**Centre of Excellence in Renewable Energy Education and Research,**
**New Campus, University of Lucknow,**
**Lucknow**

**M Sc. Renewable Energy**
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**Module REC-402: Energy Auditing and Conservation**

## Unit-2 (Contents)

**Part-A** Energy Conservation in Plant Service Systems: Centrifugal pumps: Energy consumption and saving potentials; Design consideration minimizing over design.

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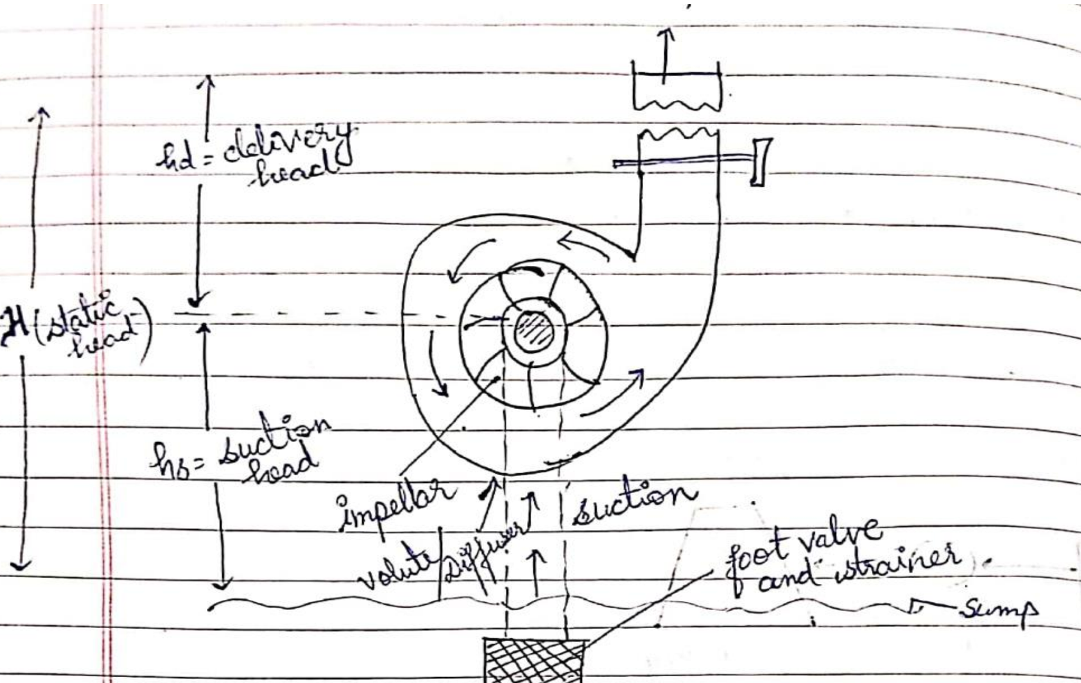
**Part-A** Energy Conservation in Plant Service Systems: Centrifugal pumps: Energy consumption and saving potentials; Design consideration minimizing over design.

## Centrifugal Pumps:




centrifugal pump is of very simple design.

Impellar, which is the only moving part is attache to a shaft and driven by a motor, impellar are generally made of bronze, polycarbonate, cast iro stainless steel as well as other materials. The diffuser houses and the impellar, captures and direct the water of the impellar.

water enters the center of the impellar and exit the impellar with the help of centrifugal force.

As water leaves the impellar a low pressure area is created, causing more water to flow, into the impellar, atmospheric pressure and centrifugal force cause this to happen.

Velocity is developed as the water flows through impellar spinning at high speed. Water speed is collected by the diffuser and converted to pressure by specially designed passage way the flow to the discharge of the pump, or to the next impellar should the pump has multistage configuration.

## Hydraulic Power / Shaft power & Estimated Input power.

Hydraulic power =

(1) $$\eta_{motor} = \frac{\text{Pump shaft power}}{\text{Electrical Input power}}$$

(2) $$\eta_{pump} = \frac{\text{Hydraulic power}}{\text{pump shaft power}}$$

(3) Hydraulic power = $\rho g Q H$

$$\boxed{H = h_d - h_s}$$

$h_d$ = delivery head
$h_s$ = suction head.

## System Characteristics :-

In a pumping system, in most cases either to transfer a liquid from a source to a required destination.

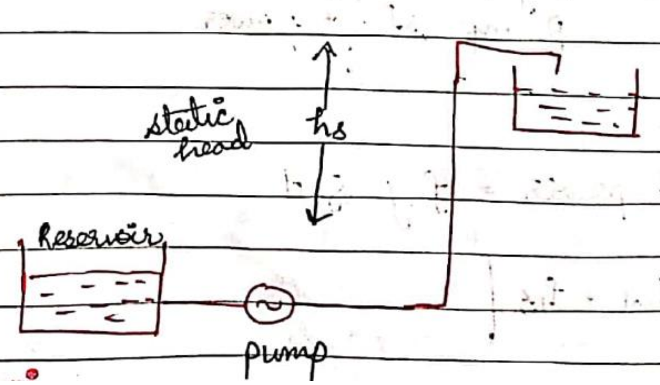
Example :- filling a high level reservoir. heat transfer in a heat exchanger.

A pressure is needed to make the liquid flow at

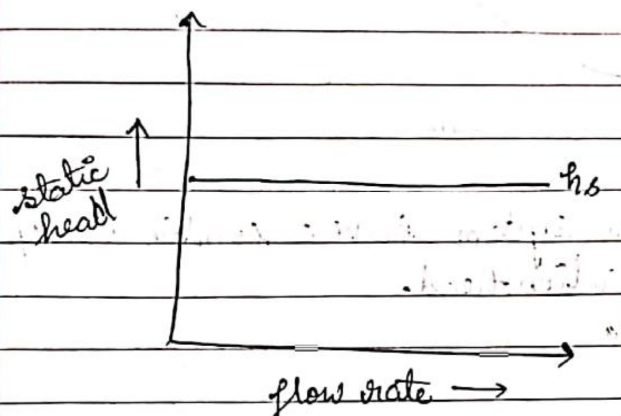
Losses are of two types :-

(1) Static head
(2) Friction head

Static head : it is the difference in height of the supplies and destination reservoir.



Exp. A system with only static head is pumping into a pressurised vessel with short pipe runs.




Friction head / Dynamic head loss :- It is the friction loss on the liquid being move in pipes, valves and equipment in the system. The frictional losses are proportional to square of the flow rate.

$$h_f = \frac{4fLV^2}{2gQ}$$

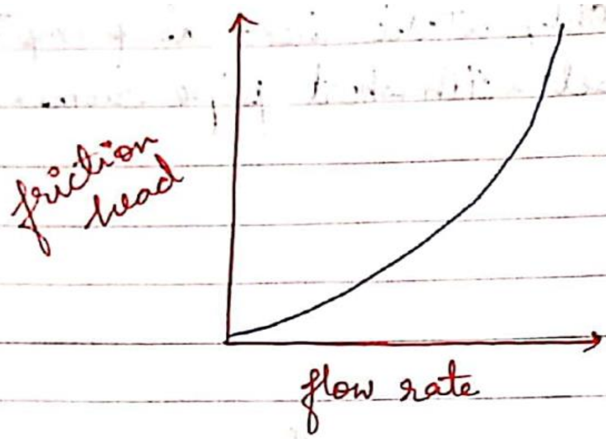
$$h_f \propto V^2$$

$\because Q$ (flow rate) $= AV$

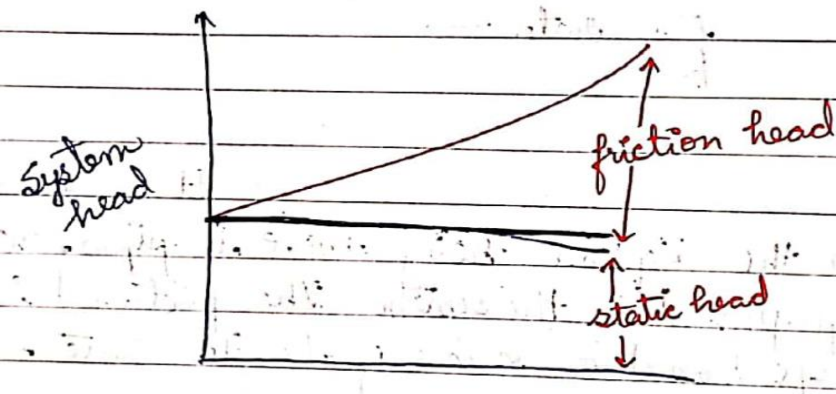
$$V = Q/A$$

$$h_f \propto \left(\frac{Q}{A}\right)^2$$

$$\boxed{h_f \propto Q^2}$$




In most of the system have a combination of static and friction head.




Suction head :- It is the vertical height of the centrifugal pump above the water surface in the tank or pump from which water is to be lifted as shown in figure. This height is also called suction lift and is denoted by '$h_s$'

Delivery head :- The vertical distance b/w the center line of the pump and the water surface in the tank, to which water is delivered is known as delivery head '$h_d$'

Static head :- The sum of suction head and delivery head is known as static head. This is represented by 'H'

$$H = h_s + h_d$$

Manometric head ($h_m$) or Available head ($h_a$) :- it is defined as the head against which a centrifugal pump has to work. It is denoted '$h_m$'.

1. $H_m$ = head imparted by the impellar to the water − loss of head in the pump

2. $$H_m = \left(\frac{P}{\rho g} + \frac{V^2}{2g} + Z\right)_{input} - \left(\frac{P}{\rho g} + \frac{V^2}{2g} + Z\right)_{outlet}$$

3. $$H_m = h_s + h_d + h_{fs} + h_{ds} + \left(\frac{V_d^2}{2g}\right)_{\text{exit loss}}$$

PERFORMANCE CURVE FOR CENTRIFUGAL PUMP

Discharge
Power
head

Discharge :- mass flow rate ($\dot{m}$) = $\rho A V$
For incompressible fluid ($\rho$) = constant.
Discharge = A × Velocity ($m^3/sec$)

Sangam

case 1 Discharge is the performance parameter

2. Net head :- change in Bernoulli head b/w inlet and outlet of the pump.

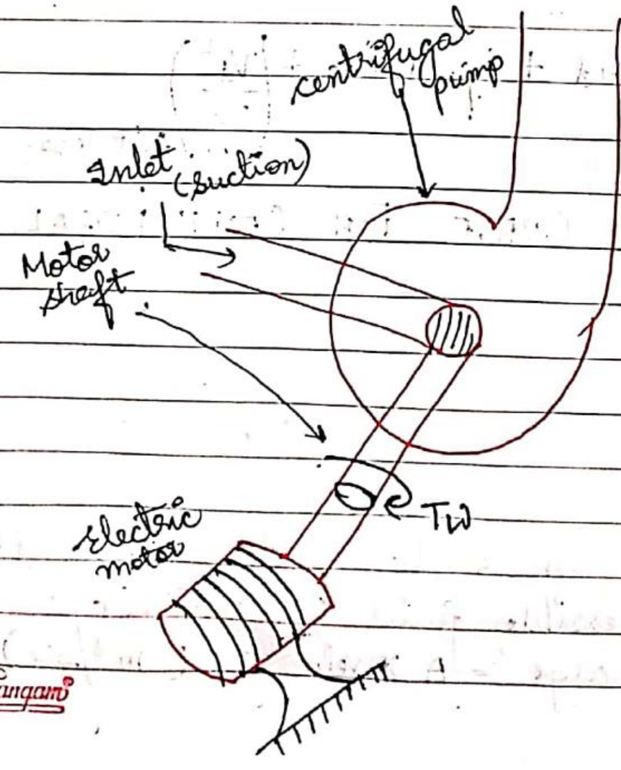
$$H = \left(\frac{P}{\rho g} + \frac{V^2}{2g} + Z\right)_{inlet} - \left(\frac{P}{\rho g} + \frac{V^2}{2g} + Z\right)_{outlet}$$

This Net head is proportional to the useful power delivered to the tube.

Useful power = $\rho g Q H$ (water power)

case 2 Head is performance parameter

(3) Brake horse power

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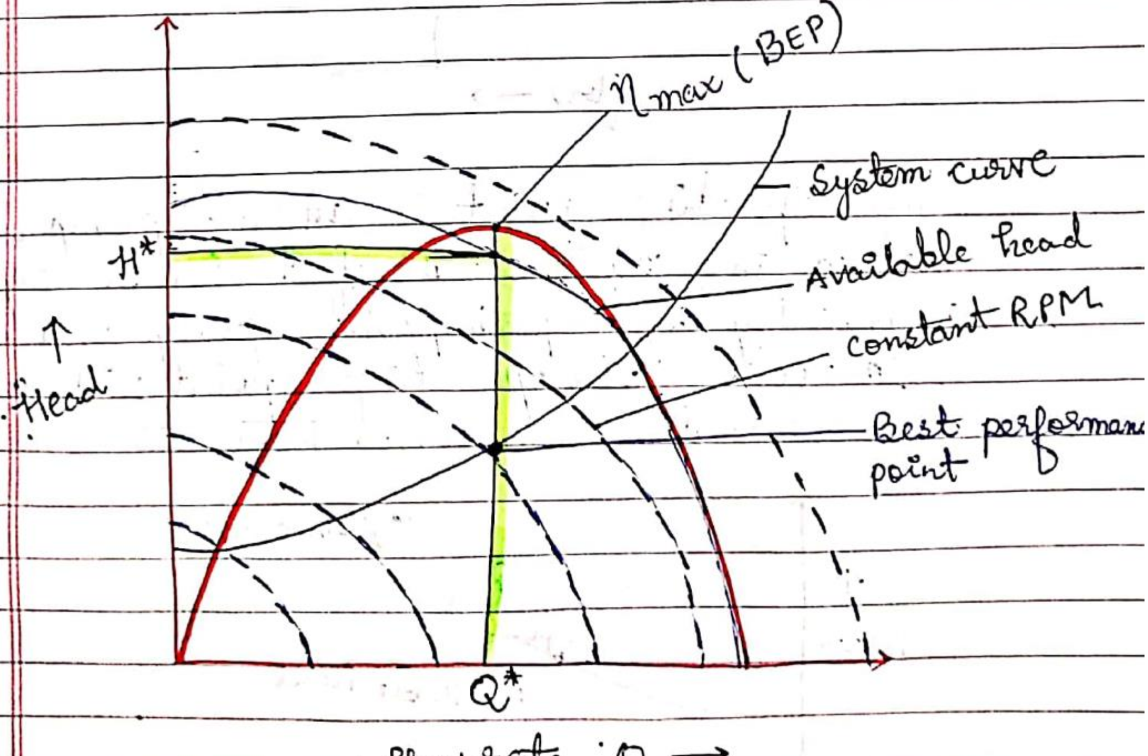
$$\eta_p = \frac{W_p}{EMP} = \frac{\rho g Q H}{P_W}$$

$W_p$ = Water power
EMP = Electric motor power

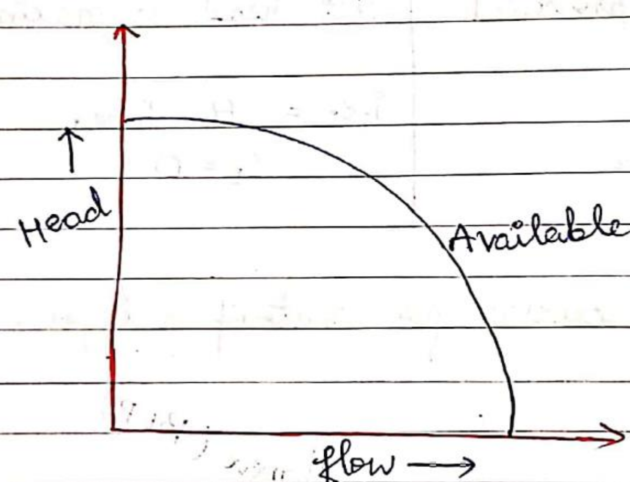
$\eta_p \propto H$ & $Q \rightarrow$ flow rate
↳ head

| Free Delivery | Shut off head |
| --- | --- |
| Max. discharge provided by the pump. | Net head is maximum |
| i.e. = $Q = Q_{max}$, $H = 0$ | i.e. = $H = h_{max}$, $Q = 0$ |

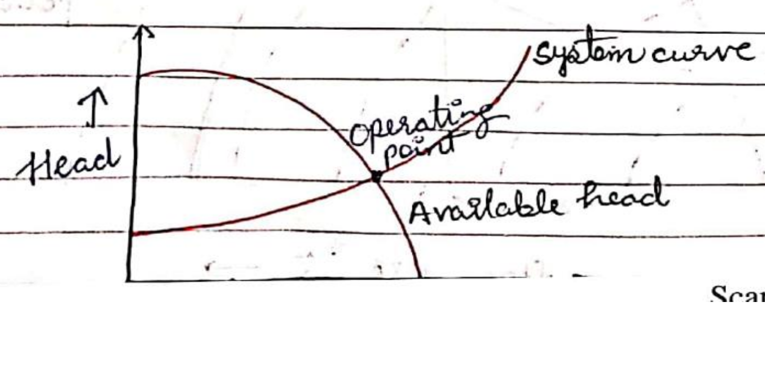
## Performance curve for centrifugal pump :-



Pump Curve :-
The performance can be expressed graphically as flow rate. The Centrifugal pump has a curve where the head falls gradually with increasing flow. This is called the pump characteristics curve (head flow curve).




Pump Operating point :- When a pump is installed in a system the effect can be explained graphically by superimposing pump and system curves. The operating point will always be where the two curves intersect.



**Part-B** Fans and Blowers: Specification, safety margin, choice of fans-controls, design considerations.

## Fans and Blowers:

Fans and blowers provide air for ventilation and industrial process requirements. Fans generate a pressure to move air (or gases) against a resistance caused by ducts, dampers, or other components in a fan system. The fan rotor receives energy from a rotating shaft and transmits it to the air.

## Difference between Fans, Blowers and Compressors

Fans, blowers and compressors are differentiated by the method used to move the air, and by the system pressure they must operate against. As per American Society of Mechanical Engineers (ASME) **the specific ratio** – the ratio of the discharge pressure over the suction pressure – is used for defining the fans, blowers and compressors.

| Equipment | Specific Ratio | Pressure rise (mmWg) |
|---|---|---|
| Fans | Up to 1.11 | 1136 |
| Blowers | 1.11 to 1.20 | 1136 – 2066 |
| Compressors | more than 1.20 | - |

**Table:** Difference between Fans, Blowers and Compressors

## Fan Performance Evaluation and Efficient System Operation

**System Characteristics (SC):**

The term "system resistance" is used when referring to the static pressure. The system resistance is the sum of static pressure losses in the system. The system resistance is a function of the configuration of ducts, pickups, elbows and the pressure drops across equipment.

for example- Bag filter or Cyclone

The system resistance varies with the square of the volume of air flowing through the system. For a given volume of air, the fan in a system with narrow ducts and multiple short radius elbows is going to have to work harder to overcome a greater system resistance than it would in a system with larger ducts and a minimum number of long radius turns. Long narrow ducts with many bends and twists will require more energy to pull the air through them. Consequently, for a given fan speed, the fan will be able to pull less air through this system than through a short system with no elbows. Thus, the system resistance increases substantially as the volume of air flowing through the system increases; square of air flow.

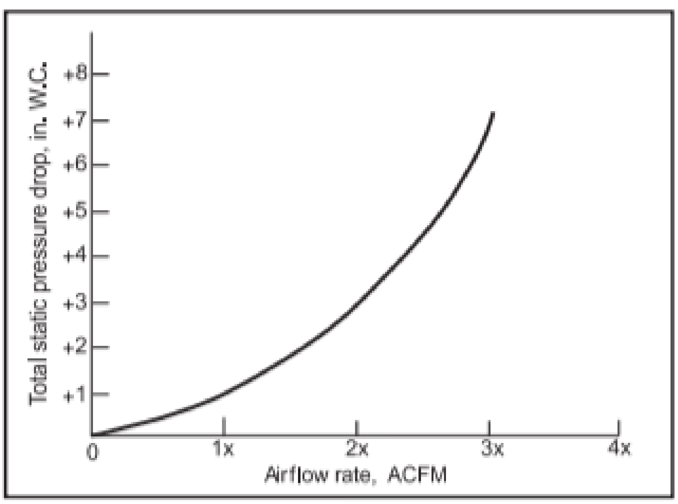



**Fig: 1:** System Curve

Conversely, resistance decreases as flow decreases. To determine what volume the fan will produce, it is therefore necessary to know the system resistance characteristics.

In existing systems, the system resistance can be measured. In systems that have been designed, but not built, the system resistance must be calculated. Typically a system resistance curve (see Figure-1) is generated with for various flow rates on the x-axis and the associated resistance on the y-axis.

**Fan Characteristics (FC):**

Fan characteristics can be represented in form of fan curve(s). The fan curve is a performance curve for the particular fan under a specific set of conditions. The fan curve is a graphical representation of a number of inter-related parameters. Typically a curve will be developed for a given set of conditions usually including: fan volume, system static pressure, fan speed, and brake horsepower required to drive the fan under the stated conditions. Some fan curves will also include an efficiency curve so that a system designer will know where on that curve the fan will be operating under the chosen conditions (see Figure-2). In the many curves shown in the Figure, the curve static pressure (SP) vs. flow is especially important.

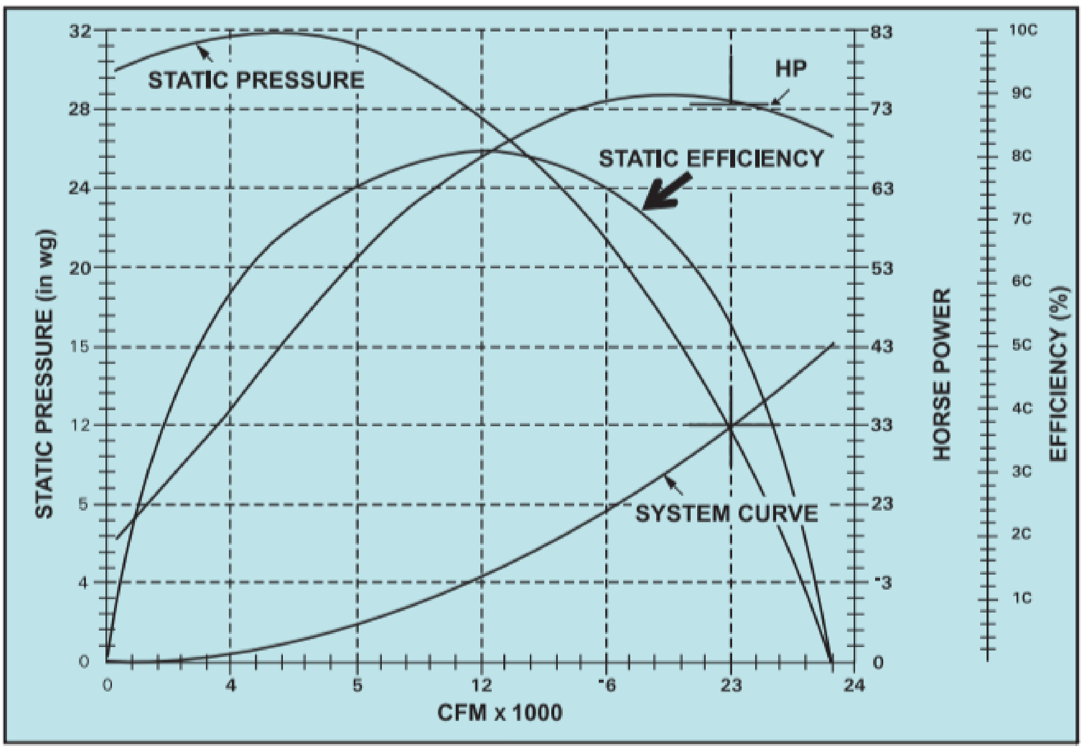



**Fig: 2**: Fan Characteristics Curve by Manufacturer

The intersection of the system curve and the static pressure curve defines the operating point. When the system resistance changes, the operating point also changes. Once the operating point is fixed, the power required could be found by following a vertical line that passes through the operating point to an intersection with the power (BHP) curve. A horizontal line drawn through the intersection with the power curve will lead to the required power on the right vertical axis. In the depicted curves, the fan efficiency curve is also presented.

**System Characteristics and Fan Curves**

In any fan system, the resistance to air flow (pressure) increases when the flow of air is increased. As mentioned before, it varies as the square of the flow. The pressure required by a system over a range of flows can be determined and a "system performance curve" can be developed (shown as SC) (see Figure 3).

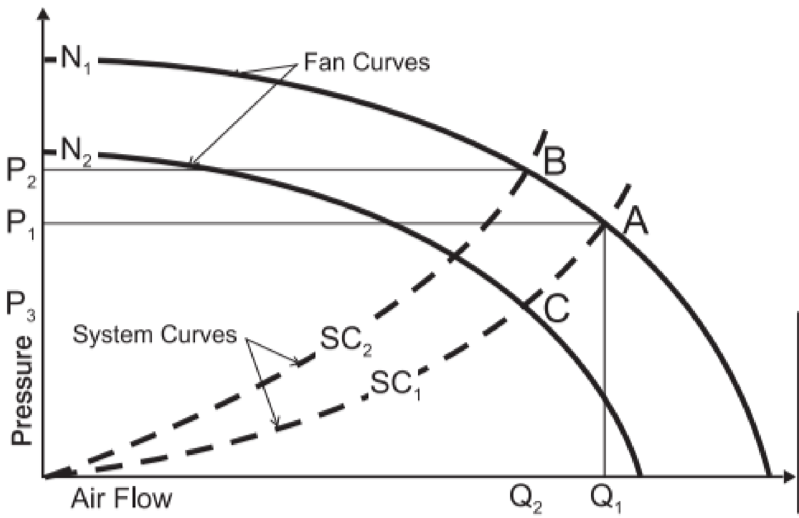



**Fig: 3:** System Curve

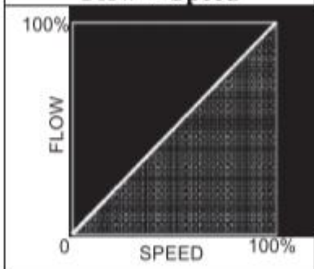
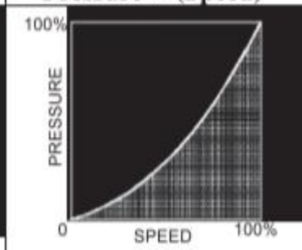
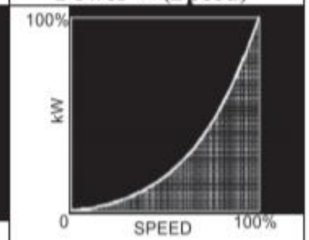
This system curve can then be plotted on the fan curve to show the fan's actual operating point at "A" where the two curves (N1 and SC1) intersect. This operating point is at air flow Q1 delivered against pressure P1.

A fan operates along a performance given by the manufacturer for a particular fan speed. (The fan performance chart shows performance curves for a series of fan speeds.) At fan speed N1, the fan will operate along the N1 performance curve as shown in Figure 3. The fan's actual operating point on this curve will depend on the system resistance; fan's operating point at "A" is flow (Q1) against pressure (P1).

**Fan Laws:**

The fans operate under a predictable set of laws concerning speed, power and pressure. A change in speed (RPM) of any fan will predictably change the pressure rise and power necessary to operate it at the new RPM.

**Where**: Q – flow, SP – Static Pressure, kW – Power and N – speed (RPM)

| Flow ∞ Speed | Pressure ∞ $(Speed)^2$ | Power ∞ $(Speed)^3$ |
| --- | --- | --- |
|  |  |  |
| $\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$ | $\frac{SP_1}{SP_2} = \left(\frac{N_1}{N_2}\right)^2$ | $\frac{kW_1}{kW_2} = \left(\frac{N_1}{N_2}\right)^3$ |
| *Varying the RPM by 10% decreases or increases air delivery by 10%.* | *Reducing the RPM by 10% decreases the static pressure by 19% and an increase in RPM by 10% increases the static pressure by 21%.* | *Reducing the RPM by 10% decreases the power requirement by 27% and an increase in RPM by 10% increases the power requirement by 33%.* |

## Safety margin:

The choice of safety margin also affects the efficient operation of the fan. In all cases where the fan requirement is linked to the process/other equipment, the safety margin is to be decided, based on the discussions with the process equipment supplier. In general, the safety margin can be 5% over the maximum requirement on flow rate.

In the case of boilers, the induced draft (ID) fan can be designed with a safety margin of 20% on volume and 30% on head. The forced draft (FD) fans and primary air (PA) fans do not require any safety margins. However, safety margins of 10 % on volume and 20% on pressure are maintained for FD and PA fans.

## Energy Saving Opportunities

**Minimizing demand on the fan:**

**1.** Minimizing excess air level in combustion systems to reduce FD fan and ID fan load.

**2.** Minimizing air in-leaks in hot flue gas path to reduce ID fan load, especially in case of kilns, boiler plants, furnaces, etc. Cold air in-leaks increase ID fan load tremendously, due to density increase of flue gases and in-fact choke up the capacity of fan, resulting as a bottleneck for boiler / furnace.

**3.** In-leaks / out-leaks in air conditioning systems also have a major impact on energy efficiency and fan power consumption and need to be minimized.

**Part-C** Air Compressor and Compressed Air Systems: Selection of compressed air layout, Encon aspects, Design consideration.

## Air Compressor and Compressed Air Systems

Air compressors account for significant amount of electricity used in Indian industries. Air compressors are used in a variety of industries to supply process requirements, to operate pneumatic tools and equipment, and to meet instrumentation needs. Only 10 – 30% of energy reaches the point of end-use, and balance 70 – 90% of energy of the power of the prime mover being converted to unusable heat energy and to a lesser extent lost in form of friction, misuse and noise.

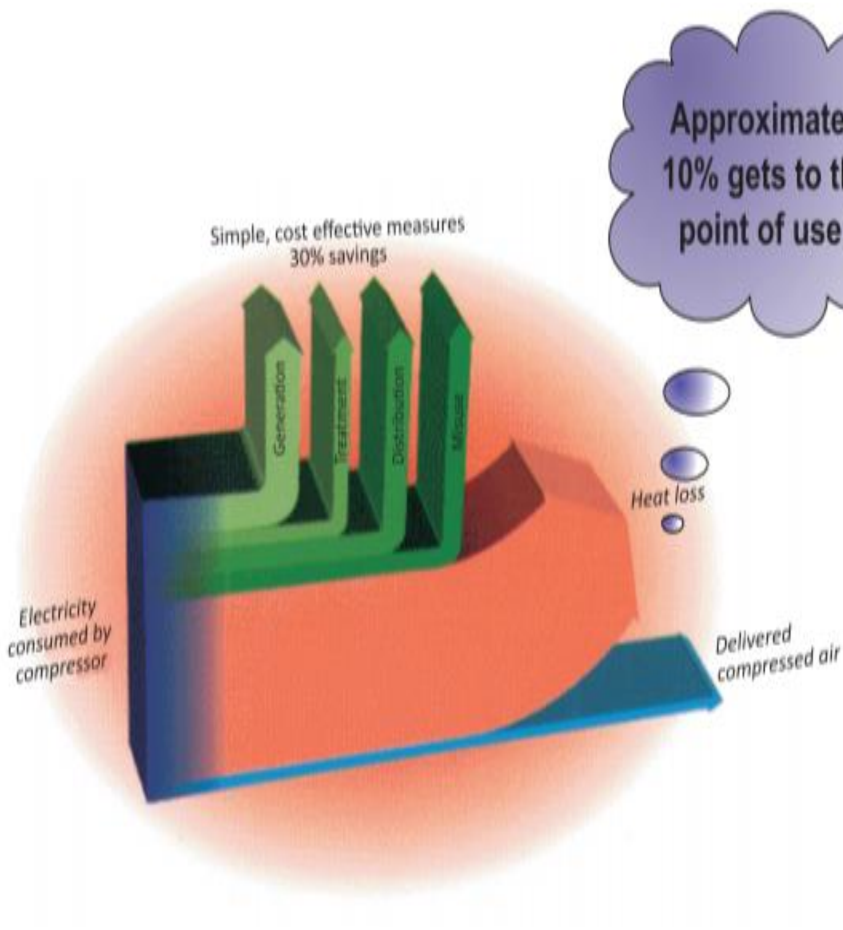



**Fig:** Sankey Diagram for Compressed Air System

## Compressor Types

Compressors are broadly classified as:

**1**. Positive displacement compressor

**2**. Dynamic compressor

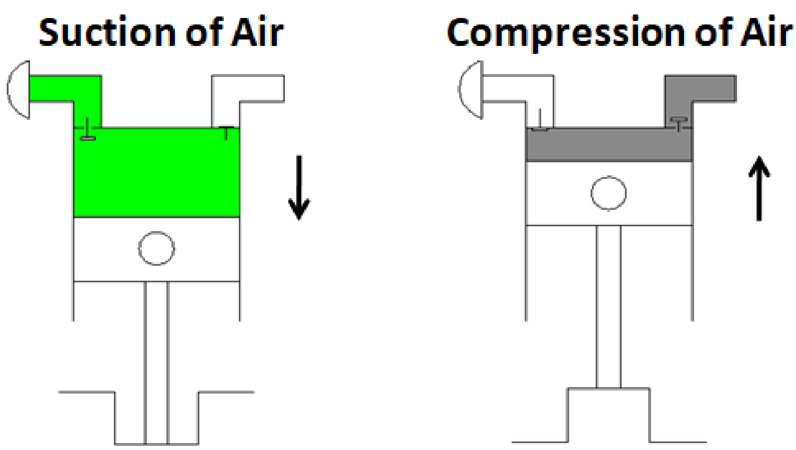
**Positive displacement compressors** increase the pressure of the gas by reducing the volume. Positive displacement compressors are further classified as reciprocating and rotary compressors.

**Dynamic compressors** increase the air velocity, which is then converted to increased pressure at the outlet. Dynamic compressors are basically centrifugal compressors and are further classified as radial and axial flow types.

## Positive Displacement Compressors

### Reciprocating Compressors

This type of compressor uses piston-cylinder arrangement to compress the air. Whenever something moves back and forth it is considered as moving in reciprocating motion. Similarly in this type piston moves back and forth inside the cylinder and compress the air. There are two sets of valves that take care of air intake and exhaust.




The compressor takes inside successive amount of volume of air from intake valve and confined it in closed surface at that time piston moves downward with the closure of intake valve. Then there is compression of air by reducing its volume. Now the piston moves upward and compresses the air and then displaces the compressed air through exhaust valve and then again intake take place and cycle repeat itself.

This type of compressor also called positive displacement machines. They are available in both as lubricated and oil-free.

The reciprocating compressor is single acting when the compressing is accomplished using only one side of piston and double acting when both the sides of piston used.

**Applications**

The reciprocating compressor generally seen where there is requirement of high pressure and low flow (or discontinuous flow up to 30 bars). Mostly where the air is used for hand tools, cleaning dust, small paint jobs, commercial uses etc.

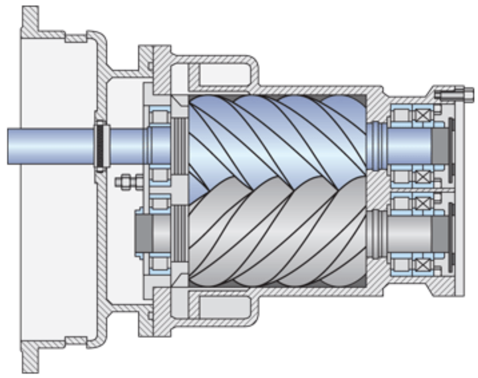
**Rotary Screw Compressors**

Rotary compressors are another type of famous compressors. It uses two Asymmetrical rotors that are also called helical screws to compress the air.

The rotors have a very special shape and they turn in opposite directions with very little clearance between them. The rotors are covered by cooling jackets. Two shafts on the rotors are placed that transfer their motion with the help of timing gears that are attached at the starting point of the shafts/compressor.

**Working principle**

Air sucked in at one end and gets trapped between the rotors and gets pushed to other side of the rotors. The air is pushed by the rotors that are rotating in opposite direction and compression is done when it gets trapped in clearance between the two rotors. Then it pushed towards pressure side.



Rotary screw compressors are of two types oil-injected and oil-free.

Oil-injected is cheaper and most common than oil-free rotary screw compressors.

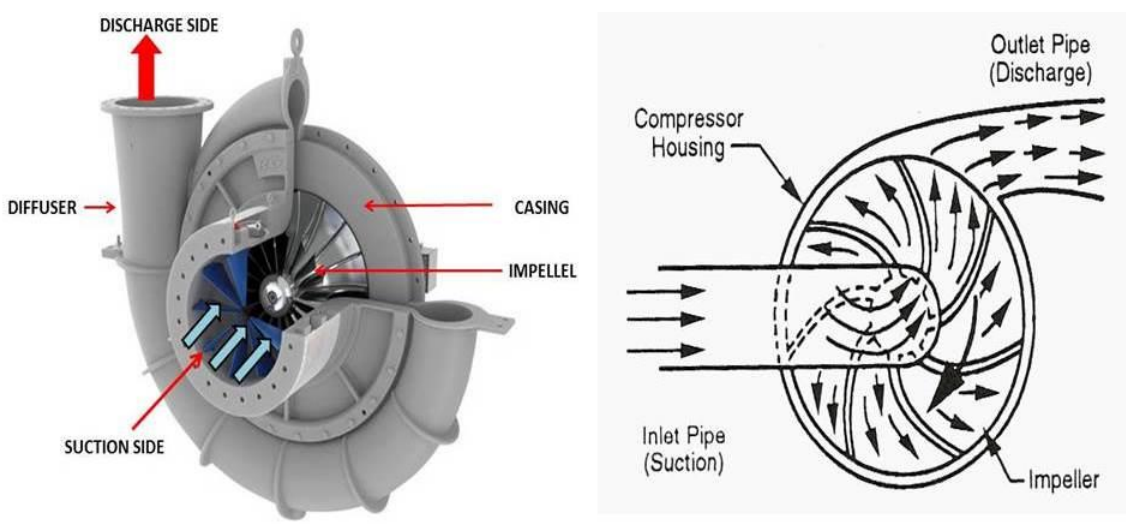
**Dynamic Compressors**

A dynamic compressor is a type of centrifugal compressor, or turbo compressor, with a radial design. Unlike displacement compressors that work at a constant flow, dynamic compressors work at a constant pressure and the performance is affected by external conditions such as changes in inlet temperatures.

**Working of Dynamic Compressors**

Air is drawn into the center of a rotating impeller with radial blades and is pushed toward the center by centrifugal force. This radial movement of air results in a pressure rise and the generation of kinetic energy. Before the air is led into the center of the impeller, the kinetic energy is also converted into pressure by passing through a diffuser and volute.

Each stage takes up a part of the overall pressure rise of the compressor unit. Depending on the pressure required for the application, a number of stages can be arranged in a series to achieve a higher pressure. This type of multi-stage application is often used in the oil and gas and process industries. Alternately, in wastewater treatment plants, low pressure, single-stage applications are used to achieve the desired pressure ratio.




**CENTRIFUGAL COMPRESSOR**

In modern configurations of centrifugal air compressors, ultra-high speed electric motors are used to drive the impellers. This results in a compact compressor without a gearbox and associated oil-lubrication system, thus making it oil-free and appropriate for applications that require 100 percent oil-free air.

## General Selection Criteria for Compressors:

| Type of Compressor | Capacity (m³/h) | | Pressure (bar) | |
|---|---|---|---|---|
| | From | To | From | To |
| **Roots blower compressor single stage** | 100 | 30000 | 0.1 | 1 |
| **Reciprocating** | | | | |
| - Single / Two stage | 100 | 12000 | 0.8 | 12 |
| - Multi stage | 100 | 12000 | 12.0 | 700 |
| **Screw** | | | | |
| - Single stage | 100 | 2400 | 0.8 | 13 |
| - Two stage | 100 | 2200 | 0.8 | 24 |
| **Centrifugal** | 600 | 300000 | 0.1 | 450 |

## Efficient Operation of Compressed Air Systems

## 1. Location of Compressors:

The location of air compressors and the quality of air drawn by the compressors will have a significant influence on the amount of energy consumed. Compressor performance as a breathing machine improves with cool, clean, dry air at intake.

### i. Cool air intake

As a thumb rule, "Every 4°C rise in inlet air temperature results in a higher energy consumption by 1% to achieve equivalent output". Hence, cool air intake leads to a more efficient compression.

It is preferable to draw cool ambient air from outside, as the temperature of air inside the compressor room will be a few degrees higher than the ambient temperature. While extending air intake to the outside of building, care should be taken to minimize excess pressure drop in the suction line, by selecting a bigger diameter duct with minimum number of bends.

### ii. Dust Free Air Intake

Dust in the suction air causes excessive wear of moving parts and results in malfunctioning of the valves due to abrasion. Suitable air filters should be provided at the suction side. Air filters should have high dust separation capacity, low-pressure drops and robust design to avoid frequent cleaning and replacement.

Air filters should be selected based on the compressor type and installed as close to the compressor as possible.

As a thumb rule "For every 250 mm WC pressure drop increase across at the suction path due to choked filters, the compressor power consumption increases by about 2 percent for the same output".

Hence, it is advisable to clean inlet air filters at regular intervals to minimize pressure drops. Manometers or differential pressure gauges across filters may be provided for monitoring pressure drops so as to plan filter-cleaning schedules.

### iii. Dry Air Intake

Atmospheric air always contains some amount of water vapour, depending on the relative humidity, being high in wet weather. The moisture level will also be high if air is drawn from damp area - for example locating compressor close to cooling tower, or dryer exhaust is to be avoided. The moisture-carrying capacity of air increases with a rise in temperature and decreases with increase in pressure.

## 2. Elevation

The altitude of a place has a direct impact on the volumetric efficiency of the compressor. It is evident that compressors located at higher altitudes consume more power to achieve a particular delivery pressure than those at sea level, as the compression ratio is higher.

## 3. Cooling Water Circuit

Most of the industrial compressors are water-cooled, wherein the heat of compression is removed by circulating cold water to cylinder heads, inter-coolers and after-coolers. The resulting warm water is cooled in a cooling tower and circulated back to compressors. The compressed air system performance depends upon the effectiveness of inter-coolers, after coolers, which in turn are dependent on cooling water flow and temperature.

Further, inadequate cooling water treatment can lead to increase, for example, in total dissolved solids (TDS), which in turn can lead to scale formation in heat exchangers. The scales, not only act as insulators reducing the heat transfer, but also increase the pressure drop in the cooling water pumping system.

Use of treated water or purging a portion of cooling water (blow down) periodically can maintain TDS levels within acceptable limits. It is better to maintain the water pH by addition of chemicals, and avoid microbial growth by addition of fungicides and algaecides.

**Air Dryers**

There are certain applications where air must be free from moisture and have a lower dew point. Dew point is the temperature at which moisture condenses. This calls for more sophisticated and expensive methods to lower the dew point of compressed air. Three common types of air dryers used are heat-less (absorption), adsorption and refrigerated dryers. They produce dry air with -10°C to -40°C dew point, depending on the type of dryers.

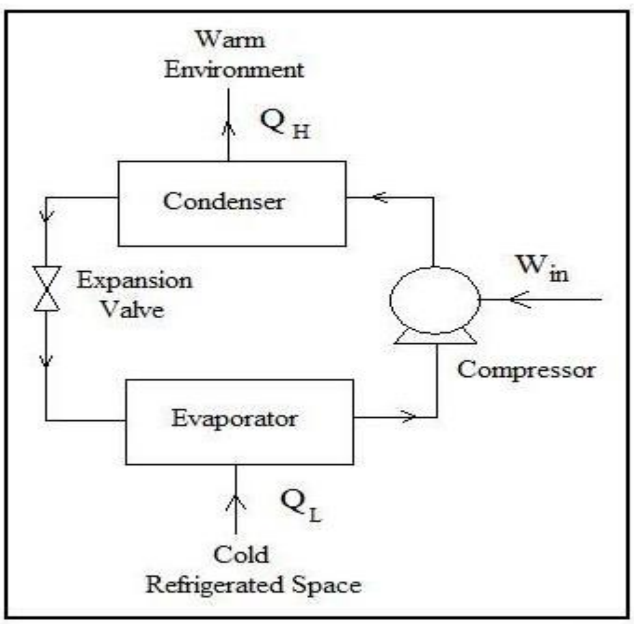
**Part-D:** Refrigeration and Air-conditioning: Heat load estimation, methods of minimizing heat loads, optimum selections of equipment.

## Introduction to Refrigeration Systems

In very basic terms, refrigeration systems are used to remove heat from one area and transfer it to another location. The vapor compression refrigeration cycle, which is very widely used for many types of refrigeration systems, including home refrigerators and freezers, refrigeration air conditioning, and automobile air conditioners.

## Vapour-Compression (VC) Refrigeration Cycle

The diagram shows the components of a vapor-compression refrigeration cycle: a compressor, condenser, expansion valve, and evaporator. A low pressure, low temperature liquid is converted to vapor in the evaporator, thus absorbing heat from the refrigerated space and keeping that space cool. The fluid is driven around the cycle by the compressor, which compresses the low temperature, low pressure vapor leaving the evaporator to high pressure, high temperature vapor. That vapor is condensed to liquid in the condenser, thus giving off heat at a high temperature to the surrounding environment. Finally, the high pressure, high temperature liquid leaving the condenser is cooled and reduced in pressure by passing it through an expansion valve. This provides the input to the evaporator which was the first step of the cycle described above.




Vapor Compression Refrigeration Cycle

The work and heat flows shown in the diagram are $W_{in}$, $Q_H$ and $Q_L$. $W_{in}$ is the work input to the compressor. The rate of work input to the compressor is most of the power requirement to run the refrigeration system. Power will probably be needed to drive one or more fans, but their power requirement will be small in comparison with that needed to drive the compressor. $Q_H$ is the high temperature heat rejected to the surroundings by the condenser. $Q_L$ is the low temperature heat absorbed from the cooled space by the evaporator.

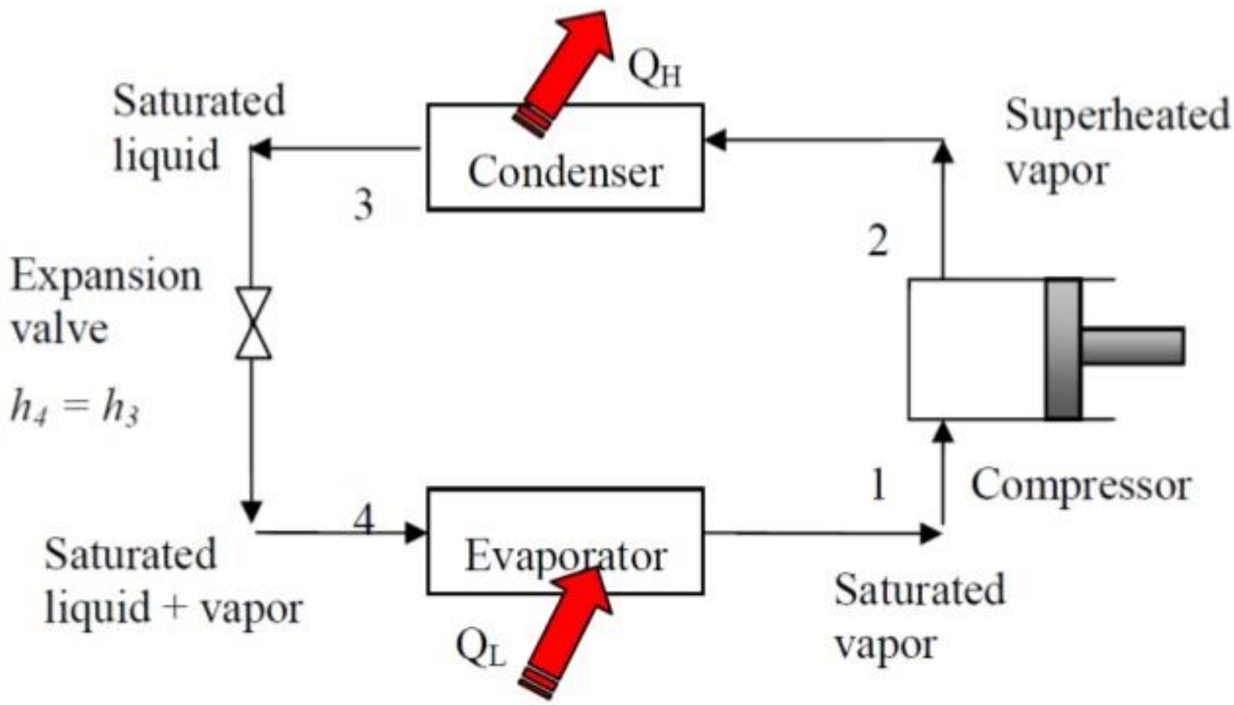



**Fig: Vapour-Compression Refrigeration Cycle**

## Simple Vapour Absorption (VA) Cycle:

The basic difference between vapour compression and vapour absorption cycles will be to replace the compressor of the vapour compression cycle by a set of equipment which fulfills the objective of compressor. The other important element i.e., condenser, expansion device and evaporator will exist in both systems.

Figure illustrates the simplest scheme of equipment required for the replacement of the compressor.

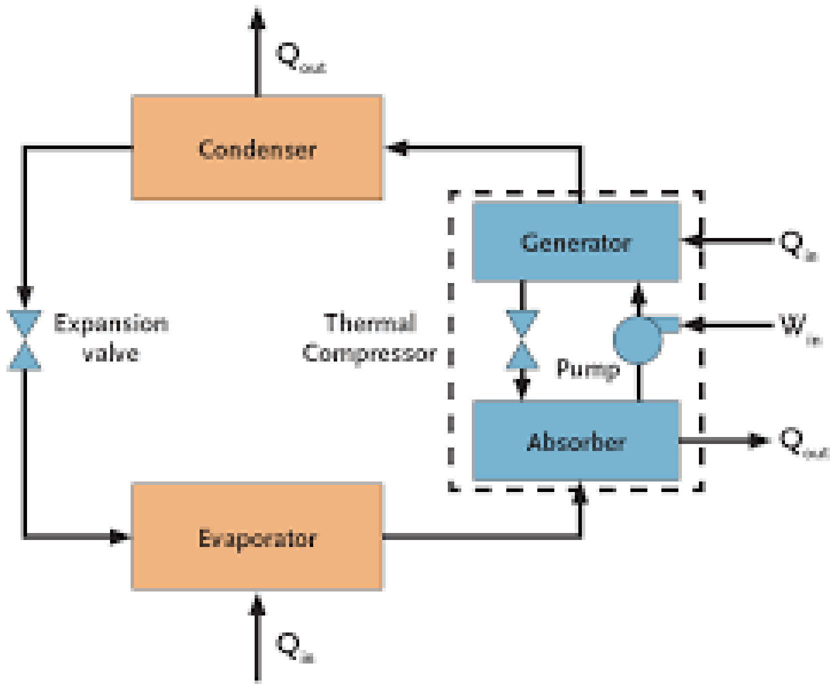



**Fig: Basic Vapour-Absorption Refrigeration Cycle**

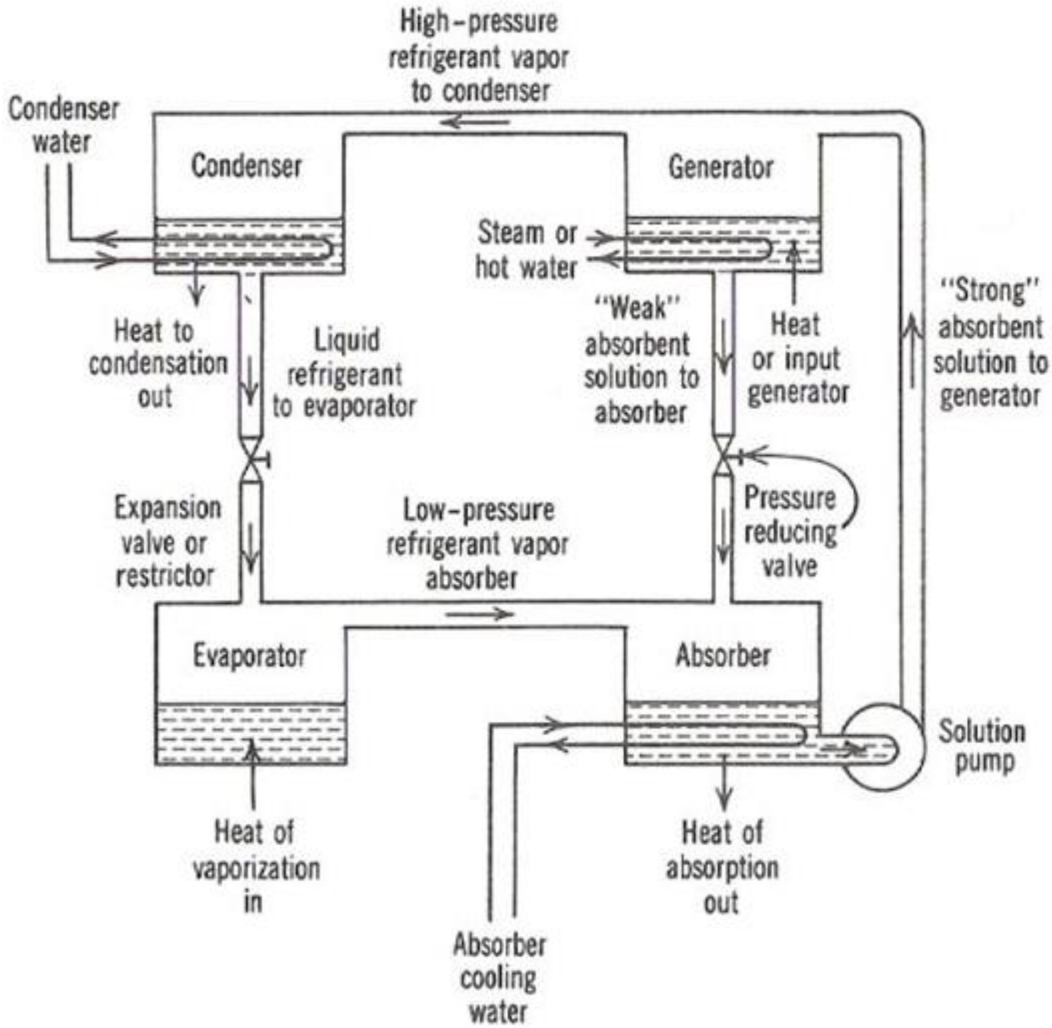
The vapor absorption refrigeration system comprises of all the processes in the vapor compression refrigeration system like compression, condensation, expansion and evaporation. In the vapor absorption system the refrigerant used is ammonia, water or lithium bromide. The refrigerant gets condensed in the condenser and it gets evaporated in the evaporator. The refrigerant produces cooling effect in the evaporator and releases the heat to the atmosphere via the condenser.

## Component (Equipment) and Working of VA Cycle:

**1) Condenser:** Just like in the traditional condenser of the vapor compression cycle, the refrigerant enters the condenser at high pressure and temperature and gets condensed. The condenser is of water cooled type.

**2) Expansion valve or restriction:** When the refrigerant passes through the expansion valve, its pressure and temperature reduces suddenly. This refrigerant (ammonia in this case) then enters the evaporator.

**3) Evaporator:** The refrigerant at very low pressure and temperature enters the evaporator and produces the cooling effect. In the vapor compression cycle this refrigerant is sucked by the compressor, but in the vapor absorption cycle, this refrigerant flows to the absorber that acts as the suction part of the refrigeration cycle.




**4) Absorber:** The absorber is a sort of vessel consisting of water that acts as the absorbent, and the previous absorbed refrigerant. Thus the absorber consists of the weak solution of the refrigerant (ammonia in this case) and absorbent (water in this case). When ammonia from the evaporator enters the absorber, it is absorbed by the absorbent due to which the pressure inside the absorber reduces further leading to more flow of the refrigerant from the evaporator to the absorber. At high temperature water absorbs lesser ammonia, hence it is cooled by the external coolant to increase it ammonia absorption capacity.

The initial flow of the refrigerant from the evaporator to the absorber occurs because the vapor pressure of the refrigerant-absorbent in the absorber is lower than the vapor pressure of the refrigerant in the evaporator. The vapor pressure of the refrigerant-absorbent inside the absorbent determines the pressure on low-pressure side of the system and also the vaporizing temperature of the refrigerant inside the evaporator. The vapor pressure of the refrigerant-absorbent solution depends on the nature of the absorbent, its temperature and concentration.

When the refrigerant entering in the absorber is absorbed by the absorbent its volume decreases, thus the compression of the refrigerant occurs. Thus absorber acts as the suction part of the compressor. The heat of absorption is also released in the absorber, which is removed by the external coolant.

**5) Pump:** When the absorbent absorbs the refrigerant strong solution of refrigerant-absorbent (ammonia-water) is formed. This solution is pumped by the pump at high pressure to the generator. Thus pump increases the pressure of the solution to about 10bar.

**6) Generator:** The refrigerant-ammonia solution in the generator is heated by the external source of heat. This is can be steam, hot water or any other suitable source. Due to heating the temperature of the solution increases. The refrigerant in the solution gets vaporized and it leaves the solution at high pressure. The high pressure and the high temperature refrigerant then enters the condenser, where it is cooled by the coolant, and it then enters the expansion valve and then finally into the evaporator where it produces the cooling effect. This refrigerant is then again absorbed by the weak solution in the absorber.

When the vaporized refrigerant leaves the generator weak solution is left in it. This solution enters the pressure reducing valve and then back to the absorber, where it is ready to absorb fresh refrigerant. In this way, the refrigerant keeps on repeating the cycle.

The pressure of the refrigerant is increased in the generator, hence it is considered to be equivalent to the compression part of the compressor.

**Difference between VC Cycle and VA Cycle:**

The major difference between the two systems is the method of the suction and compression of the refrigerant in the refrigeration cycle. In the vapor compression system, the compressor sucks the refrigerant from evaporator and compresses it to the high pressure. The compressor also enables the flow of the refrigerant through the whole refrigeration cycle. In the vapor absorption cycle, the process of suction and compression are carried out by two different devices called as the absorber and the generator. Thus the absorber and the generator replace the compressor in the vapor absorption cycle. The absorbent enables the flow of the refrigerant from the absorber to the generator by absorbing it.

Another major difference between the vapor compression and vapor absorption cycle is the method in which the energy input is given to the system. In the vapor compression system the energy input is given in the form of the mechanical work from the electric motor run by the electricity. In the vapor absorption system the energy input is given in the form of the heat. This heat can be from the excess steam from the process or the hot water. The heat can also be created by other sources like natural gas, kerosene, and heater etc. though these sources are used only in the small systems.

**Methods of Minimizing Heat Loads**

**1. Improve electrical efficiency.** Install energy-efficient lighting, refrigerators, office equipment, and other electrical loads. Doubling the energy efficiency of lighting, for example, will reduce heat gain from lighting by 50%. Improving the motor and fan efficiency of HVAC equipment is an important way to reduce heat gain.

**2. Insulate cooling system ducts.** Seal and insulate any cooling system ducts that run outside of the insulated building envelope. Heat gain into these ducts can effectively increase the cooling load by 15%. When possible, cooling ducts should be located within the conditioned space.

**3. Reduce losses from water heater and pipes.** Insulate the water heater and hot-water pipes, and turn down the temperature setting on the water heater. In southern climates it may make sense to locate the water heater in an unconditioned garage or utility room.

**4. Spot-ventilate heat sources.** Vent kitchen ranges to the outside for indoor air quality reasons as well as for cooling load avoidance. In commercial buildings, it makes sense to vent refrigeration equipment, computer rooms, vending machine rooms, mechanical equipment rooms, and other locations of significant heat generation.

**5. Minimize or vent water vapor sources.** Use spot fans or central ventilation systems to eliminate moisture sources from bathrooms and kitchen ranges. Use quiet fans that occupants will be likely to use. Clothes dryers should never be vented into the house.

## **Part-E:** Cooling Tower: Energy conservation in cooling towers and spray ponds

Cooling towers are a very important part of many chemical plants. The primary task of a cooling tower is to reject heat into the atmosphere. They represent a relatively inexpensive and dependable means of removing low-grade heat from cooling water. The make-up water source is used to replenish water lost to evaporation. Hot water from heat exchangers is sent to the cooling tower. The water exits the cooling tower and is sent back to the exchangers or to other units for further cooling. Typical closed loop cooling tower system is shown in Figure given below.

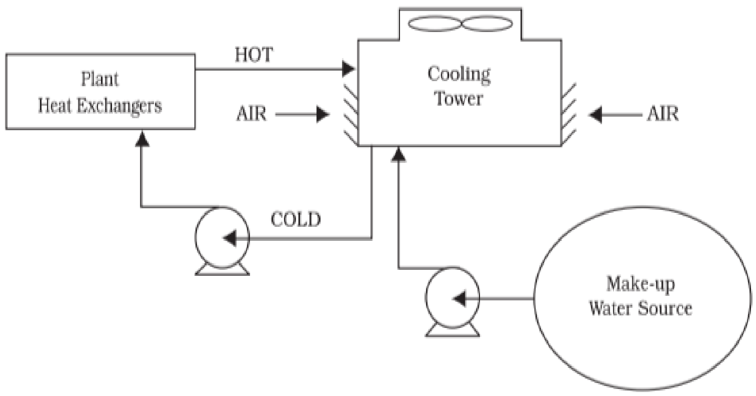



**Figure: Cooling Water System**

## Cooling Tower Performance

The important parameters, from the point of determining the performance of cooling towers, are:

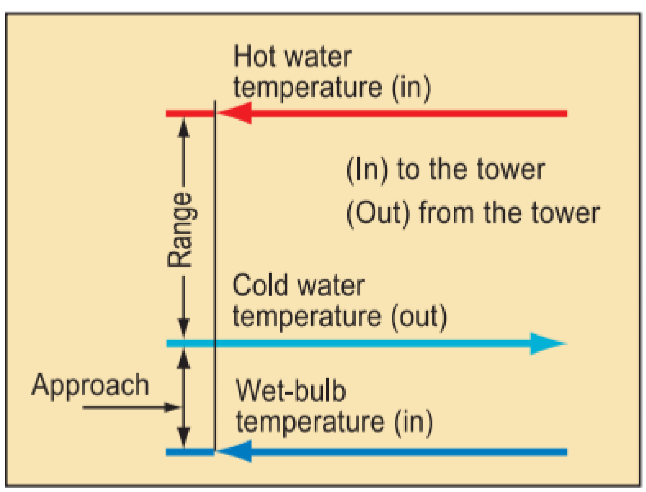



**Figure:** Range and Approach

**i) "Range"** is the difference between the cooling tower water inlet and cold water outlet temperature.

**ii) "Approach"** is the difference between the cooling tower outlet cold water temperature and ambient wet bulb temperature. Although, both range and approach should be monitored, the 'Approach' is a better indicator of cooling tower performance.

**iii) Cooling tower effectiveness** (in percentage) is the ratio of range, to the ideal range, i.e., difference between cooling water inlet temperature and ambient wet bulb temperature, or in other words it is = $\frac{\boldsymbol{Range}}{\boldsymbol{Range+Approach}}$.

**iv) Cooling capacity** is the heat rejected in kCal/hr or TR, given as product of mass flow rate of water, specific heat and temperature difference.

**v) Evaporation loss** is the water quantity evaporated for cooling duty and, theoretically, for every 10,00,000 kCal heat rejected, evaporation quantity works out to 1.8 m3 . An empirical relation used often is:

$$\textbf{Evaporation Loss (m}^3\textbf{/hr.)} = \mathbf{0.00085\ x\ 1.8\ x\ circulation\ rate}\left(\frac{\boldsymbol{m^3}}{\boldsymbol{hr}}\right) \times (\boldsymbol{T_1 - T_2})$$

$(T_1 - T_2)$ = Temperature difference between inlet and outlet water.

**vi) Cycles of concentration (C.O.C)** is the ratio of dissolved solids in circulating water to the dissolved solids in make-up water.

**vii) Blow down losses** depend upon cycles of concentration and the evaporation losses and is given by relation:

$$\textbf{Blow Down} = \frac{\textbf{Evaporation Loss}}{(\textbf{C.O.C.} - \mathbf{1})}$$

viii) **Liquid/Gas (L/G) ratio**, of a cooling tower is the ratio between the water and the air mass flow rates. Against design values, seasonal variations require adjustment and tuning of water and air flow rates to get the best cooling tower effectiveness through measures like water box loading changes, blade angle adjustments.

Thermodynamics also dictate that the heat removed from the water must be equal to the heat absorbed by the surrounding air:

$$\boldsymbol{L(T_1 - T_2) = G(h_2 - h_1)}$$

$$\boldsymbol{\frac{L}{G} = \frac{(h_2 - h_1)}{(T_1 - T_2)}}$$

**Where:**

$\boldsymbol{\frac{L}{G}}$ = liquid to gas mass flow ratio (kg/kg)

$\boldsymbol{T_1}$ = hot water temperature (°C)

$\boldsymbol{T_2}$ = cold water temperature (°C)

$\boldsymbol{h_2}$ = enthalpy of air-water vapor mixture at exhaust wet-bulb temperature (kJ/kg)

$\boldsymbol{h_1}$ = enthalpy of air-water vapor mixture at inlet wet-bulb temperature (kJ/kg)

## Factors Affecting Cooling Tower Performance

### Capacity

Heat dissipation (in kCal/hour) and circulated flow rate ($m^3$/hr) are not sufficient to understand cooling tower performance. Other factors, which we will see, must be stated along with flow rate m3 /hr. For example, a cooling tower sized to cool 4540 $m^3$/hr through a 13.9°C range might be larger than a cooling tower to cool 4540 $m^3$/hr through 19.5°C range.

### Range

Range is determined not by the cooling tower, but by the process it is serving. The range at the exchanger is determined entirely by the heat load and the water circulation rate through the exchanger and on to the cooling water.

$$\textbf{Range °C} = \frac{\textbf{Heat Load in kcals/hour}}{\textbf{Water Circulation Rate in LPH}}$$

Thus, Range is a function of the heat load and the flow circulated through the system.

Cooling towers are usually specified to cool a certain flow rate from one temperature to another temperature at a certain wet bulb temperature. For example, the cooling tower might be specified to cool 4540 $m^3$/hr from 48.9°C to 32.2°C at 26.7°C wet bulb temperature.

**Cold Water Temperature 32.2°C – Wet Bulb Temperature (26.7°C) = Approach (5.5°C)**

As a generalization, the closer the approach to the wet bulb, the more expensive the cooling tower due to increased size. Usually a 2.8°C approach to the design wet bulb is the coldest water temperature that cooling tower manufacturers will guarantee. If flow rate, range, approach and wet bulb had to be ranked in the order of their importance in sizing a tower, approach would be first with flow rate closely following the range and wet bulb would be of lesser importance.

**Heat Load**

The heat load imposed on a cooling tower is determined by the process being served. The degree of cooling required is controlled by the desired operating temperature level of the process. In most cases, a low operating temperature is desirable to increase process efficiency or to improve the quality or quantity of the product. In some applications (e.g. internal combustion engines), however, high operating temperatures are desirable. The size and cost of the cooling tower is proportional to the heat load. If heat load calculations are low undersized equipment will be purchased. If the calculated load is high, oversize and more costly, equipment will result. Process heat loads may vary considerably depending upon the process involved. Determination of accurate process heat loads can become very complex but proper consideration can produce satisfactory results. On the other hand, air conditioning and refrigeration heat loads can be determined with greater accuracy.

Information is available for the heat rejection requirements of various types of power equipment. A sample list is as follows:

Air Compressor

- Single-stage - 129 kCal/kW/hr
- Single-stage with after cooler - 862 kCal/kW/hr
- Two-stage with intercooler - 518 kCal/kW/hr
- Two-stage with intercooler and after cooler - 862 kCal/kW/hr

Refrigeration, Compression - 63 kCal/min/TR

Refrigeration, Absorption - 127 kCal/min/TR

Steam Turbine Condenser - 555 kCal/kg of steam

Diesel Engine, Four-Cycle, Supercharged - 880 kCal/kW/hr

**Wet Bulb Temperature**

Wet bulb temperature is an important factor in performance of evaporative water cooling equipment. It is a controlling factor from the aspect of minimum cold water temperature to which water can be cooled by the evaporative method. Thus, the wet bulb temperature of the air entering the cooling tower determines operating temperature levels throughout the plant, process, or system. Theoretically, a cooling tower will cool water to the entering wet bulb temperature, when operating without a heat load. However, a thermal potential is required to reject heat, so it is not possible to cool water to the entering air wet bulb temperature, when a heat load is applied. The approach obtained is a function of thermal conditions and tower capability.

**Factors that affects Cooling Tower size**

Cooling tower size is affected by the heat load, range, approach, and WBT. When three of those held constant, tower size varies in the following manner:

- Directly with the heat load
- Inversely with the range
- Inversely with the approach
- Inversely with the entering WBT

**Solved Example:**

The energy audit observations at a cooling tower (CT) in a process industry are given below:

Cooling Water (CW) Flow: 3000 $m^3$/hr

CW in Temperature: 41deg. C

CW Out Temperature: 31 deg C

Wet Bulb Temperature: 24 deg. C

Find out Range, Approach, Effectiveness and cooling tower capacity in kcal per hour of the CT?

**Ans:**

Range = (Inlet -Outlet) Cooling Water Temperature deg. C

Range = (41 – 31) = 10 deg. C

Approach = (Outlet Cooling Water - Air Wet Bulb) Temperature deg. C

Approach = (31 – 24) = 7 deg C

% CT Effectiveness = Range / (Range + Approach) x 100

% Effectiveness = 100 x [Range / (Approach + Range)]

= 10 / [10+7] x 100 = 58.8 %

Cooling capacity, kcal/hr = heat rejected = CW flow rate in kg per hour x (CW inlet hot water temp. to CT, deg. C - CW outlet cold well temp., deg. C)

Cooling capacity = 3000X1000X (41 - 31) = 30,000,000 kCal per hour = 30 Million kcal/hour.