-: AIR REFRIGERATION CYCLE :-

-: Refrigeration :-

- Refrigeration is the process of transfering heat from low tends to high temperature by using some external workdone.
- In another way it is the process of maintaining low temperature by extracting heat from low temperature to high temperature.
- Refrigeration process follows 2nd laws of thermodynamics.
- The unit of refrigeration is TR.
  (∵ TR = Turn of Refrigeration)
- The cooling effect produced by uniform melting of 1 TR of ice at 0°c in 24 hrs is called TR.

1 TR = 210 kJ/min or 3.5 kW

-: COP (Coefficient of Performance) :-

- Coefficient of performance is defined as ratio of the desired effect to the workdone.
- It is a performance measuring parameter of the refrigeration and heat pump (work consuming device).
- Mathematically,

$$COP = \frac{\text{desired effect}}{\text{workdone}}$$

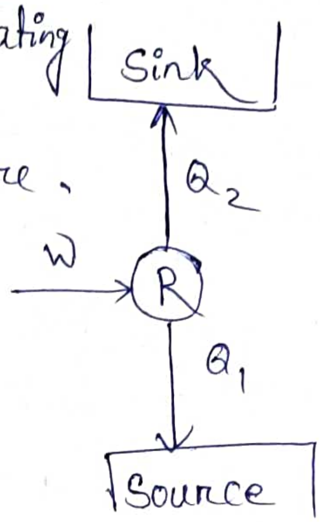
Refrigerator and heat pump :-

-: Refrigerator :-

It is a mechanical device which maintains body temperature lower than the atmospheric temperature.

where Q_1 = Heat absorb from the refrigerating space.

Q_2 = Heat rejected to the atmosphere.



So, COP of the refrigerator.

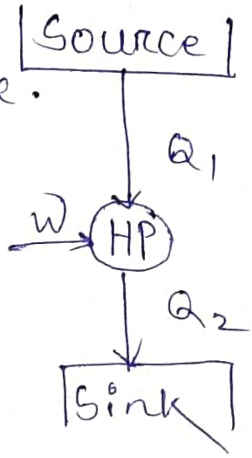
$$COP = \frac{Q_1}{W}$$

Heat pump :-

- It is a mechanical device which maintains body temperature higher than the atmospheric temperature.

where, Q_1 = Heat absorb from the atmosphere.

Q_2 = Heat rejected to the desired space.



So COP of the heat pump

$$COP = \frac{Q_2}{W}$$

COP In Temperature :-

$$(COP)_R = \frac{T_1}{T_2 - T_1}$$

$$(COP)_{HP} = \frac{T_2}{T_2 - T_1}$$

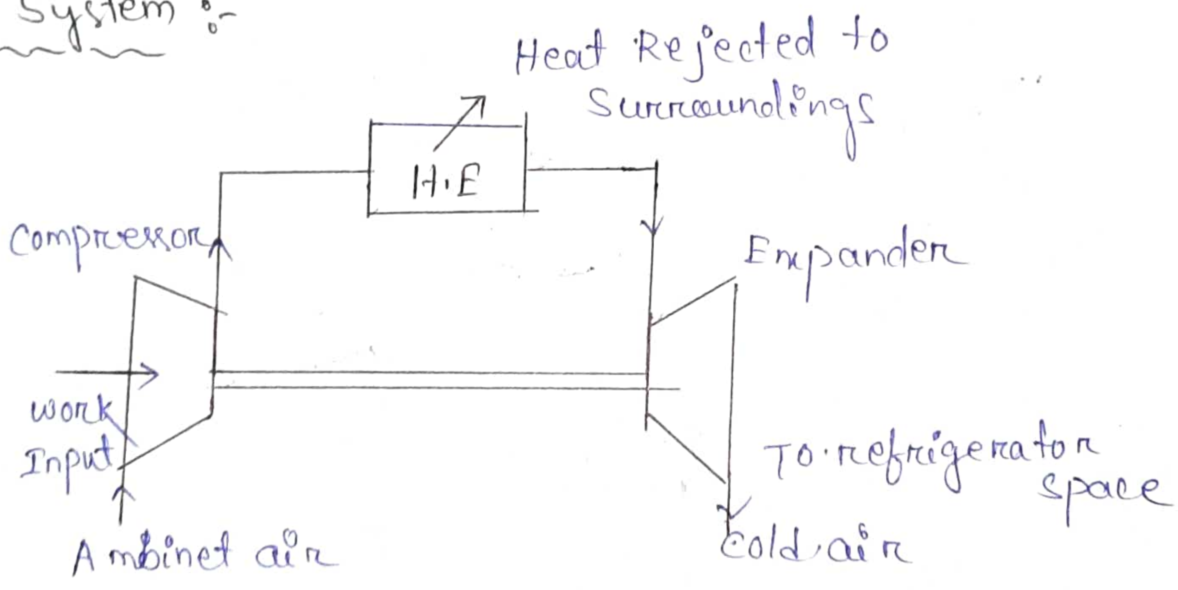
Air Refrigeration Cycle :-

- In air refrigeration cycle air is used as working fluid or refrigerant.
- Air is easily available and no cost. This is the advantage of air as the refrigerant.
- When the air absorbs the heat it undergoes no phase Change. Hence the heat carrying capacity of the air is very low. This ~~result~~ results lowers the co-efficient of performance and high power requirement.
- This system continues to be used because of low weight of the equipment.

Classification of air refrigeration cycle / Reversed Brayton Cycle / Bell-Coleman Cycle

It is 2 types; Such as
1. Open System
2. Close System.

Open System :-



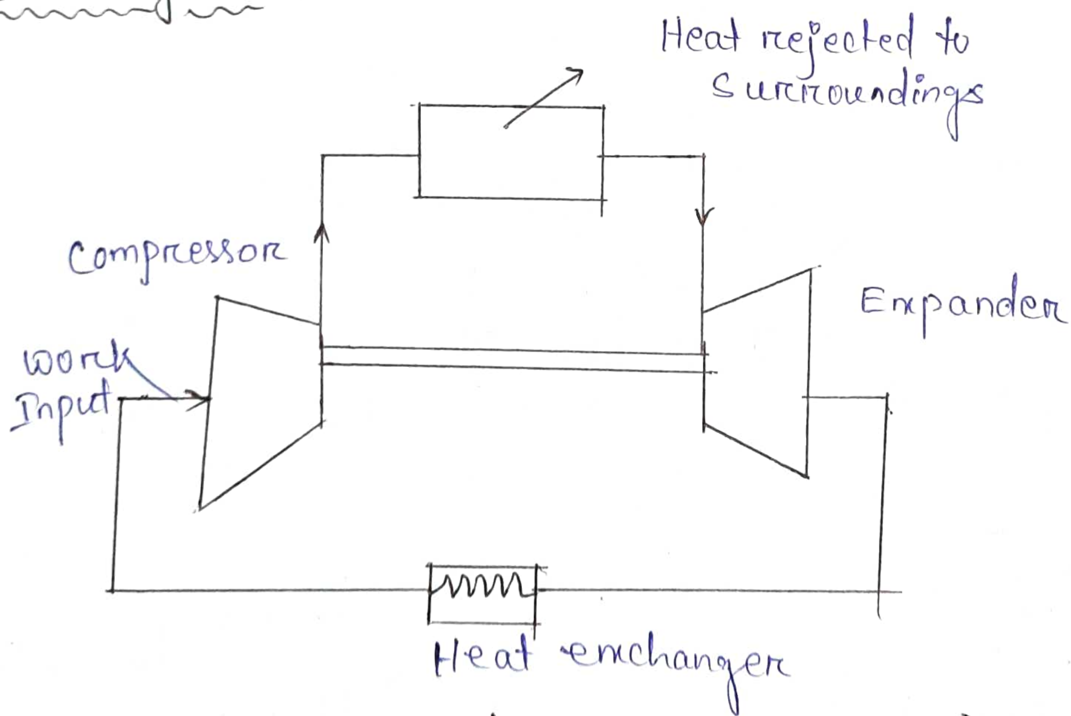
(Air refrigeration - open system)

- In the open system the refrigerator is replaced by the actual space to be cooled with the air expanded to atmospheric pressure, circulated through the cold room and then compressed to the cooler pressure.
- The pressure of operation in this system is inherently limited to operation at atmospheric pressure in the refrigerator.

Working:-

- Ambient air is taken into a compressor and get compressed.
- The compressed air is then cooled in the heat exchanger.
- In the heat exchanger, heat is rejected to the surrounding.
- The cold air is then expanded in an expander,
- The air after expansion in the expander is directed to the refrigerated space.
- The hot air from refrigerated space is discharged to atmosphere and will not be re-circulated.

Close system:-



(Air Refrigeration – Close System)

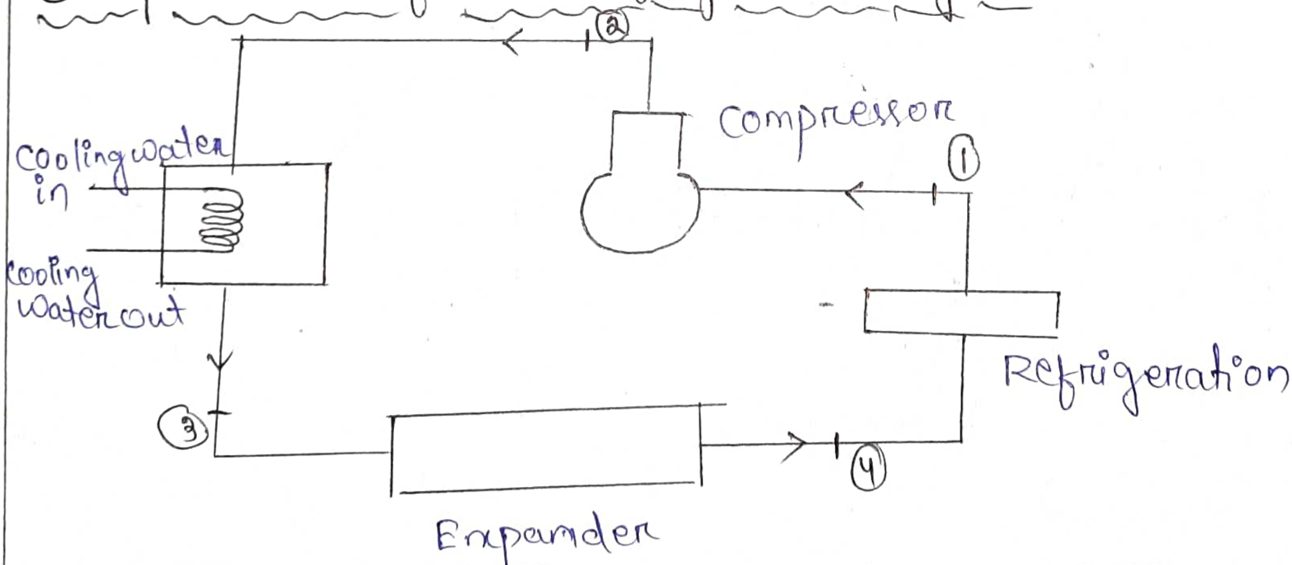
- Closed cycle are, by defination, sealed systems and consequently there is no direct contact between the working fluid and the product being cooled.
- In comparison with open cycle an additional heat exchanger is required for transferring heat from the refrigeration load.

Working :-

- The air is initially compressed in the compressor.
- In the cooling System, heat is removed from the compressed air,
- Now the high pressure cool air is passed through the heat exchangers where heat transfer take place.
- The high pressure air is expanded in an expander.
- The low pressure, low temperature air is allowed to flow through the customer load exchanger, where the air absorbs heat from the brine solution.
- The cold brine solution is sent to the space to be cooled.
- Now the heat low pressure air is cooled in the core heat exchanger and is then circulated back to the compressor.

Thus the cycle is repeated.

Components of Air-Refrigeration Cycle :-



The main components of air refrigeration cycle are.
(i) compressor
(ii) cooler
(iii) Expander
(iv) Refrigerator.

Compressor :-

The function of compressor is to compressed the refrigerant coming out from the refrigerator.

Cooler :-

The function of the cooler is to cool the refrigerant coming out from the compressor. But the Pressure of the refrigerant remains constant after the cooler.

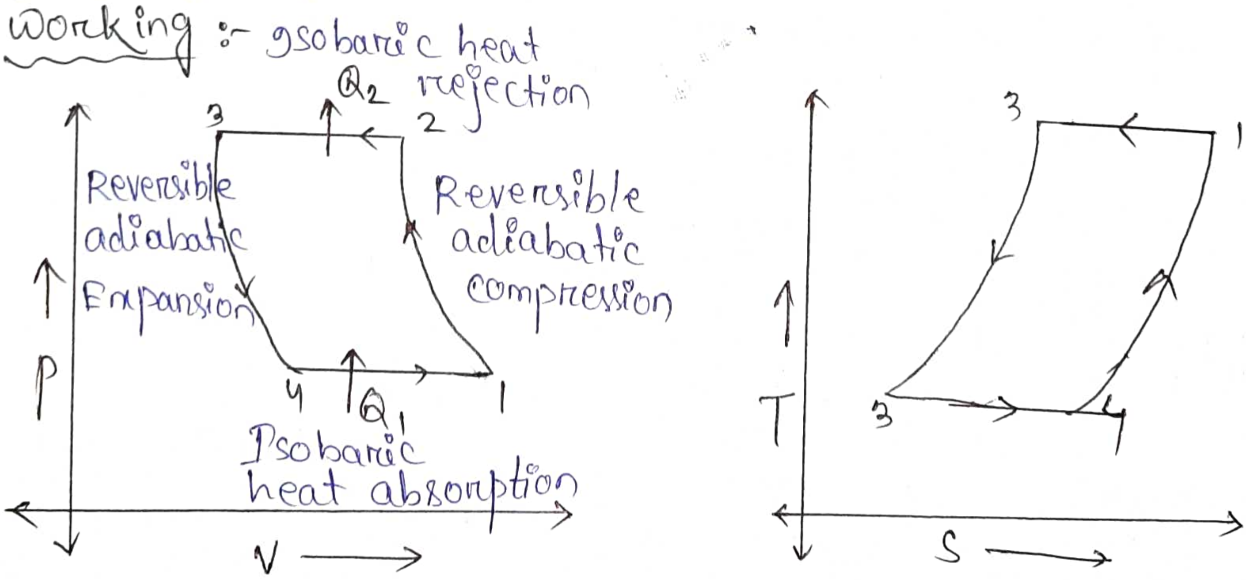
Expander :-

The high pressure and low temperature refrigerant from the cooler enter into the expander where it's pressure and temperature decreases to the refrigerator temperature.

Refrigerator :-

It is the space where the refrigerant directly or indirectly come in contact with the refrigerating space to absorb the heat.

Working :-



It is works on 4 Processes :-

Process (1-2) :- Reversible adiabatic compression

Process (2-3) :- Isobaric heat rejection

Process (3-4) :- Reversible adiabatic expansion

Process (4-1) :- Isobaric heat absorbtion,

Process (1-2) :-

- The refrigerant from the refrigerator enters to the Compressor where it gets compressed in a process i.e reversible adiabatic compression.

- In reversible adiabatic compression process the pressure and temperature of the refrigerant increases and volume decreases.

Process (2-3) :-

The high pressure and high temperature air rejects heat to the cooling water entering into the cooler at a constant pressure process.

- Thus the heat rejected $(Q) = mc_p(T_2 - T_3)$

Per m = 1kg air. So $\boxed{Q = mc_p(T_2 - T_3)}$

Process (3-4) :-

The high pressure and low temperature air from the cooler enters into the expander with it expands isentropically.

- After the expansion process the air temperature and Pressure reduces to the refrigerator.

Process (4-1) :-

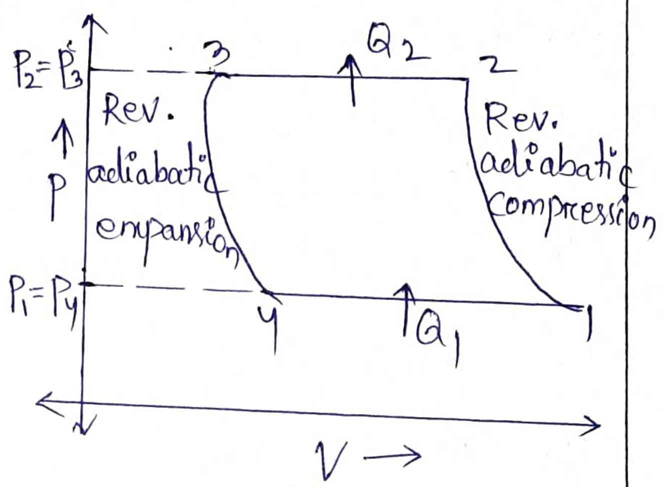
Air enters into the refrigerator and directly or indirectly absorbs the heat from the refrigerator.

Thus $Q_1 = mC_p (T_1 - T_4)$

So $W = Q_2 - Q_1$

$= C_p(T_2 - T_3) - C_p(T_3 - T_4)$

COP of adiabatic compression process :-



$$(COP)_R = \frac{Q_1}{W}$$

$$= \frac{C_p(T_1 - T_4)}{C_p(T_2 - T_3) - C_p(T_1 - T_4)}$$

$$= \frac{T_1 - T_4}{(T_2 - T_3) - (T_1 - T_4)}$$

$$= \frac{T_4\left(\frac{T_1}{T_4} - 1\right)}{T_3\left(\frac{T_2}{T_3} - 1\right) - T_4\left(\frac{T_1}{T_4} - 1\right)} \quad \text{——— (i)}$$

For process (1-2)

$$\frac{T_2}{T_3} = \left(\frac{P_2}{P_3}\right)^{\frac{\gamma - 1}{\gamma}}$$

For process (3-4)

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma - 1}{\gamma}} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma}}$$

$$\Rightarrow \frac{T_2}{T_1} = \frac{T_3}{T_4}$$

$$\Rightarrow \frac{T_2}{T_3} = \frac{T_1}{T_4} \quad \text{——— (ii)}$$

Put the value of eq^n (iii)

$$COP = \frac{T_4\left(\frac{T_1}{T_4}-1\right)}{T_3\left(\frac{T_2}{T_3}-1\right)-T_4\left(\frac{T_1}{T_4}-1\right)}$$

$$= \frac{T_4\left(\frac{T_1}{T_4}-1\right)}{T_3\left(\frac{T_1}{T_4}-1\right)-T_4\left(\frac{T_1}{T_4}-1\right)}$$

$$= \frac{T_4\left(\frac{T_1}{T_4}-1\right)}{(T_3-T_4)\left(\frac{T_1}{T_4}-1\right)}$$

$$= \frac{T_4}{T_3-T_4}$$

$$= \frac{T_4}{T_4\left(\frac{T_3}{T_4}-1\right)}$$

$$= \frac{1}{\left(\frac{T_3}{T_4}\right)-1}$$

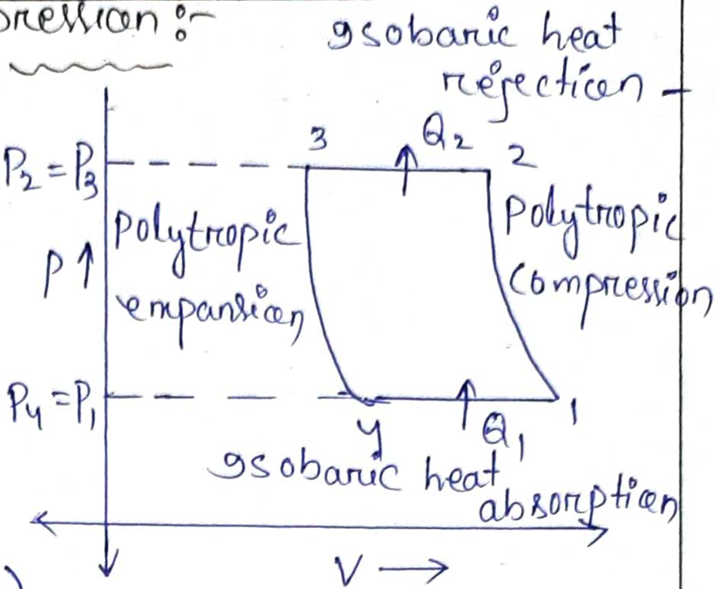
$$= \frac{1}{\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}}$$

$$= \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}$$

$$\boxed{COP = \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}}$$

COP of polytropic compression:-

$$(COP)_{poly} = \frac{\text{desired effect}}{W_{net}}$$



$$W_{net} = W_{1-2} - W_{3-4}$$

$$W_{1-2} = \frac{n}{n-1}(P_2V_2 - P_1V_1)$$

$$= \frac{n}{n-1}(mRT_2 - MRT_1)$$

$$= \frac{n}{n-1}R(T_2 - T_1) \quad [\because m = 1\,kg]$$

$$W_{3-4} = \frac{n}{n-1}(P_3V_3 - P_4V_4)$$

$$= \frac{n}{n-1}(MRT_3 - MRT_4)$$

$$= \frac{n}{n-1}R(T_3 - T_4) \quad [m = 1\,kg]$$

$$(COP)_{poly} = \frac{Q_1}{W_{net}} = \frac{Q_1}{W_{1-2} - W_{3-4}}$$

$$Q_1 = mC_p(T_1 - T_4) = C_p(T_1 - T_4) \quad (\because m = 1\,kg)$$

$$= \frac{C_p(T_1 - T_4)}{\frac{n}{n-1}R(T_2 - T_1) - \frac{n}{n-1}R(T_3 - T_4)}$$

$$= \frac{C_p(T_1 - T_4)}{\frac{n}{n-1}R[(T_2 - T_1) - (T_3 - T_4)]} \quad \text{--- (i)}$$

VAPOUR COMPRESSION REFRIGERATION SYSTEM :-

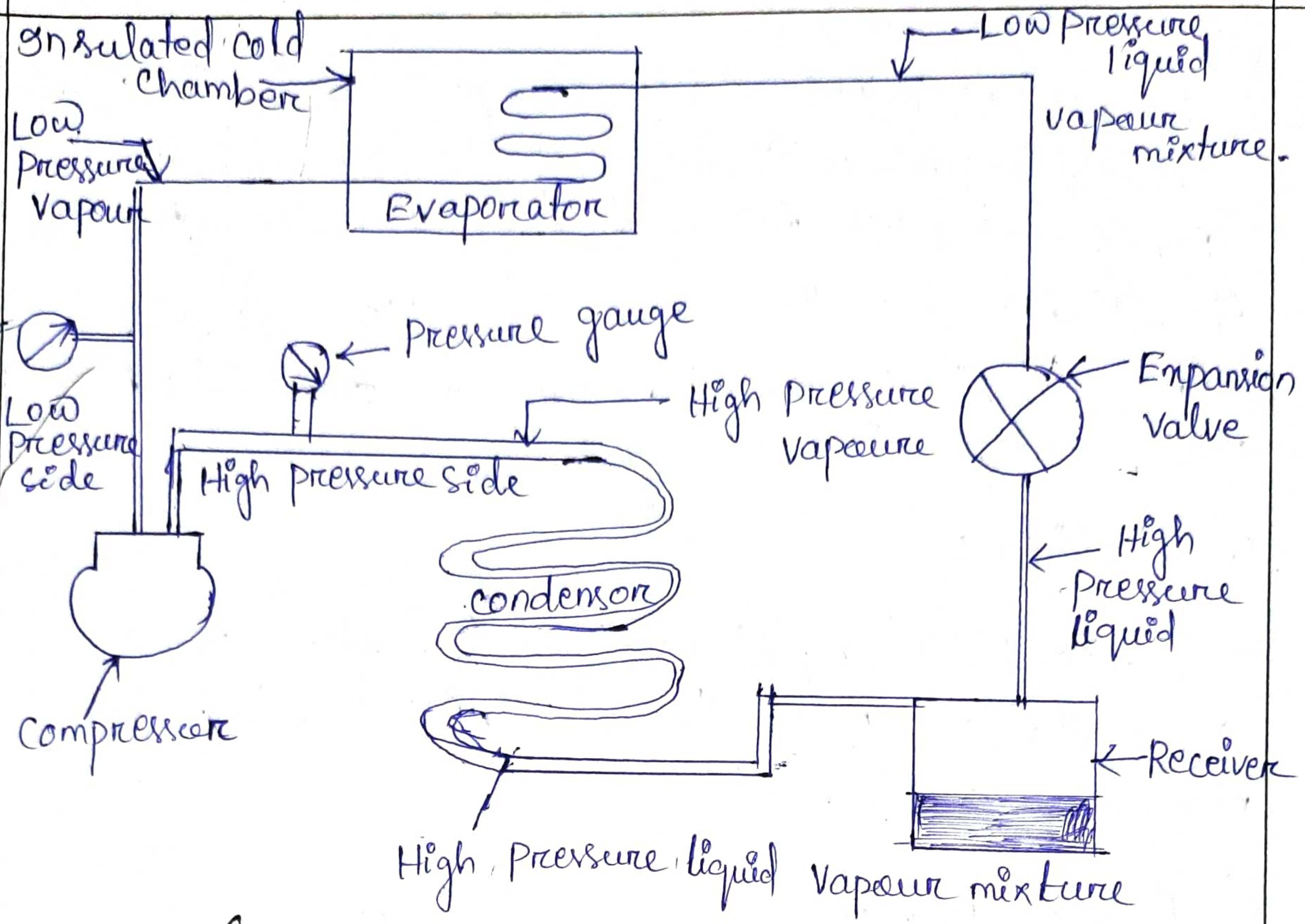
- A vapour compression Refrigeration system is an improved type of air refrigeration system.
- Now a days modern refrigerators, air conditioner uses the simple vapour compression Refrigeration system.
- This system is user friendly as the evapourater and condensor working at atmospheric pressure and temperature.
- The refrigerant (working fluid) does not leave the system as the system reuses it.
- Commonly ammonia, Sulpher dioxide is used as refrigerant.
- The system generally used for all industrial purpose form domestic refrigerator to cold storage,

Advantages :-

- It has smaller in size.
- Less running cost.
- Hig Co-efficienty Performance.

Disadvantages :-

- Initial cost is high,
- There is a problem of linkage of refrigerant,



(Vapour compression refrigerator)

- The main parts are.

1. Compressor
2. Condenser
3. Receiver
4. Expansion valve
5. Evaporator.

1. Compressor :-

- The function of compressor to compressed the low pressure and low temperator vapour refrigerant from the evaporator.

- The vapour from the evapourator is drawn to the compressor through suction strike and get compressed with discharged to condensor through discharge valve.

2. Condenser :-

- The condenser consist of a no. of coils.
- The high pressure and high temperature liquid refrigerant while passing through the coiles gives up its latent heat to the surrounding which is cooling medium (basically air and water) and converted to liquid refrigerant.

3. Receiver :-

- The condensed liquid refrigerant is stored in the receiver to supplied to the evaporator through expansion valve.

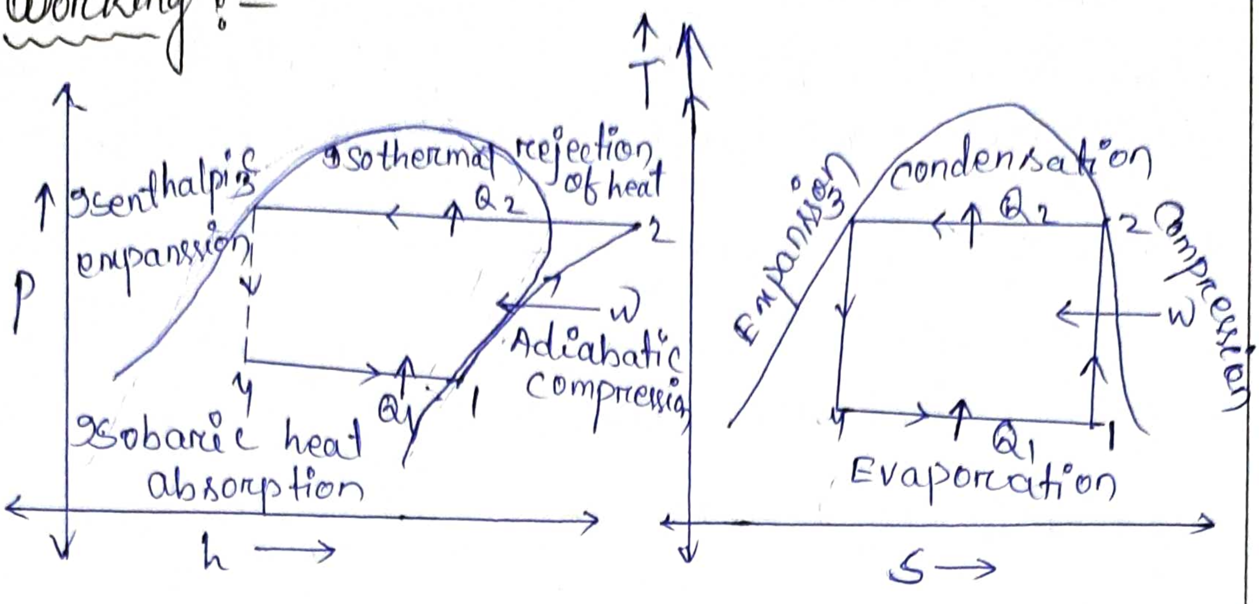
4. Expansion Valve :-

- It is also called throttle valve or refrigerant control valve.
- The high pressure liquid refrigerant is allowed to the evaporater by reducing its pressure.

5. Evaporator :-

- It is also consist of a no. of coils to which the liquid refrigerant absorbs heat from the refrigerating space which passing through the coils.
- The liquid refrigerant absorbs the latent heat from the refrigerating space and converted to vapour refrigerant.

Working :-



Process 1-2 (Compression) :-

Refrigerant vapour received from evaporator is compressed isentropically in a compressor by external source of energy; pressure and temperature increase.

Process 2-3 (Condensation) :-

- Compressor discharges vapour into the condenser where it is condensed completly i.e turns into liquid.
- Heat is rejected from the refrigerant to the cooling medium, usually water.

Process 3-4 (Expansion) :-

- From condenser the liquid refrigerant passes through the expansion valve, where it is throttled resulting in a drop in temperature and pressure.
- However, enthalpy remains constant (throttling Expansion)

Process 4-1 (evaporation) :-

- Liquid refrigerant at a low temperature passes into the evaporator where it abstract heat from the products to be cooled.

- Due to absorption of latent heat, liquid refrigerant turns into vapour and enters into the compressor.

Coefficient of Performance :-

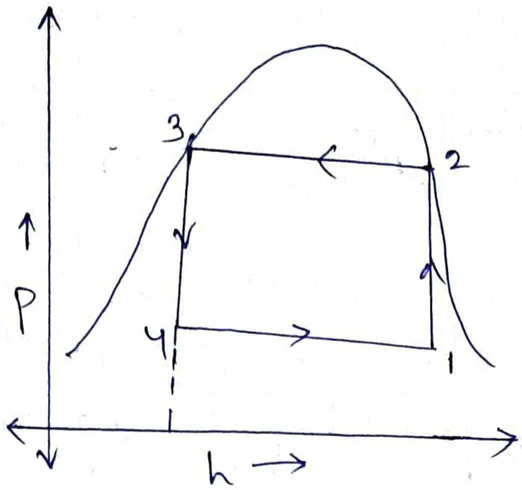
- Work input $W = h_2 - h_1$
- Refrigerating effect $N = h_1 - h_4$
- Coefficient of performance $= \frac{\text{Desire effect}}{\text{Work input}}$

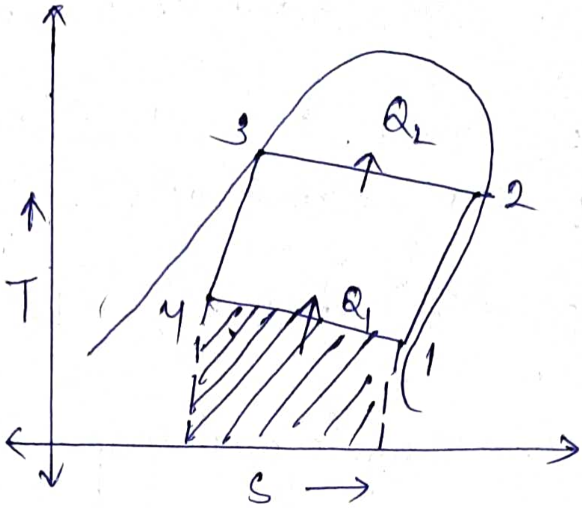
$$= \frac{h_1 - h_4}{h_2 - h_1}$$

Types of vapour compression Refrigeration cycle :-

- Cycle with dry saturated vapour after compression.
- Cycle with superheated vapour after compression.
- Cycle with wet vapour after compression.
- Cycle with superheated vapour before compression.
- Cycle with sub cooling or under cooling.

1. VCRS Cycle with dry saturated vapour after compression





$h_2 = h_g$ at CP

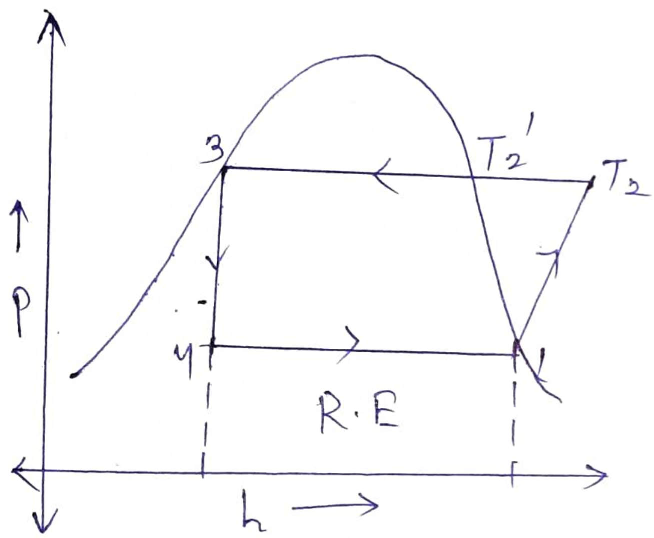
$h_1 = S_2 = S_g = S_1$ at evapurated pressure

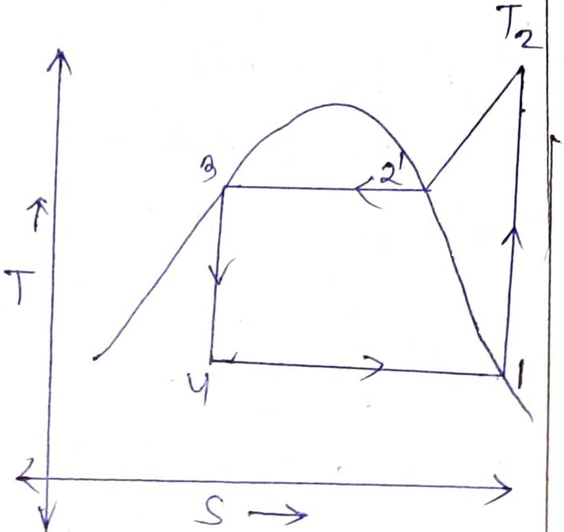
$S_2 = S_1 = S_f$ at EP $+ x \cdot S_{fg}$ at EP

$h_1 = h_f$ at EP $+ x \cdot h_{fg}$ at EP

$h_4 = h_3 = h_f$ at CP (Isentropic process)

2. VCRS Cycle with superheated vapour after compression





$S_2 = S_g @ CP + 2.3\, C_p \cdot \log\left(\frac{T_2}{T_2'}\right)$

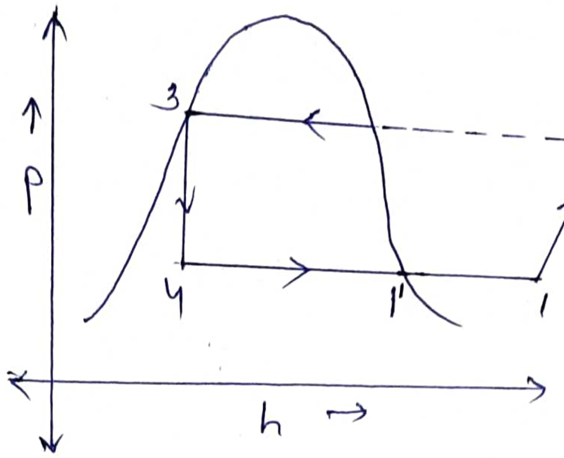
T_2 = superheated temp. (given)

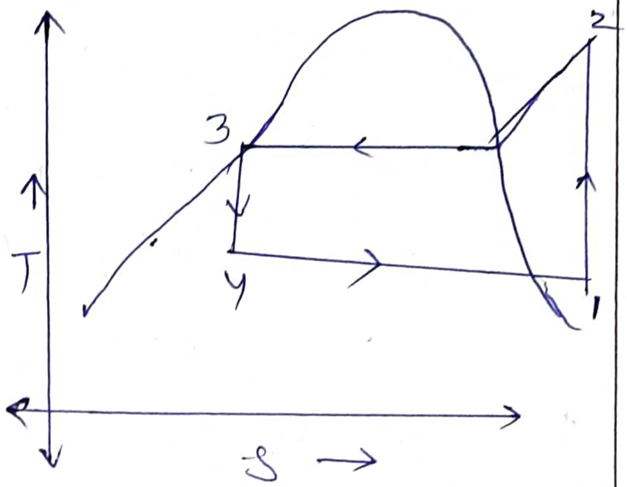
T_2' = Temp. sat at condenser pressure

$h_2 = h_g \text{ at } CP + C_p (T_2 - T_2')$

$(T_2 - T_2')$ degree of superheat

3. VCRS cycle with super heated vapour before compression





$$COP = \frac{h_1 - h_4}{h_2 - h_1}$$

$h_1 = h_1' + C_p (T_1 - T_1')$

$h_1' = h_g$ at EP

T_1 = Sup. heat temp

T_1' = T. Sat. at EP

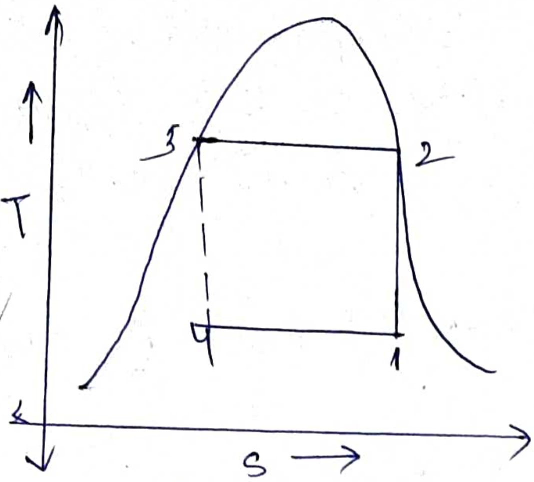
$h_2 = h_2' + C_p (T_2 - T_2')$

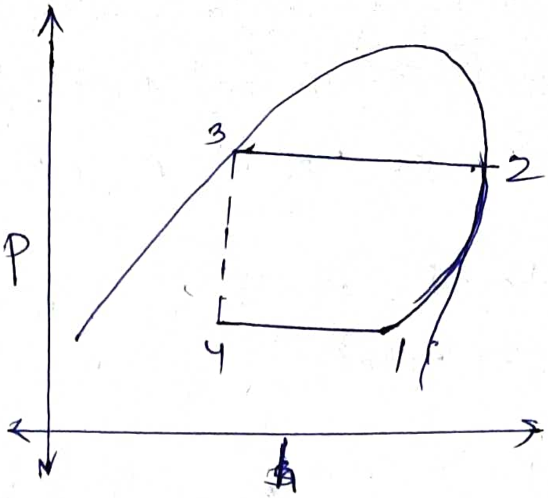
$h_2 = h_g$ at CP.

T_2 = Superheated temp.

T_2' = Sat. temp. at CP.

4. VCRS Cycle with wet-vapour after compression :-





$$COP = \frac{h_1 - h_4}{h_2 - h_1}$$

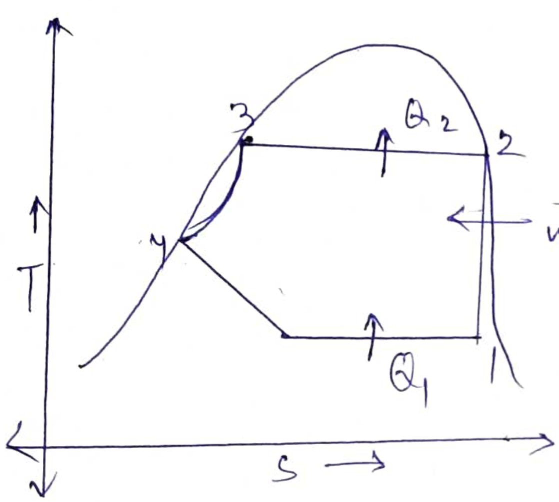
$h_1 = h_f$ at EP/ET $+ x_1 h_{fg}$ at EP

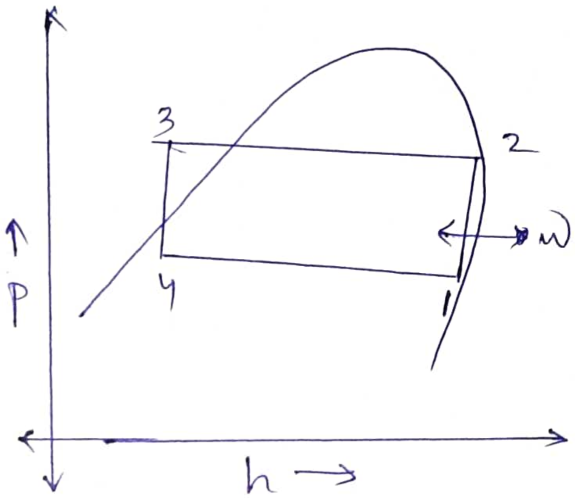
$h_2 = h_f$ at CP/CT $+ x_2 h_{fg_2}$ at CP/CT

$$S_1 = S_2 - S_1 = S_f(EP) + x_1 \left(\frac{h_{fg_1}}{T_1}\right)$$

$$S_2 = S_f(CP) + x_2 \left(\frac{h_{fg_2}}{T_2}\right)$$

5. Cycle with Sub-cooling or under cooling :-





$$COP = \frac{Q_1}{W} = \frac{h_1 - h_4}{h_2 - h_1}$$

Sub-Cooling :-

- After the condensation process the refrigerant is cooled below the saturated temp. before expansion in the throattle valve such process is called Sub-cooling or under Cooling.

- The effects of the under cooling to increases the cop of the refrigerating cycle.

- The process of under cooling is achieve by increasing the mass flow rate of the cooling water into the condenser.

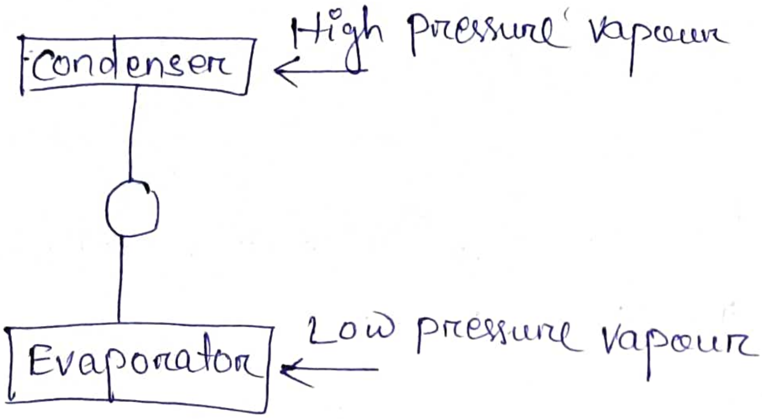
$$h_3 = h_{f_3} - C_p\,(\text{Degree of Sub cooling})$$

$$= h_{f_3} - C_p\,(T_3 - \text{Sub cooling Temp})$$

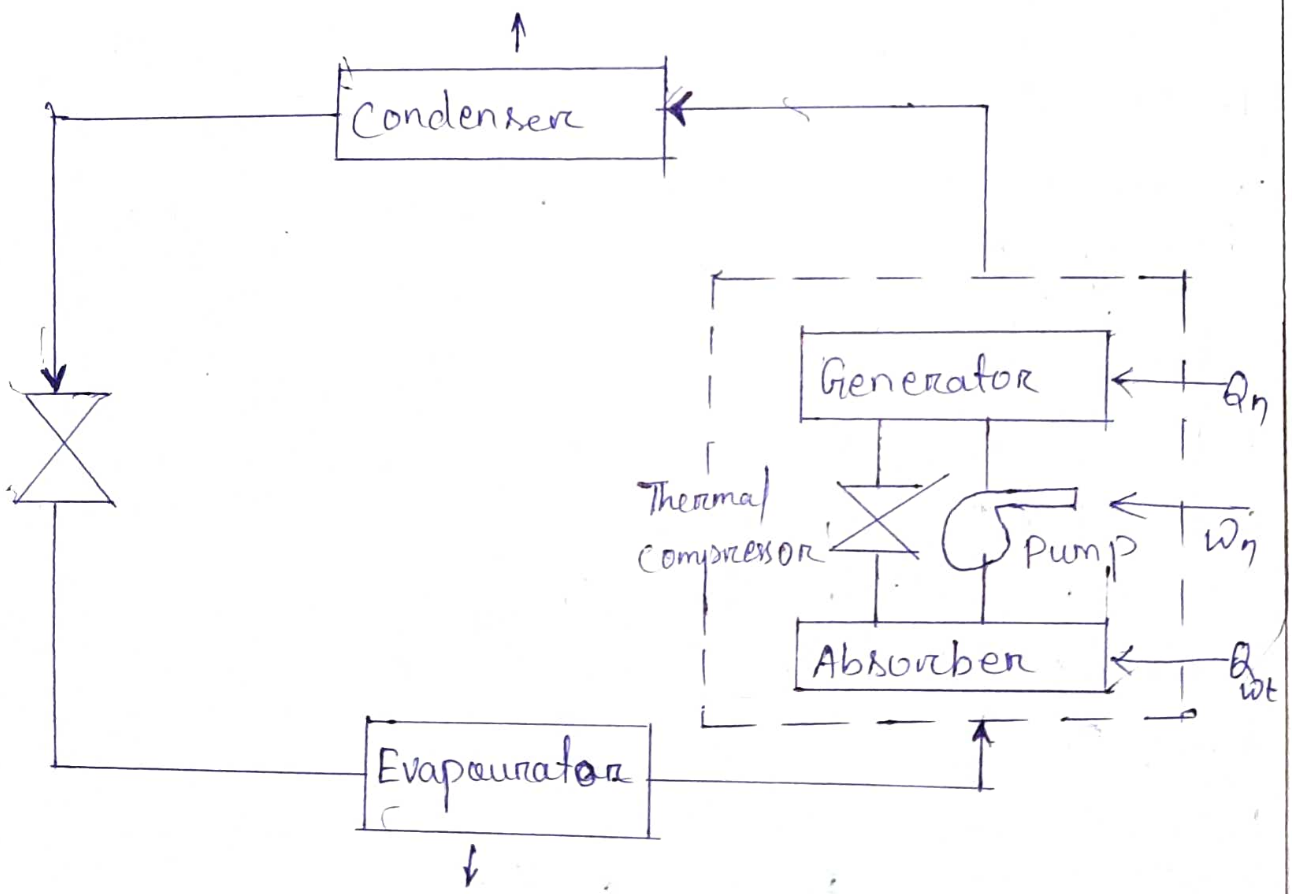
$$T_{sat} = T_3 - \text{Sub cooling temp.}$$

VAPOUR ABSORPTION REFRIGERATION SYSTEM

- The vapour absorption refrigeration system was inverted by french scientist Ferdinand carre in 1860.
- In the absorption system the compressor is replaced by an absorber, pump and generator.



(vapour absorption refrigeration system)



(simple vapour absorption Refrigerator system)

- Transfering low pressure vapour into high pressure vapour in a refrigerating system.

- The system may be used in both domestic and large industrial refrigerating systems,

Advantages :-

1. Less wear and tear because of minimum moving parts.
2. Low operating and maintenace cost.
3. Quiet in operation.
4. Performance is not affected by variation of load.

Disadvanges :-

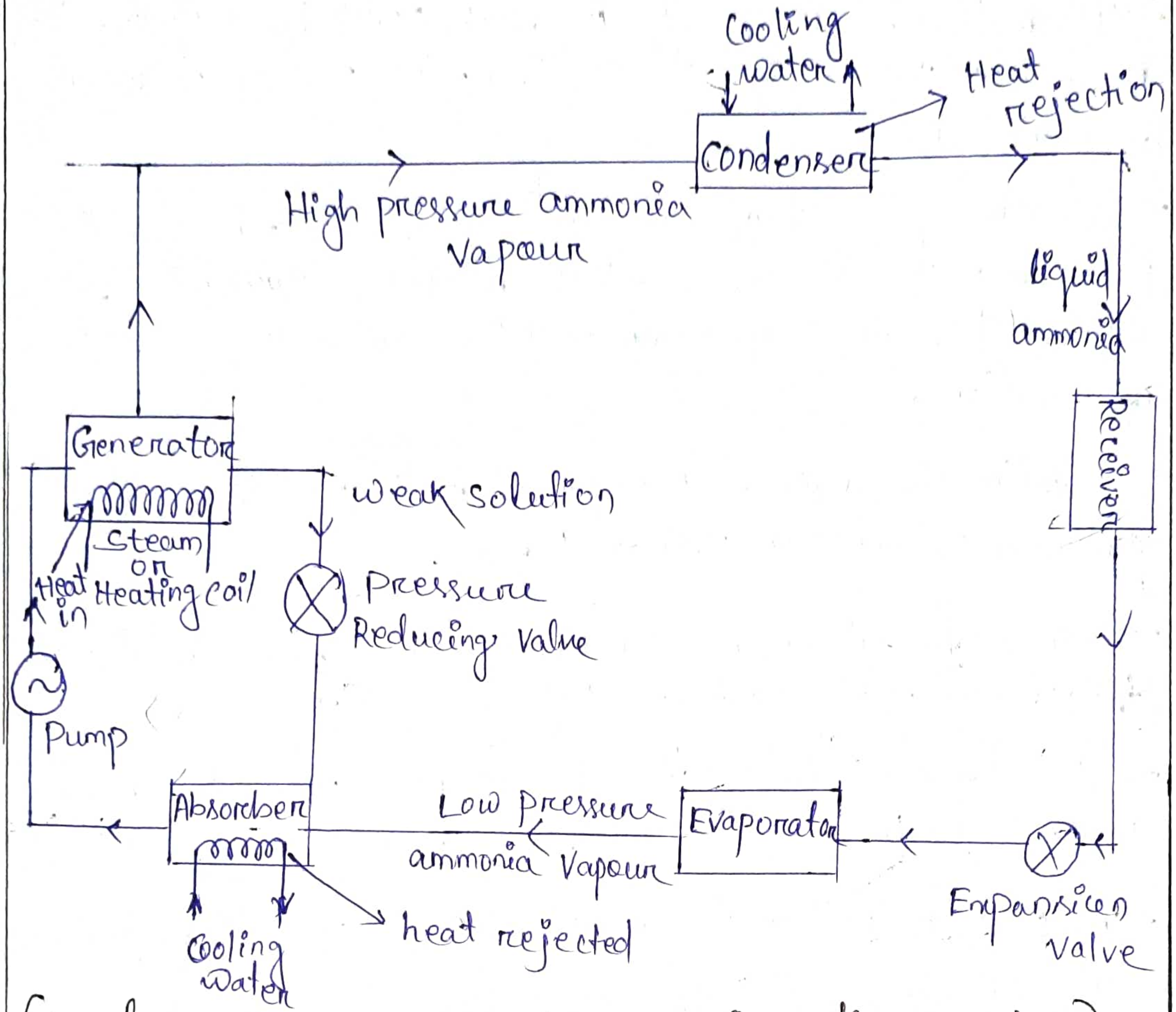
1. Low cop
2. Charging of the refrigerant in the absorption system is difficult.

Characteristics of a refrigerant :-

1. Low viscosity to minimize pump work.
2. Low freezing point.
3. Good Chemical and thermal stability
4. Small heat of dilution.

Porperties :-

1. Low boiling point,
2. High enthalpy of vapourization.
3. High Critical temperature and pressure.
4. Low specific heat.
5. Low modular weigh. 6. Chemical and thermal stability.



(Simple vapour absorption refrigeration system)

- A simple vapour absorption system, as shown in above fig. Consists of an absorption, a pump, a generator and a pressure reducing valve to replace the compressor of vapour compression system,

- The other compoments of the system are condenser, receiver, expansion valve and evaporator as in the vapour compression system.

- In this system, the low pressure ammonia vapour leaving the evaporator enters the absorber where it is absorbed by the cold water in the absorber.

- The water has the ability to absorb very large quantities of ammonia vapour and the solution, thus formed is known as aqua-ammonia.

- The absorption of ammonia vapour in water lowers the pressure in the absorber which in turn draws more ammonia vapour from the evaporator and thus raises the temperature of solution.

- Cooling arrangement is employed in the absorber to remove the heat of solution evolved there.

- Increase the absorption capacity of water, because at high temperature water absorbs less ammonia vapour.

- The strong solution thus formed in the absorber is pumped to the generator by the liquid pump.

- The pump increases the pressure of the solution up to 1 bar.

- The strong solution ~~thus~~ of ammonia vapour is driven off the solution at high ~~pres~~ pressure leaving behind the hot work ammonia solution in the generator.

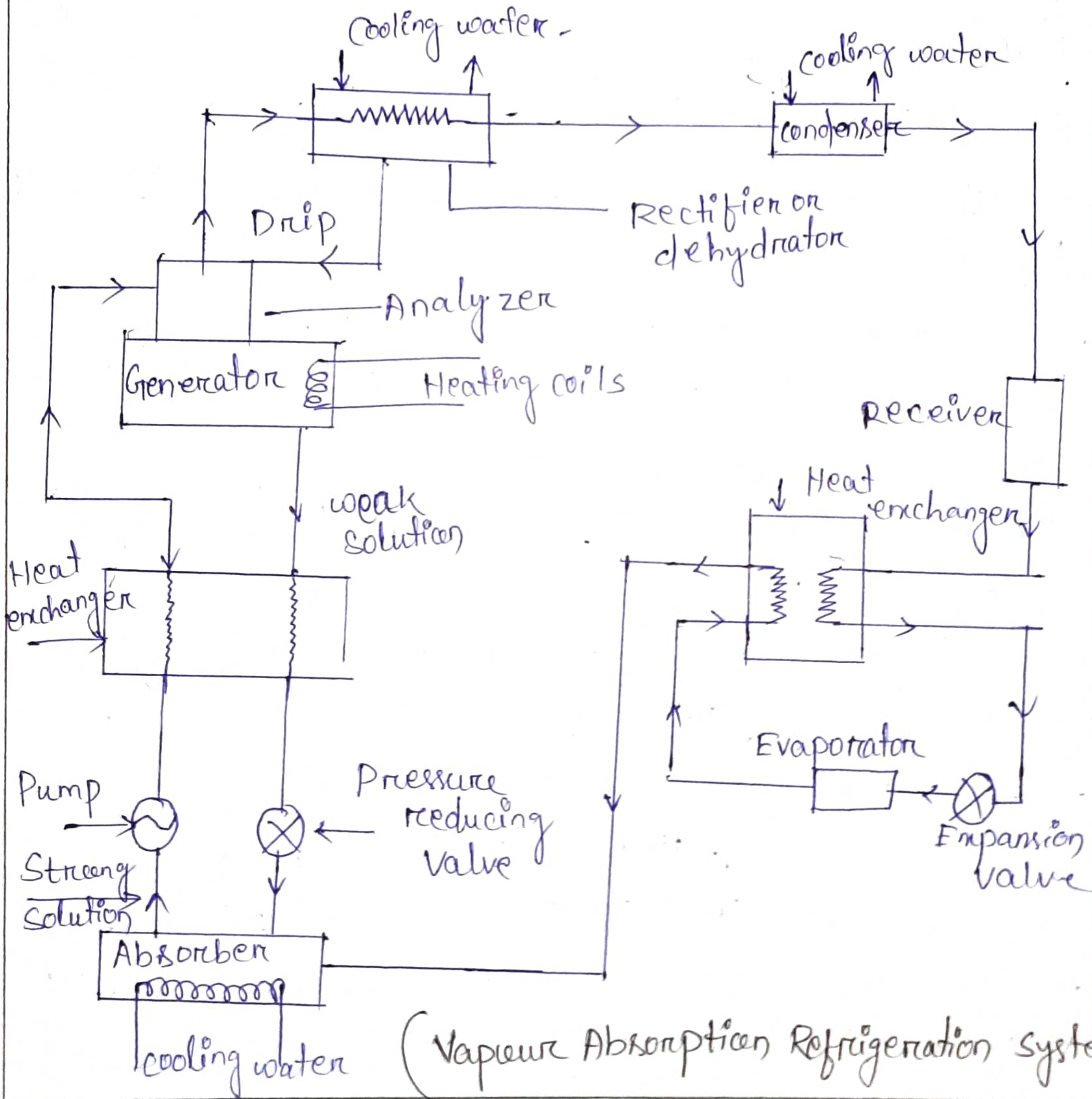
- This weak ammonia solution flows back to the absorber at low pressure after passing through the pressure reducing valve.

- The high pressure ammonia vapour from the generator is condensed in the condenser to a high pressure liquid ammonia.

- This liquid ammonia is passed to the expansion valve through the receiver and then to the evaporater. This completes the simple vapour absorption cycle.

Practical Vapour Absorption Refrigeration System :-

- Practical VARS is more efficienty and economical
- In addition to simple vapour absorption refrigeration system, it consist of
  - Analyser
  - Rectifier
  - Heat exchangers.



(Vapour Absorption Refrigeration system)

Components :-

1. Generator
2. Condenser
3. Expansion valve
4. Evaporator
5. Absorber
6. Pump
7. Analyser
8. Rectifier
9. Heat exchanger.

working principal :-

- In the generator, strong solution of ammonia is heated by external source.
- High pressure and high temperature ammonia vapour is separated from water and enters the analyser,
- Hot vapours of ammonia flow upwards, while vapour containing moisture gets dehydrated and dropped into the generator.
- The dehydrated ammonia vapours enters into the rectifier in which remaining water particles will be separated.
- Ammonia vapour enters into the condenser.
- In the condenser, ammonia vapour, gets condensed by rejecting it heat to the surrounding cooling medium.
- Liquid ammonia enters the expanssion valve through the heat exchanger.

In expansion valve expansion takes place, and low pressure liquid ammonia enters the evaporator.

- In evaporator, liquid ammonia absorbs heat from the products and converted into vapour state.
- The products are cooled in the evaporator.
- Low pressure vapour refigerant from evaporator enters the absorber.
- In the absorber, ammonia is absorbed by water and ammonia is dissolved in the water.
- This strong solution of ammonia is pumped to the generator with the help of a pump.
- Thus the cycle is repeated.

Function of Analyser:-

- When ammonia is vaporised in the generator, some water is also vaporised.
- This will flow into the condensor along with ammonia vapours.
- If these unwanted water particles are not removed before reaching the condenser, they will enter into expansion valve and gets freezed and choke the pipe line.
- Analyser removes this unwanted water particles before reaching the condenser.
- The strong solution from the absorber enters into the generator from the top of analyser.

- It comes downwards over the trays and comes in contact with ammonia vapour and gets cooled.
- The water vapour is condensed and water gets accumulated at the bootom.
- The dehydrated, ammonia vapour flow into the rectifier.

Function of ~~ref~~ rectifier:-

- Rectifier is placed after the analyser but before the condenser.
- Rectifier eliminated any water particles present in the ammonia vapour leaving the analyer,
- Rectifier has a vertical column and dephlegmentor.
- vertical rectifying column contains baffles.
- Dephlegmator accomodates external supply of cool water.
- partically dehydraacted ammonia vapour enter the rectifying column from the analyser.
- This vapour flows over baffles and come in indireect contanct with circulating cold water coils.
- moisture gets condensed and drips down to the generator.
- Dry ammonia vapour leaves the ~~rief~~ rectifier and falls into the condenser.

Function of heat exchanger :-

- It is located between generator and absorber.
- The strong solution at low temperature is pumped from the absorber to the generator.
- The hot weak solution is returned back from the generator to the absorber.
- Both solution will pass through the heat exchanger.
- Heat exchange takes place between the two fulids.
- The strong solution is heated.
- The weak solution gets cooled.

* Advantages of heat exchanger :-

- Reduces the cost of heating in the generator.
- Reduces the cost of cooling in the absorber.
- Improves ~~over~~ overall efficiency of the system.

COP of VARS :-

- Coefficient of performance of vapour absorption system is

$$COP = \frac{\text{Desired effect}}{\text{Work done}}$$

$$= \frac{\text{Heat absorbed in evaporater}}{\text{Heat supplied in generator}}$$

$$COP = \frac{Q_E}{Q_G}$$

Q_E = Heat absorbed @ Evaporator, T_E = temp. of evaporater

Q_C = Heat rejected @ condenser, T_C = temperature of condenser

Q_G = Heat added @ Generator, T_G = temp. of Generator.

- For a Perfect reversible system,

$$Q_C = Q_G + Q_E$$

Assumption:-

- Heat absorption in the generator and evaporator takes place with negaligible temp. difference.
- Heat dissipation in the condenser also with negligible temp. difference.

$$\Rightarrow \frac{Q_C}{T_C} = \frac{Q_G}{T_G} + \frac{Q_E}{T_E} \qquad \left[\therefore S = \frac{Q}{T}\right]$$

initial Entropy = Final Entropy

$$\Rightarrow \frac{Q_G + Q_E}{T_C} = \frac{Q_G}{T_G} + \frac{Q_E}{T_E} \qquad (\because Q_C = Q_G + Q_E)$$

$$\Rightarrow \frac{Q_G}{T_C} + \frac{Q_E}{T_C} = \frac{Q_G}{T_G} + \frac{Q_G}{T_E}$$

$$\Rightarrow \frac{Q_G}{T_G} - \frac{Q_G}{T_C} = \frac{Q_E}{T_C} - \frac{Q_E}{T_E}$$

$$\Rightarrow Q_G\left(\frac{T_C - T_G}{T_G \cdot T_C}\right) = Q_E\left(\frac{T_E - T_C}{T_C \cdot T_E}\right)$$

$$\boxed{COP = \frac{Q_E}{Q_G} = \left(\frac{T_C - T_G}{T_G}\right)\left(\frac{T_E}{T_E - T_C}\right)}$$

Difference between VARS & VCRS :-

VARS	VCRS
1. The only moving Part is Pump	1. The moving Part is Compressor.
2. A very small wear & tear.	2. For the same capacity more wear, tear & noise.
3. It uses the heat energy for the refrigerating effect.	3. It used the mechanical energy for the refrigerating effect.
4. The load variation does not affect the VARS.	4. The performance of VCRS lower at part load condition.
5. The condition of the refrigerant leaving the evaporator doesn't affected the performance of VARS.	5. The condition of the vapour must be super heat for the better performance of VCRS.
6. It required large build of area.	6. Medium to small build of area.
7. It has low maintenace cost.	7. It has high maintenace cost.

Expansion device :-

- The expansion device is an important device that divides the high pressure side and the low pressure side of a refrigerating system.

- It is connected between the receiver and the evaporator.

- The expansion device performs the following functions:-
  - It reduces the high pressure liquid refrigerant to low pressure liquid refrigerant before being fed to the evaporator.
  - It maintains the desired pressure difference between the high and low pressure sides of the system, so that the liquid refrigerant vaporised at the designed pressure in the evaporator.
  - It controls the flow of refrigerant according to the load on the evaporator.

Classification of expansion devices :-

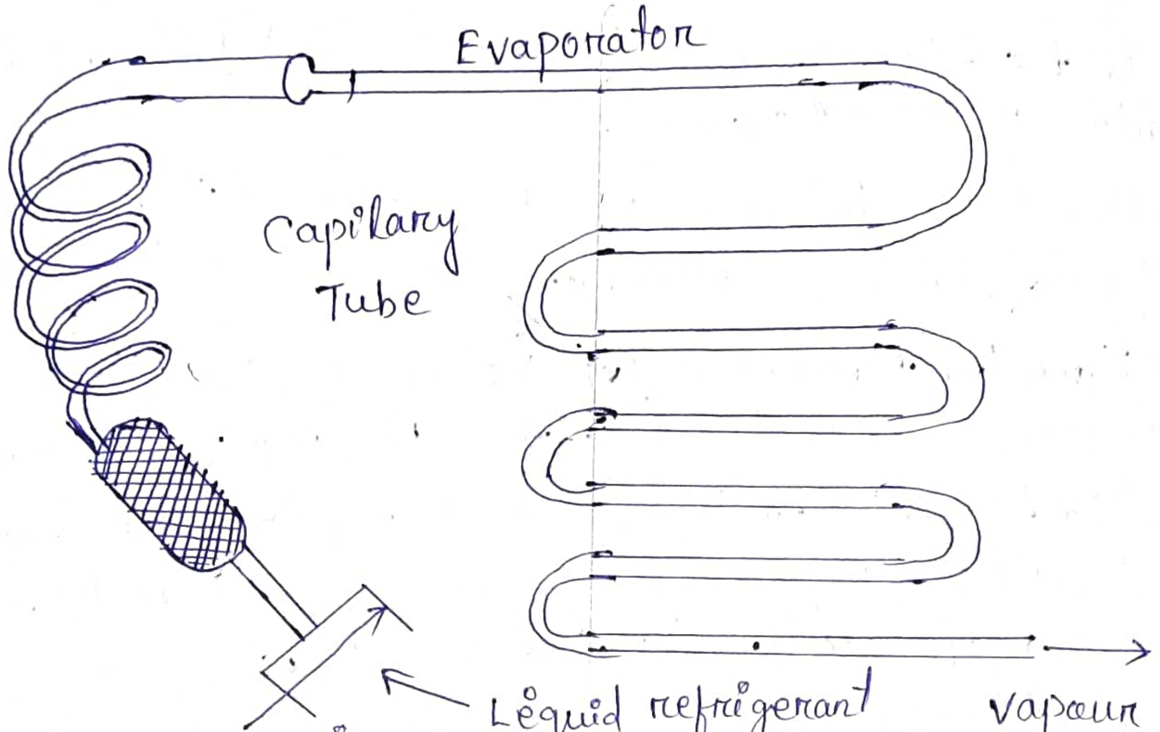
- Expansion devices used in mordern refrigeration system may be classified as;
  - Variable - restrictive type,
  - constant - restrictive type,

- In variable :- restrictive type device, the opening through which refrigerant fluid flows can be adjusted to suit the variation in discharge pressure, suction pressure or load.

- Example :-
  - Automatic expansion device
  - Thermostatic expansion device.

- In constant :- restrictive type device, the opening through which refrigerant fluid flows is constant and cannot be adjusted to suit the variation in the load etc,
- Example :- Capillary tube.

Capillary tube :-



(Capillary Tube)

- The capillary tube, as shown in above figure, is used as an expansion device in small capacity hermetic sealed refrigeration unit such as domestic refrigerators water coolers, room air-conditioners and freezers.
- It is a copper tube of small internal diameter and of varying length depending upon the application.
- The inside diameter of the tube used in refrigeration work is generally about 0.5 mm to 2.25 mm and the length varies from 0.5 m to 5 m.

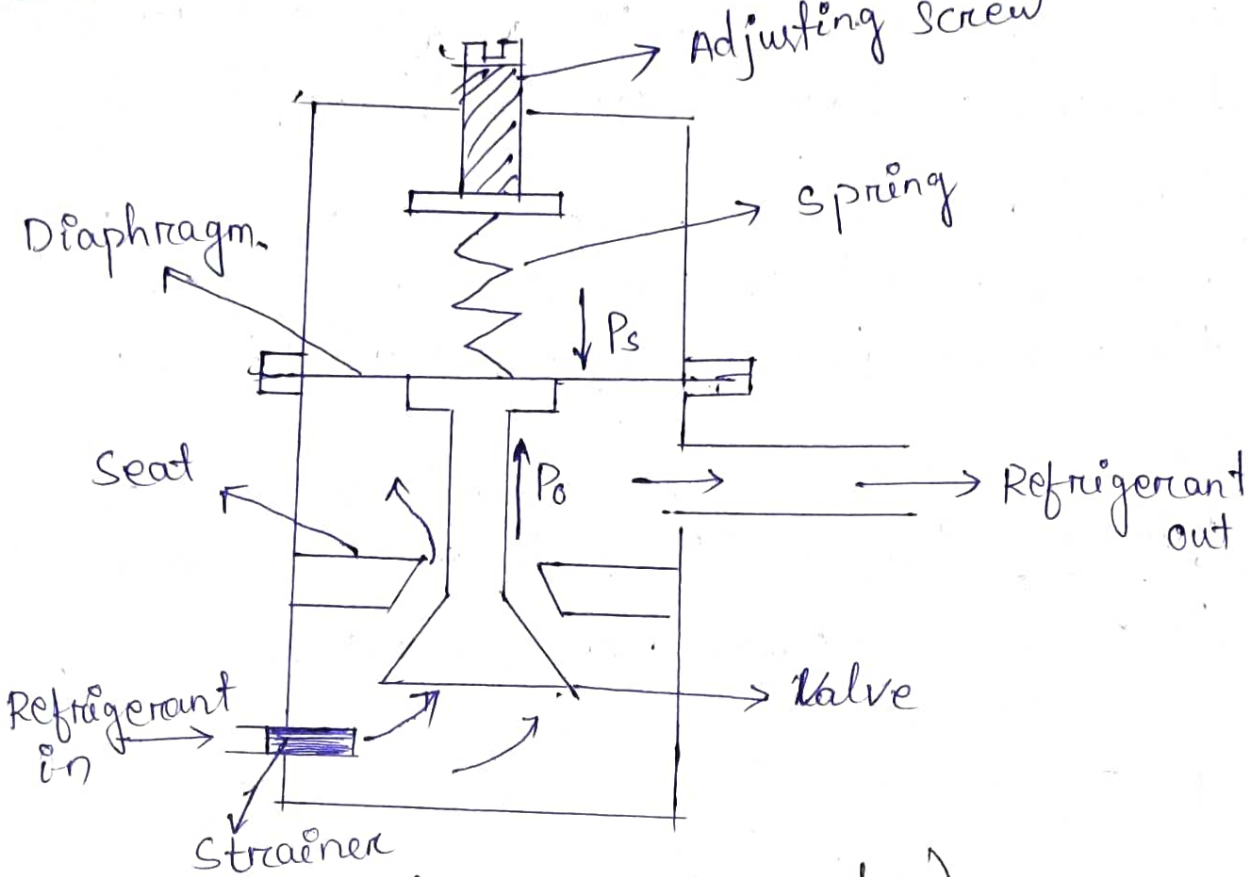
- It is installed in the liquid line between the condenser and the evaporator.
- A fine mesh screen is provided at the inlet of the tube in order to protect it from contaminants.
- A small filter drier is used in some systems to provide additional freeze-up application.
- In its operation, the liquid refrigerant from the condenser enters the capillary tube.
- Due to the frictional resistance offered by a small diameter tube, the pressure drops.
- Greater pressure difference between the condenser and evaporator is needed for a given flow rate of the refrigerant.
- The diameter and length of the capillary tube once selected for a given set of conditions and load cannot operate efficiently at other conditions.

Advantages:-

- The cost of capillary tube is less than all other forms of expansion device.
- When the compressor stops, the refrigerant continues to flow into the evaporator and equalises the pressure between the high side and low side of the system. This considerably decreases the starting load on the compressor. Thus a low starting torque motor can be used to drive the compressor which is a great advantage.

Automatic expansion valve :-

- The automatic expansion device is designed to keep the evaporator pressure constant.
- Therefore, it is also called as constant pressure expansion device.



(Automatic expansion valve)

- It consists a diaphragm which is subjected to two opposite pressure.
- On top of the diaphram adjustable spring exerts a downward pressure (P_s) which moves the diaphragm in opening direction, while its lower surface is directly exposed to evaporator pressure (P_e) which moves the diaphragm in a closing direction.
- Since the diaphragm is connected to a valve which controls the amount of refrigerant flowing through

the valve, this device automatically maintains the evaporator at constant pressure and hence the temperature.

- Any increase in evaporator pressure pushes the diaphragm up, causing the valve to move in closing direction and admit less refrigerant.

- Any decrease in evaporator pressure results in the movement of diaphragm downwards, so that the valve opens more and admits more refrigerant.

- At correct spring setting the ammount of fluid flowing through the valve exactly balances the compressor pumping capasity at designed suction pressure.

Limitation of automatic expansion device:-

- The automatic expansion device do not meet the requirements of modern refrigeration systems.

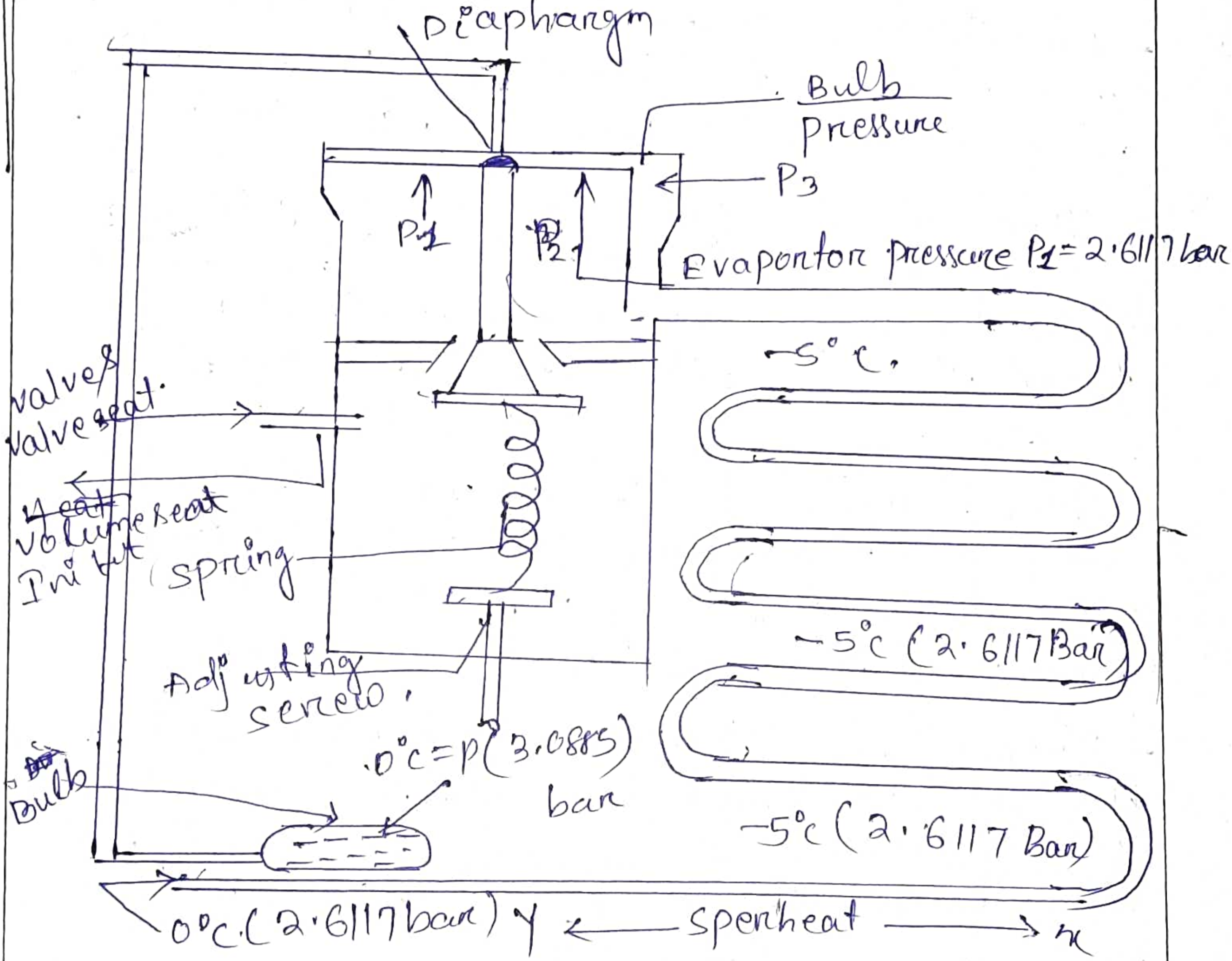
- It permits starving of the evaporator or flowing liquid refrigerant into the compressor under the variation of load.

- when refrigeration load drops, P_e drops and valve opens more.

- under new conditions compressor capacity remains same but the feed rate of the valve increases,

Thermostatic expansion Valve :-

- The thermostatic expansion valve is designed to regulate the rate of liquid refrigerant flow into an evaporator in the exact proportion to the rate of evaporation of the liquid refrigerant.
- It is also called as superheat controlled expansion valve because the force needed to operate the valve is derived from the superheat of refrigerant vapour in the evaporator coil.



- It construction is illustrated in above fig.
- It incorporates a feeler bulb which is partially filled with the same liquid refrigerant used in the evaporator.
- The liquid in the bulb is called power fluid.
- The feeler bulb is located at the outlet of the evaporator i.e suction line.
- The feeler bulb is in close contact with suction line so that the bulb and power fluid closely assume the temperature of the vapour refrigerant leaving the evaporator.
- Any change in temperature of the refrigerant will cause a change in pressure in the feeler bulb which will be communicated to the top of diaphragm.
- The evaporator pressure and spring force act beneath the diaphragm in closing direction of the valve whereas pressure exerted by power fluid above the diaphragm acts in the opening direction.
- Any increase in heat load or decrease in refrigerant will increase the superheat and the pressure on the top of the diaphragm, moving it, to open the valve and admit more refrigerant to the evaporator.
- Decrease in load or increase in refrigerant flow will reduce the superheat and the pressure on top of the diaphragm, allowing the spring to move the valve to a closed position.
- Under normal operating conditions the valve achieves a balanced condition ($P_b = P_s + P_e$) where the refrigerant flow balances the heat load.

Refrigerants :-

The refrigerant is a heat carrying medium which during the cycle in the refrigeration system absorbs heat from a low temperature system and discards the heat so absorbed to a higher temperature system.

- The natural ice and mixture of ice and salt were the first refrigerants.

- In 1834 ether, ammonia, sulphur dioxide, methyl chloride and carbon dioxide came into use, as refrigerants in compression cycle refrigeration machines.

- Most of the early refrigerant materials have been discarded for safety reasons or lack of chemical or thermal stability.

- In the present days, many new refrigerants including halo-carbon compounds, hydro-carbon compounds are used for air conditioning and refrigeration application.

Desirable properties of an ideal refrigerant :-

- We have discussed above that there is no ideal refrigerant. A refrigerant is saide to be ideal if it has all of the following properties:-

1. Low boilling and freezing point.
2. High critical pressure and temperature.
3. High latent heat of vaporisation.
4. Low specific heat of liquid, and high specific heat of vapour.

5. Low specific volume of vapour
6. High thermal conductivity
7. Non-corrosive nature.
8. Non-flammable and non-explosive
9. Non-toxic
10. Low cost.
11. Easily and regular availability.
12. Easy to liquify at moderate pressure and temperature.
13. Ease of locating leaks by odour or suitable indicator.
14. Mixes well with oil.
15. High coefficient of performance
16. Ozone friendly.

Thermodynamic properties of Refrigerants :-

1. Boilling temperature :-

- The boilling temperature of the refrigerant at atmospheric pressure should be low.
- If the boiling temperature of the refrigerant is high at atmospheric pressure, the compressor should be operated at high vaccum.
- The high boiling temperature reduces the capacity and operating cost of the system.

Freezing temperature :-

- The freezing temperature of a refrigerant should be well below the operating evaporator temperature.
- Since the freezing temperature of most of the refrigerants are below −35°C, therefore this property is taken into consideration only in low temperature operation.

Evaporator and condenser pressure :-

- Both the evaporating and condensing pressures should be positive and it should be as near to the atmospheric pressure as possible.
- The positive pressure are necessary in order to prevent leakage of air and moisture into the refrigerating system.
- It also permits easier detection of leaks.
- Too high evaporating and condensing pressure would require stronger refrigerating equipment resulting in higher initial cost.

Critical temperature and pressure :-

- The critical temperature of a refrigerant is the highest temperature at which it can be condensed to a liquid, regardless of a higher pressure.
- It should be above the highest condensing temperature that might be encountered.
- If the critical temperature of a refrigerant is too near the desired condensing temperature, the excessive power consumption results.

Coefficient of performance and power requirements :-

- For an ideal refrigerant operating between -15°c evaporator temperature and 30°c condenser temperature, the theoritical coefficient of performance for the reversed carnot cycle is 5.74.

Latent heat of vaporisation :-

- A refrigerant should have a high latent heat of vaporisation at the evaporator temperature.
- The high latent heat results in High refrigerating effect per kg of refrigerant circulated which reduces the mass of refrigerant to be circulated per tonne of refrigeration.

specific volume :-

- The specific volume of the refrigerant vapour at evaporator temperature indicates the theoretical displacement of the compressor,
- The reciprocating compressor are used with refreigerants having high pressures and low volumes of the suction vapour.
- The rotary compressors are used with refrigerants having intermediate pressures and volume of the suction vapour.

Chemical Properties of Refrigerants :-

Flammability :-

- We have already discussed that hydro-carbon refrigerants such as ethane, propane etc. are highly flammable.
- Ammonia is also somewhat flammable and becomes explosive when mixed with air in the ratio of 16 to 25 percent of gas by volume.
- The halo-carbon refrigerant are neither flammable nor explosive.

Toxicity :-

- The toxicity of refrigerant may be of prime or secondary importance; depending upon the application.
- Some non-toxic refrigerants when mixed with certain percentage of air become toxic.

Solubility of water :-

- Water is only slightly soluble in R-12, at -18°c, it will hold six parts million by weight.
- The solution formed is very slightly corrosive to any of the common metals.
- The solubility of water with R-12 is more than R-12 by a ratio of 3 to 1.
- Ammonia is highly soluble in water. Due to this reason, a wetted cloth is put at the point of leak to avoid harm to the persons working in ammonia refrigerating plants.

Miscibility :-

- The ability of a refrigerant to mix with oil is called miscibility. This property of refrigerant is considered to be a secondary factor in the selection of a refrigerant.
- The degree of miscibility depends upon the temperature of the oil and pressure of the refrigerating vapour.
- The freon group of refrigerant are highly miscible refrigerants while ammonia, Carbon dioxide, Sulpher dioxide and methyl chloride are relatively non-miscible.
- The non-miscible refrigerants require larger heat transfer surfaces due to poor heat conduction properties of oil.

Effect on perishable materials :-

- The refrigerants used in cold storage plants and in domestic refrigerators should be such that in case of Leakage, it should have no effect on the perishable materials.
- The freon group of refrigerants have no effect upon dairy products, meats, vegetables, flowers and furs.
- There will be no change in colour, taste or texture of the material when exposed to freon.
- Methyle chloride vapours have no effect upon furs, flowers, eating foods are drinking beverages.
- Sulphur dioxide destroys flowers, plants and furs; but it does not affect food.

Designation System for refrigerants :-

- The refrigerants are internationally designated as 'R' followed by certain numbers such as R-11, R-12, R-114 etc.
- A refrigerant followed by a two-digit number indicates that a refrigerant is derived from methane base while three-digit number represents ethane base. The number assigned to hydro-carbon and halo-carbon refrigerants have a special meaning.
- The first digit on the right is the number of fluorine atoms in the refrigerant.
- The second digit from the righ is one more than the hydrogen (H) atoms present.
- The third digit from the right is one less than the number of carbon (C) atoms, but where this digit is zero, it is omitted.
- The general chemical formular for the refrigerant either for methane or ethane base, is given as $C_m H_n Cl_p F_q$, in which $n+p+q = 2m+2$.

Where m = Number of carbon atoms.
n = number of hydragen atoms.
p = Number of Chlorine atoms.
q = Number of fluorine atoms.

- As discussed above, the number of the refrigerant is given by $R(m-1)(n+1)(q)$. Let us consider the following refrigerant to find its chemical formular and the ~~nu~~ number.

Dichloro-difluoro-methane :-

- Number of Chlorine atoms $p = 2$
- Number of fluorine atoms $q = 2$ and
- Number of hydrogen atoms $n = 0$

we know that $n + p + q = 2m + 2$

$$0 + 2 + 2 = 2m + 2 \quad \text{or} \quad m = 1$$

- i.e. Number of carbon atoms = 1
- The chemical formula for dichloro-difluoro-methane becomes CCl_2F_2 and the number of refrigerant becomes $R(1-1)(0+1)(2)$ or R-012 i.e. R-12,

Dichloro-tetrafluoro-ethane :-

- Number of Chlorine atoms $p = 2$
- Number of fluorine atoms $q = 4$

Number of hydrogen atoms $n = 0$

we know that $n + p + q = 2m + 2$

$$0 + 2 + 4 = 2m + 2 \quad \text{or} \quad m = 2$$

- i.e. Number of Carbon atoms = 2
- Thus, the Chemical formula for dichloro-tetrafluoro ethane becomes $C_2Cl_2F_4$ and the number of refrigerant becomes $R(2-1)(0+1)(4)$ or R-114.

Substitute for CFC :-

- Two of the chemical classes under consideration for replacing CFCs are hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs)
- HCFCs Contribute to the destruction of stratospheric ozone, but to a much lesser extent than CFCs. Use of

HCFCs as transitional refrigerants will allow industry to phase out the production of CFCs and will offer environmental benefits over the continued use of CFCs. Because they contain hydrogen, HCFCs break down more easily in the atmosphere than do CFCs.

- Therefore, HCFCs have less ozone depletion potential in addition to less global-warming potential.

Commonly used Refrigerants :-

R-11 (Trichloro monofluoro methane) (CCl_3F)

- It is non-toxic, non-flammable and non-corrosive.
- It is miscible with lubricating oil under all conditions. It is a low pressure refrigerant suitable with a centrifugal compressor operating at low speed.
- It is employed for 50 tons capacity air conditioning plants.
- Its colour code is orange.

R-12 (Dichloro difluoro methane CCl_2F_2) :-

- It is a highly stable refrigerant and widely used for domestic, commercial refrigeration application and automobile applications.
- It is non-toxic, non-flammable, non-explosive and safe to use.
- It is colourless, odourless and leak is detected by halide torch or an electronic leak detector.
- Its cylinder colour code is white.

R-22 (Monochloro difluoro methane - $CHClF_2$):-

- It is low temperature refrigerant and extensively used in air conditioning applications with reciprocating compressor.
- It is also used in low temperature applications such as cold storages.
- It is non-toxic, non-flammable and non-corrosive refrigerant.
- It is non-toxic, so also used in low temperature application such as cold storages.
- Leakage of refrigerant may be detected with halid torch.
- Its cylinder colour code is green.

R134a (Tetrafluoroethane - CF3CH2F)

- R134a is also known as Tetrafluoroethane (CF3CH2F) from the family of HFC refrigerant. With the discovery of the damaging effect of CFCs and HCFCs refrigerants to the ozone layer, The HFC family of refrigerant has been widely used as their replacement.
- It is now being used as a replacement for R-12 CFC refrigerant in the area of centrifugal, rotary screw, scroll and reciprocating compressors.
- It is safe for normal handling as it is non-toxic, non-flammable and non-corrosive.

R-717 (Ammonia NH_3):-

- Ammonia is one of the oldest and most widely used refrigerant where high toxicity is secondary.
- It is most effecient but toxic and explosive.
- It attacks copper and used only in the system fabricated

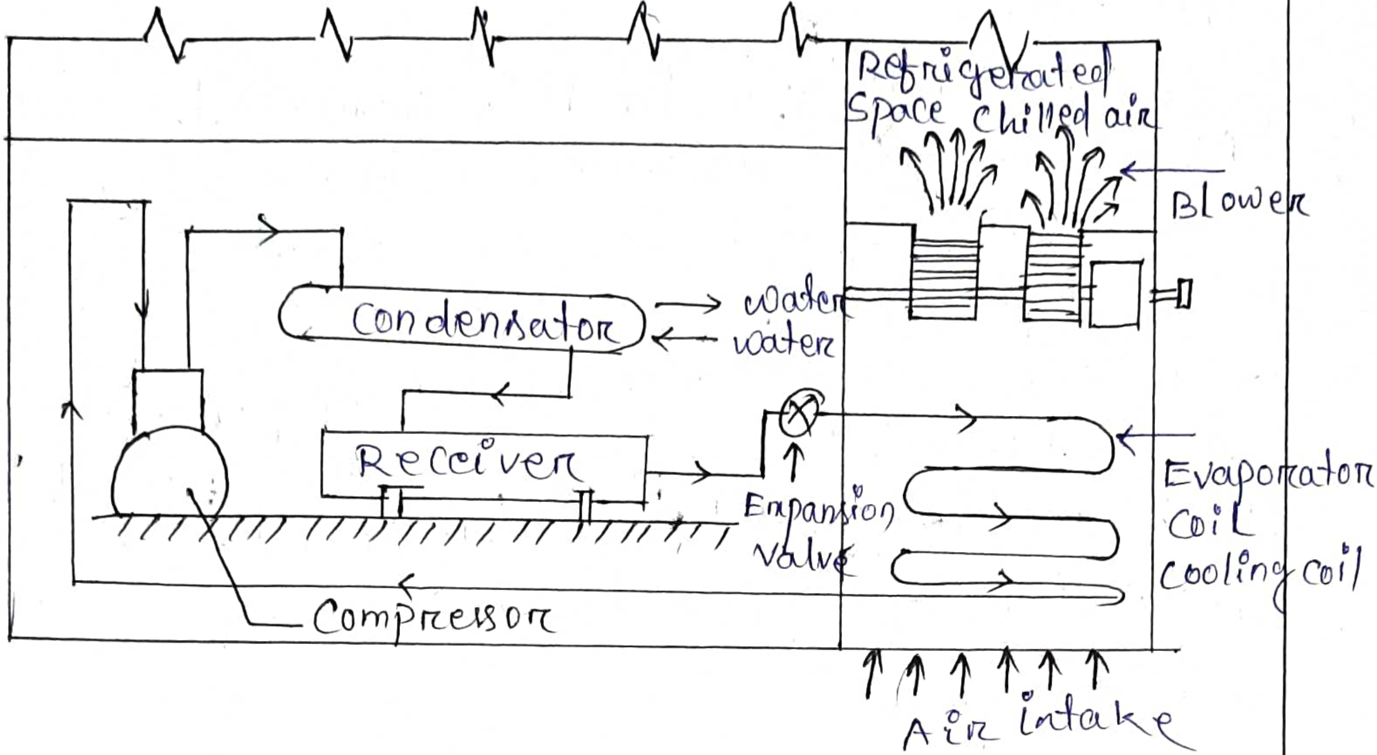
from steel.

- It is most widely used in large commercial and industrial plants, absorption system, cold storages and ice plants.
- It is suitable for open-type reciprocating or screw type compressors.
- The leakage of this refrigerant may be easily detected by sulphur candle, which gives off a dense white smoke when NH_3 vapour is present.

Applications of refrigeration :-

Cold storage :-

- Cold storage is a space designed to store perishable food stuff within well defined temperature and humidity.
- The air is cooled by passing it over a cooling coil of a refrigerant plant and supplied back to the space or room.
- The most appropriate temperature to retard the deterioration of vegetables and fruits is about 0.5°c to 1°c above the freezing point of these products.
- But some fruits such as banana cannot tolerate low temperature and for such fruits higher temperature should be maintained in the storage space.
- The cold storage prevents the spoilage of perishable commodities and make them ~~ab~~ available in all the season and in places where they are not harvested.
- It is used for preservation of fish, meat, fruits and vagetables.



- It works an evapour compression system.
- Refrigerant at low temperature enters the cooling coil and produces the refrigeration effect in the coil.
- The refrigerant vapour drawn from the coil is compressed to high-pressure and delivered to condenser where it is condensed to liquid state.
- The liquid refrigerant is throttled down to low temp. and pressure before entering the cooling coil.
- The warm air is drawn through the coil by blower.
- The air is cooled at it comes in contact with cooling coil. Chilled air is blown into room through dampers.

Advantages of cold storage :-

- It prevents the spoilage of perishable products like vegetables and fruits.
- It makes the availability of commodities in all seasons.
- It is used for preservation of fish, meat, fruits etc. for a considerable period.

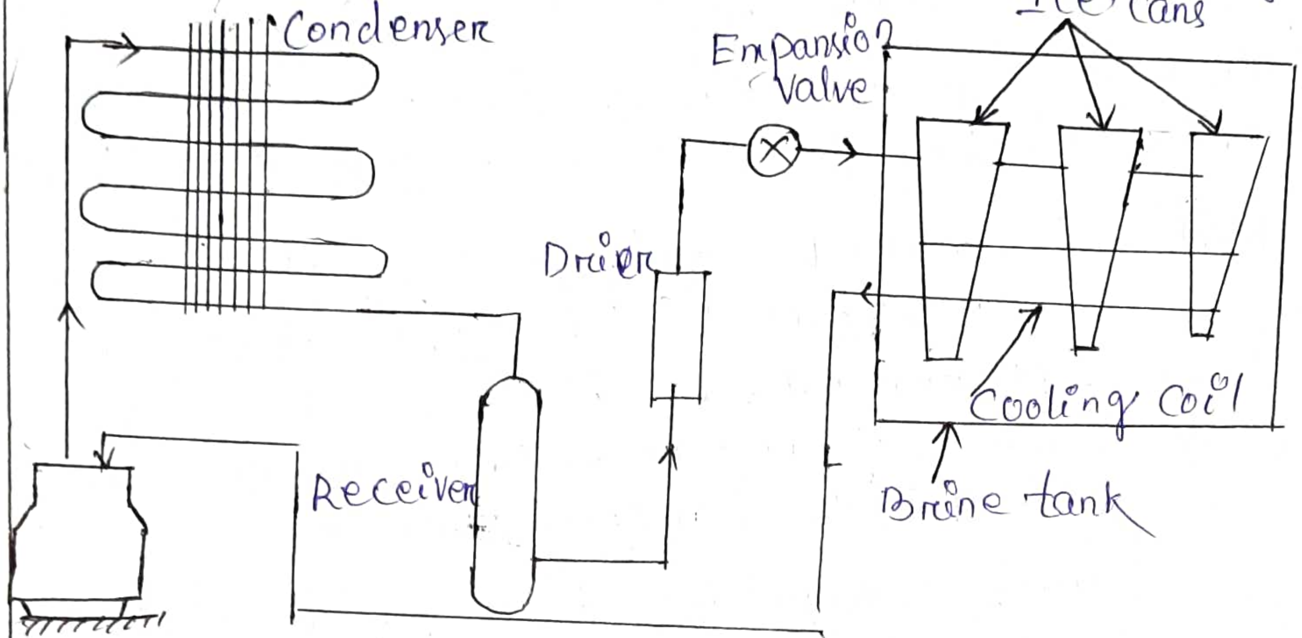
Dairy Refrigeration :-

- Dairy is an indispensable part of the global food system and it plays a crucial role in the sustainability of rural areas in particular. It is a well-known fact that the dairy industry actively contributes to the economies of a number of countries.
- An increasing demand worldwide is noticeably emerging at present and the industry is globalising.
- Milk and dairy products are very essential for human nutrition and development, especially, in children. Although milk is a highly nourishing food, raw fresh milk is highly liable to rot and can be easily spoiled by the growth of microorganisms.
- Fresh milk is collected from the farm, transported to cooling centres to prevent spoilage, then to processing units to produce other dairy products and finally delivered to the consumers in several ways.
- The transportation of fresh milk from farms to cooling centres and processing units may take time. Consequently cooling milk in time becomes major problem associated with raw fresh milk.
- The milk should be cooled within three to four hours of collecting it from the farm, which otherwise leads to spoilage. Thus, refrigeration plays a vital role in dairy industry.

Ice plant :-

Ice is manufactured artificially from clean water by chilling. Ice making plant consists of a vapour compression system with ammonia as the refrigerant.

- The working of an ice plant is illustrated in Figure.



- It has brine tank made of about 6mm thick m.s plates and insulated to prevent heat transfer from surrounding into it.
- Ice cans are made up of galvanised sheet of about 2 mm thick and are tapered downwards.
- Clean water is taken in cans which are placed in brine tank.
- The water level in the can should be below (20 to 30mm) the brine level and the cans should be projected above the brine level in order to prevent brine spilling into the ice cans.
- The cooling coil is wrapped around the cans giving appropriate contact.

- Brine is used as a secondary refrigerant and is chilled to about $-10°c$ by ammonia evaporating at $-15°c$.
- High pressure vapour delivered from the compressor enters the condenser where it is condensed to liquid state.
- Liquid refrigerant flows though the drier and expansion valve.
- Its pressure decreases as it expands through valve.
- Low pressure liquid refrigerant flows through the cooling coils and evaporates by absorbing heat from brine.
- The chilled brine in turns extracts heat from water i.e. chills the water in the cans until it forms ice.
- The ice blocks form and grow inwards from the can surface.
- Air agitation is used to force dissolved gases and solids to the centre of the can.
- These are pumped out and replaced with cooled fresh water.
- The ice blocks from cans can be easily removed by shaking the cans.
- They can also be removed by lifting the cans from the tank and placing them in a hot water at $21°c$.
- The hot water helps to remove ice blocks from cans.
- The removal of ice blocks by using hot water is known as throwing.

Water Cooler :-

- The purpose of a water cooler is to make cold water available at a constant temp. irrespective of ambient temp.
- They are meant to produce cold water at about 7°c to 13°c for quenching the thirst of the people working in hot environment.
- The warm or normal water can serve the physical requirement of our system for proper functioning of the body organs but it does not quench the thirst especially in hot summer.
- The temperater of cold water is controlled with the help of a thermostatic switch set within 7°c to 13°c range.
- water coolers may be classified as -
    - Storage cooler
    - Instantaneous cooler.
- In storage cooler, a cooling coil is wrapped around the water storage tank, and all the times cold water is available in the tank.
- In instaneous cooler cooling coil is wrapped around the pipe line. Water is cooled to the desired temp. by the time it reaches the tank.

Water Cooler (Storage type) :-

The storage type water coolers are widely used where continuous water supply is not available.

- It consist a storage tank in which water is filled.
- The water is maintained at constant level with the help of float valve.

- Insulation is provided around the tank to prevent heat transfer from the surrounding into it.
- This type of cooler uses vapour compression system with R-12 as refrigerant and is usually mounted at the bottom of the tank.
- High pressure refrigerant vapour ~~compression system~~ enters the condenser where it is converted into liquid state.
- Liquid refrigerant then enters the capillary tube via strainer.
- It loses heat in the suction line where heat exchanger is provided.
- Liquid refrigerant expand to lower pressure as it flows through capillary tube.
- Low pressure and low temperature refrigerant flows through evaporator coil which is wrapped around the storage tank.
- It absorbs heat from water and evaporates.
- Thus the water is cooled.

Psychrometry :-

- The atmospheric air consist of dry air and water vapour.
- The dry air and water vapour cumiletively called moist air.
- The study of moist air is called psychromety.
- At atmospheric temperature and pressure, the moist air is assumed to behave like ideal gas for the study of psychometry.

Psychrometric terms :-

1. Dry air :-

The pure air which is a mixture of no of gasious product i.e N_2, CO_2, O_2, SO_2 ...... etc.

2. Moist air :-

- It is a mixture of dry air and water vapour.
- The ammount of water vapour present in the moist air depends upon the temperature and pressure of the dry air.

3. Water vapour :-

- It is the moisture present in dry air.
- The moisture content in air is an important factor in all air-conditioning system.

4. Saturated air :-

- It is mixture of dry air and water vapour in which the dry air has defused maximum amount of water vapour.

5. Specific humidity or humidity ratio (w)

- It is the mass of the water vapour present in one kg of dry air.
- It is also called humidity ratio.
- It is denoted by w.

Mathematically,

$$w = 0.622 \frac{P_v}{P_b - P_v}$$

where, P_v = Vapour pressure, P_b = Barometric pressure

- It's unit is gm/kg of dry air.

6. Relative humidity :- (RH)

- It is the ratio of actual mass of water vapour present in a given volume of moist air to the mass of the water vapour present in the same volume of saturated air.
- It is denoted by 'φ'.

$$\phi = \frac{P_v}{P_s}$$

where, P_v = Vapour pressure

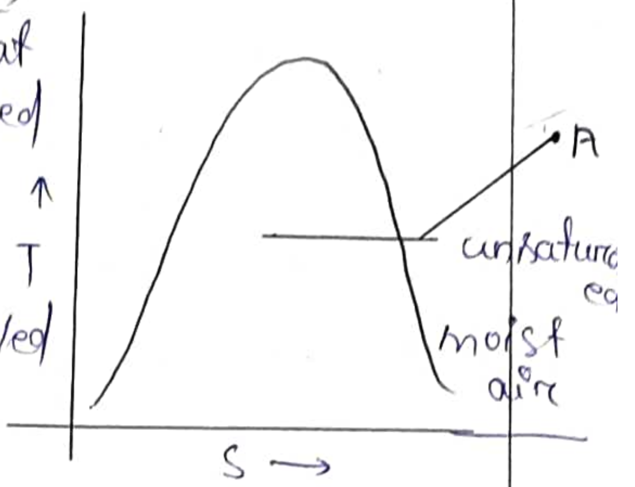
P_s = Vapour pressure at saturated state.

7. Dry Bulb-Temperature :- (DBT)

- It is the normal atmospheric temperature recorded by the thermometer.
- It is written as DBT.
- Symbole :- t_{db}.

8. Dew Point Temperature (DPT) :-

Let us consider a moist air is at a state of 'A' which is considered as unsaturated moist air at sperheated states.



- The unsaturated moist air is cooled at a constant pressure of to the saturation point.
- During the cooling process the water vapour present in the moist air gives of the latent heat and forms a dew at saturated state.
- Therefore dew point temp is a saturation temp at which the unsaturated moist air froms a dew.

Dew point depression (DPD) :-

It is the difference between DBT and DPT.

$$DPD = DBT - DPT$$

~~Weig~~ wet Bulb Temperature :-

- A psychrometer cosist of 2 thermometers.
- one thermometer is directly open to the atmosphere which measure the dry bulb temp. of the air.
- Another thermometer bulb is wraped with a musline cloth with measure wet bulb temperature.
- The WBT represents the dryness of the air.
- The WBT temp is a equilibrium temperature reached by heat transfer form air to the water wick due to the temperature difference. Causing the vapouration of water into the air to the partial pressure difference.

Wet bulb Depression (WBD)

It is the difference between the DBT & WBT.

$WBD = DBT - WBT$

D. **Enthalpy of Moist air :-**

- The enthalpy of the moist air is the submission of enthalpy of dry air and enthalpy of water vapour.
- Enthalpy of dry air :- $1.005\, t_d$

  Enthalpy of water vapour :- $\omega(2500 + 1.88\, t_d)$

Degree of Saturation :-

- It is the ratio of specific humidity of the air to the specific humidity of the air at saturated state.
- It is denoted by μ.

mathematically,

$$\mu = \frac{\omega}{\omega_s}$$

$$\omega_s = 0.622 \frac{P_s}{P_b - P_s}$$

where ω = specific humidity

Pressure of water vapour :-

$$P_v = P_w - \frac{(P_b - P_w)(t_d - t_w)}{1544 - 1.44\, t_d}$$

where P_w = Saturated Pressure at WBT

P_b = Barometric pressure.

t_d = DBT

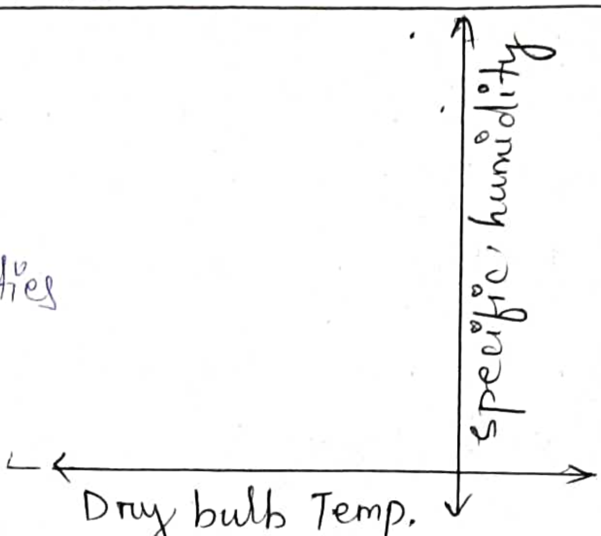
t_w = WBT

Vapour density :-

$$\rho_v = \frac{\omega(P_b - P_v)}{R T_d}$$

$R = 0.287\ kJ/kg.K$

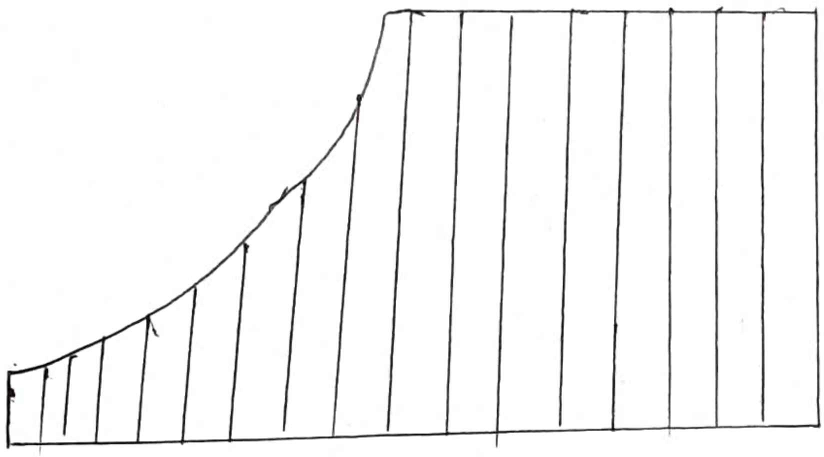
Psychrometric Chart :-



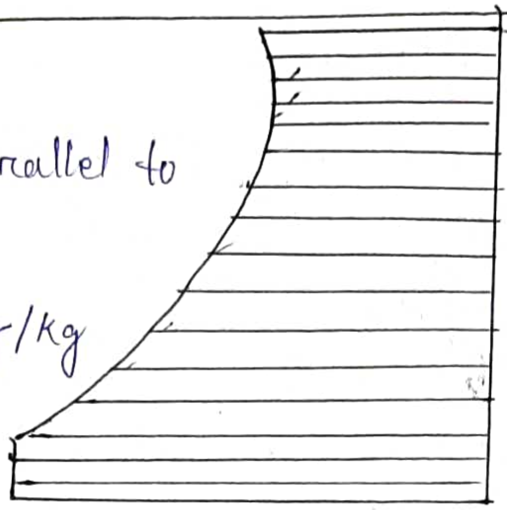
- Psychrometric chart is a graphical representation of various thermodynamic properties of moist air.
- The Psychometric chart is useful in find out different properties required for air conditioning process.
- It is normally draw for standard atm. pr. i.e 760mm Hg.
- In psychometric chart DBT is taken as absica and Specific humidity taken as odinate.
- In psychrometric chart the saturation curve represent 100% relative humidity.
- It also represents the WBT & DPT at various DBT.

Dry bulb temperature lines :-

- These are vertical parallel lines to the ordinats and uniformly spaced.
- The temperature range 6°c to 45°c.
- The DBT line have difference 5°c.

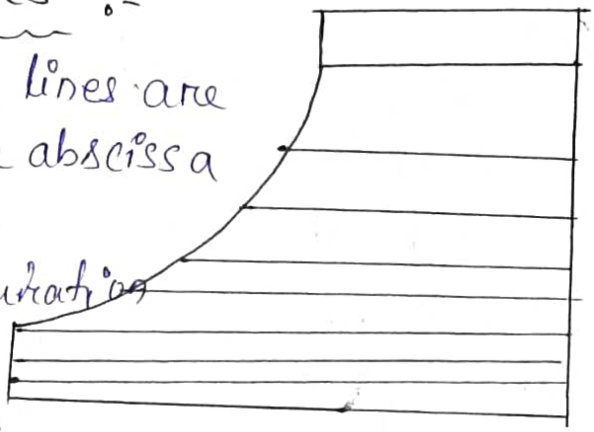


Specific humidity line :-



- These are the horizontal parallel to the absica.
- It ranges from 0 to 0.030 kg/kg of dry air.
- The specific humidity line have difference of 0.001 kg.

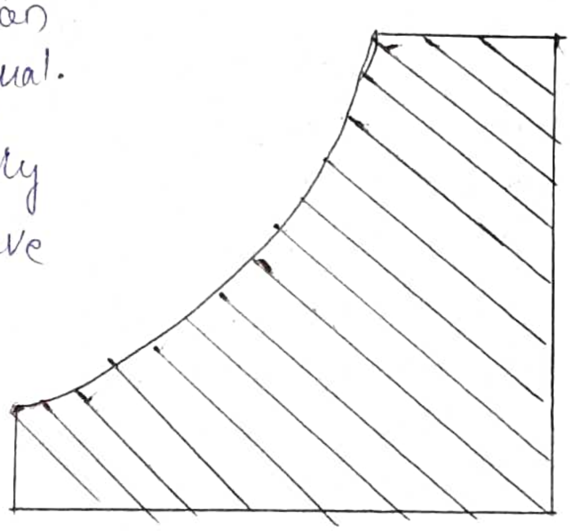
Dew point temperature lines :-



- The dew point temperature lines are horizontal i.e parallel to the abscissa and non-uniformly spaced.
- At any point on the saturation curve; the dry bulb and dew point temp. are equal.

Wet bulb temp. lines :-

The WBT lines are inclined straight lines and non-uniformly spaced.



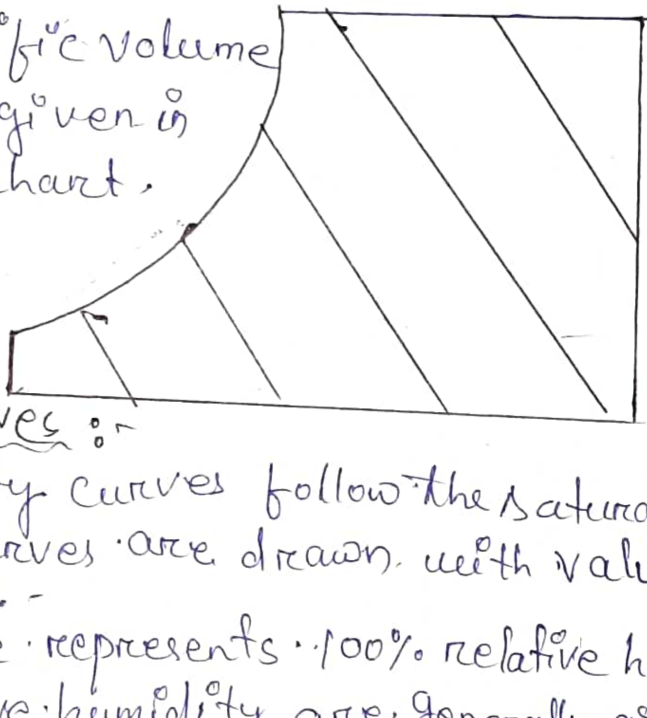
- At any point on the saturation curve, the DBT and WBT are equal.
- The values of WBT are generally given along the saturation curve of the chart.

Enthalpy lines :-

- The enthalpy lines are inclined straight lines & uniformly spaced.
- These lines are parallel to the WBT lines and are drawn up to the saturation curve.
- Some of these lines coincide with wet bulb temp. lines also.
- The values of total enthalpy are given on a scale above the saturation curve.

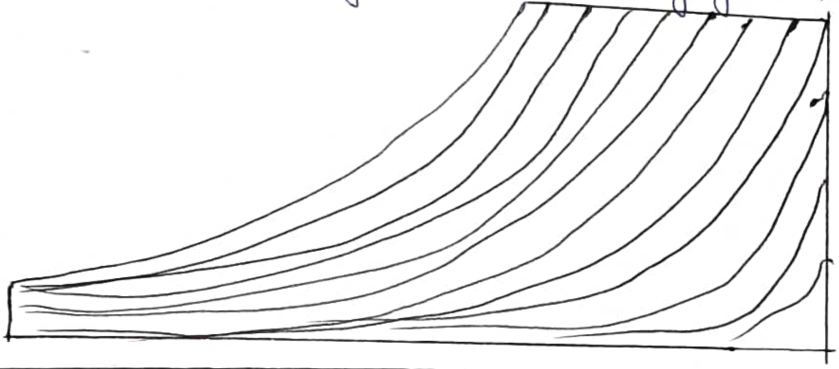
Specific volume lines :-

- The specific volume lines are obliquely inclined straight lines and uniformly spaced,
- The values of specific volume lines are generally given in the middle of the chart.



Relative humidity curves :-

- The relative humidity curves follow the saturation curve.
- Generally, these curves are drawn with values 10%, 20%, 30%......, 100%.
- The saturation curve represents 100% relative humidity.
- The values of relative humidity are generally given along the curves.

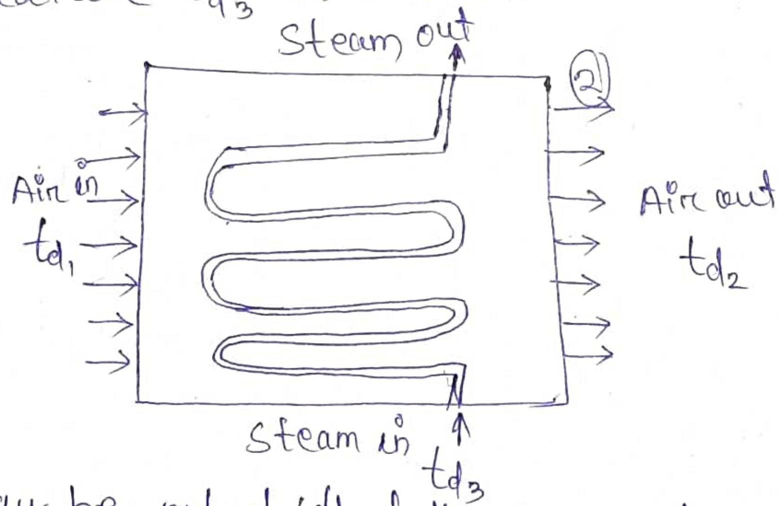


Psychrometric process :-

- Certain processes are to be carried out on air to vary its properties to the requirements in air conditioning for human comfort or industrial use.
- The following processes may be carries out on air -
  - Sensible heating
  - Sensible Cooling
  - Humidification and dehumidification.
  - Heating and dehumidification.
  - Cooling and humidification.
  - Cooling and dehumidification.

Sensible heating :-

- The heating of air without any change in its specific humidity, is known as sensible heating.
- Let air at temp, t_{d_1} passes over a heating coil of temperature t_{d_3} as shown.



- It may be noted that the temperature of air leaving the heating coil (t_{d_2}) will be less than t_{d_3}.
- The process of sensible heating on the psychometric chart, is shown by a horizontal line 1-2 extending

from left to right.

- The heat absorbed by the air during sensible heating may be obtained from the psychrometric chart by the enthalpy difference $(h_2 = h_1)$.
- It may be noted that the specific humidity during the sensible heating remains constant. $(\omega_1 = \omega_2)$.
- The dry bulb temperature increases from t_{d_1} to t_{d_2} and relative humidity reduces from ϕ_1 to ϕ_2.
- The amount of heat added during sensible heating may also be obtained from the relation.

Heat added, $Q = h_2 - h_1$

$$= C_{pa}(t_{d_2} - t_{d_1}) + \omega C_{ps}(t_{d_2} - t_{d_1})$$

$$= (C_{pa} + \omega C_{ps})(t_{d_2} - t_{d_1})$$

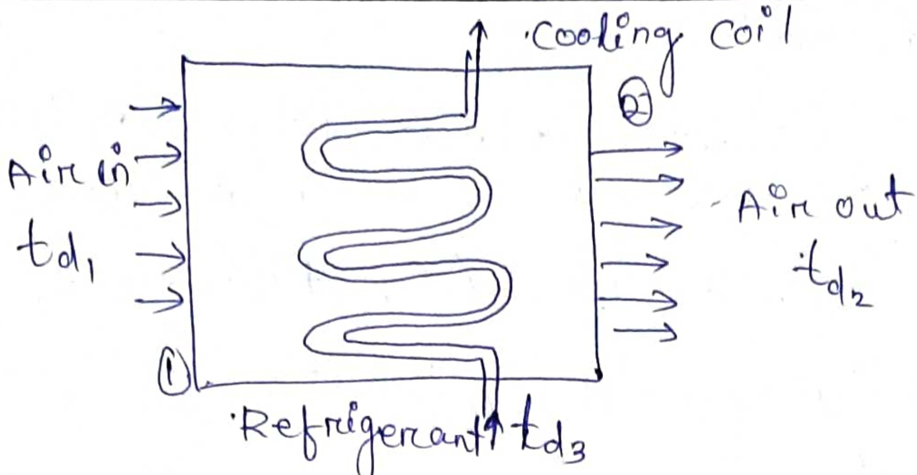
$$= C_{pm}(t_{d_2} - t_{d_1})$$

- The term $(C_{pa} + \omega C_{ps})$ is called humid specific heat (C_{pm}) and its value is taken as 1.022 kJ/kg.K.

Heat added, $Q = 1.022 (t_{d_2} - t_{d_1})$ kJ/kg.

Sensible Cooling :-

- The cooling of air without any change in its specific humidity is known as sensible cooling.
- Let air at temperature t_{d_1} passes over a cooling coil of temp t_{d_3} as shown.



- It may be noted that the temp. of air leaving the cooling coil (t_{d_2}) will be more than t_{d_3}.
- The process of sensible cooling on psychometric chart, is shown by a horizontal line 1-2 extending from right to left.
- The point 3 represents the surface temperature of the heating coil.
- The heat rejected by air during sensible cooling may be obtained from the psychrometric chart by the enthalpy difference ($h_1 - h_2$).
- It may be noted that the specific humidity during the sensible cooling remains constant ($\omega_1 = \omega_2$)
- The dry bulb temperature reduces from t_{d_1} to t_{d_2} and relative humidity increases from ϕ_1 to ϕ_2.
- The amount of heat rejected during sensible cooling may also be obtained from the relation.

Heat rejected, $Q = h_1 - h_2$

$$= C_{pa}(t_{d_1} - t_{d_2}) + \omega C_{ps}(t_{d_1} - t_{d_2})$$

$$= (C_{pa} + \omega C_{ps})(t_{d_1} - t_{d_2})$$

$= C_{pm}(t_{d_2} - t_{d_1})$

- The terms $(C_{pa} + w\, C_{ps})$ is called humid specific heat (C_{pm}) and its value is taken as 1.022 kJ/kg.k.

Heat rejected, $Q = 1.022(t_{d_1} - t_{d_2})$ kJ/kg.k.

Humidification and dehumidification :-

Humidification :-

- The process of increasing the moisture content in the air without altering the dry bulb temp. is called humidification.
- During humidification DBT of air remains constant.
- There will be increase in relative humidity WBT dew point temp.
- Change in enthalpy is $h_2 - h_1 = L(w_2 - w_1)$

where, L = Latent heat of vaporisation at DBT.

Dehumidification :-

- The process of decreasing the moisture content of air without altering the dry bulb temp. is called dehumidification.
- During dehumidification DBT of air remains constant.
- There will be decrease in relative humidity WBT dew point temperature.
- Change in enthalpy is

$$h_1 - h_2 = L(w_1 - w_2)$$

where, L = Latent heat, measured at DBT.

Air conditioning defination :

Air conditioning is defined as the process of simultaneous control of temp, humidity, cleanliness and distribution to meet the requirements of the conditioned space.

- The meaning of the key wards in the above defination is given below.
- control of themperature implies that maintaining the temperature for human comfort.
- It needs heating in winter or cooling in summer.
- Control of humidity means increasing or decreasing the moisture content in the air.
- It depends on ~~the~~ weather conditions.
- Moisture content in the air is increased in winter and decreased in summer.
- Control of cleanliness means improving the purity of air by removing dust and other undesirable elements.
- Cleanliness of air is ensured through the use of filters.

Morden application :-

1. It is used in cinema halls, office buildings, public auditoriums, homes, class-rooms etc.
2. Also provided in research test cabinets, factories workshops etc, for better control to product quality, texture and uniformity.
3. Automobiles, railways, jute, and cloth industries, photography, restaurants, printing industries and hospital.

Comfort air Conditioning :-

Comfort air conditioning requires the careful consideration of the temp, humidity, air movement, Purity and noise.

- Temperature and humidity can be controlled by means of appropriate air conditioning equipment and a refrigeration system.
- Air movement is maintained at the desired speed with the help of distribution system and grilles.
- Air is cleaned by passing through the filters and by using different types of separators.
- Large sized particles are removed by means of inertia separators and small size particles of about 0.3 micron are removed by using electrostatic separators.
- In this way the comfort air conditioning system create Conditions Co-ductive to human health and comforts.

Air conditioning System :-

- An air conditioning system consists of assembly of different components to produce design conditions of air within the required space.
- The essential components of air conditioning system are.

(i) outdoor air intake
(ii) pre heater
(iii) Filter
(iv) De-humidifier
(v) Humidifier.
(vi) Heating Coil.
(vii) Refrigeration system

(i) outdoor air intake :-

ventilation and marginal weather cooling screens. louvers, dampers etc, are used which constitute outdoor air intake components.

(ii) Pre-heater :-

– To heat up air that enters the space to be conditioned generally in winter AC system.

(iii) Filters :-

The main function of filter is to remove dust, dirt and other harmful bacteria from the air.

(iv) Dehumidifier :-

A direct spray washer or cooling coil which is supplied with chilled water.

(v) Humidifier :

It is used to reheat the air in summer and winter AC systems in order to control temperature and humidity.

(vi) Refrigeration system :-

Refrigeration system to produce and maintain low temperature.

Classification of air conditioning System :-

– Air Conditioning Systems are classified as given below

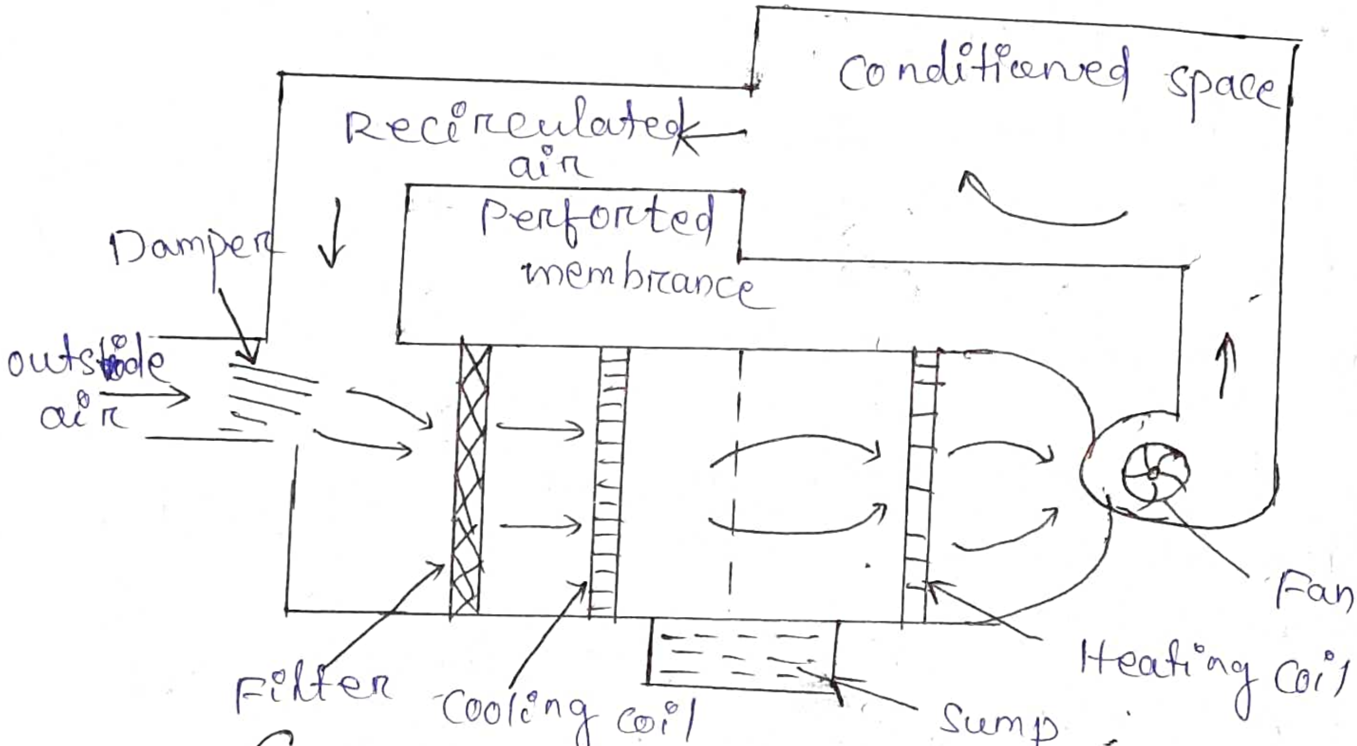
– According to the seasons of the year.

- Summer air conditioning
- Winter air conditioning
- Year round air conditioning.

- According to the application of the system
  - Comfort air conditioning
  - Industrial air conditioning
- According to the location of equipment.
  - unitary system.
  - Central satation system
  - combination system.

Summer air conditioning System :-

- It is the most important type of air conditioning, in which the air is cooled and generally dehumidified.
- The schematic arrangement of a typical summer air conditioning system is shown below.

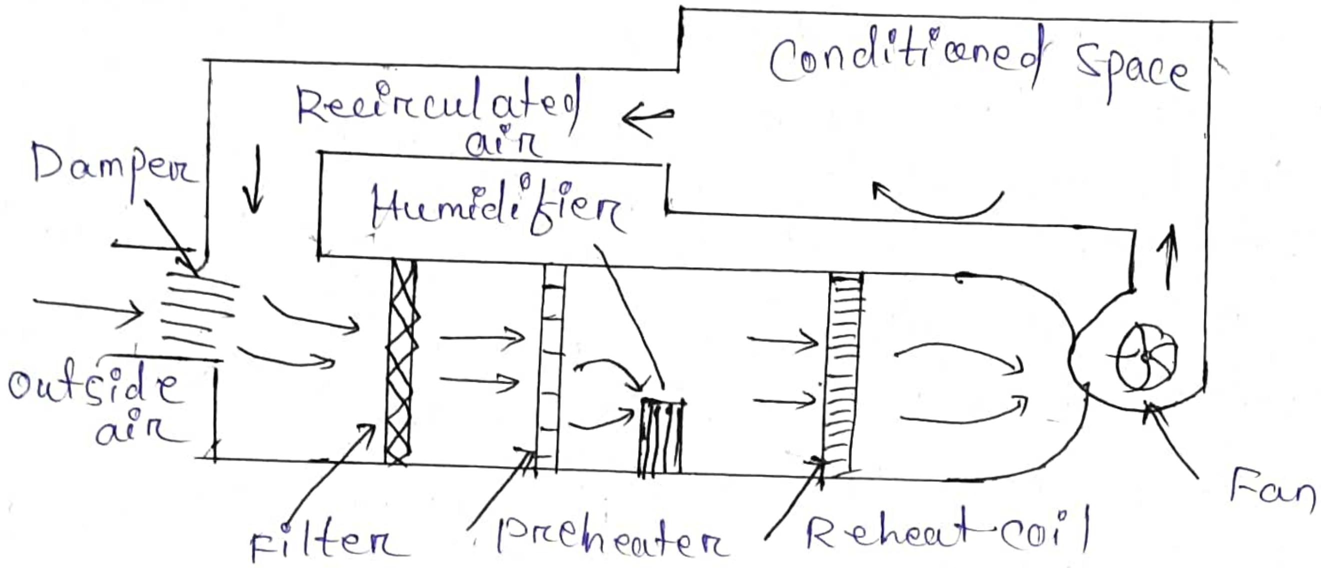


(Summer air conditioning system)

- The outside air flows through the damper, and mixes up with recirculated air.
- The mixed air passes through a filter to remove dirt, dust and other impurities.
- The air now passes through a cooling coil. The coil has a temperature much below the required DBT of the air in the conditioned space.
- The cooled air passes through a perforated membrane and loses its moisture in the condensed form which is collected in a sump.
- After that the air is made to pass through a heating coil which heats up the air slightly.
- This is done for bring the air to the designed DBT and relative humidity.
- Now the conditioned air is supplied to the conditioned space by a fan.
- From the conditional space, a part of the used air is exhausted to the atmosphere by the exhaust fans or ventilators.
- The remaining part of the used air is again conditioned as show.
- The outside air is sucked and made to mix with the re-circulated air in order to make up for the loss of conditioned air through exhaust fans or ventilation from the conditioned space.

Winter air conditioning system :-

- In winter air conditioning, the air is heated, which is generally accompanied by humidification.
- The schematic arrangement of the system is shown in figure.



- The outside air flows through a damper and mixes up with the recirculated air.
- The mixed air passes through a filter to remove dirt, dust and other impurities.
- The air now passes through a preheat coil in order to prevent the possible freezing of water and to control the evaporation of water in the humidifier.
- After that the air is made to pass through a reheat coil to bring the air to the designed DBT.
- Now the conditioned air is supplied to the conditioned space by a fan.

From the conditioned space, a part of the used air is exhausted to the ~~out~~ atmosphere by the exhaust fans or ventilators.

- The remaining part of the used air is again conditioned as shown.
- The outside air is sucked and made to mix with re-circulated air, in order to make up for the loss of conditioned air through exhaust fans or ventilation from the conditioned space.