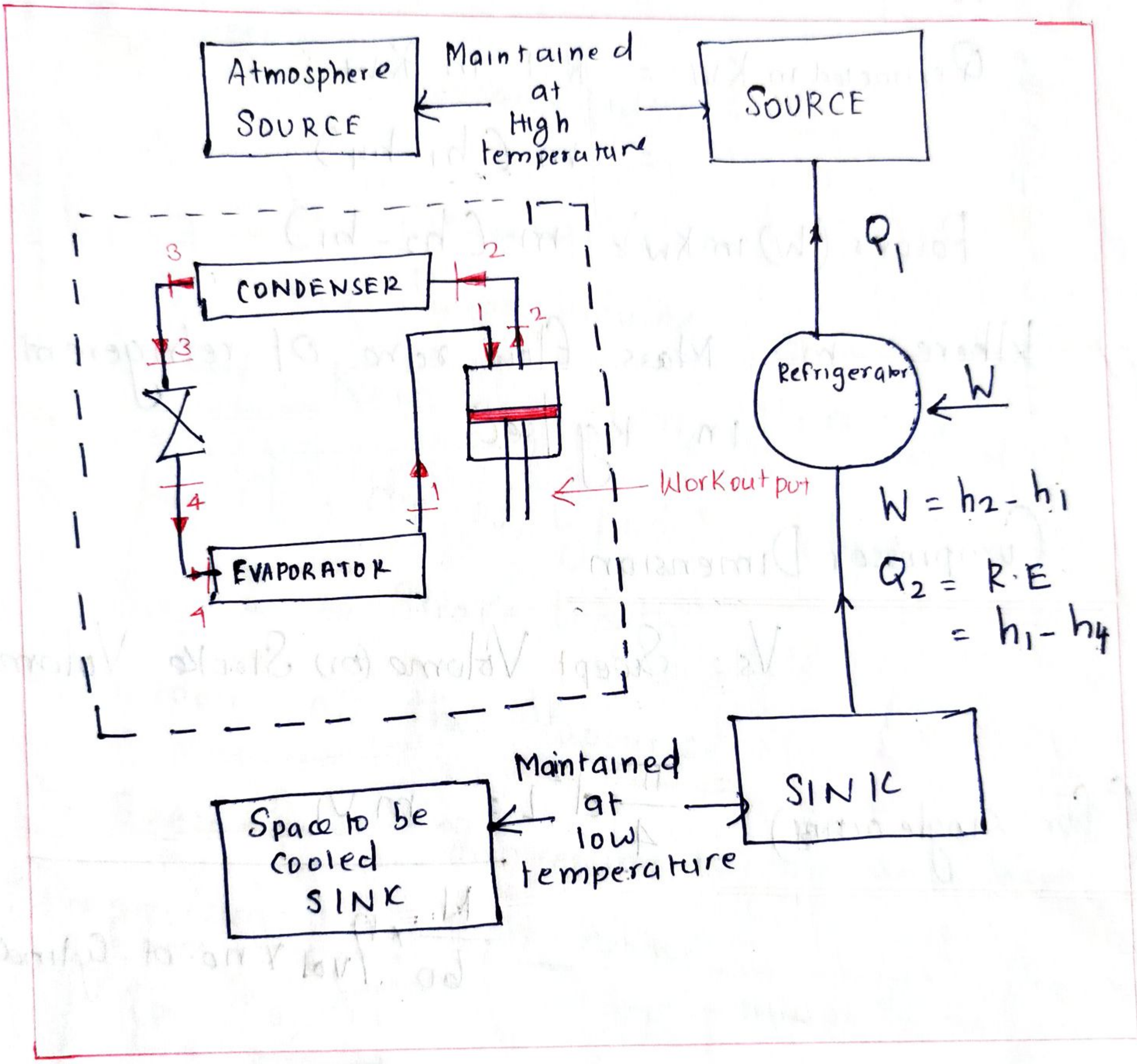
UNIT - 5. Refrigeration and Airconditioning

Vapour Compression Cycle :-



Process 1-2 Isentropic Compression

Process 2-3 Condensation

process 3-4 Throttling

process 4-1 Evaporation

$$C.O.P = \frac{R.E}{W} = \frac{h_1 - h_4}{h_2 - h_1}$$

Q_R in Kw $= m(h_2 - h_3)$

$Q_{extracted}$ in Kw $=$ R.E in Kw

$= m(h_1 - h_4)$

Power (W) in Kw $= m(h_2 - h_1)$

Where m: Mass flow rate of refrigerent in kg/sec

Compressor Dimension

V_s: Swept Volume (or) Stroke Volume

(for single acting) $= \frac{\pi}{4} d^2 L = \frac{m v_1}{\frac{N}{60} \times \eta_{vol} \times \text{no. of. Cylinders}}$

(for double acting) $= \frac{\pi}{4} d^2 L = \frac{m v_1}{\frac{N}{60} \times \eta_{vol} \times 2 \times \text{no. of. Cylinders}}$

N = r.p.m

η_{vol} = Volumetric efficiency = $1 - K\left[\left(\frac{V_1}{V_2}\right) - 1\right]$

Where

K = Clearance ratio = $\frac{V_c}{V_s}$

V_c = Clearance Volume

V_s = Swept Volume

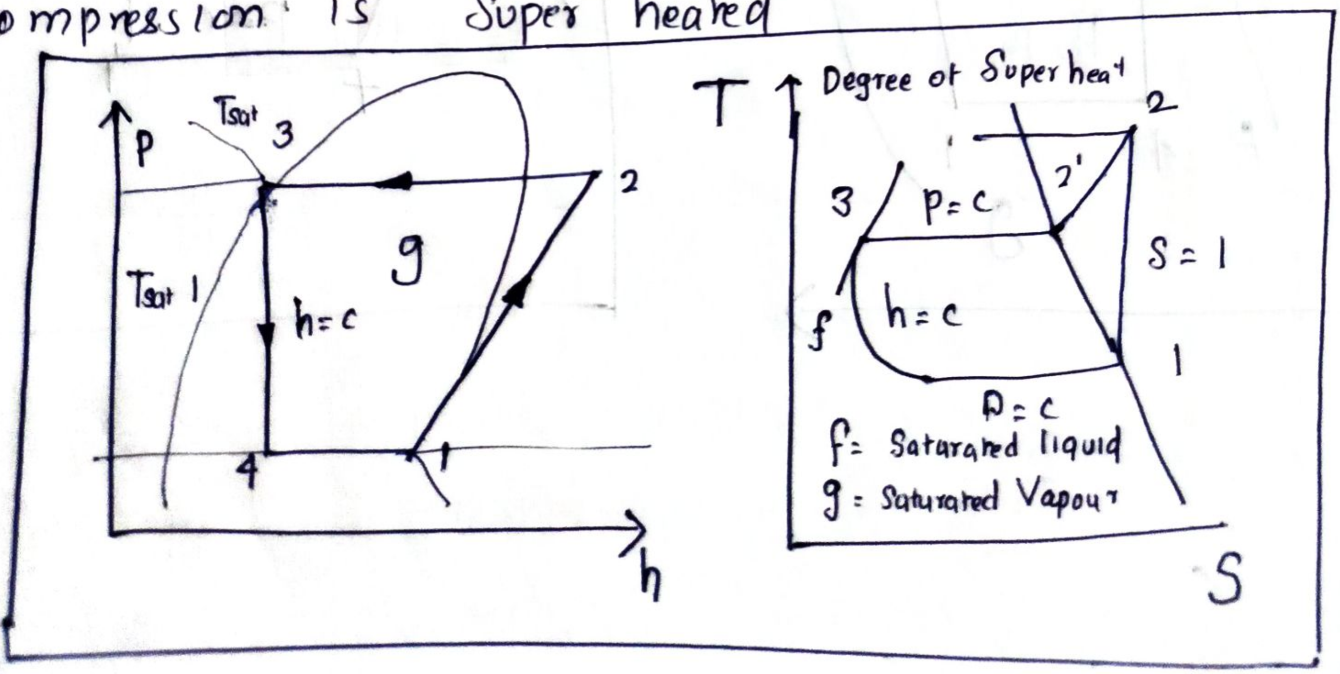
If K is not given K = 0 $\eta_{vol} = 1$

d = dia of Cylinder or bore

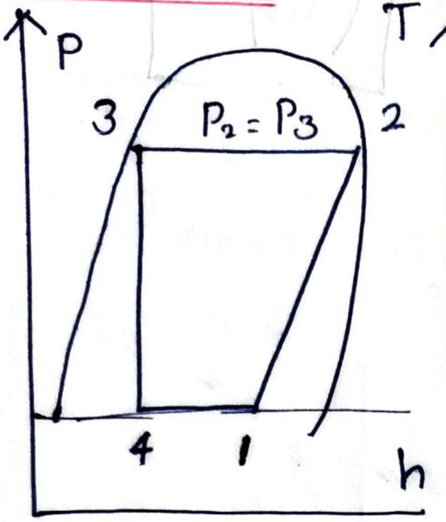
L = Stroke length

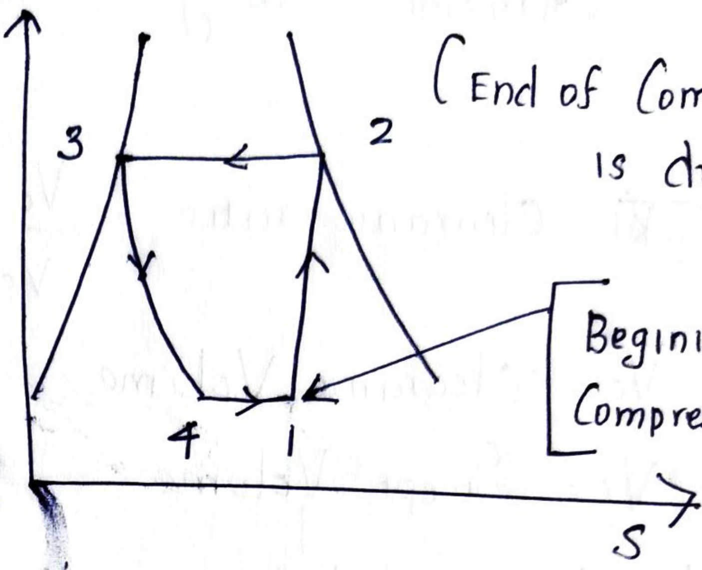
Condition of the Vapour :-

① . Begining of Compression is dry and end of Compression is Super heated

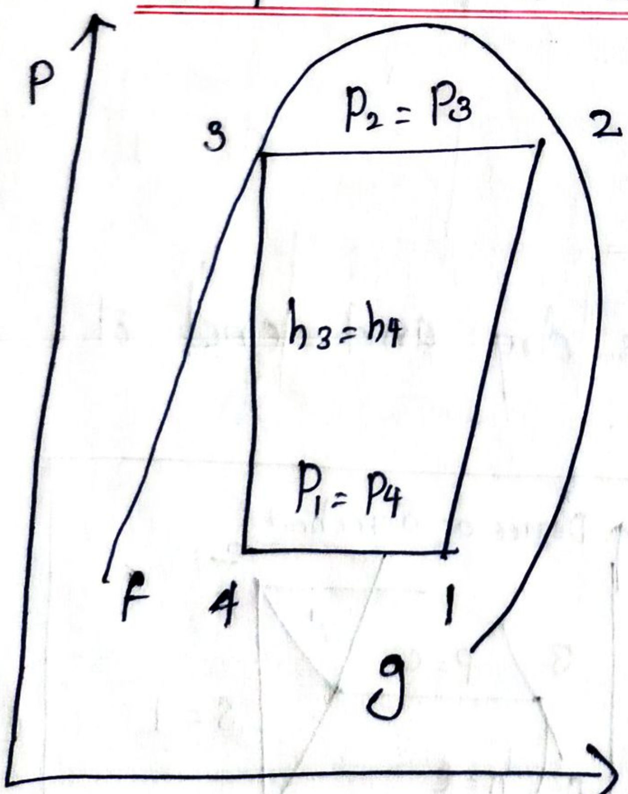


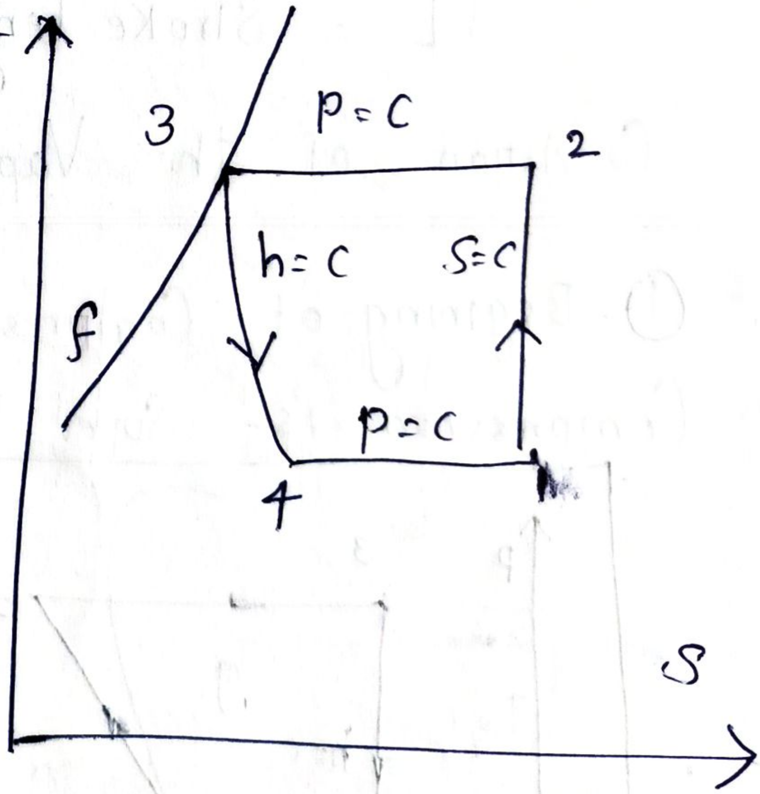
2. End of Compression is dry and Begining of Compression is Wet



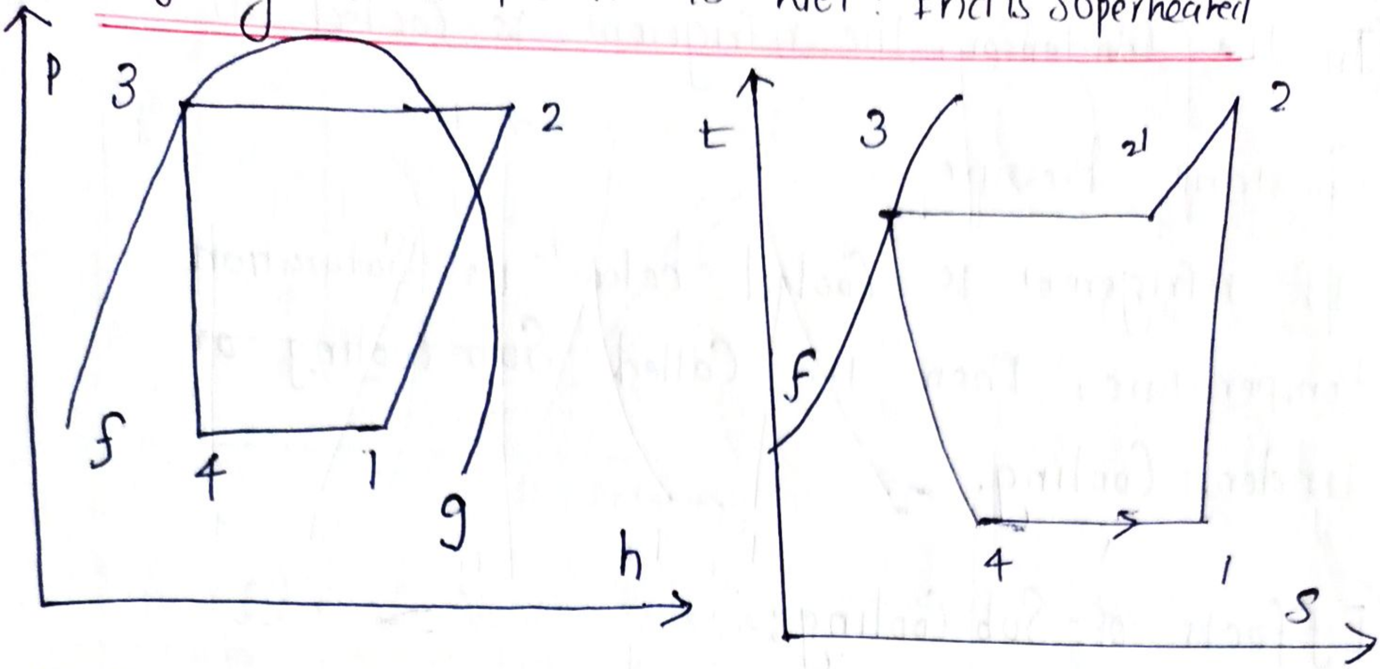


3. End of Compression is also Wet and Begining of Compression is Wet

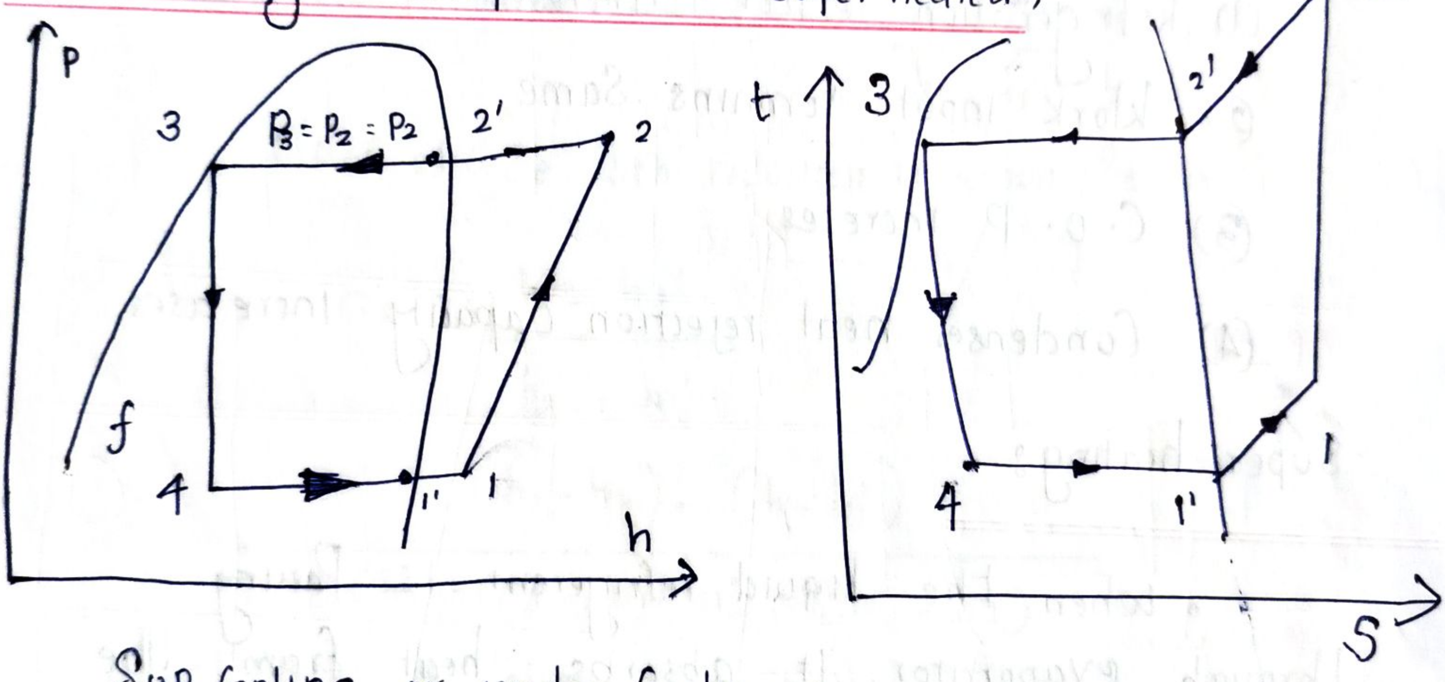




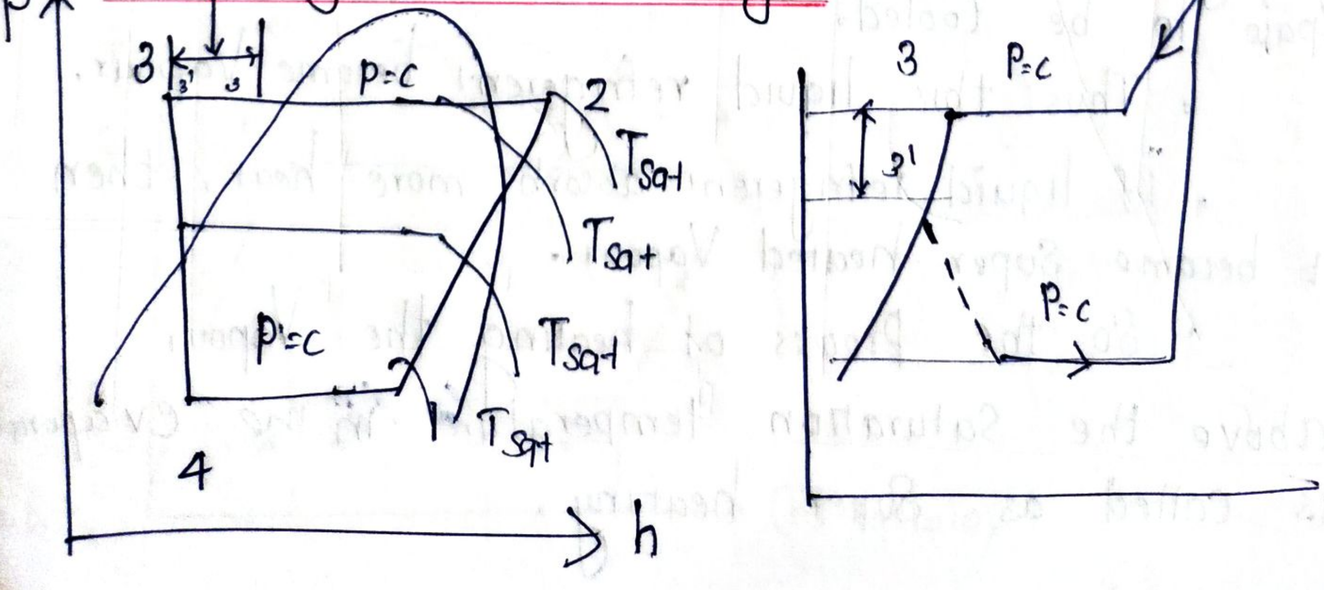
4. Begining of Compression is Wet : End is Superheated



5. Begining of Compression is Super heated ;



Sub Cooling or under Cooling :-



- In the Condenser, the refrigerent is Cooled at Constant Pressure.
- If refrigerent is Cooled below its Saturation temperature, then its Called Sub Cooling or under Cooling.

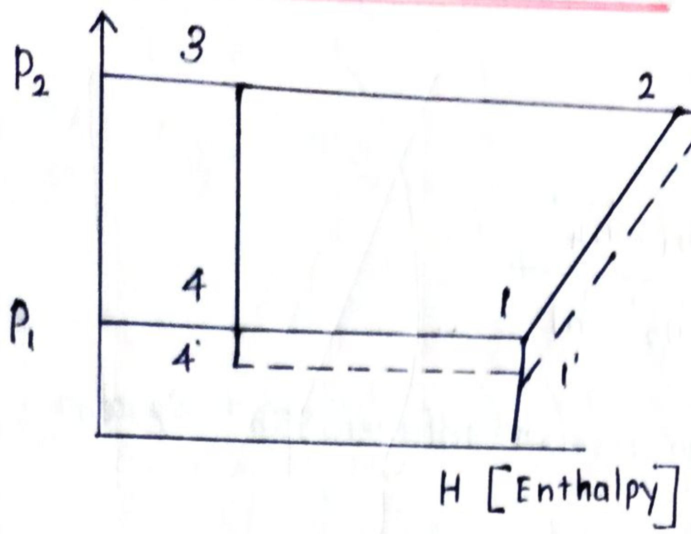
Effects of Sub Cooling:-

(i) Refrigeration effect Increses.
(2). Work input remains Same
(3) C. O. P increses
(4) Condenser heat rejection Capacity increases.

Super heating:-

- When the liquid refrigerent is Passing through evaporator, It absorbs heat from the Space to be Cooled.
- Thus this liquid refrigerent become Vapour.
- If liquid refrigerent absorb more heat, then It become Super heated Vapour.
- So the Process of heating the Vapour above the Saturation temperature in the evaporator is called as Super heating.

Performance Calculations:



(i) Effect of Suction Pressure

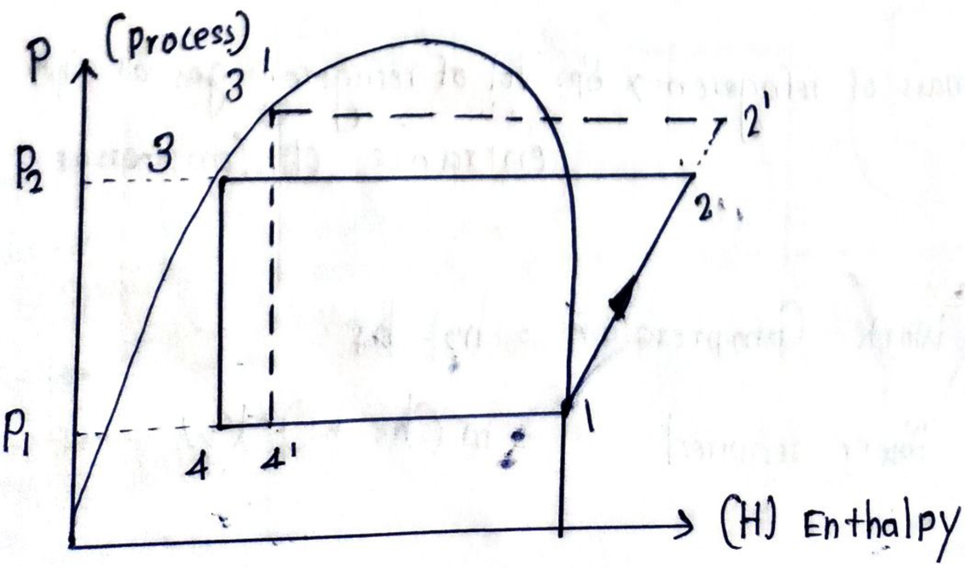
$$\text{C.O.P of original Cycle} = \frac{h_1 - h_4}{h_2 - h_1}$$

C.O.P of Cycle with reduction is Suction Pressure

$$\text{C.O.P} = \frac{h_1' - h_4'}{h_2' - h_1'}$$

$$= \frac{(h_1 - h_4) - (h_1 - h_1')}{(h_2 - h_1) + (h_1 - h_1) + (h_2' - h_2)}$$

(ii) Effect of delvery Pressure



$$\text{Original C.O.P} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$\left.\begin{matrix}\text{The C.O.P of Increased} \\ \text{delivery Pressure}\end{matrix}\right\} = \frac{h_1 - h_4'}{h_2' - h_1}$$

Calculations is a Vapour Compression refrigeration System

(i) Refrigeration effect :

$$R.E = h_1 - h_4 \text{ KJ/Kg}$$

(ii) Mass of refrigerent Circulated :

$$\dot{m} = \frac{\text{One tonne of refrigeration}}{\text{Refrigeration effect}}$$

$$\dot{m} = \frac{3.5}{h_1 - h_4} \text{ in Kg/sec - tonnes}$$

(iii) Theoretical piston displacement :

$$= m \times (v_g)$$

= Mass of refrigerent x Sp. Vol of refrigerent gas at 18 entrance of Compressor

(iv) Power

(a) Work Compression $= h_2 - h_1$

Power required $= m(h_2 - h_1)$ KW

(b) For polytropic process ($PV = C$)

Work of Compression $= \frac{n}{n-1}[P_2V_2 - P_1V_1]$ in Nm/kg

Power required $= m \cdot \frac{n}{n-1}[P_2V_2 - P_1V_1]$ Watts

[V] Heat rejected to Compressor cooling water:

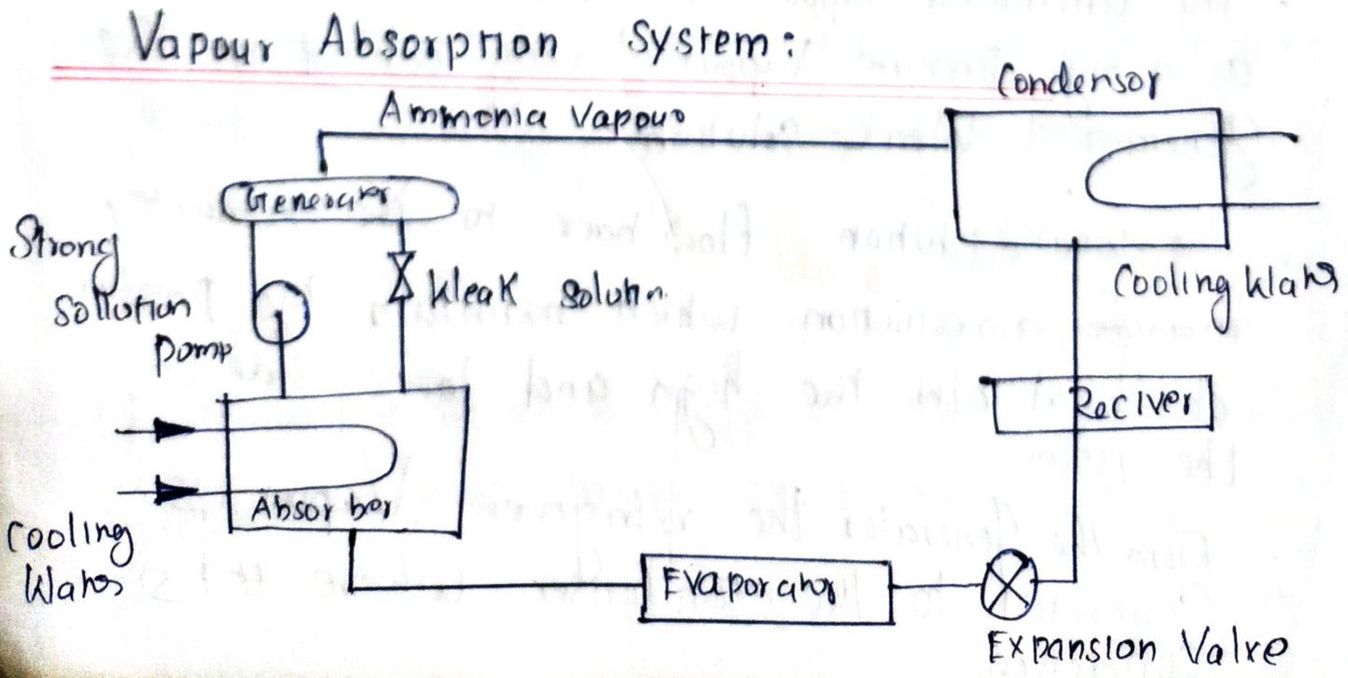
$$= \left[\frac{n}{n-1}[P_2V_2 - P_1V_1] - [h_2 - h_1]\right]$$

[VI] Heat removed through Condenser

$$m = (h_2 - h_3) \text{ in kJ/s}$$

m: mass of refrigerant circulated in kg/sec

Vapour Absorption System:



- If Compressor in Vapour Compression System were replaced with a generator absorber assembly the result work be a Simple Vapour absortion System.

- Low Pressure refrigerent Vapour [Ammonia) Comming from the evaporator is absorbed in the absorber by the weak Solution of refrigerent in Water.

- Cooling arrangement in absorber. This increase amonia absorption Capacity of water.

- The Pumps draw Strong Solution from the absorber, build up a pressure upto 10 bar and force the Strong Solution in the Generator.

- In the generator, Strong solution of amonia is heated by Some external Source Such as a gas or Steam.

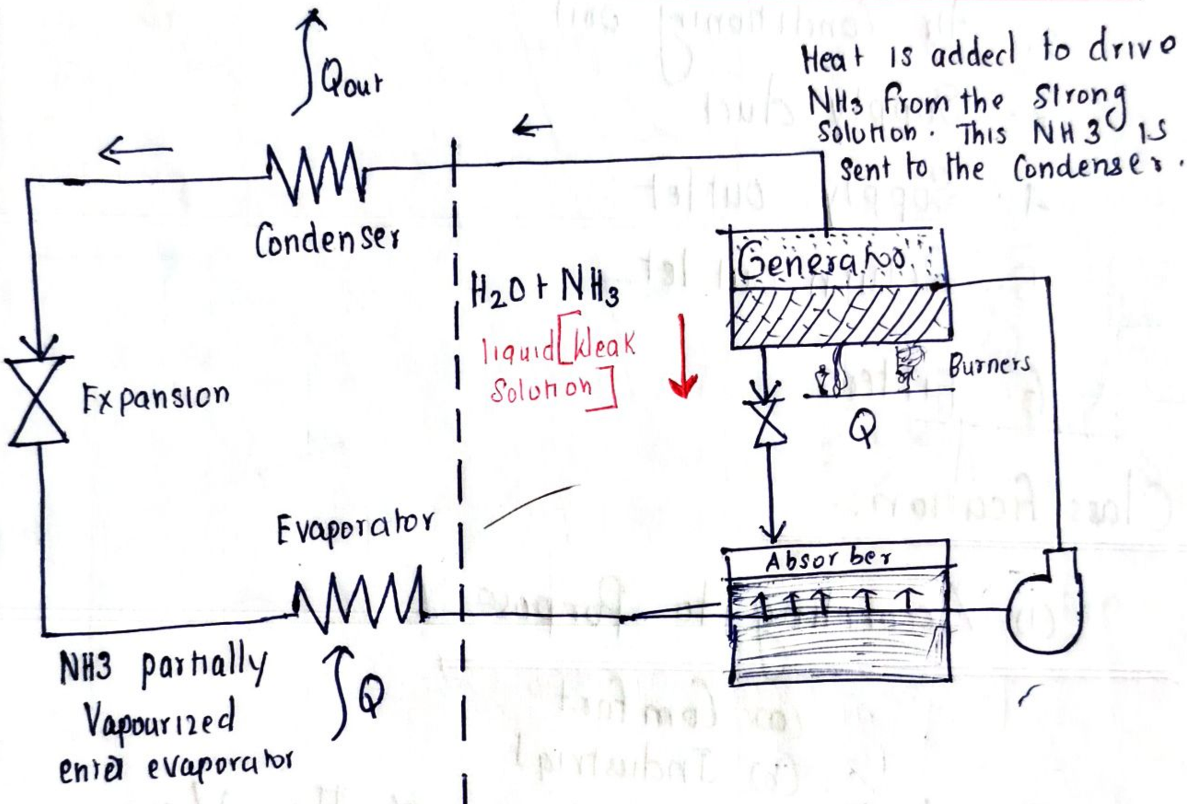
- The ammonia Vapour is driven out of the Solution as a high Pressure Vapour leaving behind in the Generator a weak Solution.

- The weak solution flow back to the absorber through a restriction which maintain the pressure differential b/w the high and low Side of the system

- From the Generator the refrigerent Vapour is Connected to the condenser where it is Condensed

• Then the high Pressure liquid Ammonia is passed through a throttle Valve to the evaporator Where it absorbs its latent heat thus Producig Cooling effect.

Ammonia - Water absorption System



1. Ammonia enters the Condenser as Vapour.
2. It is Condensed into liquid in the Condenser.
3. The liquid ammonia enters the expansion Valve as a liquid.
4. It partially flashes to Vapour in the expansion Valve.
5. Remaining liquid Ammonia is further Vapourized as it absorbs heat in the evaporator.

Air Conditioning System:

Air Conditioning deals With the Study Conditioning the air for human Com fort.

Equipment of Air Conditioning System

1. Circulation Fan
2. Air Conditioning unit
3. Supply duct
4. Supply outlet
5. Return out let
6. Filters

Classification:

(1) According to Purpose

(a) Com fort
(b) Industrial

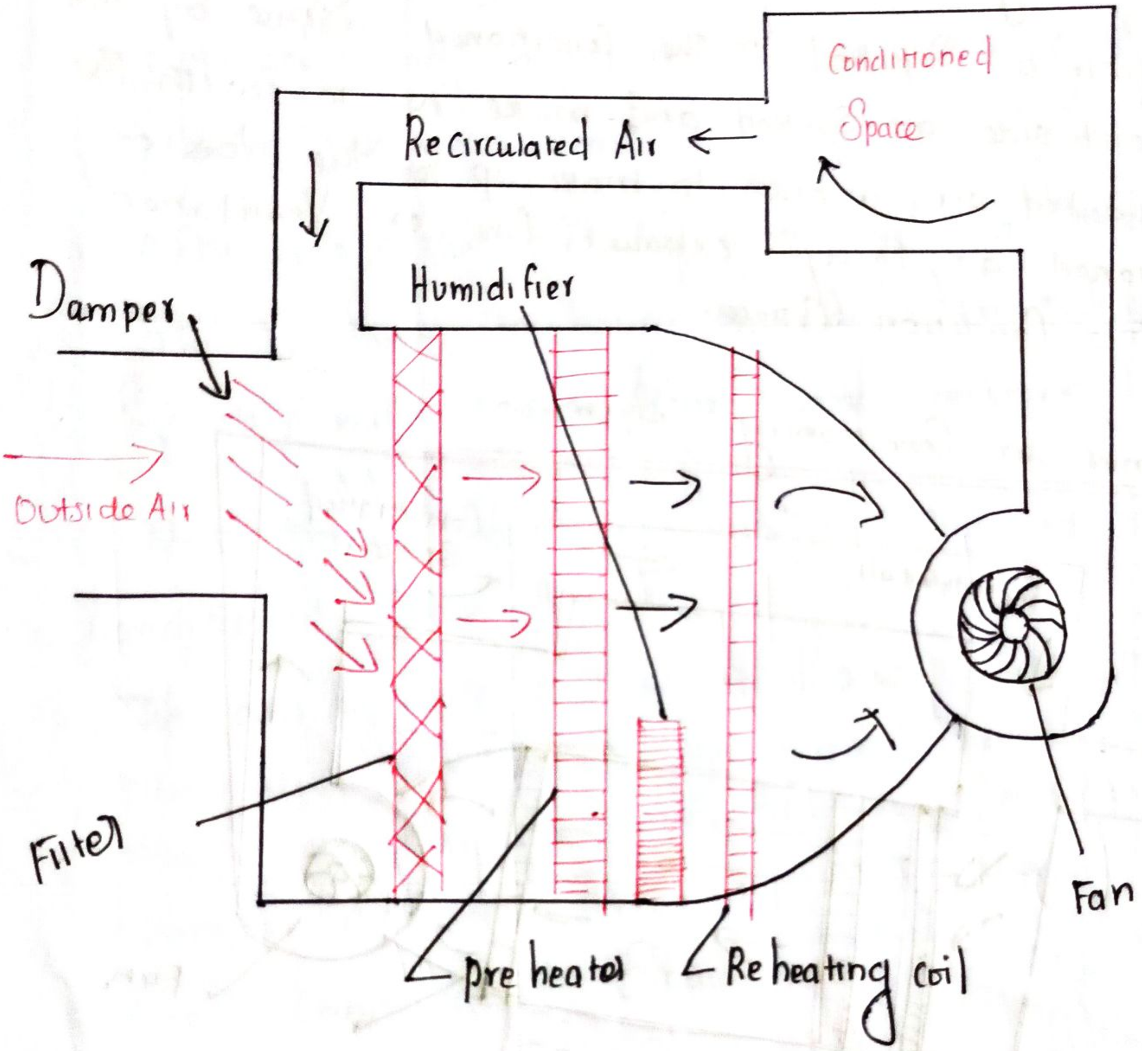
(2) According to Season of The Year

(a) Winter air Conditioning system
(b) Summer air Conditiony System
(c) Year round "

(3) According to arrange ment

(a) Unitary A/c system
(b) Central A/c System

(i) Winter Air Conditioning System



- Air heated which generally accompanied by humidification.

  outside the air passes through a damper and mixes up the recirculated air.

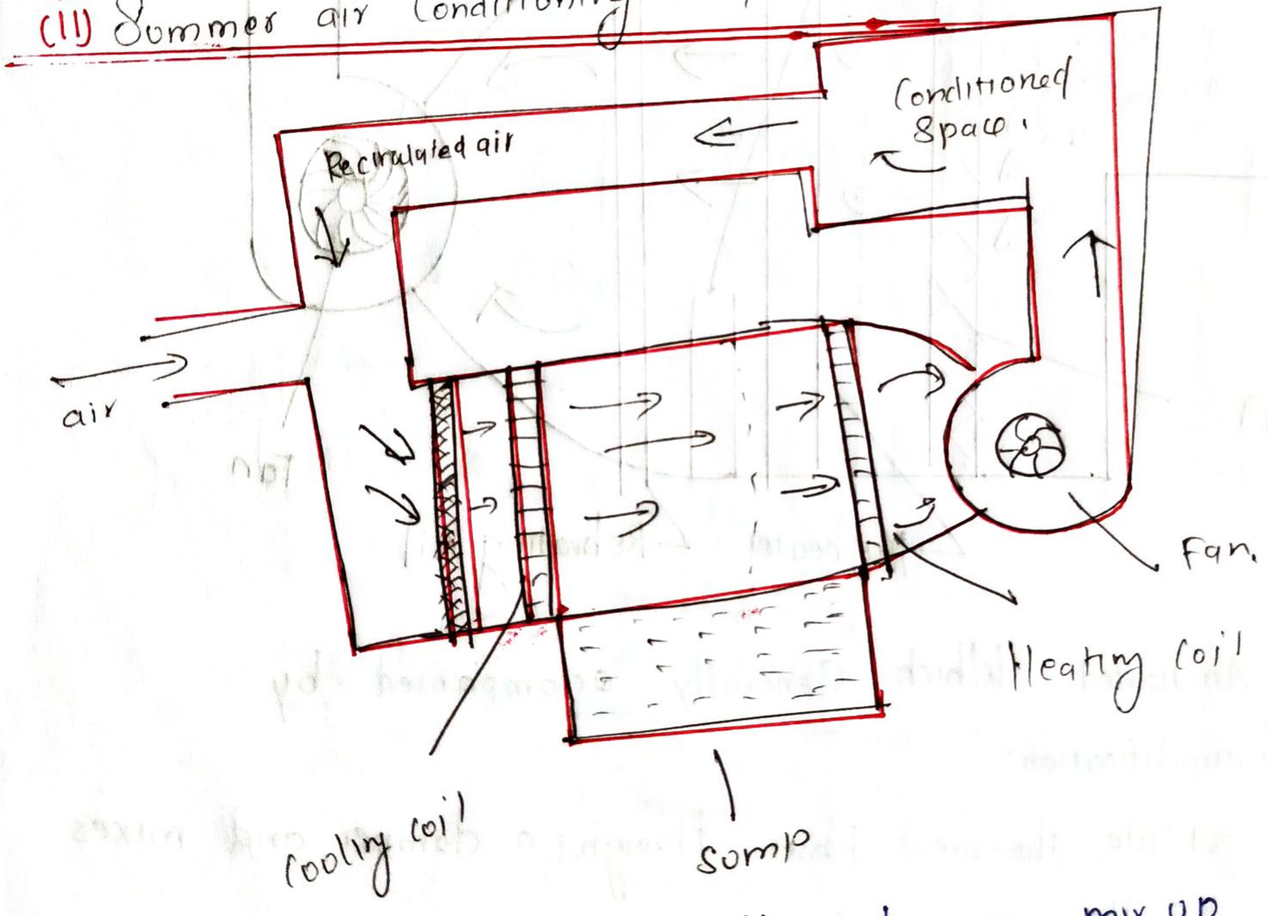
- The mixed air passes through a filter to remove dirt dust and other impurities.

- Air know passes through pre heater in order to prevent the possible freezing of water and control Evaporation water in humidifier

After that, the air passes through a reheat coil to attain the designed dry bulb temperature.

- The air is supplied to the conditioned space by fan
- The out side air sucked and make to mix with the recirculated air, in order to make up for the loss of conditioned air through exhaust fans or ventilation from the conditions space.

(ii) Summer air conditioning system.



- outside air passes through the damper, mix up with recirculated air.
- The air passes through cooling coil. The coil has a temperature much below the required dry bulb temperature of the air in

Conditioned Space.

- The Cooled air Passes through a Perforated membrane and moisture is removed and Collected in a Somp.
- After that the air Passes through a heating coil.
- This is done to bring the air to the designed by dry bulb temperature and relative humidity.
- Now this Conditioned air is Supplied to Conditioned Space by a fan.
- The outside air is sucked and Made to Mix with the recirculated air in order to make up for the loss of Conditioned air through exhaust fan or Ventilation from the Conditioned Space.

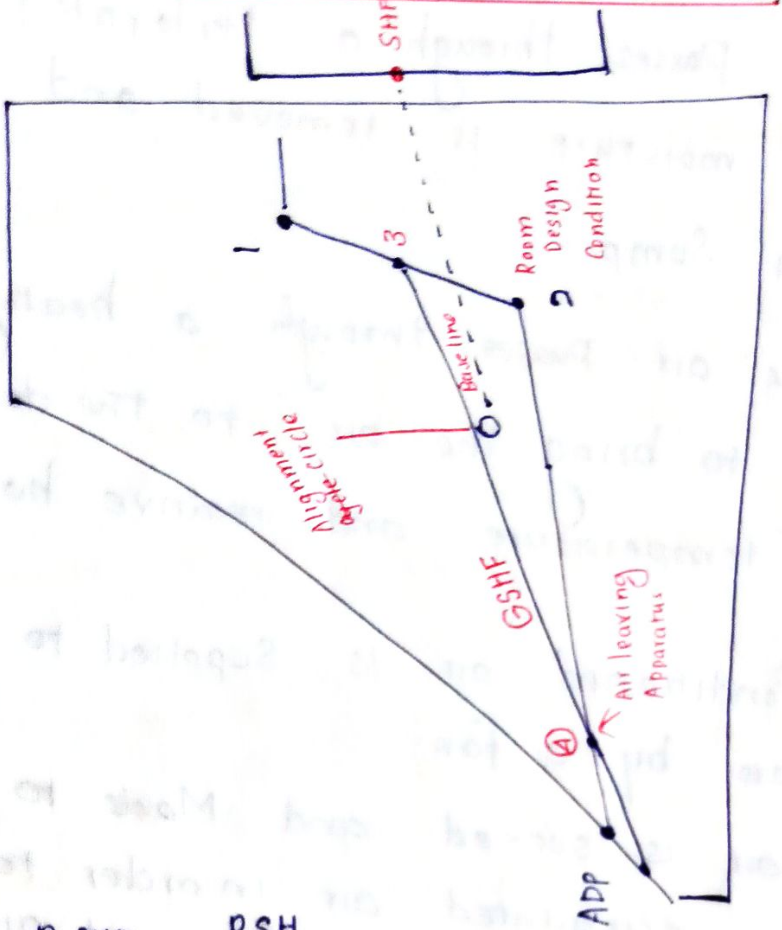
Year - round air Conditioning system:.

(i) It is soitable for both Winter & Sommer air Conditioning.

(2) There are so many Combination for Providing Year round Air Conditiong.

(3) The arrangement of the combination should be such that one part is working in winter and the other in Sommer.

Room Sensible Heat factor (RSHF)



$$RSHF = \frac{RSH}{RSH + RLH}$$

RSHF : Room Sensible heat factor

RSH = Room Sensible heat

RLF = Room Latent heat

RTH = RSH + RLH = Room Total Heat

Grand Sensible Heat factor [GSHF]

- It is ratio of total Sensible heat to the grand total heat that the Cooling Coil Should handle.
- Normal practice outside air Ventilator, Cracks, Small openings infiltrated air due to mixes with the Conditioned room air.

Sensible Heat factor S.H.F

Q_s: Sensible heat removed $= m_a [h_x - h_2]$

Q_L: Latent heat removed $= m_a [h_1 - h_x]$

Sensible heat factor (S.H.F) $= \frac{Q_s}{\text{Total heat}}$

Total Heat $= Q_s + Q_L$

$$S.H.F = \frac{Q_s}{Q_s + Q_L}$$

Latent heat factor $= L.H.F = \frac{Q_L}{Q_s + Q_L}$

Where

hf: Specific enthalpy of liquid refrigerent (kJ/kg)

x: Dryness fraction of refrigerent

hfg: Specific enthalpy of evaporation (kJ/kg)

hg => " " dry refrigerent (kJ/kg)

Sf: Specific entropy of liquid refrigerent (kJ/kg K)

Sfg: Specific entropy of evaporation kJ/kgK

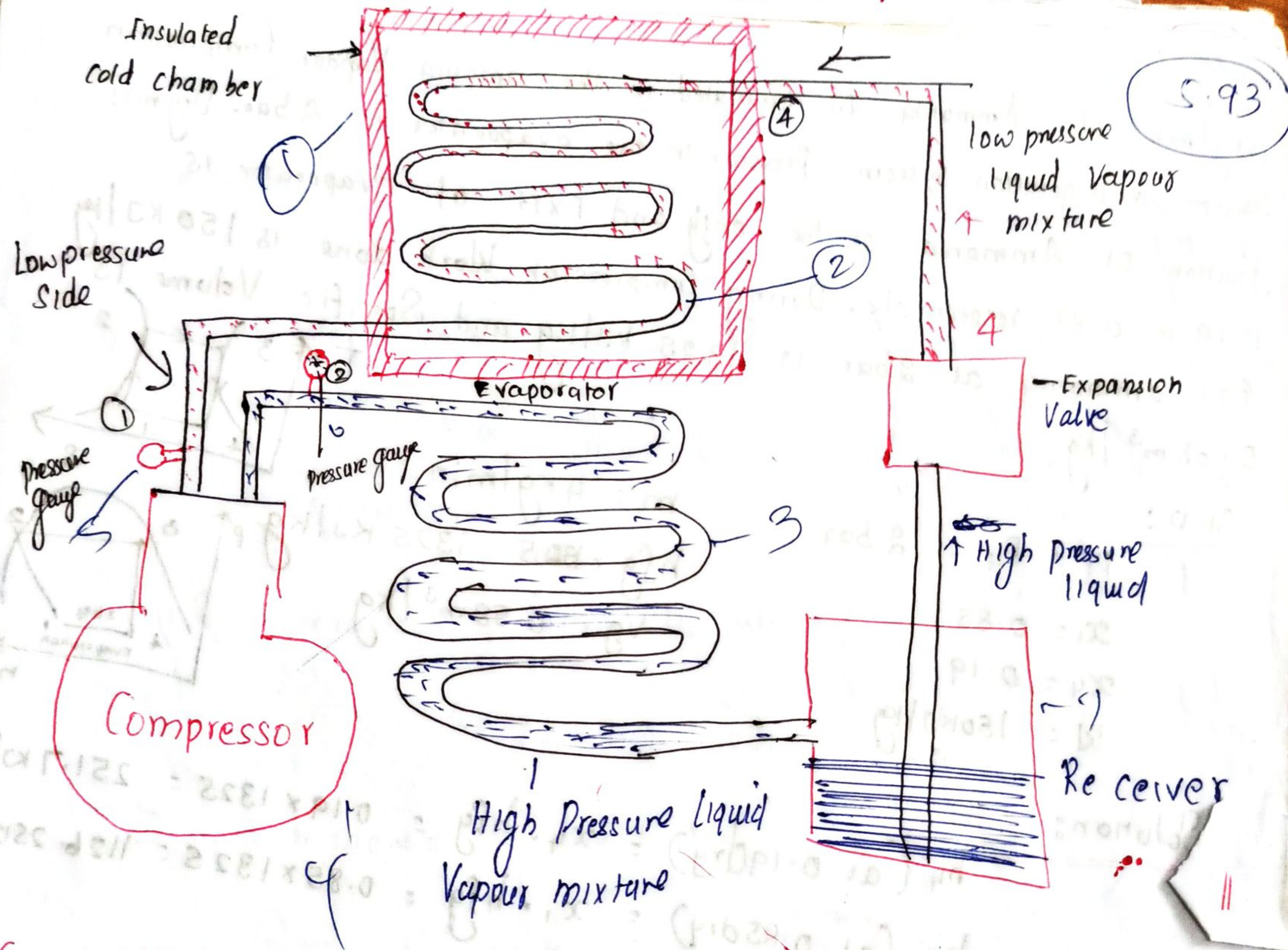
Sg: Specific entropy of dry refrigerent [kJ/kg K]

$h_{fg} = h_g - h_f$

$S_{fg} = S_g - S_f$

The following formula are useful to solve Problems Corrosponding to the State of refrigerent

State of refrigerent	Enthalpy	Entropy
Wet refrigerent	$h = h_f + x \cdot h_{fg}$	$S = S_f + x \cdot S_{fg}$
Dry Refrigerent	h_g	S_g (or) $S_f + \frac{h_{fg}}{T}$
Superheated refrigerent	$h = h_1 + C_p [T \; T']$	$S = S' + C_p \ln \frac{T}{T'}$



Compressor :-

(1) increse the temp & pressue of refrigerent above the atmospheric Conditi..

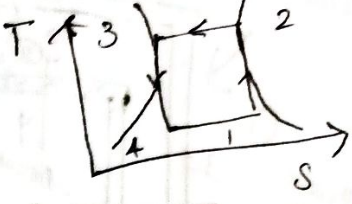
Condenser :- cool the Vapour and vapour Convert into liquid

Receiver : It is storage tank which stores the liquid.

Expansion Valve :- It is used to reduce the temperature and Pressure of the liquid refrigerent.

Evaporator :- Absorbing the heat from the space

4 kg/min of Ammonia is Circulated in the amonia Vapour Compression ~~System~~ refrigeration system. Pressure in the evaporator is 2 bar. Dryness fraction of Ammonia at the entry and Exit of evaporator is 0.19 & 0.85 respectively. During Compression Work done is 150 KJ/kg. Of ammonia at 2 bar is 1325 KJ/kg and Specific Velome is 0.58 m^3/kg.



G.D:

$P_1 = P_4 = 2$ bar

$x_1 = 0.85$

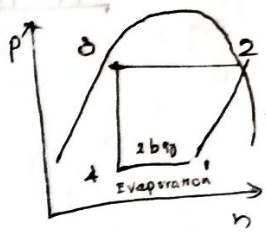
$x_4 = 0.19$

$W = 150$ KJ/kg

$m = 4$ kg/min

$h_{fg} = 1325$ KJ/kg

$V_g = 0.58\ m^3/kg$



Solution:

h_4 (at 0.19 dry) $= x_4 \cdot h_{fg} = 0.19 \times 1325 = 251.7$ KJ/kg

h_1 (at 0.85 dry) $= x_1 \cdot h_{fg} = 0.85 \times 1325 = 1126.25$ KJ/kg

Refrigeration effect (R)

$R = h_1 - h_4$

$= 1126.25 - 251.7$

$R = 874.5$ KJ/kg

C.O.P $= \frac{R}{W} = \frac{874.5}{150} = 5.83$ //

Volume of Vapour entering the Compressor/min

$V_3 = V_1$ = Specific Volume x mass of refrigerent/min

$= 0.58 \times 4$

$= 2.4\ m^3/min$ //

Refrigeration load $= m_a [h_3 - h_4]$

Dehumidified air Quantity $m_a = \frac{\text{Room total heat}}{h_2 - h_4}$

Mass of Water Vapour removed Per hour m_w

$(m_w) = m_a (\omega_1 - \omega_3) \times 3600$

~~Refrigeration~~

1. Q removed from the Water

$$Q_R = m_w \, C_{pw} \, (\Delta T)$$

2. Q removed to make ice

$$Q_{R\,ice} = m_{ice} \, C_{p\,ice} \, (\Delta T)_{ice}$$

3. Total heat removed

$$= Q_{R\,water} + Q_{R\,water\ to\ ice} + Q_{R\,ice}$$

4. Tone of refrigeration

$$(TR) = \frac{Q_R}{3.5}$$

T: tone of refrigeration

h_1: enthalpy at entry of Compressor

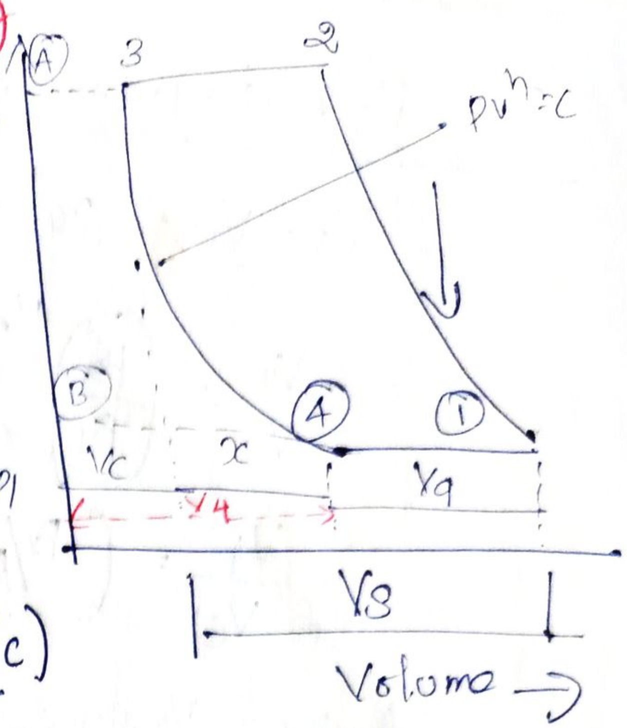
h_{f3}: enthalpy at entry of the evaporator or enthalpy at exit of the Condenser.

η_v: Volumetric efficiency of the Compressor

V_{s_1}: Specific Volume of Saturated refrigerent at Point 1

Volumetric efficiency

From p-V diagram



$$V_a = V_s - x$$

$$x = V_4 - V_c$$

$$\eta_{vol} = \frac{V_s - x}{V_s}$$

$$= \frac{V_s - (V_4 - V_c)}{V_s}$$

common

$$= \frac{V_s - V_c\left(\frac{V_4}{V_c} - 1\right)}{V_s}$$

V_s common

$$= \frac{V_s\left\{1 - \frac{V_c}{V_s}\left[\frac{V_4}{V_c} - 1\right]\right\}}{V_s}$$

$$= 1 - \frac{V_c}{V_s}\left[\frac{V_4}{V_c} - 1\right] \quad \text{—— (1)}$$

Both Compression & Expansion follow the law of $PV^n = C$

$$P_3 V_3^n = P_4 V_4^n$$

$$\frac{V_4}{V_3} = \left(\frac{P_3}{P_4}\right)^{\frac{1}{n}}$$

Important form...

From P-V diagram We Know that

$V_3 = V_c, \quad P_4 = P_1 \quad P_3 = P_2$

$$\frac{V_4}{V_c} = \left(\frac{P_3}{P_4}\right)^{1/n}$$

$$\frac{V_4}{V_c} = \left(P_2/P_1\right)^{1/n}$$

Applying $\frac{V_4}{V_c}$ in eq (1)

$$\eta_{vol} = 1 - \frac{V_c}{V_s}\left[\frac{V_4}{V_c} - 1\right] \quad \text{--- (1)}$$

$$\eta_{vol} = 1 - \frac{V_c}{V_s}\left[\left(P_2/P_1\right)^{\frac{1}{n}} - 1\right] \quad \text{--- (2)}$$

Clearance ration $(C) = \frac{V_c}{V_s}$

$$\eta_{vol} = 1 - C\left[\left(P_2/P_1\right)^{1/n} - 1\right]$$

(multi[illegible] Subration [illegible])

$$1 - C\left(P_2/P_1\right)^{1/2} + C$$

$$\eta_{vol} = 1 + C - C\left[P_2/P_1\right]^{1/n}$$

5.91

Important formula for unit : 5

1. No heat tranfer $[h_1 = h_2]$

2. $$\phi_2 = \frac{P_{v2}}{P_{vs_2}}$$

3. Sensible heat removed $(Q_s) = m_a (h_x - h_2)$

4. Latent heat removed $(Q_L) = m_a (h_1 - h_x)$

5. Sensible heat factor $S.H.F = \frac{Q_s}{\text{Total heat}}$

$$S.H.F = \frac{Q_s}{Q_s + Q_L}$$

6. Latent heat factor $L.H.F = \frac{Q_L}{Q_s + Q_L}$

$$V_2 = \frac{x}{y}$$

$$m_a = \frac{V}{V_2}$$

7. Capasity of Cooling coil 'Q'.

Q = Heat removed from air

$m_a = (h_1 - h_2)$

8. Increse ~~the~~ in Wet bulb temperature $= tw_2 - tw_1$

9. Increse in DBT $= td_2 - td_1$

10. Increase in Specific enthalpy $: h_2 - h_1$

11. change in Relative humidity $= \phi_2 - \phi_1$

12. Amout of moisture added $=(m_w)$

$$m_w = m_a (\omega_2 - \omega_1)$$

12. Total heat adder per Kg of dry air $= h_2 - h_1$

13. Capacity of Cooling coil Q_2

$$Q_2 = m_a [h_1 - h_2]$$

14. Capacity of heating coil $Q_1 = m_a (h_3 - h_2)$

15 Water Vapour removed in kg/sec

$$m_w = m_a [\omega_3 - \omega_1]$$

16 Specific Volume $v_1 = \frac{x_1}{x_2}$

17. By Pass factor $B.F = \frac{t_s - t_2}{t_s - t_1}$

18. Capacity of Humidifier

$$m_w = m_a (\omega_3 - \omega_1)$$

(or)

$$m_a (\omega_3 - \omega_2)$$

19. Room sensible heat factor (RSHF)

$$= \frac{Q_s}{Q_s + Q_L}$$

Problems

Air conditioning plant is required to supply 60 m³ of air per minute at a DBT of 21°C and 55 % R.H. The outside air is at DBT of 35°C & 60 % R.H. Determine the mass of water drained and capacity of cooling coil. Assume the air conditioning plant is first to dehumidify and then to cool the air.

From chart $V_2 = 0.84$

$$V_2 = \frac{x}{y}\left[V_{final} - V_{initial}\right] + V_{initial}$$

$$= \frac{57}{70}\left[0.85 - 0.8\right] + 0.8$$

$$= 0.84071 \ m^3/kg$$

$$m_a = \frac{V}{V_2} = \frac{60/60}{0.84071} = 1.189465 \ kg/sec$$

Mass of water drained in kg/sec $m_w = m_a\left[\omega_1 - \omega_2\right]$

$$= 1.189465\left[0.0212 - 0.0086\right]$$

$$= 0.01499 \ \text{kg of water/sec}$$

$$= 53.954 \ \text{kg of water/hr.}$$

Capacity of cooling coil Q

Q = Heat removed from air

$$= m_a\left[h_1 - h_2\right]$$

$$= 1.189465\left[89.5 - 43.5\right]$$

$$= 54.7154 \ kW$$

Air at WBT 12°C and DBT 14°C is heated to a DBT of 23°C and no moisture is added (i) Find DPT the moisture Content and the total heat added per kg of dry air (ii) what is the effect on the relative humidity as the air is heated? If 200 m³ of air is heated every mins and the density of air is 1.3 kg/m³. Calculate the heat added per min the.

From chart :

DPT = 10.3°C

Moisture Content : $\omega_1 = \omega_2 = 0.008 \frac{\text{kg of Vapour}}{\text{kg of dry air}}$

Moisture Content added $= \omega_2 - \omega_1 = 0$

Total heat added per kg of dry air $= h_2 - h_1$

$= 43.5 - 34$

$= 9.5 \text{ kJ/kg}$

Change in relative humidity

$\phi_2 - \phi_1 = 44\% - 76\%$

$= -32\%$

So relative humidity decrese

Heat added per min : Q

$Q = m_a (h_2 - h_1)$

Where $m_a = \frac{V}{v_1} = V \times \rho_1$

$= 200 \times 1.3$

$= 260 \text{ kg/min}$

$Q = 260 (9.5)$

$= 2470 \text{ kJ/min}$