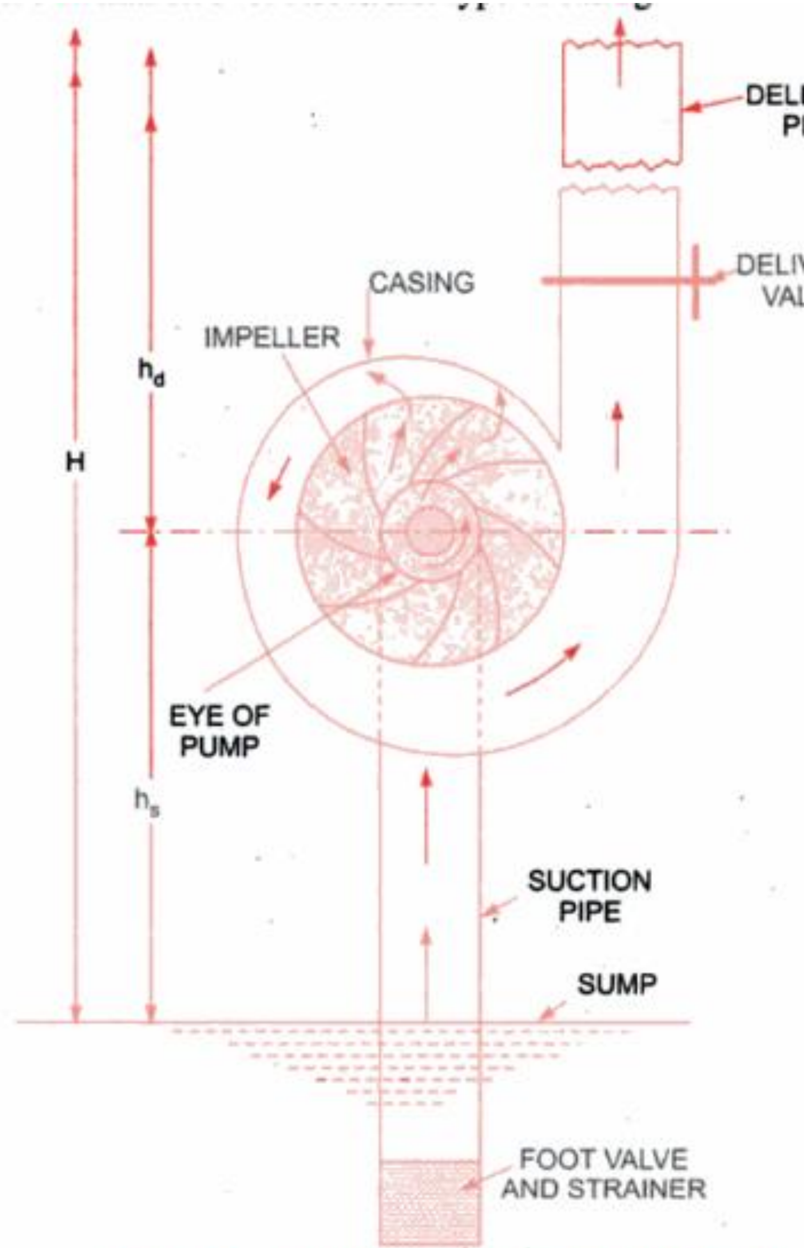


Fig. 19.1 *Main parts of a centrifugal pump.*

Manometric head: The head against which the centrifugal pump has to work is called as Manometric head. It is denoted by H_m

4. **Manometric Head (H_m).** The manometric head is defined as the head against which a centrifugal pump has to work. It is denoted by 'H_m'. It is given by the following expressions :

(*a*) H_m = Head imparted by the impeller to the water – Loss of head in the pump

$$= \frac{V_{w_2} u_2}{g} - \text{Loss of head in impeller and casing} \quad \text{...(19.4)}$$

$$= \frac{V_{w_2} u_2}{g} \text{ ...if loss of pump is zero} \quad \text{...(19.5)}$$

(*b*) H_m = Total head at outlet of the pump – Total head at the inlet of the pump

$$= \left(\frac{P_o}{\rho g} + \frac{V_o^2}{2g} + Z_o\right) - \left(\frac{p_i}{\rho g} + \frac{V_i^2}{2g} + Z_i\right) \quad \text{...(19.6)}$$

where $\frac{p_o}{\rho g}$ = Pressure head at outlet of the pump = h_d

$\frac{V_o^2}{2g}$ = Velocity head at outlet of the pump

= Velocity head in delivery pipe = $\frac{V_d^2}{2g}$

Z_o = Vertical height of the outlet of the pump from datum line, and

$\frac{p_i}{\rho g}, \frac{V_i^2}{2g}, Z_i$ = Corresponding values of pressure head, velocity head and datum head at the inlet of the pump,

i.e., $h_s, \frac{V_s^2}{2g}$ and Z_s respectively.

(*c*) $$H_m = h_s + h_d + h_{f_s} + h_{f_d} + \frac{V_d^2}{2g} \quad \text{...(19.7)}$$

where h_s = Suction head, h_d = Delivery head,

h_{f_s} = Frictional head loss in suction pipe, h_{f_d} = Frictional head loss in delivery pipe, and

V_d = Velocity of water in delivery pipe.

Cavitation

- Cavitation is defined as the phenomena of formation of vapour bubbles of a flowing liquid in a region where the pressure of the liquid falls below its vapour pressure and the sudden collapsing of these vapour bubbles in a region of higher pressure.
- When the vapour bubbles collapse , a very high pressure is created.
- The metallic surfaces, above which these bubbles collapse, is subjected to these high pressure, which cause pitting action on the surface. Thus cavities are formed on the metallic surface and also considerable noise and vibrations are produced.

Effect of cavitation

The following are the effects of cavitation:

1. The metallic surfaces are damaged and cavities are formed on the surfaces.
2. Due to sudden collapse of vapour bubble, considerable noise and vibrations are produced.
3. The efficiency of a turbine decreases. Due to pitting action, the surface of the turbine blades becomes rough and the force exerted by water on the turbine blades decreases. Hence, the work done by water or output horse power becomes less and thus efficiency decreases

Precaution against cavitation

The following precautions should be taken against cavitation:

1. The pressure of the flowing liquid in any part of the hydraulic system should not be allowed to fall below its vapour pressure. If the flowing liquid is water, then the absolute pressure head should not be below 2.5 m of water.
2. The special materials or coatings such as aluminum –bronze and stainless steel, which are cavitation resistant materials , should be used.

Priming

Priming is the operation in which the suction pipe ,casing of the pump and a portion of the delivery pipe up to the delivery valve is completely filled up from outside source with the liquid to be raised by the pump before the starting of the pump. Thus the air from these parts of the pump is removed.

The work done by impeller per unit weight of the liquid per second is known as head generated by the pump.

The head generated by the pump = $\frac{1}{g} V_{w2} u_2$, meter. This equation is independent of the density of liquid. This means that when pump is running in air, the head generated is in terms of air. If the pump is primed with water, the head is generated is same meter of water.

But as the density of air is very low , the generated head of air in

Net Positive Suction head-NPSH

To avoid cavitation, pressure at the suction side must be higher than Vapour pressure of the liquid which is being pumped through the centrifugal pump. This difference of suction pressure head and vapour pressure head is known as Net Positive Suction head (NPSH)

Net Positive Suction Head(NPSH) = Net head at Pump inlet – vapor pressure head of liquid to be pumped

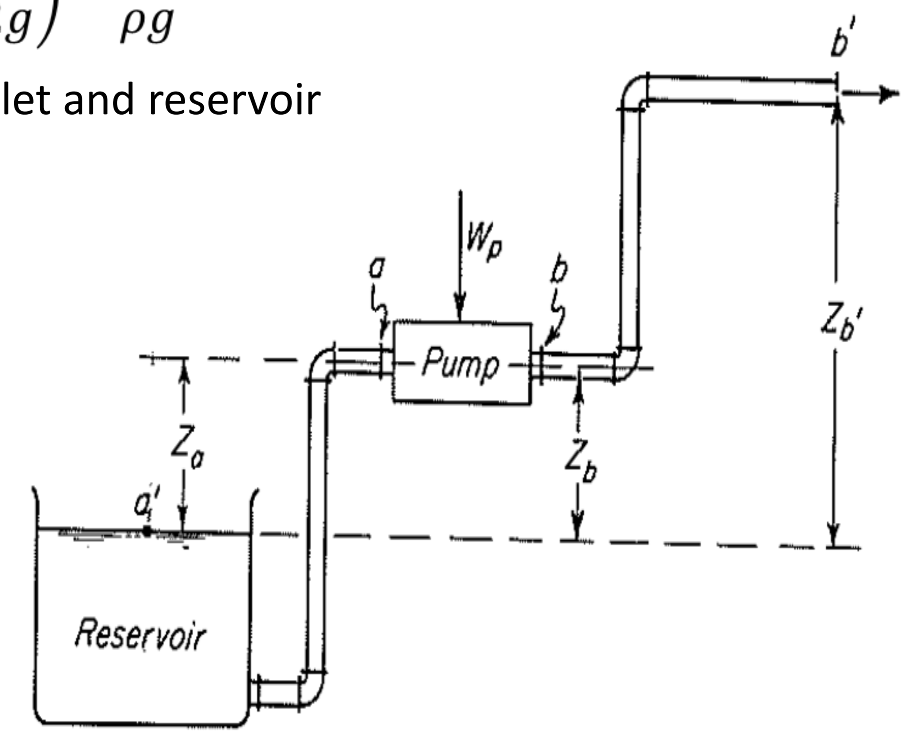
$$= \left(\frac{p_s}{\rho g} + \frac{V_s^2}{2g}\right) - \frac{p_v}{\rho g}$$

Applying Bernoulli's equation between at pump inlet and reservoir

$$\left(\frac{p_s}{\rho g} + \frac{V_s^2}{2g}\right) + Z_a + h_{fs} = \frac{p_a}{\rho g}$$

$$\frac{p_s}{\rho g} = \frac{p_a}{\rho g} - \frac{V_s^2}{2g} - Z_a - h_{fs}$$

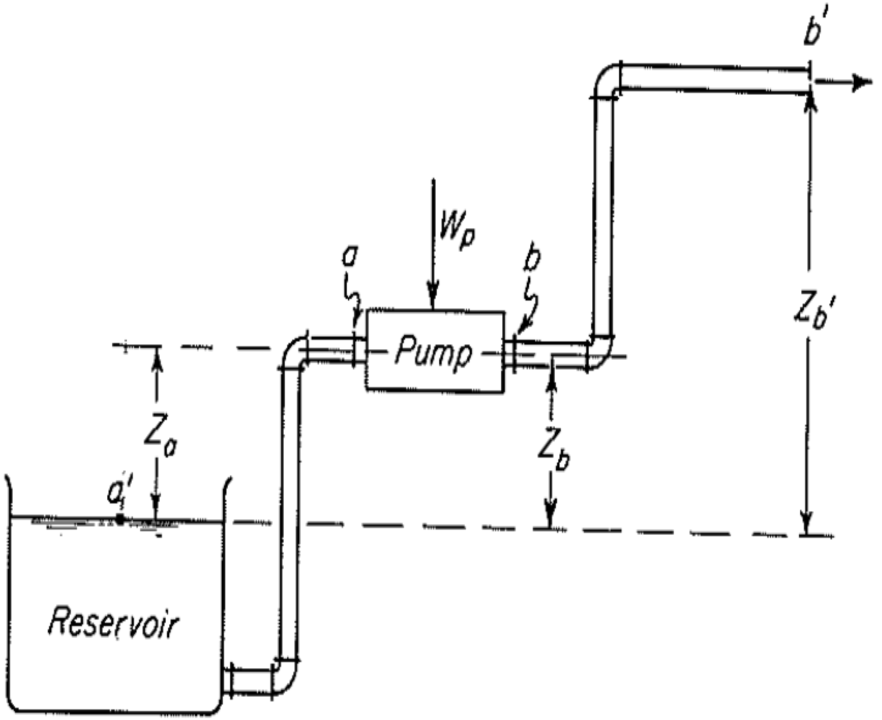
$$NPSH = \frac{p_a}{\rho g} - \frac{V_s^2}{2g} - \frac{p_v}{\rho g} - Z_a - h_{fs} + \frac{V_s^2}{2g}$$



NPSH…. Continue

$$NPSH = \frac{p_a}{\rho g} - \frac{p_v}{\rho g} - Z_a - h_{fs}$$

The right hand side of above equation is the total suction head. Hence NPSH is equal to total suction head. Thus NPSH may also be defined as the **total head required to make the liquid flow through the suction pipe to the pump impeller**.



$NPSH_A$ and $NPSH_R$

- For pump installation, a distinction is made between the **required NPSH** and the **available NPSH.**
- The value of required NPSH is given by the pump manufacturer. This value can also be determine by experimentally.
- For determining its value, the pump is tested and minimum value of hs is obtained at which pump gives maximum efficiency without any objectionable noise (i.e. Cavitation free). The required NPSH varies with the pump design, speed of the pump and capacity of the pump.
- When the pump is installed , the available NPSH is calculated from equation

$$NPSH_A = \frac{p_a}{\rho g} - \frac{p_v}{\rho g} - Z_a - h_{fs}$$

- In order to have cavitation free operation of centrifugal pump , the available NPSH should be greater than the required NPSH.

Efficiency Of Centrifugal Pump

In case of centrifugal pump, the power is transmitted from the shaft of the electric motor to the shaft of the pump and then to the impeller. From the impeller the and then, the power is given to water.

Thus power is decreasing from the shaft of the pump to the impeller and then to the water.

the following are the important efficiency of the pump:

1. Manometric efficiency(η_{man})
2. Mechanical efficiency (η_{mech})
3. Overall efficiency (η_{o})

Efficiency Of Centrifugal Pump

MANOMETRIC EFFICIENCY

$$\eta_{man} = \frac{\text{Manometric head}}{\text{Head Imported By Impeller To Water}}$$

MECHANICAL EFFICIENCY

$$\eta_{mech} = \frac{\text{Rotor Or Impeller Power}}{\text{Shaft power}}$$

OVERALL EFFICIENCY

$$\eta_{o} = \frac{\text{Power Output Of Pump}}{\text{Power Input Of Pump}}$$

Characteristic curves of centrifugal pump

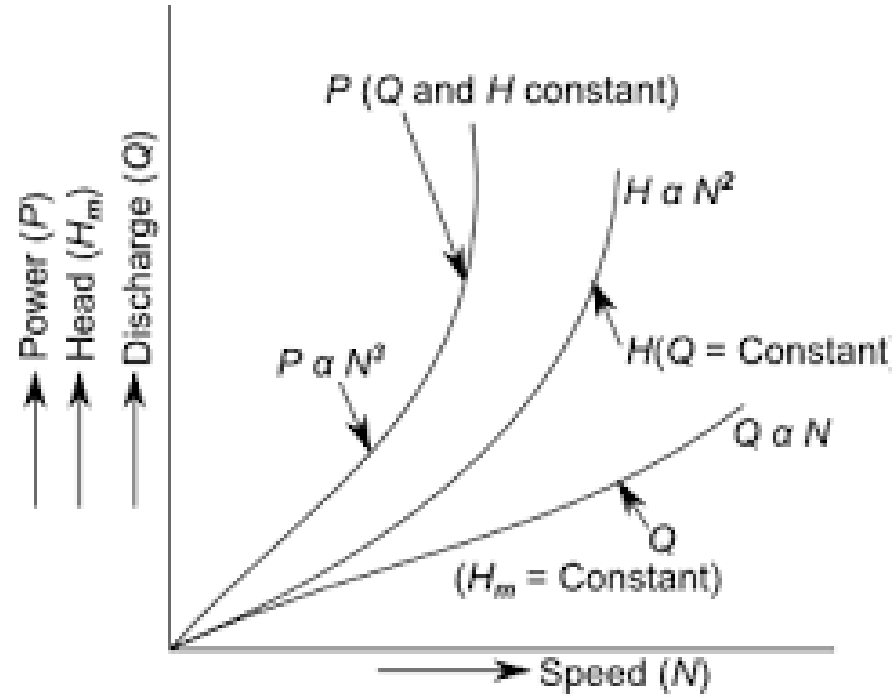
- Characteristics curves of centrifugal pumps are defined as those curves which are plotted from the results of a number of tests on the centrifugal pump.
- These curves are necessary to predict the behavior and the performance of the pump when the pump is working under different flow rate , head and speed. The following are the important characteristic curves for pumps.

1. Main characteristic curves.
2. Operating characteristic curves and
3. Constant efficiency or Muschel curves

Main characteristic curves

The main characteristic curves of a centrifugal pump consists of variation of head (manometric head, Hm), power and discharge with respect to speed.

For plotting curves of manometric head versus speed, discharge is kept constant,
For plotting curves of discharge versus speed , manometric head is kept constant, and



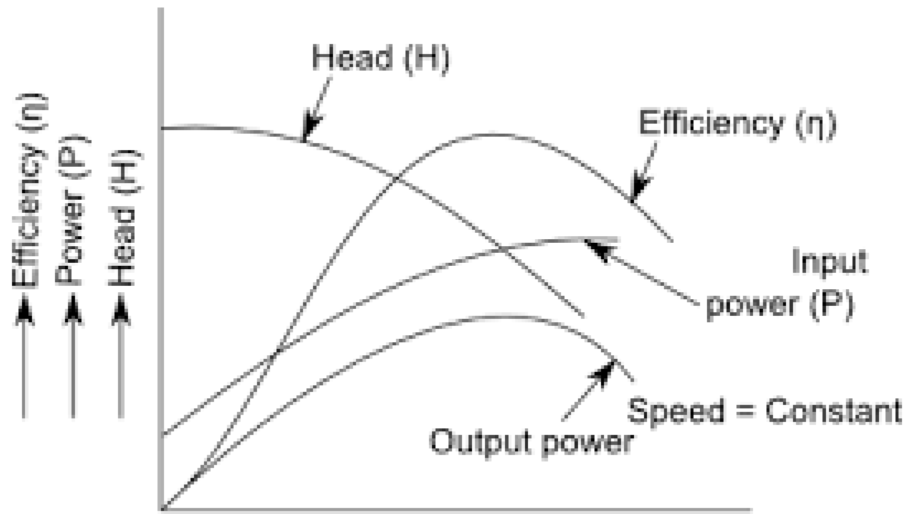
Main characteristics curves of a pump.

For plotting curves of power versus speed manometric head and discharge are kept constant

Operating characteristic curves

If the speed is kept constant , the variation of manometric head , power and efficiency with respect to discharge gives the operating characteristic curves of the pump.

The input power curve shall not pass through the origin. It will be slightly away from the origin on the y-axis, as even at zero discharge some power is needed to overcome the mechanical losses.

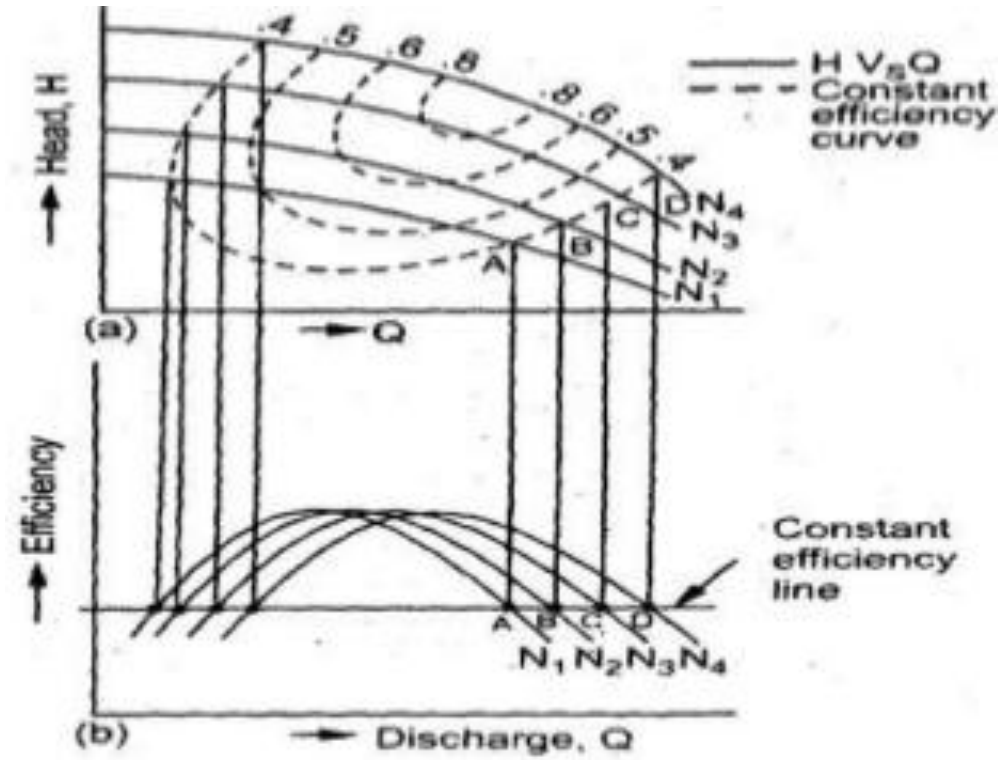


Operating characteristic surves of a pump.

The head curve will have maximum value of head when discharge is zero.
The output curve will start from origin as at Q=0, output power (ρgQH) will be zero.
The efficiency curve will start from origin as at Q =0, η=0

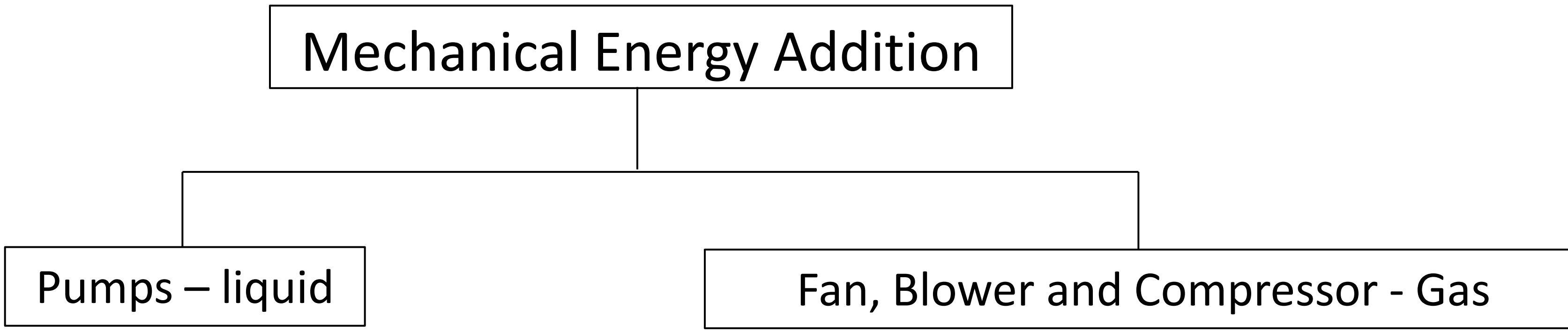
Constant efficiency curve

For obtaining constant efficiency curves for a pump, the head versus discharge curves and efficiency versus discharge curves for different speed are used.



For plotting constant efficiency curves (Also known as Iso-efficiency curves), horizontal lines representing constant efficiency are drawn on the η - Q curves. The points at which these lines cut the efficiency curves at various speeds are transferred to the corresponding H~Q curves. The points having the same efficiency are then joined by smooth curves represents the iso efficiency curves.

Fans, Blowers and Compressors



- Fans Blowers and Compressors are used to deliver gas at higher pressure as compared to initial state.

Sl No	Name of the Equipment	Pressure rise and Compression Ratio
1	Fan	1.5 atm, 1.11
2	Blowers	1.5 – 2.7 atm, 1.11-1.20
3	Compressors	2 – 1000 atm, greater than 1.2

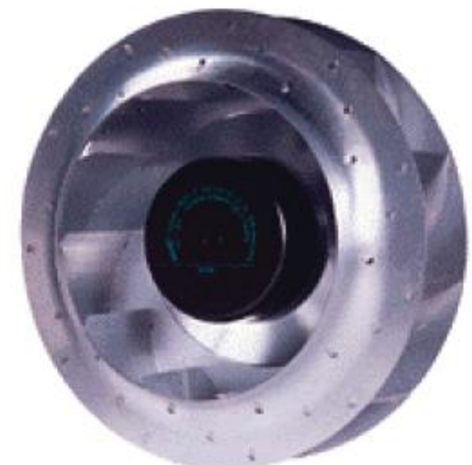
- Pumps & Fans do not have an appreciable changes in density (Flow of fluid is incompressible)
- Blowers and Compressors - density change of fluid is appreciable.

Fans

Large fans are usually centrifugal, operating on exactly the same principle as centrifugal pumps. Their impeller blades, however, may be curved forward, this would lead to insatiability in a pump but not in a fan

- Centrifugal flow Fan (Air flow changes twice)
- Axial Flow Fan (No change in direction of air)

Centrifugal fans

Paddle Blade (Radial blade)	Forward Curved (Multi-Vane)	Backward Curved
		

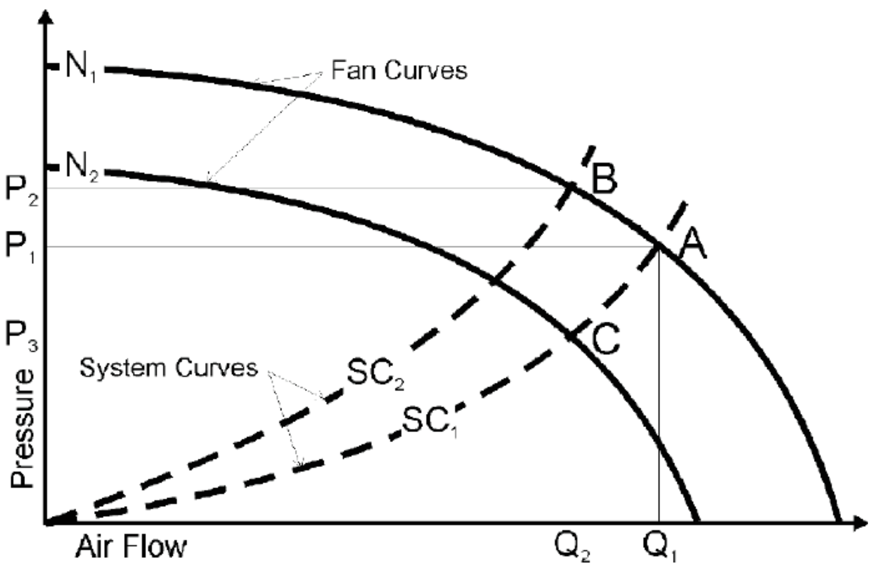
- Radial fans can generate high static pressures to range of 1.8 atm.
- Design is simple, used for high temperature applications.
- Forward curved fans are used for moving large air volume against relatively low air pressures
- Designed for low temperature applications
- Backward inclined fans power consumption drops within airflow range
- Non-overloading as the changes in static pressure does not overload the motor.

System characteristics and Fan curve

Characteristic curves for Fan are called as "Fan Curves"

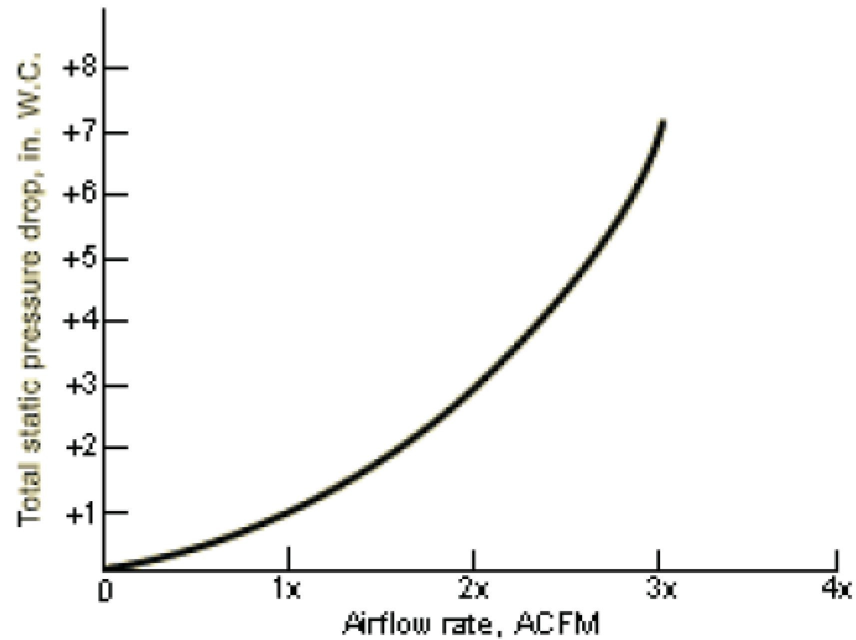
Developed for a given set of operating conditions.

- Fan volume
- System static pressure
- Fan speed & Brake Horse Power



System resistance in Fans

- System resistance refers to Static Pressure losses in the system (losses encountered in short radius elbows and narrow ducts)
- It varies as the square of the volume of air flowing the system
- Effect – less volume of air which is being pumped through the system.
- Resistance decreases as the flow decreases.
- To determine the volume of air fan will produce it is important to know the system resistance characteristics.



Fan efficiency

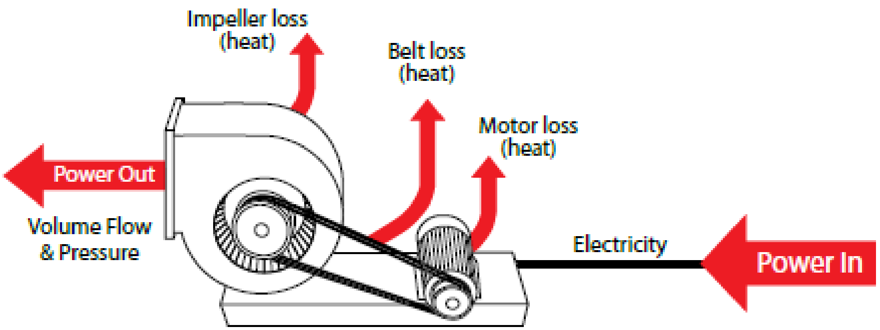
$$Fan\ Efficiency\ = \frac{Power\ transferred\ to\ air\ stream}{Power\ delivered\ to\ fan\ shaft}$$

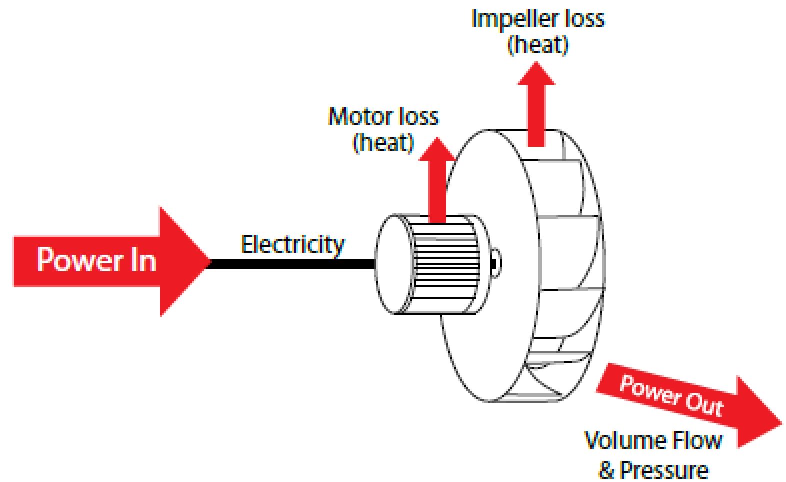
- Fan efficiency is expressed in terms of Total efficiency and Static Efficiency

$$Total\ Efficiency\ = \frac{Total\ Pressure\ \times air\ flow}{BHP\ \times 6362}$$

  - Total Pressure in inches of water gauge
  - Air flow in CFM
  - BHP is Brake horse power
  - 6362 is unit consistency factor

$$Static\ Efficiency\ = \frac{Static\ \ Pressure\ \times air\ flow}{BHP\ \times 6362}$$





$$\eta_{overall} = \eta_F \times \eta_T \times \eta_M \times \eta_C$$

$\eta_{overall}$ = overall fan efficiency

η_F = fan, $\eta_F = \eta_{SE} \times \eta_{catalog}$

η_T = transmission

η_M = motor

η_C = control system

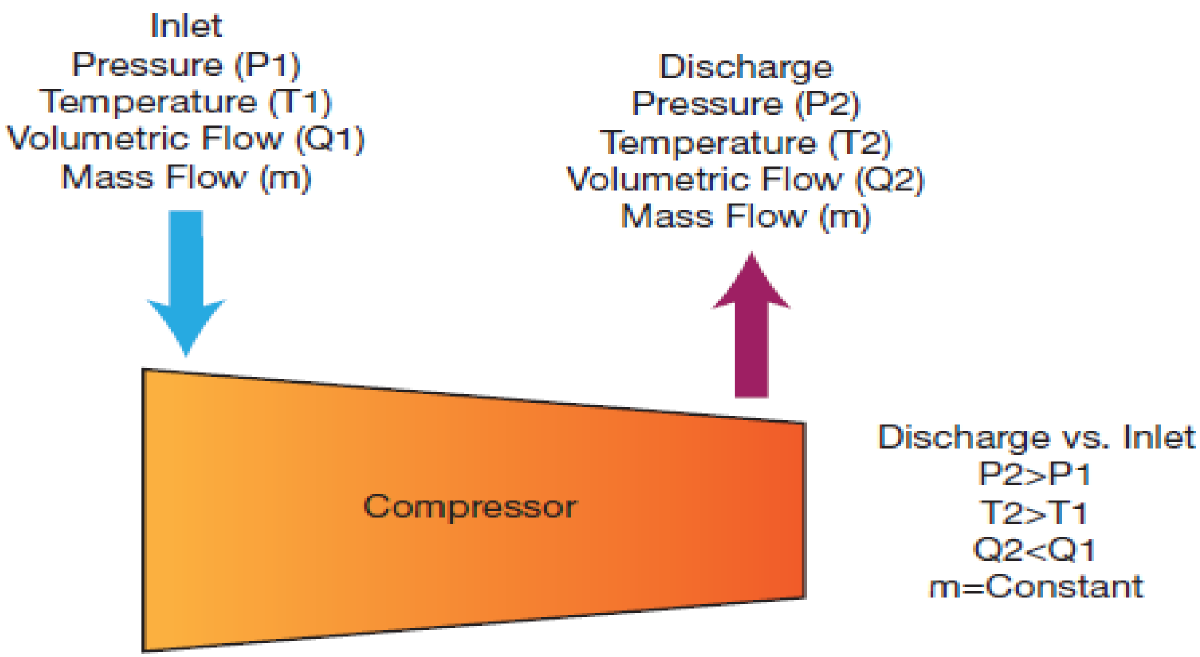
η_{SE} = System Effect, zero System Effect means $\eta = 1.0$

$\eta_{catalog}$ = catalog fan efficiency, affected by proper fan selection

Compressors

Compressors

- Primary objective of compressors is to compress the fluid into small volume while increasing the pressure and temperature of the fluid.



Compressors

Positive displacement Compressors

- Used for discharge applications up to 6 atm.
- Suited with high discharge and medium pressure applications
- Operate in a similar manner as that of reciprocating pumps
- Prevention of leak and temperature rise is more important
- Cylinder head and walls are jacketed to facilitate refrigerant cooling
- Multistage compressors are used in order to achieve higher compression ratios

Centrifugal Compressors

- Series of impellers rotating at high speeds inside a casing
- Handle 340,000m^3/hr of air or process gas at pressure of 20 atm.
- Interstage cooling is required in high pressure units

Compressor efficiency

Compressor efficiency. The ratio of the theoretical work (or fluid power) to the actual work (or total power input) is, as usual, the efficiency and is denoted by η. The maximum efficiency of reciprocating compressors is about 80 to 85 percent; it can be up to 90 percent for centrifugal compressors.

Vacuum pumps

- A compressor that takes suction at a pressure below atmospheric and discharges against atmospheric pressure is called a vacuum pump.
- Any type of blower or compressor, reciprocating, rotary or centrifugal can be adapted to vacuum practice by modifying the design to accept very low density gas at the suction and attain the large compression ratios necessary
- As the absolute pressure at suction decreases, the volumetric efficiency drops and approaches zero at the lowest absolute pressure attainable by pump.
- Usually the mechanical efficiency is also lower than for compressors. The required displacement increases rapidly as the suction pressure falls, so large machine is needed to move much gas.
- The compression ratio used in vacuum pumps is much higher than in compressors, ranging up to 100 or more, with a correspondingly high adiabatic discharge temperature. Actually however , the compression is nearly isothermal because of the low mass flow rate and the effective heat transfer from the relatively large area of exposed metal.