

## **LEARNING MATERIALS**

**SEMESTER : 5TH SEMESTER**

**BRANCH : MECHANICAL ENGINEERING**

**SUBJECT : REFRIGERATION & AIRCONDITIONING  
(TH-5)**

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## RAC

Refrigeration → Means a continued extractions of heat from a body whose temp is already below the temp of atmospheric surroundings.

Or It may be defined as the process of removing heat from a substance under controlled condition.

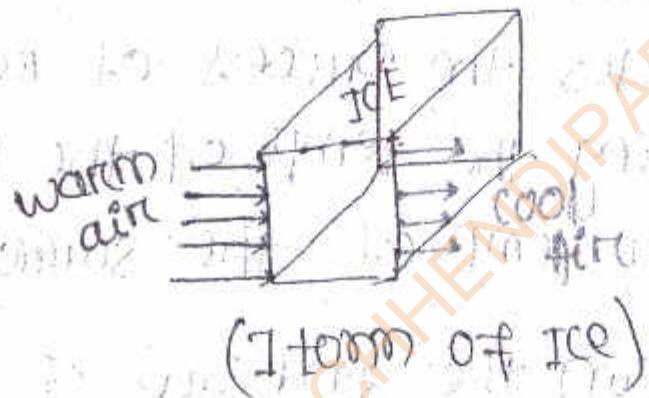
- It also includes the process of reducing and maintaining the temp of the body below general temp of the surrounding.
- It works upon the 2nd law of T.D. about the direction of heat transfer.
- Removing of heat transfer.
- The removal of heat from one place and depositing it to another using intermediate (evapor compression, Refrigeration system).

## \* Refrigeration Effect

The amount of heat absorbed by the refrigeration system from the space to be cooled in a given time is called Refrigeration Effect.

→ Unit : kJ/min

### Units of Refrigeration →



- The practical unit of Refrigeration is tonne of Refrigeration.
- A tonne of refrigeration is defined as the amount of Refrigeration Effect produced by the uniform melting of 1 tonne (1000 kg) of Ice from and at  $0^{\circ}\text{C}$  in 24 hours.
- Latent heat of ice  $335 \text{ kJ/kg}$ .

1 TOR (Tonne of Refrigeration) =  $335 \times 1000$   
(in 24 hours)

$$1\text{TOR} = 335000$$

$$1\text{ hour} = \frac{335000}{24} = 13958.3$$

$$1\text{min} = \frac{335000}{24 \times 60} = 232.6 \text{ kJ/min}$$
  
$$= 232.6 \text{ kJ/min}$$

$$1\text{sec} = \frac{232.6}{60} = 3.87 \text{ kJ/sec (3.5)}$$

$$1 \text{ kJ/sec} = \text{kWatt}$$

→ In actual practice 1 TR is taken as 210 kJ/min. which is equivalent to 3.5 kW.

$$1\text{TOR} = 210 \text{ kJ/min} = 3.5 \text{ kW}$$

co-efficient of performance of refrigerator (COP)

→ Ratio of heat extracted to the workdone

$$\boxed{\text{COP} = \frac{Q}{W}}$$

•  $Q$  = amount of heat extracted in the Refrigerator

•  $W$  = Amount of workdone

problem :-

find the COP of a refrigeration system

If the work input is 80 kJ/kg and refrigeration Effect produced is 160 kJ/kg.

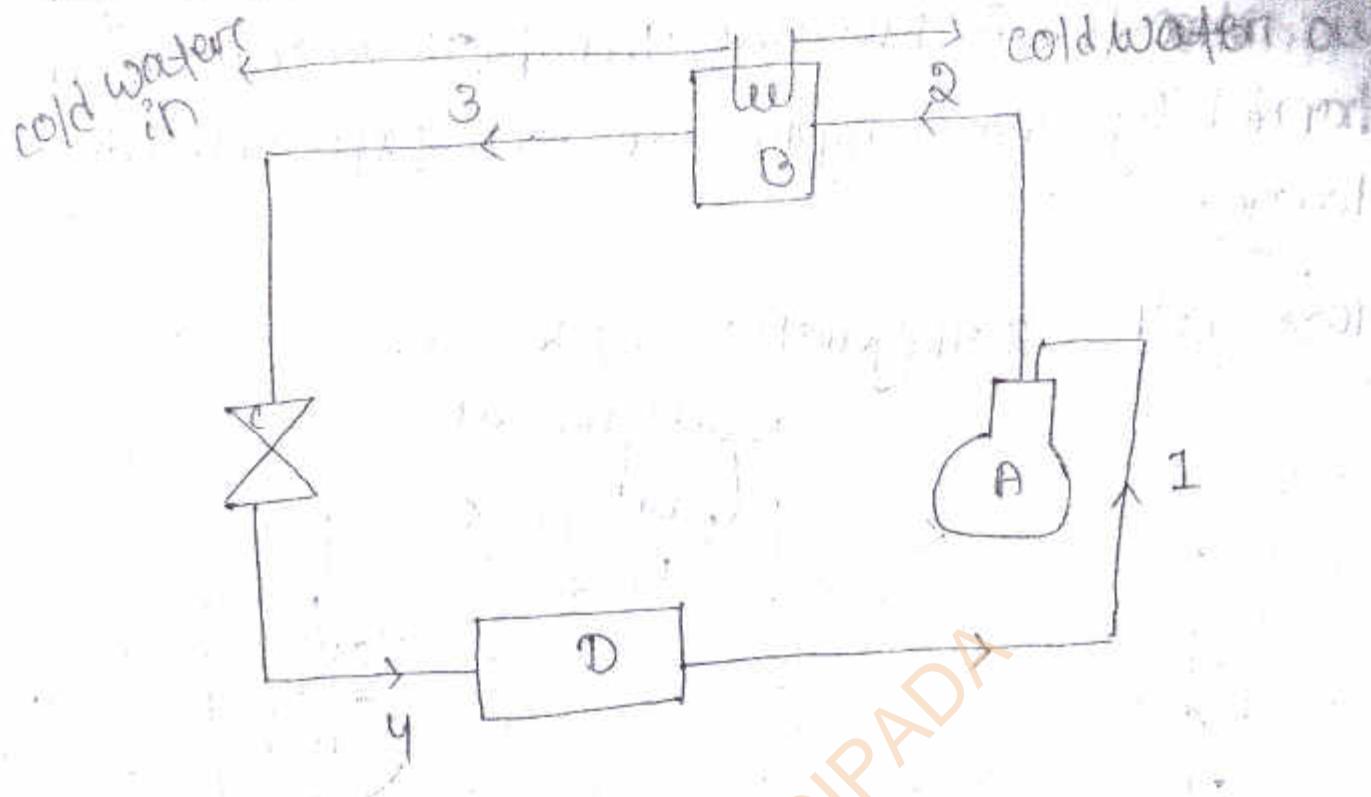
Given data →

$$W = 80 \text{ kJ/kg}$$

$$Q = 160 \text{ kJ/kg}$$

$$\text{COP} = \frac{Q}{W} = \frac{160}{80} = 2$$

## open air refrigeration cycle



A → compressor (1-2)

B → Heat. Exchanger (2-3)

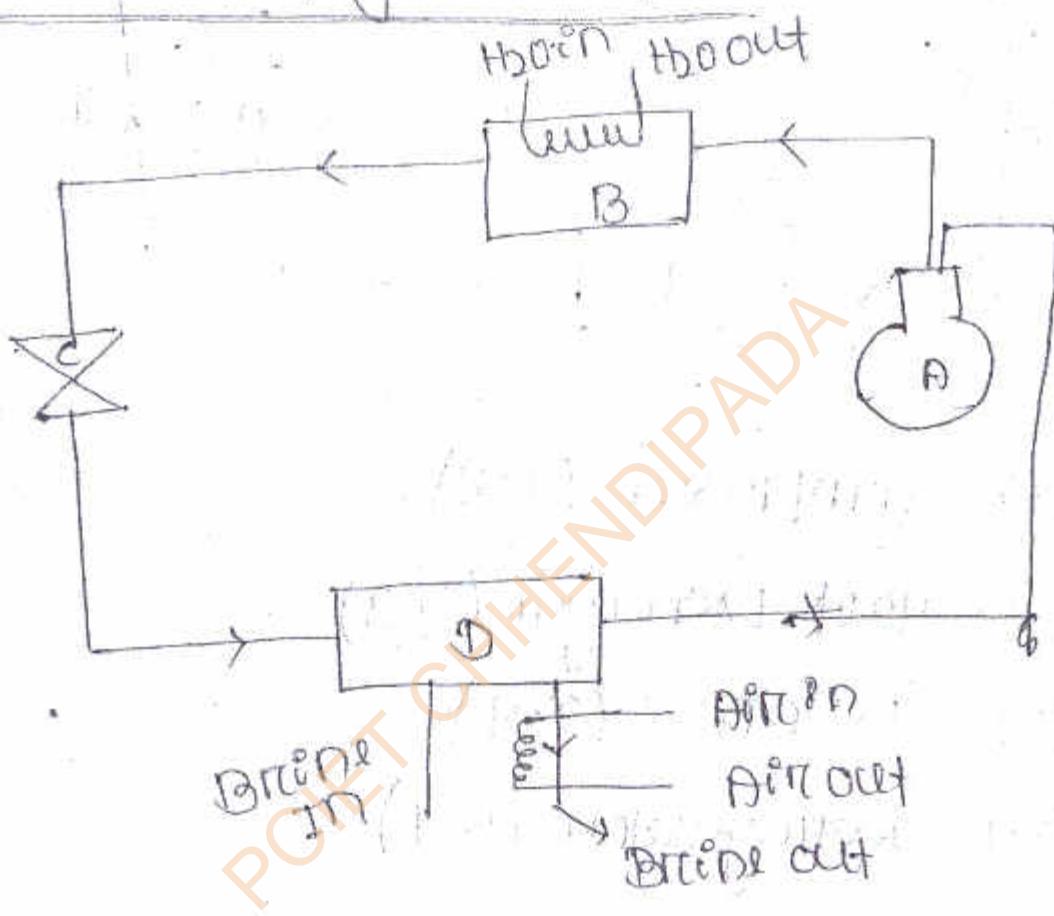
C → Expander (3-4)

D → Refrigerator (4-1)

→ In open air refrigeration cycle, the air is directly fed to the space / surrounding to be cooled. (i.e. Refrigerator) allowed to circulate through the cooler and then return to compressor to start the another cycle.

→ Since the air is supplied to the refrigeration at atmospheric pressure, therefore volume air handled by the compressor and expander is large.

CLOSE AIR REFRIGERATION CYCLE →



A → compressor

B → cooler

C → Expander

D → Refrigerator

Brine :

Acqua solution of sodium chloride (NaCl) is called brine.

\* The water that contain salt is called brine.

- In closed/dense air refrigeration cycle the air pass through the pipes and components parts of the system all time. This air in the system is used for absorbing heat from the other fluid i.e. brine and this cool brine is circulated into this space to be cooled.
- The air in the closed system does not come in contact directly with the space to be cooled.

Advantages →

- since it can work at a suction pressure higher than atmospheric pressure therefore the volume of air is handled by compressor and expanders are smaller as compared to open air cycle.
- The operating pressure ratio can be increased which a result higher COP.

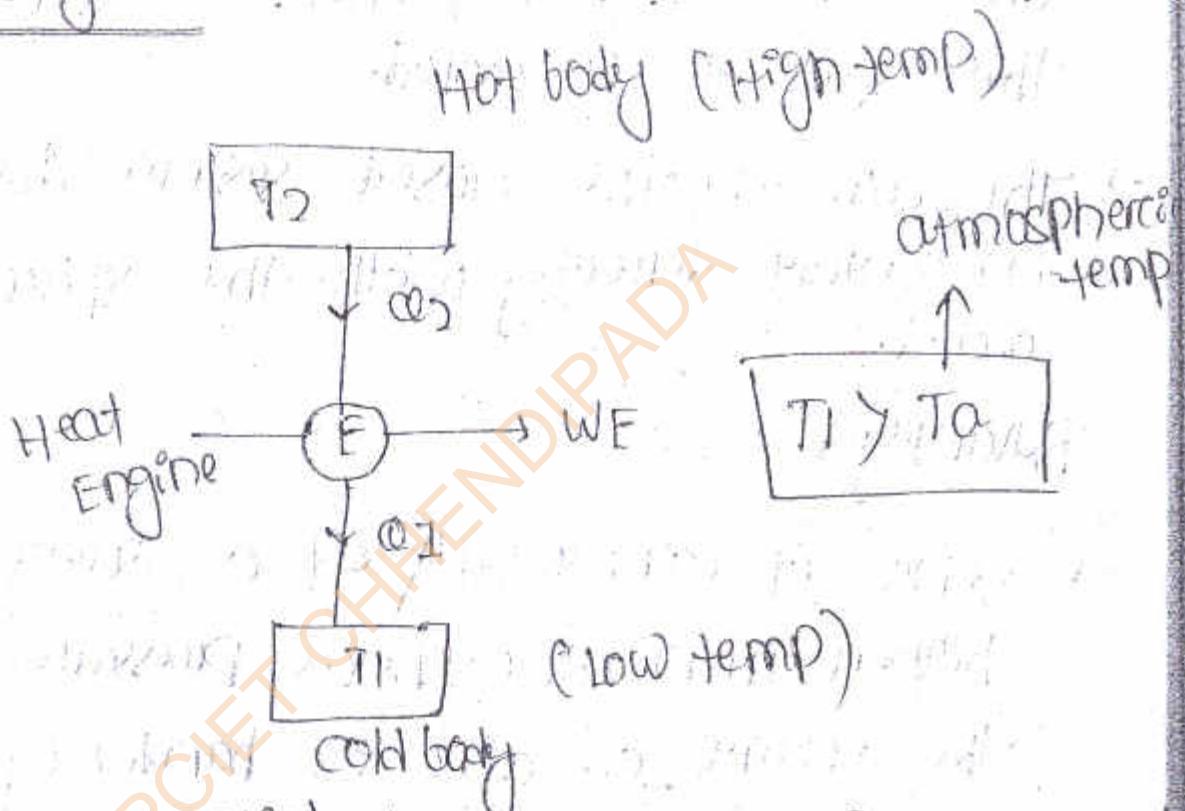
Refrigerant :-

It is a heat carrying medium in which heat absorb from space by evaporating / Latent heat at low temperatures, and reject heat to atmosphere by condensing at high temperatures.

→ It consists of Evaporation & condensation which absorb heat & produce cooling.

Difference b/w Heat Engine, Refrigerator and heat pump →

Heat Engine →



→ The heat supplied to the engine is converted into useful work. If  $Q_2$  is the heat supplied to the engine and  $Q_1$  is the heat rejected from the engine.

Now work done by the engine,

$$WE = Q_2 - Q_1$$

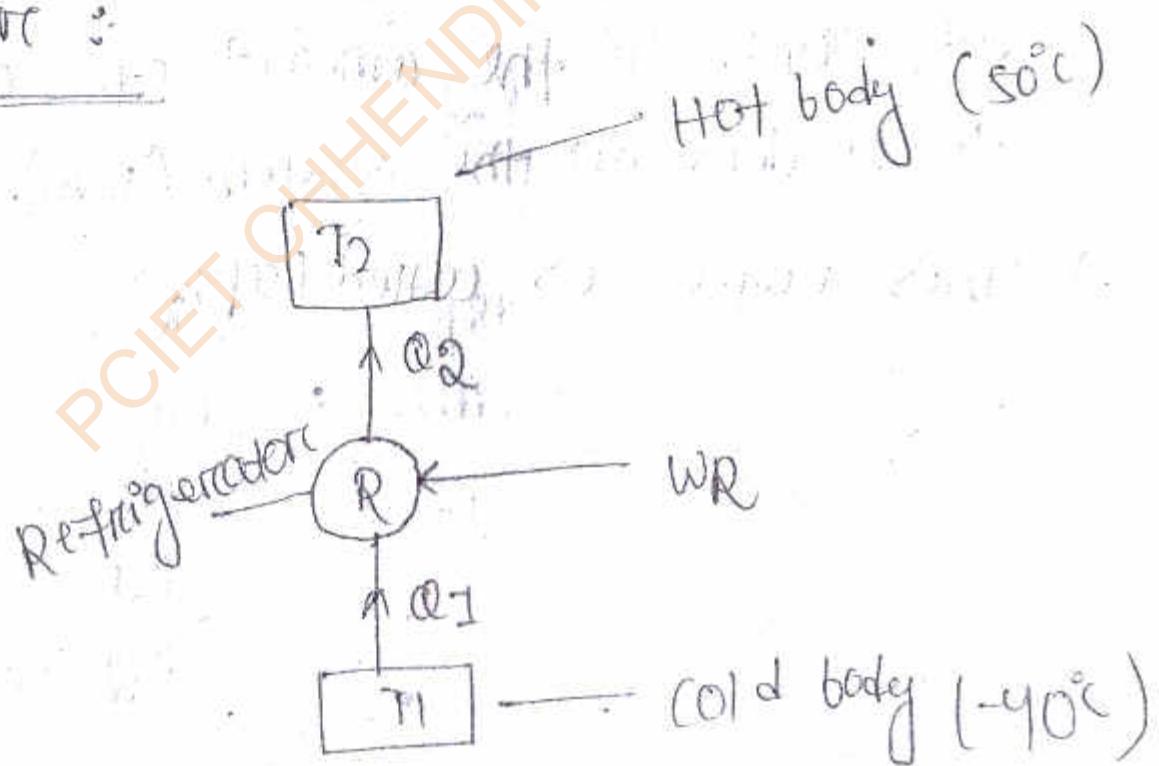
$$Q_2 = WE + Q_1$$

The performance of Engine is expressed by Efficiency or COP of Engine.

$$\eta_E \cdot /(\text{COP})_E = \frac{\text{Workdone}}{\text{Heat supplied}} = \frac{WE}{Q_2}$$

$$\frac{WE}{Q_2} = \frac{Q_2 - Q_1}{Q_2}$$

Refrigerator :



- A Refrigerator is Reversed heat Engine which either cool or maintain the temp of a body  $T_1$  Lower than atmospheric temp ( $T_a$ ).

This is done by extracting heat ( $Q_1$ ) from the cold body and deposit it onto a hot body ( $Q_2$ ).

Work done by Refrigerator,

$$W_R = Q_2 - Q_1$$

(1st law of T.D.)

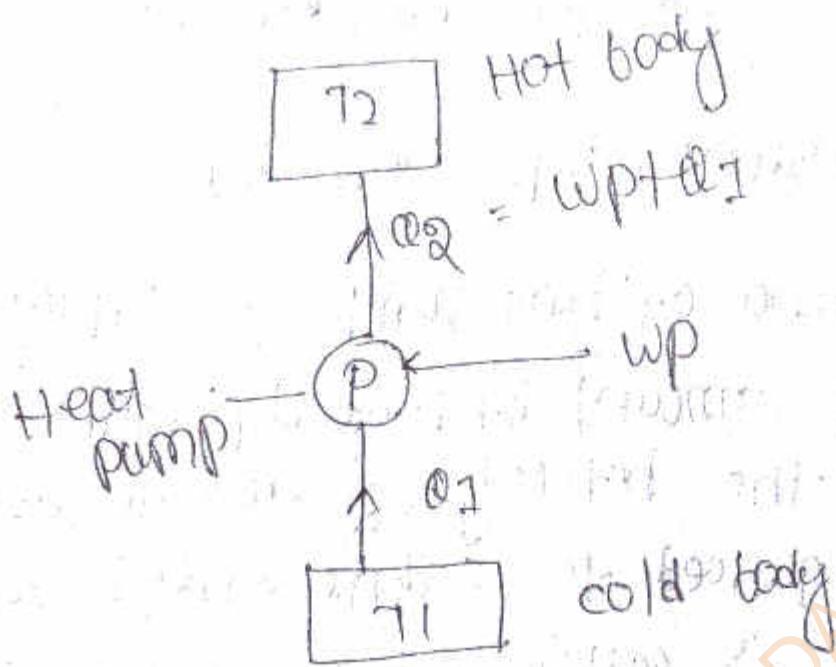
→ The performance of a refrigerator is expressed by the ratio of heat taken from the cold body ( $Q_1$ ) to the amount of work required to be done on the system ( $W_R$ ).

→ This ratio is called  $(COP)_R$

$$= \frac{Q_1}{W_R}$$

$$= \frac{Q_1}{Q_2 - Q_1}$$

## Heat pump :



- Any refrigeration system is a heat pump which extract heat ( $Q_1$ ) from a cold body and delivers it into a hot body.
- Thus there is no difference b/w the cycle operation of a heat pump & a refrigerator.
- The main difference b/w these two is in their operating temperatures.
- A Refrigerator works b/w the cold body temp  $T_1$  and atmospheric temp ( $T_a$ ). whereas a heat pump operates b/w the hot body temp ( $T_2$ ) and the atmospheric temp ( $T_a$ ).

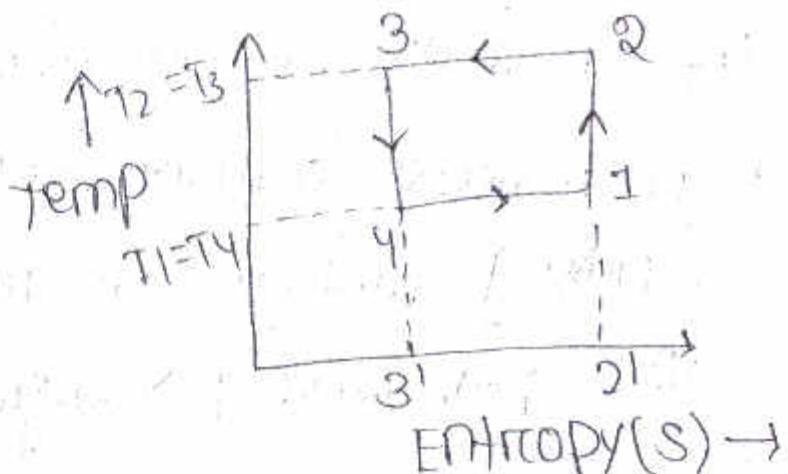
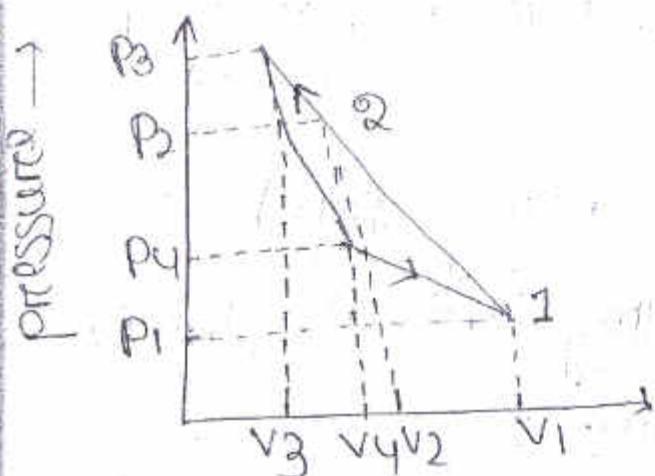
- a) refrigerator used for cooling in summer  
& heat pump used for heating in winter.

$$\text{Workdone, } WP = Q_2 - Q_1$$

- The performance of heat pump is Expressed by the ratio of amount of heat deposited or delivered to the hot body  $Q_2$  to the amount of work required to be done on the system ( $WP$ ) this is called COP of pump or E.P.R (Energy performance ratio)

$$E.P.R = \frac{Q_2}{WP} = \frac{Q_2}{Q_2 - Q_1}$$

A<sup>c</sup>t<sup>c</sup> refrigeration working on Reversed Carnot cycle  $\rightarrow$



volume  $\rightarrow$   
(P-v diagram)

(T-S diagram)

PROCESS, 1-2  $\rightarrow$  Isentropic compression process

2-3  $\rightarrow$  Isothermal compression process

3-4  $\rightarrow$  Isentropic Expansion process

4-1  $\rightarrow$  Isothermal Expansion.

$\rightarrow$  In refrigeration system the Carnot cycle is considered as Reversed Carnot cycle.

We know that a heat Engine working in Carnot cycle has the max<sup>m</sup> efficiency.

Lightly a refrigerating system working on Reversed Carnot cycle will have the maximum possible COP, but we know that it is not possible to make an engine working on

cannot cycle.  
cannot cycle similarly it is also not possible to make a refrigerating m/c working on the reverse carnot cycle.

- A reverse carnot cycle using air as working medium or refrigerant as shown the P-V and T-S diagram.

Let,  $P_1, V_1, T_1$  be the pressure, volume and temp. of air.

process (1-2) [S=c]

- The air is compressed isentropically as shown by the curve P-V & T-S diagram.
- During this process the pressure of air increases, specific volume decreases from  $V_1$  to  $V_2$  and temp increases from temp ( $T_1$ ) to temp ( $T_2$ ).
- we know that in this process no heat is absorbed or rejected by the air.

process (2-3)

The air is now compressed isothermally i.e constant temp ( $T_2 = T_3$ ) as shown by 2-3 on P-V and T-S diagram.

→ During this process the pressure of air increases from  $P_2$  to  $P_3$  and specific volume decreases from  $V_2$  to  $V_3$ .

We know that the heat rejected by the air during isothermal compression per kg of air.

$q_{II0}$  = heat rejection

$$q_{II} = q_{2-3} = \text{area } 2-3 - 3'-2'$$

$$q_{II} = T_3 (S_2 - S_3) \quad [ \because T_2 = T_3 ]$$
$$= T_2 (S_2 - S_3)$$

### Process (3-4)

The air is expanded isentropically as shown by the curve 3-4 on P-V & T-S diagram.

→ The pressure of air decreases from  $P_3$  to  $P_4$  specific volume increases from  $V_3$  to  $V_4$  and the temp decreases from (3-4).

In this process no heat is absorbed or rejected by the air.

## process (4-1)

The air is now expanded isothermally i.e. at constant temp  $T_4 = T_1$  as shown by the curve 4-1 on P-V & T-S diagram.

→ The pressure of air decreases from 4-1 & specific volume increases from volume  $V_4$  to  $V_1$ .

Hence heat absorbed by the air or heat rejected / extracted from the cold body during isothermal expansion.

$$q_A = q_{4-1} = \text{Area } 4-1-21-31$$

$$q_A = T_4 (S_1 - S_3) \quad [ \because T_4 = T_1 ] \\ = T_1 (S_1 - S_3)$$

work done during the cycle per kg of air

$$\text{work done (WR)} = q_{12} - q_A$$

$$= q_{2-3} - q_{4-1}$$

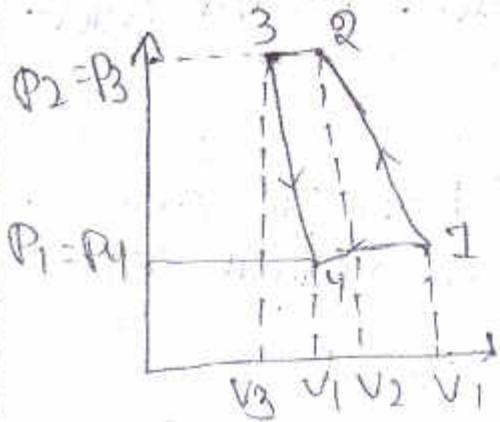
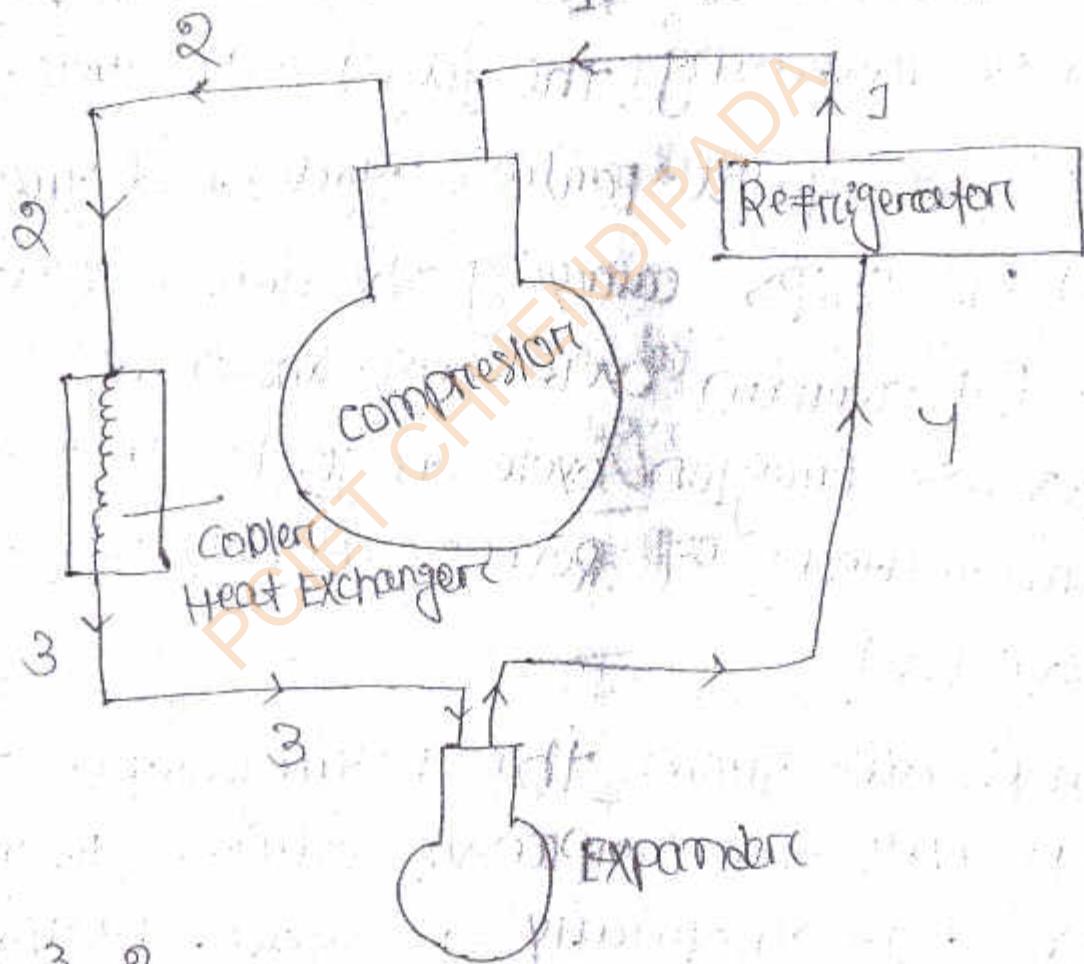
$$= (T_2 - T_1)(S_2 - S_3)$$

$$(COP)_R = \frac{\text{Heat absorbed}}{\text{WR}}$$

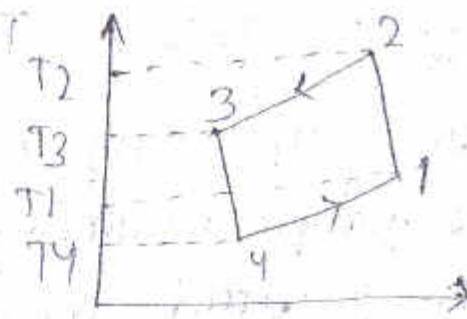
$$= \frac{T_1 (S_2 - S_3)}{(T_2 - T_1)(S_2 - S_3)}$$

$$2) \frac{Q_A}{W_R} = \frac{T_1}{T_2 - T_1}$$

calculation of COP of Bell-Coleman cycle /  
Reversed Brayton cycle / Joule cycle  $\rightarrow$



(P-V diagram)



(T-S diagram)

process,

| 1-2 → Isentropic compression process

| 2-3 → constant pressure cooling process.

| 3-4 → Isentropic expansion process

| 4-1 → constant pressure expansion process.

- a) Bell cole man air refrigeration m/c was developed by bell cole man and light for by reversing the joule air cycle.
- It is one of the earliest types of Refrigerators used in ships carrying the frozen meat.  
The bell coleman cycle also known as reverse brayton cycle or Joule cycle is a modification of reverse carnot cycle.

process (1-2)

The cold air from the refrigerator is drawn into the compressor cylinder where it is compressed isentropically as shown by the curve 1-2 on p-v & T-s diagram.

- During the compression stroke both pressure and temp. increases and specific volume of air delivered from compressor reduce from  $V_1$  to  $V_2$ .

→ During the isentropic process no heat absorbed or rejected by the air.

### 2-3 process

The warm air from the compressor is now pass into the cooler where it is cooled at constant pressure ( $P_3 = P_2$ ) Reducing the temp from  $T_2$  to  $T_3$  (The temp of cooling water) as shown by the curve 2-3 on p-v & T-s diagram.

This specific volume also reduced from  $V_2$  to  $V_3$ .

We know that heat rejected by the air during constant pressure per kg of air

$$q_{rej} = \dot{Q}_{2-3} = c_p(T_2 - T_3)$$

### process 3-4

The air from the cooler is now drawn into the expander cylinder where it is expanded isentropically from pressure  $P_3$  to  $P_4$  (Refrigerator pressure) which is equal to the atmospheric pressure.

The temp of air during expansion fall from  $T_3$  to  $T_4$  (i.e. <sup>the</sup> temp much below the temp of surroundings)

- The Expansion process is shown by the curve 3-4 on P-V & T-S diagram.
- The specific volume of air at entry to the refrigerator increases from  $v_3$  to  $v_4$ .
- We know that during isentropic Expansion of air, no heat is absorbed or rejected by the air. process (4-1)
- The cold air from the Expander is now pass to the refrigerator where it is expanded at constant pressure ( $p_4 = p_1$ ).
- The temperature of air increases from  $T_4$  to  $T_1$ . This process is shown by the curve 4-1 on the P-V & T-S diagram.
- Due to the heat from the refrigerator the specific volume of the air changes from  $v_4$  to  $v_1$ .
- we know that the heat absorbed by the air or (heat extracted from the refrigerator or refrigerating Effect produced) during constant pressure expansion per kg of air.

$$Q_A = Q_{4-1} = CP(T_4 - T_1)$$

Work done during the cycle per kg of air  $\rightarrow$

$$= \text{Heat rejected} - \text{Heat absorbed}$$

$$= q_{12} - q_A$$

$$= CP(T_2 - T_3) - CP(T_4 - T_1)$$

co-efficient of performance (COP)

$$\text{COP} = \frac{\text{Heat absorbed}}{\text{Workdone}} = \frac{q_A}{q_{12}}$$

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

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

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

now taking common,

$$= \frac{T_4 \left( \frac{T_1}{T_4} - 1 \right)}{T_3 \left( \frac{T_2}{T_3} - 1 \right) - T_4 \left( \frac{T_1}{T_4} - 1 \right)} \quad \text{--- (2)}$$

→ for isentropic compression process 1-2

(1) Ratio of specific heat

$$\frac{T_2}{T_1} = \left( \frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} \quad \text{--- (2')}$$

Similarly for isentropic expansion process 3-4

$$\frac{T_3}{T_4} = \left( \frac{P_3}{P_4} \right)^{\frac{\gamma-1}{\gamma}} \quad \text{--- (2'')}$$

Since  $P_2 = P_3$  and  $P_1 = P_4$  therefore

from the eqn & p 3

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} \quad \text{or} \quad \frac{T_2}{T_3} = \frac{T_1}{T_4}$$

Now substituting this value in eqn 2)

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

$$= \frac{1}{\frac{T_3}{T_4} - 1}$$

$$\boxed{COP = \frac{1}{\left( \frac{P_3}{P_4} \right)^{\frac{\gamma-1}{\gamma}} - 1}}$$

Problem -

In a refrigeration plant working on a bell-comer man cycle, air is compressed to 5 bar from 1 bar. Its initial temp is  $10^{\circ}\text{C}$ . After compression the air is cooled upto at  $20^{\circ}\text{C}$ . In a cooler before expanding back to a pressure of 1 bar. Determine the COP of the plant and net refrigerating effect.

Take  $\text{CP} = 1.005 \text{ kJ/kg}$   
 $\text{CV} = 0.718 \text{ kJ/kg}$

Given data:

$$P_2 = P_3 = 5 \text{ bar}$$

$$P_1 = P_4 = 1 \text{ bar}$$

$$T_1 = 10^{\circ}\text{C} = 10 + 273 = 283 \text{ K}$$

$$T_3 = 20^{\circ}\text{C} \rightarrow 293 \text{ K}$$

$$\text{CP} = 1.005 \text{ kJ/kg}$$

$$\text{CV} = 0.718 \text{ kJ/kg}$$

$$\gamma = \frac{\text{CP}}{\text{CV}} = 1.39$$

Isentropic index for compression and expansion process,  $\gamma = \frac{\text{CP}}{\text{CV}} = 1.39$

for isentropic compression (I-2)

$$\frac{T_2}{T_1} = \left( \frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow \frac{T_2}{T_1} = \left( \frac{5}{1} \right)^{\frac{1.39-1}{1.39}} = (5)^{0.28} = 1.57$$

for Isoentropic Expansion (3-4)

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

$$= 1.57$$

$$\left[ \therefore \frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} \right]$$

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

$$\boxed{T_3 = 72 \\ T_1 = T_4}$$

$$\Rightarrow T_4 = \frac{T_3}{1.57} = \frac{293}{1.57} = 186 \text{ K}$$

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

COP of the plants,  $\frac{\text{Heat absorbed}}{\text{Work done}}$

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

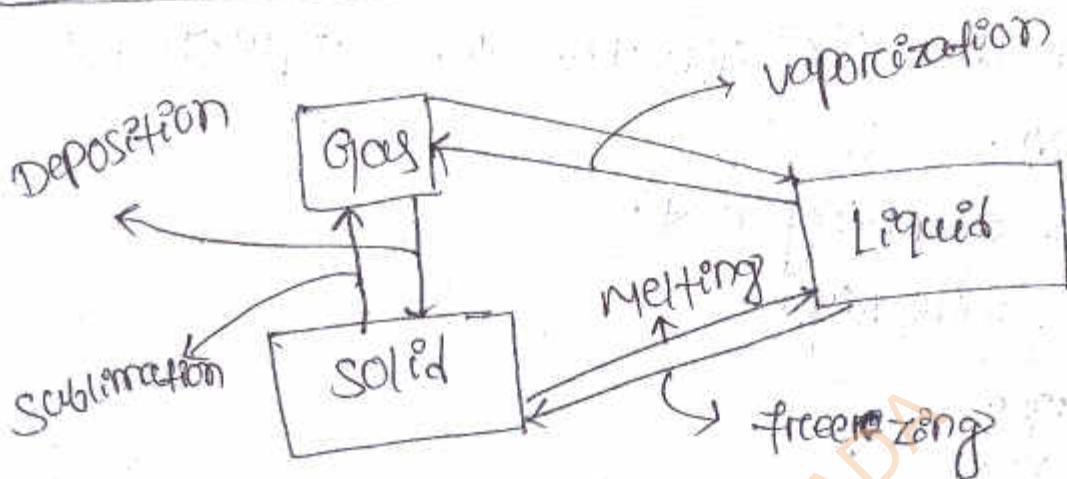
$$= \frac{186}{293 - 186} = 1.73$$

Net refrigerating Effect, = Heat absorbed during  
constant pressure (4-1)

$$= CP(T_1 - T_4)$$

$$\text{heat input} = 97.48 \text{ kJ/kg}$$

simple vapour compression Refrigeration system →



(Refrigeration & Phase change )  
dig.

- A vapour compression refrigeration system is an improved type of air refrigeration system in which a suitable working substance termed as Refrigerant is used.
- The refrigerant is usually used for this purpose once ammonia ( $\text{NH}_3$ ), carbon dioxide ( $\text{CO}_2$ ), sulfur dioxide ( $\text{SO}_2$ ).
- The refrigerant used does not leave the system but circulated throughout the cycle.
- The first vapour compression system was developed in 1834 by Jacob Perkins.

Advantages and disadvantages of vapour compression refrigeration system over air refrigeration system →

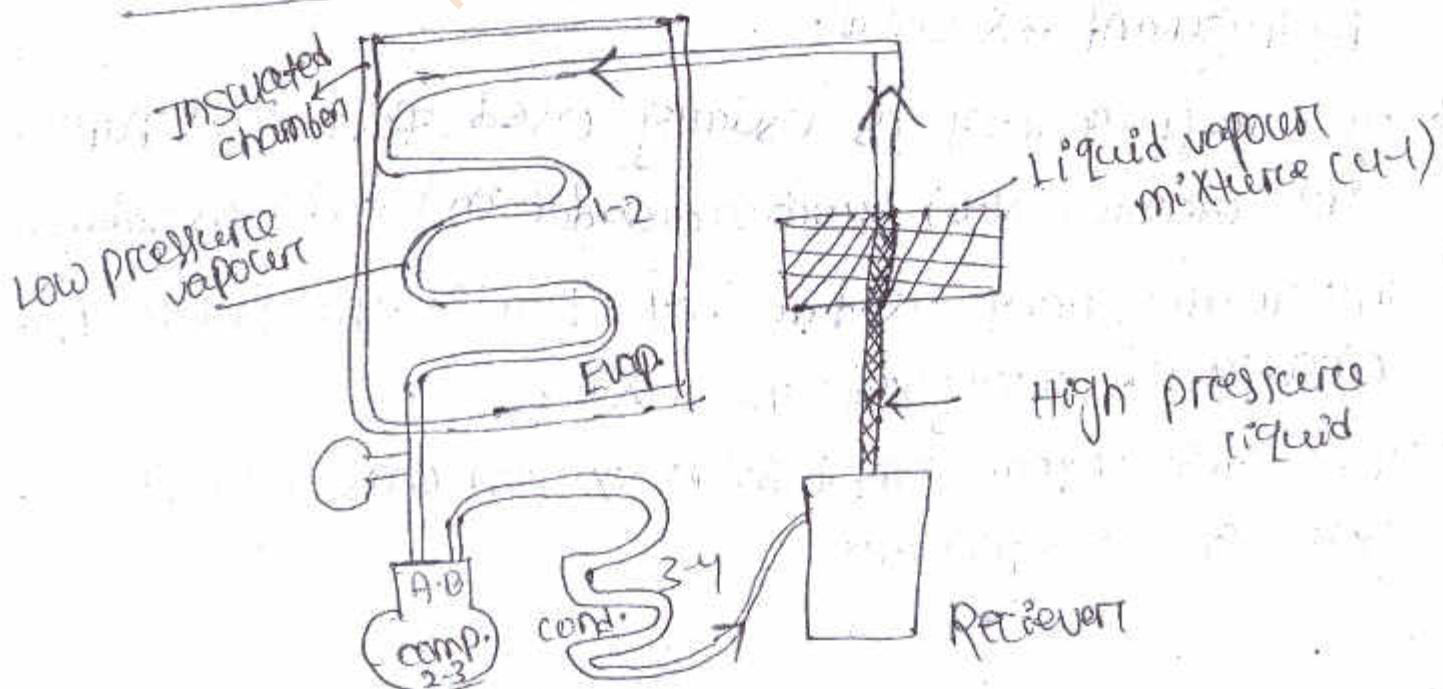
### Advantages :

- It has similar size for the given capacity of refrigeration.
- It has less running cost.
- The COP is wide high.

### Disadvantages

- The initial cost is very high.
- The prevention of leakage of refrigerant is the major problem in vapour compression system.

### \* Mechanism of a simple vapour compression Refrigeration system →



## Evaporator :-

An evaporator consist of coils of pipe in which the liquid vapour refrigerant at low pressure and temp is evaporated and change into vapour refrigerant at low pressure and temp.

- In evaporating the liquid vapour refrigerant absorbed its latent heat of vaporization from the medium (air, water, brine) which is to be cooled.

## compressor :-

- The low pressure and temp vapour refrigerant from evaporator is drawn into the compressor through the inlet and suction valve A-B whence it is compress to a high pressure and temp.
- This high pressure and temp vapour refrigerant is discharge into the condenser through the discharge valve.

## condenser :-

- condenser is used to cool the vapour and the vapour will converted into liquid.
- The condenser or cooler consist of coils of pipe in which the high pressure and temp vapour refrigerant is condense.

→ The refrigerant while passing through the condenser gives up its latent heat to the surrounding.

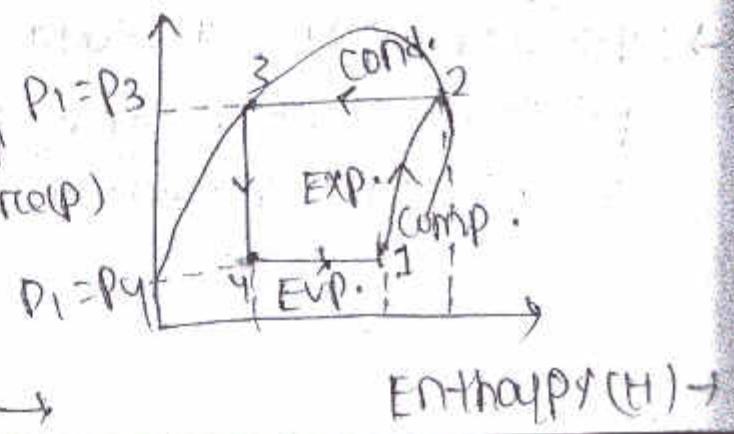
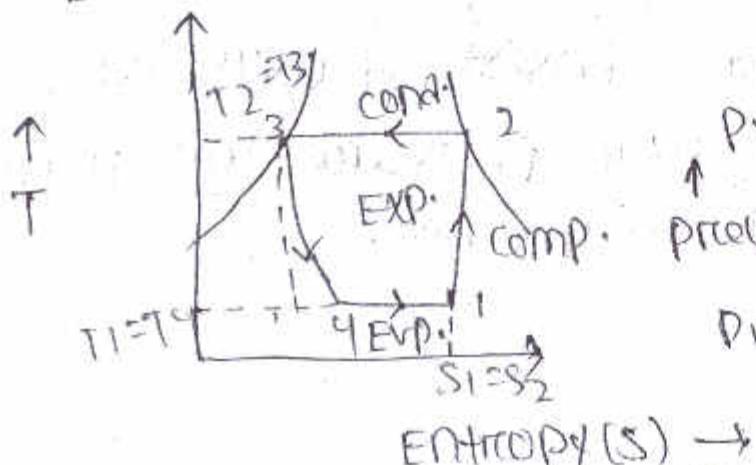
### Receiver :

→ The receiver is a storage tank which stores the liquid refrigerant.

→ The condensed liquid refrigerant from the condenser is stored in a vessel known as receiver, from whence it is supplied to the evaporator through the expansion valve or throttle valve / control valve.

### Types of vapour compression cycle →

- ⇒ cycle with dry saturated vapour after compression.
- ⇒ cycle with wet vapour after compression.
- ⇒ cycle with superheated vapour after compression.
- ⇒ cycle with superheated vapour before compression.
- ⇒ cycle with under cooling or sub cooling of refrigerant.
- ⇒ cycle with dry saturated vapour after compression.



- A vapour compression cycle with dry saturated vapour after compression is shown by the T-S & P-H diagram.
- At point 1 let  $T_1, P_1$  &  $s_1$  be the temp, pressure & entropy of the vapour refrigerant respectively.

### Process (1-2) [Compression process]

- The vapour refrigerant at low pressure ( $P_1$ ) and temp ( $T_1$ ) is compressed isentropically to dry saturated vapour as shown by the vertical line 1-2 on T-S diagram and by the curve 1-2 on P-H diagram.
  - The pressure & temp raise from  $P_1$  to  $P_2$  and temp  $T_1$  to  $T_2$ .
- workdone during isentropic compression per kg of refrigerant

$$W_f = h_2 - h_1$$

whence,

$h_1$  = Entropy of vapour refrigerant

(Suction of the compression) at temp  $T_1$

$h_2$  = Entropy of vapour refrigerant at temp  $T_2$  (discharge of compressor)

## process (2-3) [condensing process]

- The high pressure & temp vapour refrigerant from the compressor is pass through the condenser whence it is completely condensed at constant pressure  $P_2$  and temp  $T_2$  as show by the horizontal line 2-3 on T-S & P-H diagram.
- The vapour refrigerant is converted into liquid refrigerant while passing through the condenser gives its latent heat to the surrounding condensing medium.

## Expansion process (3-4) →

- The liquid refrigerant at pressure ( $P_3 = P_2$ ) and temp ( $T_2 = T_3$ ) is expanded by throttling process through the expansion valve at low pressure  $P_1 = P_4$  & temp ( $T_1 = T_4$ ) as shown by the curve 3-4 on P-H & T-S diagram.
- The liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporized in the evaporator.

## Evaporating process (4-1) / Evaporating process →

Liquid vapour mixture of the refrigerant pressure  $p_1 = p_4$  and temp  $T_4 = T_1$  is evaporated and change into vapour refrigerant constant pressure and temp as show by the horizontal line 4-1 on T-S & P-H diagram.

During EVAPORATION the liquid vapour refrigerant absorbs its latent heat of vapourisation from the medium. (air, water brine solution)

Refrigerating Effect (RE) =

Heat absorbed / Extracted - refrigerant Evaporating

per kg of

$$RE = h_1 - h_4$$

$h_1 - h_4 = hf_3$   
↑ sensible heat at temp  $T_3$ .

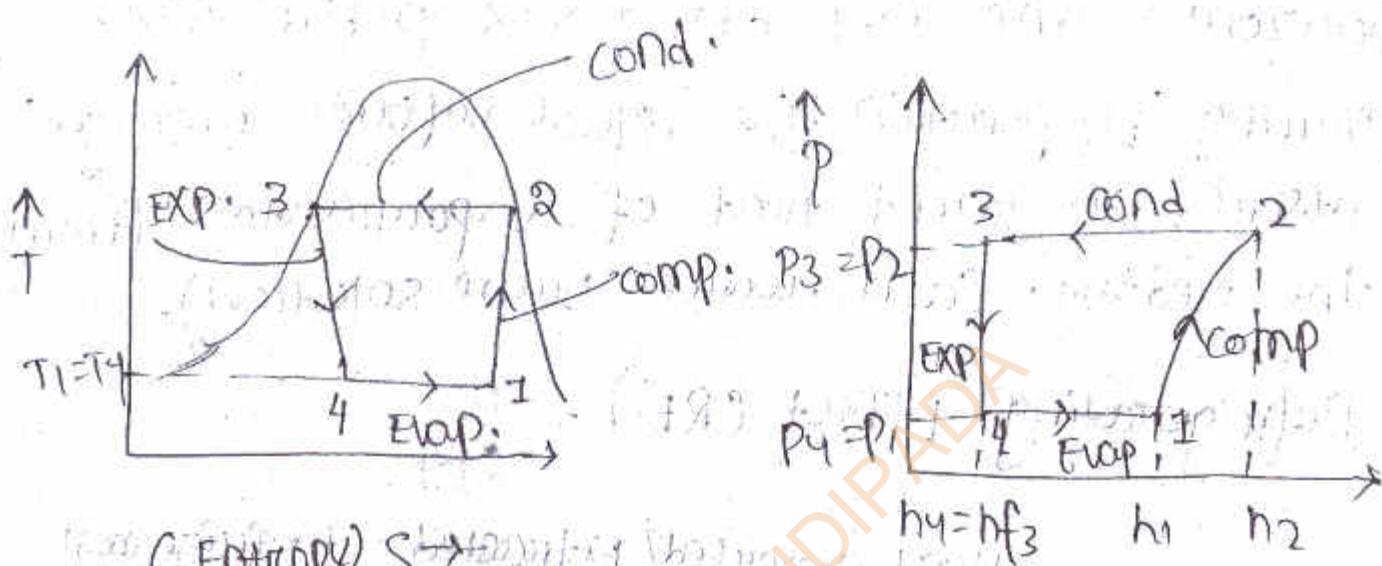
(e.g. Enthalpy of liquid refrigerant leaving the condenser.)

COP = Refrigerating Effect (RE)

workdone

$$COP = \frac{h_1 - h_4}{h_2 - h_1} = \frac{h_1 - h_{f3}}{h_2 - h_1}$$

→ cycle with wet vapour after compression →



→ A vapor compression cycle with wet vapour after compression is shown by the curve on T-s & p-h diagram.

- In this cycle the Enthalpy at point 2 is found out with the help of dryness fraction at this point.
- The dryness fraction at point 1 & 2 may be obtained by equating Entropy at point 1 & 2

COP & Refrigerating Effect

worke done

$$= \frac{h_1 - h_{f3}}{h_2 - h_1}$$

problem →

In an ammonia ( $\text{NH}_3$ ) vapour compression system the pressure in the evaporator is 2 bar.  $\text{NH}_3$  at exit is 0.85 dry and at entry its dryness fraction is 0.19. During compression the workdone per kg of  $\text{NH}_3$  is 150 kJ. Calculate the COP and the volume of vapours entering the compression per minute. If the rate of  $\text{NH}_3$  circulation is 4.5 kg/min the latent heat & specific volume at 2 bar are 1325 kJ/kg and 0.58 m<sup>3</sup>/kg.

Given data:

$$P_1 = P_4 = 2 \text{ bar} \text{ (Pre. at Evap.)}$$

$$\text{NH}_3 \text{ Exit } (x_1) = 0.85$$

$$(\text{entry}) x_4 = 0.19$$

$$\text{workdone} = 150 \text{ kJ/kg}$$

$$(\text{Mass of Refg.}) m_0 = 4.5 \text{ kg/min}$$

$$\text{S.P. volume} = 0.58 \text{ m}^3/\text{kg}$$

$$\text{Latent heat} = 1325 \text{ kJ/kg}$$

Dryness fraction →

\*

$$x = \frac{m_s}{m_s + m_w}$$

$m_s \rightarrow$  mass of dry steam

$m_w \rightarrow$  mass of water vapour

DIG

→ Since the  $NH_3$  vapour at entry to the evaporator (i.e. at point 4) has dryness fraction ( $x_4$ ) = 0.19, therefore the Enthalpy at point 4 is

$$h_4 = x_4 \times h_{fg}$$

Enthalpy = dryness fraction  $\times$  latent heat

$$h_4 = 0.251 \cdot 74.671 \text{ kJ/kg}$$

Enthalpy of ammonia vapour dryness fraction,

$$h_1 = x_1 \times h_{fg}$$

$$= 0.85 \times 1325$$

$$= 1126.25 \text{ kJ/kg}$$

Heat extracted from the evaporation refrigerating effect,  $RE = h_1 - h_4 = 874.545 \text{ kJ/kg}$

work during compression,  $W = 150 \text{ kJ/kg}$  (from notes)

$$\text{COP} = \frac{RE}{W}$$

$$= \frac{874.5}{150} = 5.83$$

volume of vapour entering the compression per minute. = mass of refrigerant  $\times$  SP volume

$$m_a \times V_g$$

$$= 4.5 \times 0.58$$

$$= 2.61 \text{ m}^3/\text{min}$$

problem :-

The temp limit of  $\text{NH}_3$  refrigerating system are  $25^\circ\text{C}$  and  $-10^\circ\text{C}$ . If the gas is dry at the end of compression.

calculate the cop of the cycle assuming no under cooling of the liquid  $\text{NH}_3$ .

use the following table for properties of  $\text{NH}_3$ .

Temp $^\circ\text{C}$	Liquid heat $\text{kJ/kg}$	Latent heat	Liquid Entropy $\text{kJ/kg}\text{K}$
25	298.9	1166.94	1.1242
-10	133.37	1297.68	0.5443

Given data :-

$$T_2 = T_3 = 25^\circ C \Rightarrow 25 + 273 = 298 K$$

$$T_1 = T_4 = -10^\circ C \Rightarrow -10 + 273 = 263 K$$

$$h_4 = h_{f3} = 298.9 \text{ kJ/kg} \text{ (liquid heat)}$$

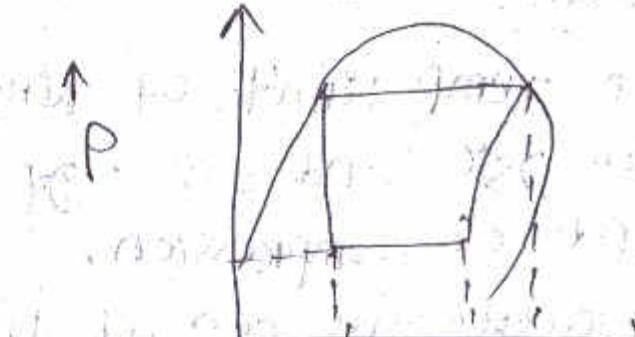
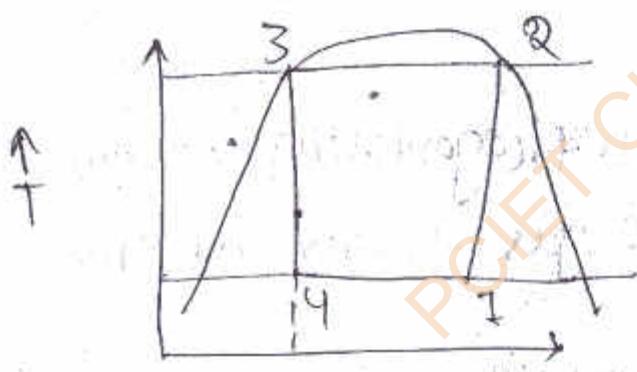
$$h_{fg} = 1166.94 \text{ kJ/kg.} \text{ (latent heat)}$$

$$s_{f2} = 1.1242 \text{ kJ/kg}$$

$$h_{f1} = 138.37 \text{ kJ/kg} \text{ (liquid heat)}$$

$$h_{fg1} = 1297.68 \text{ kJ/kg}$$

$$s_{f1} = 0.54 \text{ kJ/kg}$$



Let,  $x_1$  = dryness fraction at point 1

so ENTHALPY at point 1

$$S_1 = \frac{s_{f1} + x_1 \times h_{fg1}}{T_1}$$

$$S_1 = \frac{0.54 + x_1 \times 297.68}{263}$$

$$S_1 = 0.54 + 4.93 u_1 \quad \text{--- (1)}$$

$$S_1 = 0.54 + 4.93 u_1 \quad \text{--- (2)}$$

Similarly,  $S_2 = \frac{S_f^2 + h_f g_2}{T_2}$

$$= \frac{1.1242 + 1166.94}{298}$$

$$S_2 = 5.04$$

Since Entropy at point 1 = Entropy at Point 2

so equating 1 & 2

$$S_1 = S_2$$

$$\Rightarrow 0.54 + 4.93 u_1 = 5.04$$

Enthalpy at point 1 on (P-H)

$$h_1 = h_f^1 + u_1 \times h_f g_1$$

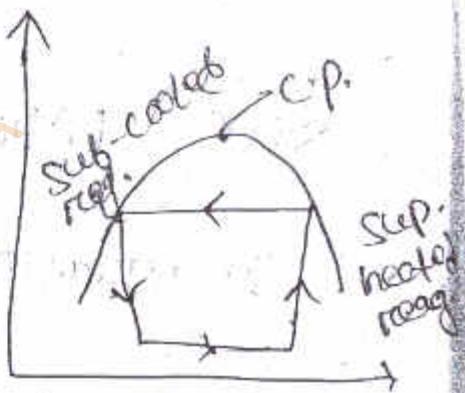
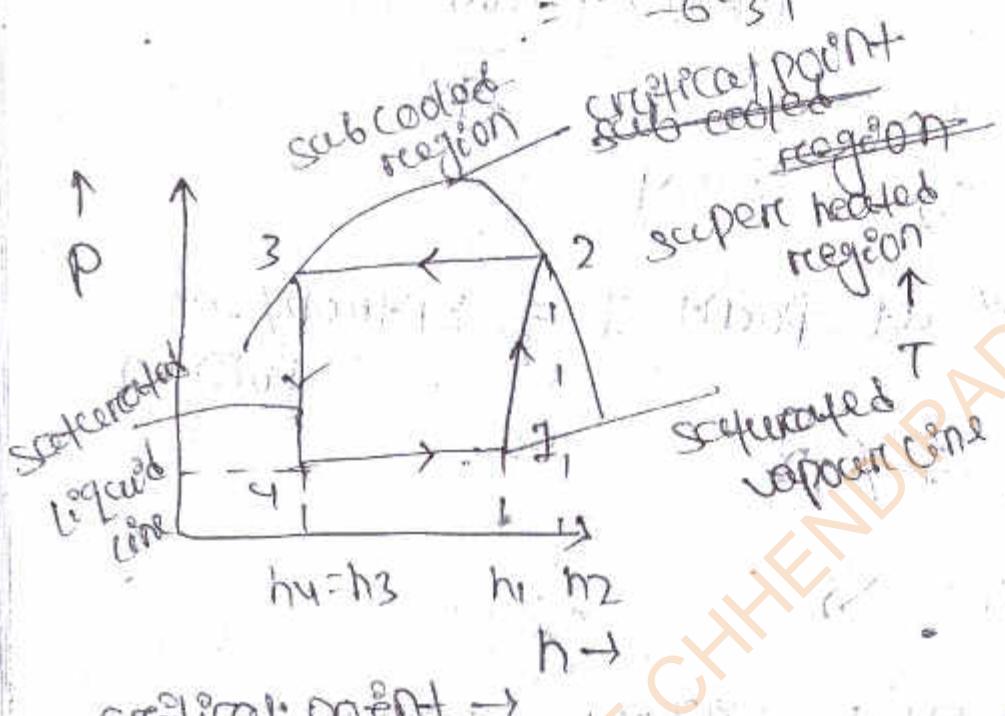
$$h_1 = 1316.26 \text{ kJ/kg}$$

$$h_2 = h_f^2 + h_f g_2$$

$$= 1166.94 + 1.1242$$

$$= 1168.06 \text{ kJ/kg}$$

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



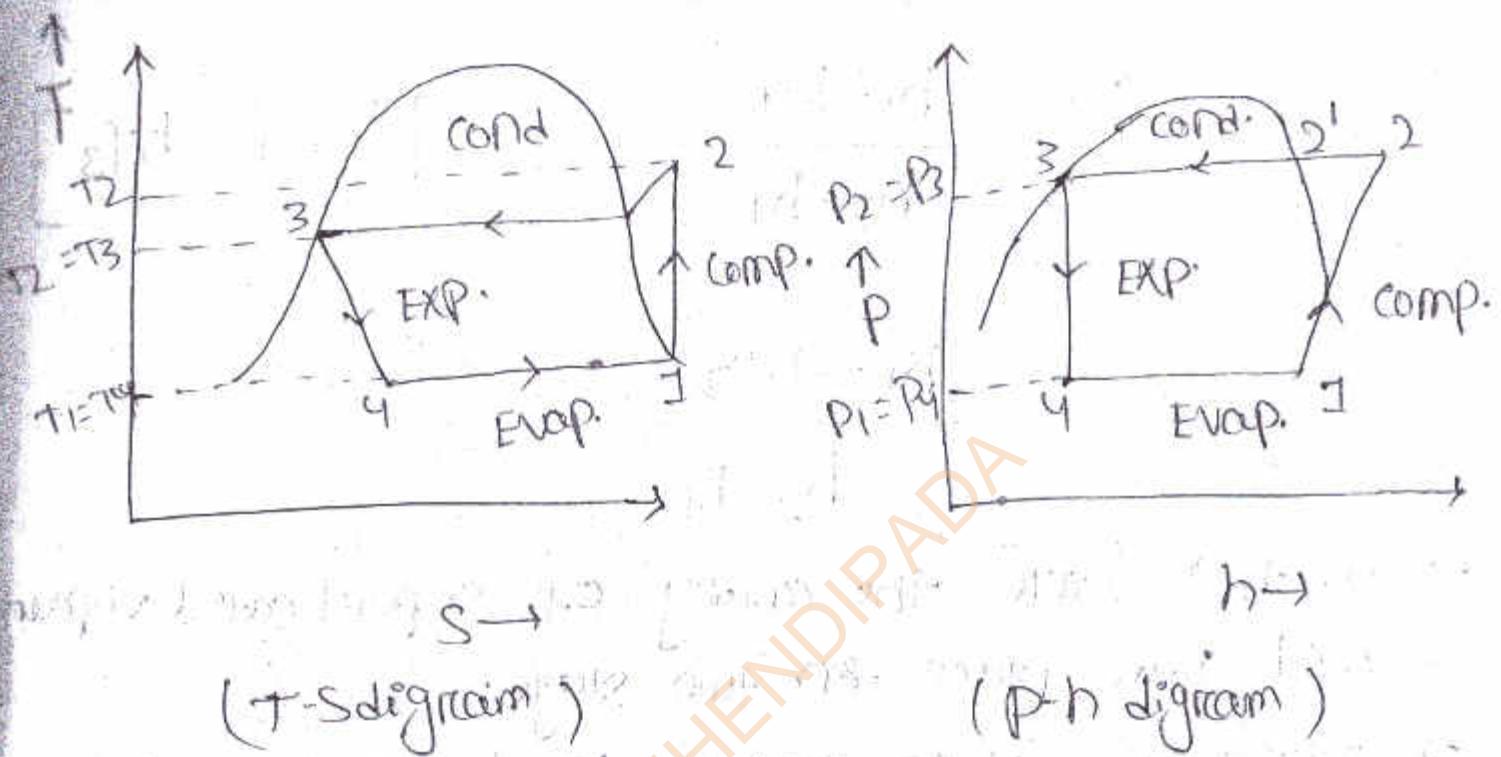
critical point →

**critical point** is the point of saturated liquid line on left hand side and saturated vapour line on right hand side.

$$h_4 = h_{f3}$$

→ It easier to find the Enthalpy of those point which are in saturation curve so  $h_4$  would be replaced by  $h_3 + \Delta h_f - \Delta h_f_3$ .

Vapour compression cycle with superheated vapours after compression →



- Super heated vapour is a vapour at a temp higher than its vaporizing point at the absolute pressure where the temp is measured.
- A vapour compression cycle with a superheated vapour after compression is shown on the above fig on T-S & P-h diagram.
- In this cycle the enthalpy at point 2 is found out with the help of degree of superheat.
- The degree of superheat may be found out by equating the entropy at point 1 & 2 on compression process.

→ Now,

## COP, Refrigerating Effect

work done

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

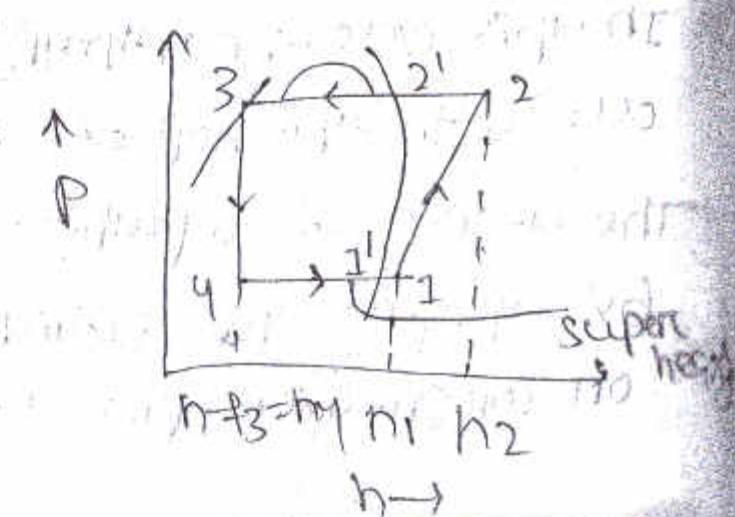
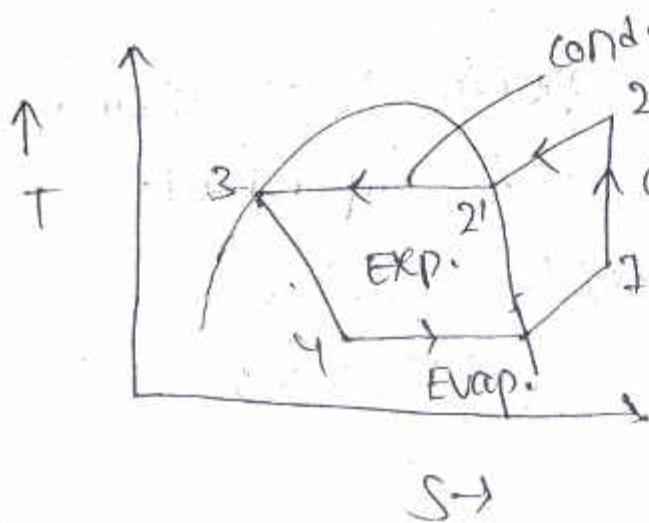
$$[\because h_4 = h_{f3}]$$

$$= \frac{h_1 - h_{f3}}{h_2 - h_1}$$

→ In this cycle the cooling of superheated vapour will take place in two stages.

→ firstly it will be condensed to dry saturated stage at constant pressure by the graph 2 to 2' and secondly it will be condensed at constant temp by graph 2' to 3.

ii) vapour compression cycle with superheated vapour before compression →



A vapor compression cycle with superheated vapour before compression is shown by the above curves T-S & P-H diagram.

In this cycle the evaporation starts at point 4 and continue upto 11, when it is dry saturated.

Vapour is now superheated before entering the compressor upto the point 1.

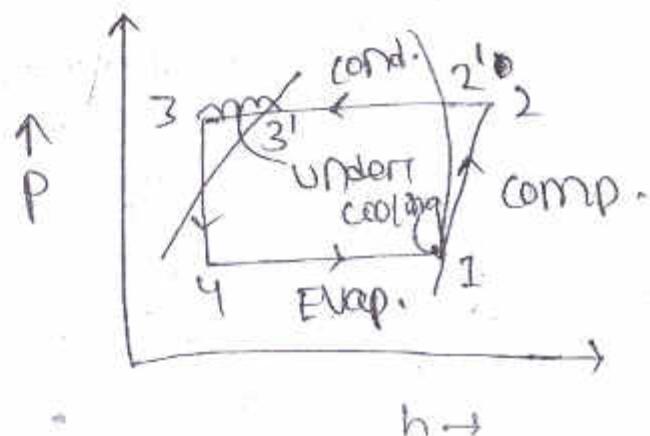
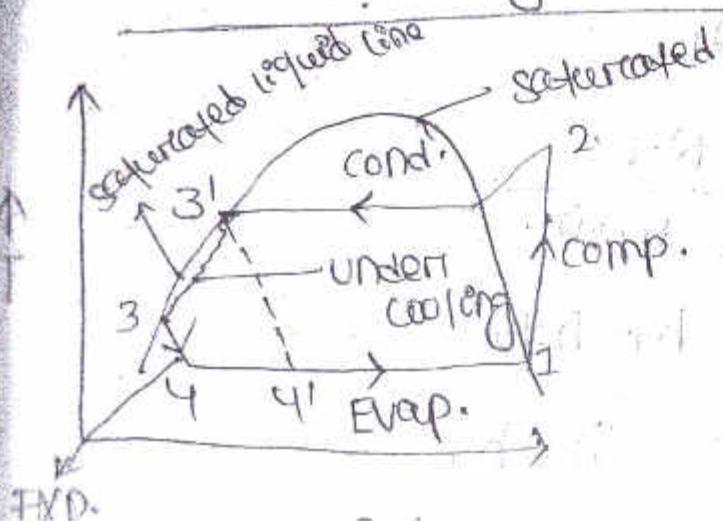
$$\text{The COP, } \text{COP} = \frac{\text{R.E}}{\text{W.D.}}$$

$$= \frac{h_1 - h_{f3}}{h_2 - h_1}$$

### NOTE

In this cycle the heat is absorbed or extracted in two stages firstly from point 4 to point 11 and secondly from point 11 to 1.

Vapor compression cycle with under cooling or sub-cooling of refrigerant →



- Some time the refrigerant after condensation process 21 to 31 is cooled below the saturation temp ( $T_3'$ ) before expansion by throttling.
- Such a process is called under cooling or sub-cooling of the refrigerant.
- The sub cooling of the refrigerant is generally done along the liquid line as show on the above diagram, Here refrigerant Effect is increase.
- The ultimate effect of the under cooling is to increase the value of COP under the same set of condition.
- The process of undercooling is generally brought about by circulating more quantity of cooling water through the condenser.
- Some times this process is also brought about by adding a heating in a heat exchanger.

$$R.E. = h_1 - h_4 \quad [ \because h_4 = h_{f3} ]$$

$$\text{workdone} = h_2 - h_1$$

$$COP = \frac{R.E.}{W.D.}$$

$$= \frac{h_1 - h_{f3}}{h_2 - h_1}$$

NOTE :-

$$h_{fg} = h_f' - c_p X \text{ Degree of under cooling}$$

\*  $h_f$  : specific Enthalpy of saturated liquid

$h_g$  : specific Enthalpy of saturated gas

$h_{fg}$  : Represent Enthalpy difference b/w gas and liquid and tells how much heat is needed to change 1 kg of boiling water to steam.

OR  $h_{fg}$  = latent heat of Evap.

(Energy required to transfer saturated water into dry saturated steam)

$$h_{fg} = h_g - h_f$$

→ Difference b/w specific Enthalpy value of the substance.

problem →

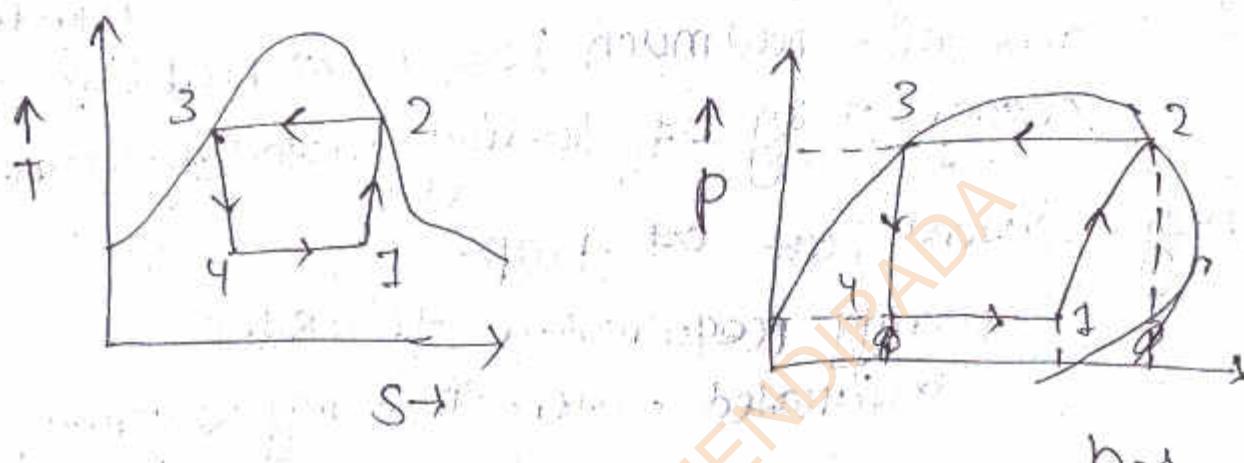
A vapour compression refrigerator works b/w the pressure limit of 60 bar and 25 bar. The working fluid is just dry at the end of compression and there is no under cooling of the liquid before the expansion valve. Determine

1) COP of the cycle

2) capacity of the Refrigerator if the fluid flow is at rate of 5 kg/min.

<u>pressure (bar)</u>	<u>saturation temp (K)</u>	<u>Enthalpy liquid/vapour</u>	<u>Entropy liquid/vapour</u>
60	295	151.96 / 293.29 56.32 / 322.58	0.554 / 1.033 0.226 / 1.246
25	261		

Given data:



$$\text{pressure, } P_2 = P_3 = 60 \text{ bar}$$

$$P_1 = P_4 = 25 \text{ bar}$$

temperature,

$$T_2 = T_3 = 295 \text{ K}$$

$$T_1 = T_4 = 261 \text{ K}$$

$$h_4 = h_3 = 151.96 \text{ kJ/kg}$$

$$h_1 = h_2 = 56.32 \text{ kJ/kg}$$

$$h_2 = h_3 = 293.29 \text{ kJ/kg}$$

$$h_1 = 322.58 \text{ kJ/kg}$$

$$s_{f1} = 0.226$$

$$s_{f2} = 0.554$$

$$s_{g1} = 0.226$$

$$Sg_1 = S_1 = 1.0332 \text{ kJ/kg-K}$$

Let,  $x_1$  = dryness fraction of the vapour refrigerant entering to the compression at point 1.

$S_1$  = Entropy at point 1.

$$S_1 = S_{f1} + x_1 (S_{fg1})$$

$$= S_{f1} + x_1 (Sg_1 - S_{f1})$$

$$S_1 = S_{f1} + x_1 S_{fg1}$$

$$= S_{f1} + x_1 (Sg_1 - S_{f1})$$

$$[\because Sg_1 = S_{f1} + S_{fg1}]$$

$$= 0.226 + x_1 (1.12464 - 0.226)$$

$$S_1 = 0.226 + 1.024 x_1 = 1.0332$$

$$S_2 = Sg_2 = 1.0332 \text{ kJ/kg-K}$$

Since Entropy at point equal to the Entropy at point 2 Therefore equating eq<sup>n</sup>  $\Rightarrow$   $x_1$

$$x_1 = 0.79$$

NOW Enthalpy 1.

$$h_1 = h_{f1} + x_1 h_{fg1}$$

$$= h_{f1} + x_1 (h_{g1} - h_{f1})$$

$$h_1 = 266.66 \text{ kJ/kg} \quad [ \because h_{fg1} = h_f + h_{g1} ]$$

$$\begin{aligned} \text{COP} &= \frac{h_1 - h_2}{h_2 - h_1} \\ &= \frac{266.66 - 151.96}{293.29 - 266.66} \\ &= 4.30 \end{aligned}$$

Capacity of refrigerator,

Heat Extracted on Refrigerating Effect produced per kg of refrigerant =  $h_1 - h_f$

$$\begin{aligned} &= 266.66 - 151.96 \\ &= 114.7 \text{ kJ/kg} \end{aligned}$$

Since the fluid flow at the rate of 5 kg per minute so total heat extracted equal to  $5 \times 114.7$

$$= 573.5 \text{ kJ/min}$$

Capacity of refrigerator,

$$\frac{573.5}{210} = 2.73$$

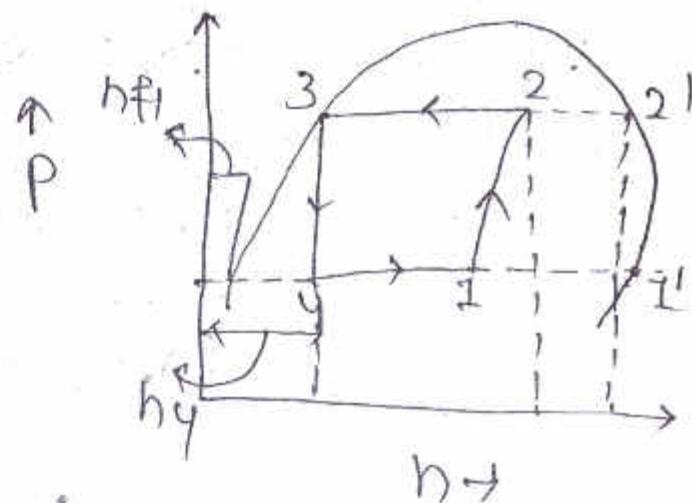
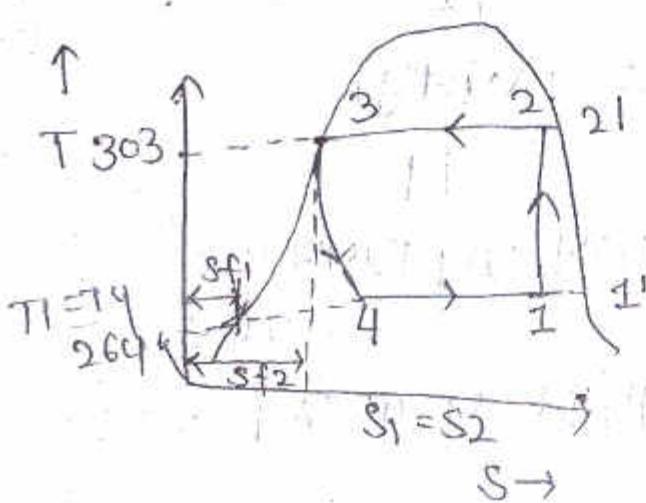
$$1 \text{ TOR} = 210 \text{ kJ/min}$$

Dt: 11 Dec. 21

Ques: An ammonia refrigerating m/c fitted with an expansion valve works b/w the temperature limit  $-10^{\circ}\text{C}$  and  $30^{\circ}\text{C}$ . The vapour is 95% dry at the end of isentropic compression and the fluid leaving the condenser is at  $30^{\circ}\text{C}$ . Assuming actual COP as 60% of the theoretical calculate the kilogram of ice produced per kW hour at  $0^{\circ}\text{C}$  from water at  $10^{\circ}\text{C}$ . Latent heat of ice is  $335 \text{ W/kg}$ . Ammonia has following properties.

Temp $^{\circ}\text{C}$	Liquid heat $h_f \text{ W/kg}$	Latent heat $h_{fg} (\text{W/kg})$	Liquid Entropy ( $S_f$ )	Total S of dry sat kg
30	323.08	1145.80	1.2037	4.984
-10	135.37	1297.68	0.5443	5.477

Given data:



$$\text{Temp}, \quad T_1 = 74 = -10^\circ\text{C} \Rightarrow 263\text{K}$$

$$T_2 = 73 = 30^\circ\text{C} \Rightarrow 303\text{K}$$

~~$$x_2 = 95\% = 0.95$$~~

$$h_{f3} = h_{f2} = 323.08, \quad h_{f1} = h_{f4} = 135.37$$

$$h_{fg1} = 1297.68 \text{ kJ/kg}$$

$$h_{fg2} = 1145.80 \text{ kJ/kg}$$

$$sf_1 = 0.5443$$

$$sf_2 = 1.2037$$

TOTAL ENTHALPY OF DRY Saturated VAPOR,

$$S_2' = 4.9842$$

$$S_1' = 5.4770$$

Let  $x_1$  = dryness fraction at point 1.

$$S_2 = sf_2 + \frac{h_{fg2}x_2}{T_2}$$

$$S_1 = sf_1 + \frac{x_1 h_{fg1}}{T_1}$$

$$S_1 = 0.5443 + x_1 \frac{1297.68}{263}$$

$$S_1 = 0.5443 + 4.93x_1 \rightarrow$$

$$S_2 = S_{f2} + x_2 \frac{h_{fg2}}{T_2}$$

$$S_2 = 1.2037 + 3.78 x x_2$$

$$S_2 = 1.2037 + 3.78 \times 0.95$$

$$S_2 = 4.79 \longrightarrow \text{??}$$

Since it is an Isentropic process,

$$\text{so } S_1 = S_2$$

$$\Rightarrow 0.5443 + 4.93 x_1 = 4.79$$

$$\Rightarrow 4.93 x_1 = 4.79 - 0.5443$$

$$x_1 = 0.86$$

Enthalpy at point 1

$$h_1 = h_{f1} + x_1 h_{fg1}$$

$$= h_{f1} + x_1 (h_g - h_f)$$

$$h_1 = 1251.37$$

$$h_2 = h_{f2} + x_2 h_{fg2}$$

$$= 323.08 + 0.95 \times 1145.8$$

$$h_2 = 1411.59$$

$$\text{COP} = \frac{h_1 - h_4}{h_2 - h_1} \quad [ \because h_4 = h_{f3} ]$$

$$\text{COP} = \frac{1251.37 - 323.08}{1411.59 - 1251.37}$$

$$= 5.79$$

Dt: 13 dec 21

$$\text{Actual COP} = 60\% = 0.6$$

$$0.6 \times 5.79 = 3.47$$

$$1 \text{ kW} \text{ & } 0 \text{ hr} = 3600 \text{ W} = W$$

Actual heat extracted on refrigerating effect produced in per kW hours

$W \times \text{Actual COP}$

## Vapour absorption refrigeration system

Q. What is vapour absorption?

A) In this system an absorber, a pump, a generator and a pressure reducing valve replace the compressor.

→ The low pressure ammonia vapours leaving the evaporator enters the absorber where it is absorbed by the cold water in the absorber.

\* The vapour absorption refrigeration system include all processes in a vapour compression refrigeration system such as absorber, heat pump, pressure reducing valve, generator, condenser, Expansion and Evaporation.

→ Here refrigerant use or working fluid use in vapour absorption ammonia ( $\text{NH}_3$ ) water ( $\text{H}_2\text{O}$ ) lithium bromide ( $\text{LiBr}$ )

Q) Where is vapour absorption refrigeration system is used.

A) Vapour absorption refrigeration system is based for place where heat energy is easily available at a low cost.

→ This process is based for steam power plant.

Steam power plant can easily run this refrigeration system using the waste of heat produce in the power plant.

c) why water is used in vapour refrigeration system?

a) The water use as the absorbent in the solution is unsaturated and it has the capacity to absorb more ammonia gas. As ammonia from evaporator enters the absorbent it is partially absorbed by water and the strong solution of Ammonia water is form. ( $\text{NH}_3\text{-H}_2\text{O}$ )

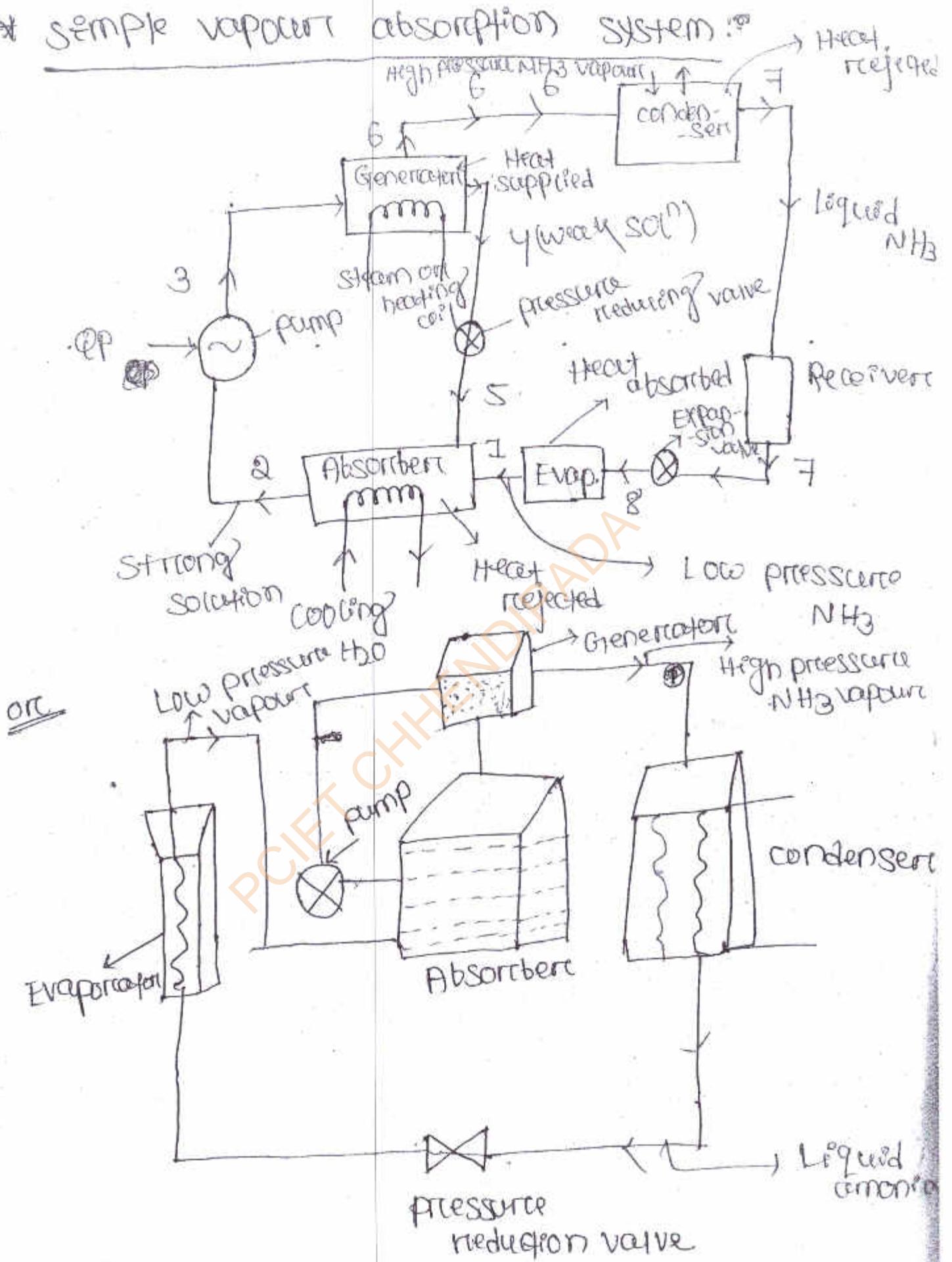
c) which energy is used in vapour absorption Refrigeration system : $\rightarrow$  Heat energy

a) The vapour absorption system used heat Energy instead of Mechanical Energy as in vapour compression system in order to change the condition of refrigerant required for the operation of refrigerating cycle.

c) why ammonia is used in vapour absorption system?

a) Strong soln.

# \* Simple vapour absorption system :-



- The simple vapour absorption system consists of an absorber, a pump, a generator and a pressure reducing valve to replace the vapour compression system.
- The other components of the system are condenser, receiver, expansion valve and evaporator as in the vapour compression system.
- In this system low pressure ammonia 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 quantity 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 rise the temp of the solution.
- Here some of cooling arrangement water is employed in the absorber to remove the heat of the soln present there.
- This is necessary in order to increase the absorption capacity of water because at high temp. water absorbs less ammonia vapour.

The strong solution formed in the absorber is pumped to the generator by liquid pump. The pump increases the pressure of the sol<sup>n</sup> up to 10 bar.

The strong sol<sup>n</sup> of ammonia in the generator is heated by some external source such as steam. During the heating process the ammonia vapour is driven off the sol<sup>n</sup> at high pressure leaving behind the hot weak ammonia solution in the generator. This weak ammonia sol<sup>n</sup> flows back to the absorber at low pressure after passing through a 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 pass to the expansion valve through the receiver and then go to the evaporator.

# comparison of vapour compression system.

DT-15 Dec 21  
absorption

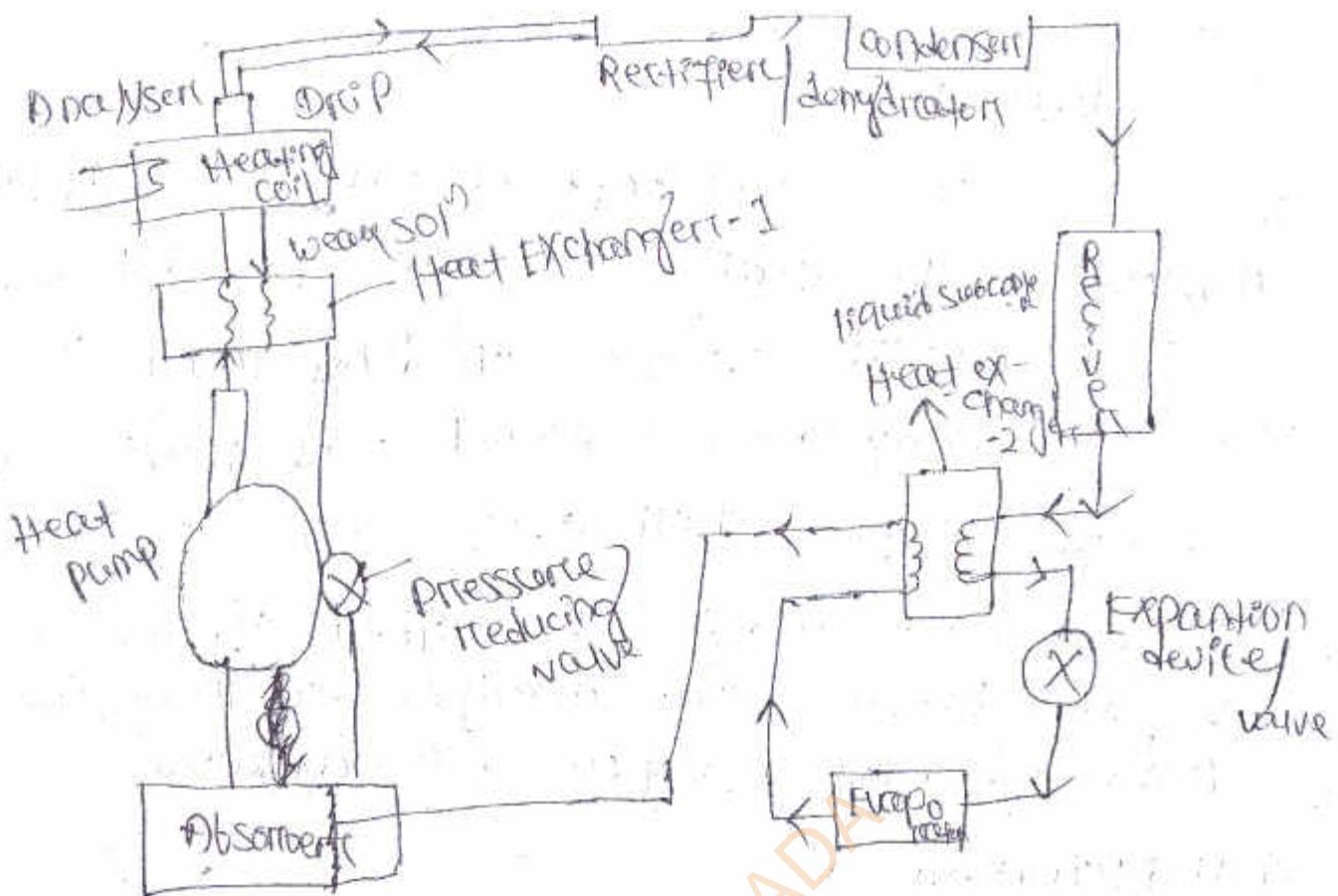
## vapour compression

## vapour Absorption system

- 1) The system has more wear & tear and produce more noise due to the moving part of the compressors.
  - 2) Electric power is needed to drive the system.
  - 3) COP is max<sup>m</sup> or more.
  - 4) Mechanical Energy is supplied through a compressor.
  - 5) Charging of refrigerant to the system is easier.
- 1) Only moving part in the system is an aqua pump (water pump). Hence the quiet in operation and less wear & tear.
  - 2) Waste low grade solar power can be used.
  - 3) No need of electric power.
  - 4) Less COP or min<sup>m</sup> COP.
  - 5) Heat energy is used.

## \* Practical vapour absorption system →

- The simple vapour absorption is not very economical. In order to make the system more practical an absorber, a rectifier and two heat exchangers heated in fitted in this operation.
- These accessories help to improve the performance & working of the plant.



Analysers →

when ammonia is vapourise in the generator, some water is also vapourised and will flow into the condenser along with ammonia vapours in this simple system.

- If this unwanted water particle are not removed before enter into the condenser they will enter into the expansion valve where they freeze and chock the pipe line.
- The analysers may be built as an integral part particles flowing to the condenser, an analysers is use. of the generator are made as a separate piece of equipment.
- The analysers consist of a series of

## Rectifier →

In case of the water vapour are not completely remove in the analysers a close type of vapour cooler called rectifier or dehydrator is used.

- It is generally water cooled and may be of the double pipe shell and tube type.
- Its function is to cool further the ammonia vapour leaving the analysers so that the remaining water vapour are condensed.

## Heat Exchangers →

- The heat exchangers provide b/w the pump and the generator is use to cool the weak <sup>hot</sup> solution returning from the generator to absorber.
- The heat remove from the weak sol<sup>n</sup> rises the temp of strong solution leave the pump and going to the analysers & generator.
- This operation reduce the heat supplied to the generator & the amount of cooling required for the absorber.

## Heat Exchangers -2

- The heat exchangers provide b/w condenser & evaporator may be called liquid sub-cooler.

In this heat exchanger, the liquid refrigerant leaving the condenser is sub-cooled <sup>by the</sup> low temp ammonia vapour from the evaporator.

This sub-cooled liquid is now pass to the expansion valve next to the evaporator.

PCIET CHHENDIPADA