

HANDWRITTEN NOTES OF

(REFRIGERATION & AIR CONDITIONING)

BY

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Refrigeration And Air Conditioning

- | | |
|--|---|
| 1) Basic Concept (Obj)
2) Vapour Compression
Refrigeration System
(Conv.+Obj)
3) Refrigerant
(Theory Obj)
4) Vapour Absorption
Refrigeration System (Obj) | 5) Psychrometry (Obj)
6) Summer & Winter A/C
(Conv.+Obj)
7) Duct Design
(Obj) |
|--|---|

Basic Concepts

Refrigeration Effect :-

It is Amount of heat, which is Required to extract in order to provide and maintain lower temperature than that of Surroundings.

Refrigerant :-

It is Working fluid or Working Substance, that is used to extract the heat from the Storage space/ system.

C.O.P or E.P.R :-

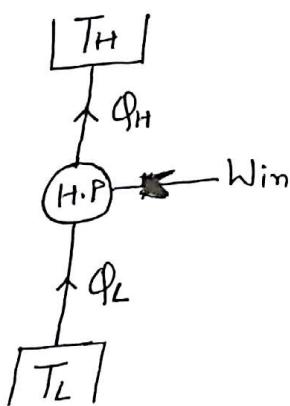
Coefficient of Performance or Energy Performance Rate :-

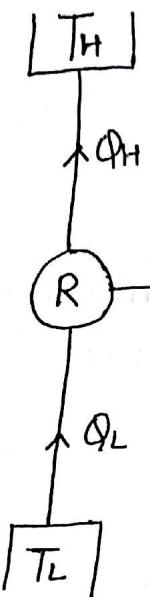
It is Ratio of Desired effect to the Work input.
or

It is defined as Ratio of Refrigeration effect to the Work input.

$$C.O.P = \frac{\text{Desired Effect}}{W_{in}} = \frac{T_H}{T_H - T_L} = \frac{T_L}{T_H - T_L}$$

↓ ↓
 Heat Pump Refrigeration
 (D.E. ↑ Temp) (D.E. ↓ Temp)





(Refrigerator)

Objective

$$(C.O.P)_R = \frac{T_L}{T_H - T_L}$$

gmb

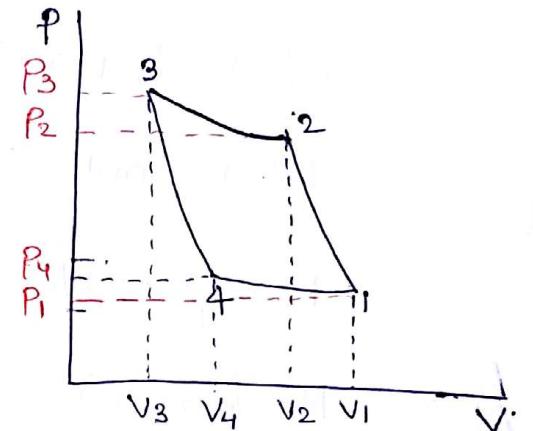
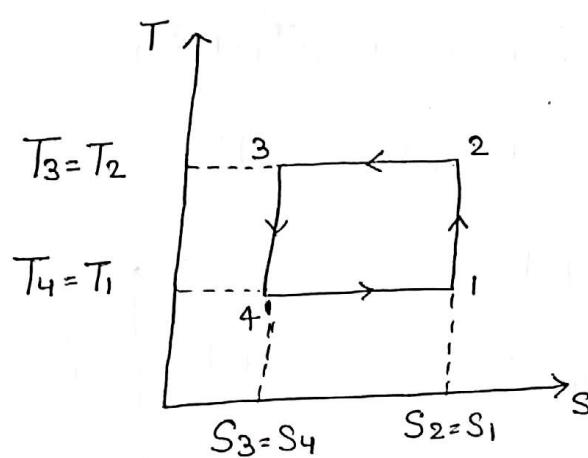
$$(C.O.P)_{HP} = (C.O.P)_R + 1 = \frac{1}{\eta_E}$$

↓
This Relation or Expression is applicable b/w the "Same
Temperature" limits.

Ideal Refrigeration Cycle :-

OR

Reversed Carnot Cycle :-



$$dQ = \cancel{\dot{S}_{gen}^0} + \frac{dQ}{T}$$

$$\boxed{dQ = TdS}$$

$$\text{Process (1-2)} \rightarrow dQ = TdS = 0$$

$$\text{Process (2-3)} \rightarrow dQ = T(S_3 - S_2) = -ve$$

Process (1-2) \rightarrow Reversible Adiabatic or Isentropic Compression.

Process (2-3) \rightarrow Heat Rejection at Constant Temperature.

Process (3-4) \rightarrow Isentropic Expansion.

Process (4-1) \rightarrow Heat Supply at Constant Temperature

$$C.O.P = \frac{\text{Desired Effect}}{W_{net}}$$

- (1-2) Isentropic Compression
- (2-3) Isothermal Compression
- (3-4) Isentropic Expansion
- (4-1) Isothermal expansion

$$C.O.P = \frac{\text{Desired Effect}}{W_{\text{net}}}$$

$W_{\text{net}} = Q_{\text{net}}$ → from Ist Law of Thermodynamics

$$W_{\text{net}} = Q_{\text{net}} \Rightarrow Q_{1-2} + Q_{2-3} + Q_{3-4} + Q_{4-1}$$

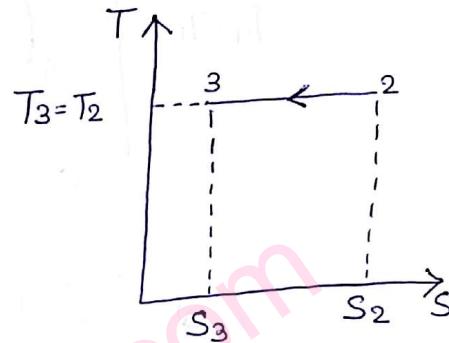
$$W_{\text{net}} = Q_{\text{net}} = Q_{2-3} + Q_{4-1} \quad \dots \textcircled{1}$$

$$dS = \frac{dQ}{T} \Rightarrow dQ = TdS$$

$$dQ = T_H(S_3 - S_2) = -T_H(S_2 - S_3)$$

$$dQ_{(2-3)} = -T_H(S_1 - S_4) \quad \dots \textcircled{2}$$

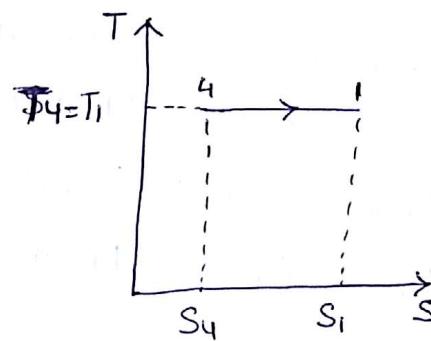
$$dQ_{(4-1)} = T(S_F - S_I) = T_L(S_1 - S_4) \quad \dots \textcircled{3}$$



using $\textcircled{2}$ & $\textcircled{3}$ in $\textcircled{1}$

$$\begin{aligned} W_{\text{net}} &= Q_{\text{net}} \Rightarrow Q_{2-3} + Q_{4-1} \\ &\quad - T_H(S_1 - S_4) + T_L(S_1 - S_4) \\ &= (T_L - T_H)(S_1 - S_4) \end{aligned}$$

$$W_{\text{net}} = -Vc$$



As the Value of Network output is having negative expression,
therefore our Assumed System is Work Absorbing device.

$$C.O.P = \frac{\text{Desired Effect}}{W_{\text{in}}} = \frac{D.E.}{(T_H - T_L)(S_1 - S_4)} \rightarrow \underline{\text{Process}(1-4)}$$

IRC → Ideal Refrigeration
 cycle.
 RCC → Reversed Carnot
 cycle.

$$C.O.P = \frac{T_L (S_1 - S_4)}{(T_H - T_L) (S_1 - S_4)}$$

Objective

$$(C.O.P)_{I:RC} = \frac{T_L}{(T_H - T_L)}$$

If Heat is Rejected by any System, then it must be gain by other System and the System which gains this Rejected Heat, then its entropy must be increase.

NOTE :-

- 1) Reversed Carnot Cycle (C.O.P) as a function of temperature limits only.
- 2) If there are "n" no. of Reversible Refrigerator, operating b/w same Temp. limits, with different working fluids or Refrigerant then the value of max. Possible (COP) or Reversed Carnot (COP) or Ideal (C.O.P) is having same value.
- 3) Reversed Carnot C.O.P is Independent of Working fluid.

Reversed Carnot — function of — temp. limits
 ↳ Independent of Working fluid

Unit Of Refrigeration :-

1 Tonne of Refrigeration

$$1 \text{ TR} = 3.5 \text{ kW} = 210 \frac{\text{KJ}}{\text{min}} = 50 \frac{\text{Kcal}}{\text{min}}$$

It is the amount of Heat, which is Required to extract from 1000 Kg of Water at 0°C in Order to convert it into equivalent ice at 0°C in 24 hours/day.

NOTE :-

(Qn) Producing ice at 0°C

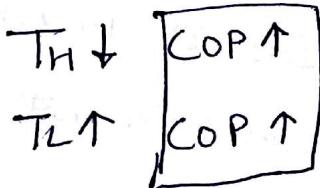
$$\downarrow \text{COP} = \frac{T_L}{(T_H - T_L)} \uparrow$$

if we $\uparrow T_H$ then $(T_H - T_L)$ will \uparrow

Such that, $T_L = \text{Constant}$, $T_H \uparrow$ $\text{COP} \uparrow$

- a) $(\text{COP})_S > (\text{COP})_W$
- b) $(\text{COP})_S < (\text{COP})_W$
- c) $(\text{COP})_S = (\text{COP})_W$
- d) Based on given Data

B.G.



Summer	Winter
$T_L = 0^{\circ}\text{C}$	$T_L = 0^{\circ}\text{C}$
$T_H = 30^{\circ}\text{C}$	$T_H = 10^{\circ}\text{C}$

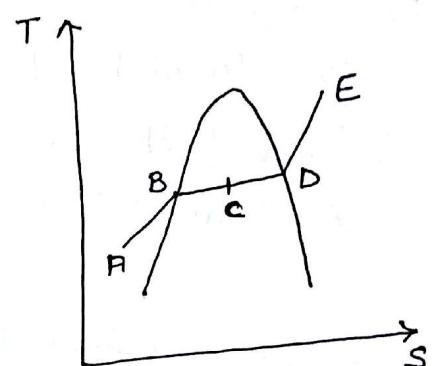
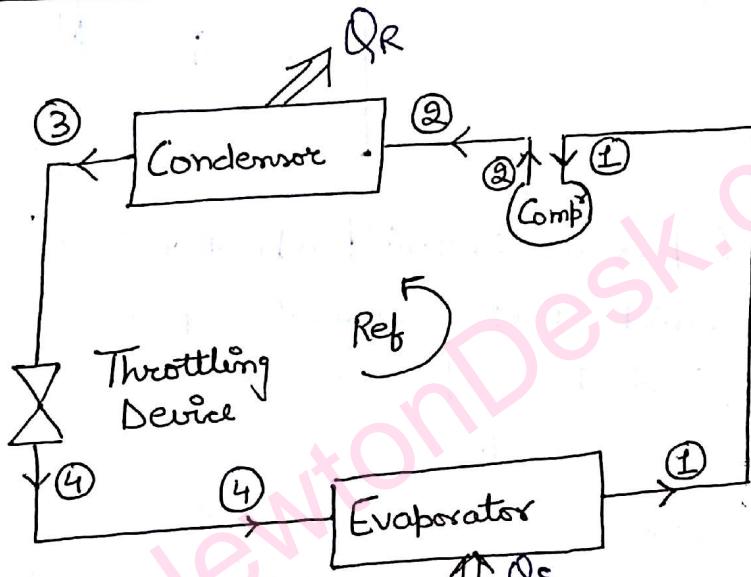
$T_L = \text{Constant}$

$$(T_H)_S > (T_H)_W$$

$$(\text{COP})_S < (\text{COP})_W$$

Pure Substance :-

1) $h_B = h_f$	$(h_g - h_f)$	1) $S_B = S_f$
2) $h_D = h_g$	$(h_g - h_f)$	2) $S_D = S_g$
3) $h_c = h_f + x h_{fg}$		3) $S_c = S_f + x(S_g - S_f)$
4) $h_E = h_g + (C_p)_{vap} [T_E - T_D]$		4) $S_E = S_g + (C_p)_{vap} \ln \left(\frac{T_E}{T_D} \right)$
5) $h_A = h_f - (C_p)_{lif} (T_B - T_A)$		5) $S_A = S_f - (C_p)_{lif} \ln \left(\frac{T_B}{T_A} \right)$

Vapour Compression Refrigeration System :- VCRSVapour Compression Refrigeration System

Process (1-2) \rightarrow Isentropic / Reversible Adiabatic Compression

Process (2-3) \rightarrow Constant Pressure heat Rejection

Process (3-4) \rightarrow Constant Enthalpy Expansion

Process (4-1) \rightarrow Constant Pressure heat Addition

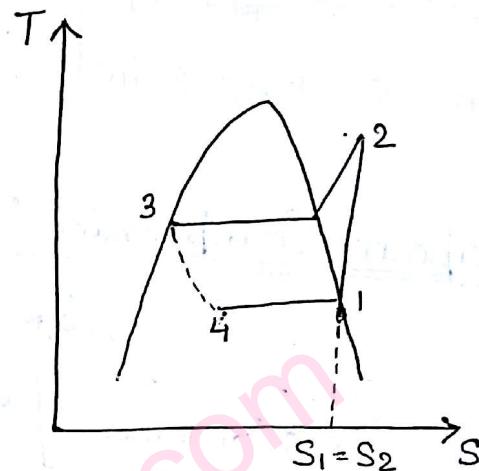
Assumption :-

- 1) Entry to the Compressor and exit of evaporator (State 1) is Saturated Vapour.
- 2) Exit of the Condenser & entry of throttling (State 3) is Saturated liquid

$$C.O.P = \frac{\text{Desired Effect}}{W_{in}}$$

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

Compressor is Work producing



(Qn) Why Isentropic Expansion is not preferable in VCRS?

The State of Working fluid, at the entry of expander (evaporator) is Saturated liquid, and then expression of Work is given by,

$$W = -\int V_f dP$$

$$V_g \gg V_f$$

Where V_f is Specific volume of Saturated liquid, which is negligible in Comparison to the V_g i.e. Specific volume of Saturated Vapour, handled by the Compressor.

So, the expansion work is negligible in Comparison to the Compression Work, therefore the use of isentropic expansion will not justify the cost of expander.

NOTE :-

- 1) Refrigeration Effect (R.E) $\rightarrow (h_1 - h_4) \frac{\text{KJ}}{\text{kg}}$
- 2) Work input (W_{in}) $\rightarrow (h_2 - h_1) \frac{\text{KJ}}{\text{kg}}$
- 3) Refrigeration Capacity (R.C) $\rightarrow \dot{m} \times R.E \text{ (KW)}$
- 4) Power input (P_{in}) $\rightarrow \dot{m} \times W_{in} \text{ (KW)}$

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

$$W_{in} = h_2 - h_1 \text{ KJ/kg}$$

$$R.C = \dot{m} \times (h_1 - h_4) = \dot{m} \times R.E \text{] KW}$$

$$P_{in} = \dot{m} \times (h_2 - h_1) = \dot{m} \times P_{in}$$

Volumetric Efficiency of Reciprocating Compressor

It is defined as the Ratio of "Actual volume at the entry of Compressor to the theoretical Swept volume".

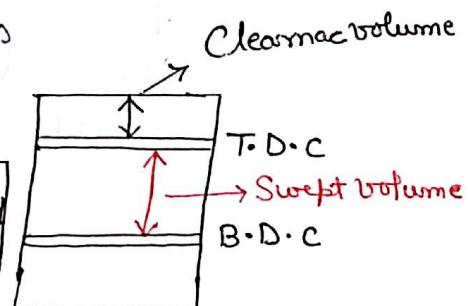
Objective

$$\eta_v = \frac{\dot{m} v_{entry}}{\frac{\pi}{4} D^2 L \times \frac{N}{60} \times K}$$

$$\text{Specific volume} \rightarrow v = \frac{\text{Vol}}{\text{mass}}$$

$$\text{Vol} = \dot{m} \times v_{entry}$$

$$\eta_v = \frac{\text{Act. Vol}_{entry}}{\text{Swept Vol.}}$$



Where,

\dot{m} \rightarrow mass flow rate Kg/sec

v \rightarrow specific volume at entry of Compressor m^3/kg

D \rightarrow Bore / Diameter (m)

L \rightarrow Stroke Length (m)

N \rightarrow Speed (x Pm)

K \rightarrow No. of Cylinders

$\dot{m} \rightarrow \text{kg/sec}$

$v \rightarrow \text{m}^3/\text{kg}$

$D \rightarrow \text{m}$

$L \rightarrow \text{m}$

$N \rightarrow \text{x Pm}$

$K \rightarrow \text{No. of Cylinders}$

Objective

$$\eta_v = \frac{(\dot{m} V)_{\text{entry}}}{\frac{\pi}{4} D^2 L \times \frac{N}{60} \times K}$$

Volumetric Efficiency

NOTE :-

1) volumetric Efficiency is also Calculated by the expression,

$$\eta_v = 1 + C - C \left[\frac{P_{\text{higher}}}{P_{\text{lower}}} \right]^{\frac{1}{n}}$$

for RAC

$$\eta_v = 1 + C - C \left[\frac{P_{\text{cond}}}{P_{\text{eva}}} \right]^{\frac{1}{n}}$$

where $n \rightarrow$ Polytropic Index

$C \rightarrow$ Clearance Ratio



it is defined as the Ratio of Clearance volume
to the theoretical Swept volume.

$$C = \frac{V_c}{V_s}$$

objective

$$\eta_v = \frac{(\dot{m} V)_{\text{entry}}}{\frac{\pi}{4} D^2 L \times \frac{N}{60} \times K}$$

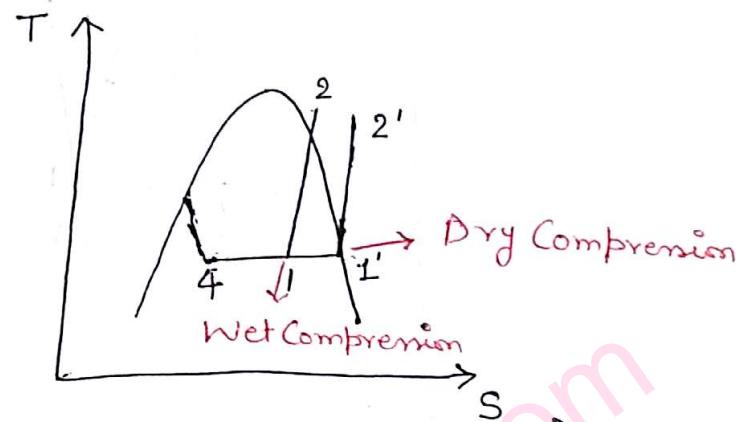
$$\eta_v = 1 + C - C \left[\frac{P_c}{P_e} \right]^{\frac{1}{n}}$$

Dry Compression v/s Wet Compression :-

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Dry Compression means entering point to the Compressor is from Saturated Vapour.

Wet Compression means entering Point to the Compressor is from Wet region (Liquid + vapour).



Disadvantage of Wet Compression over ~~Dry~~ Compression :-

- 1) Refrigeration Effect (R.E.) ↓

$$(R.E)_{Dry} = h_4' - h_4$$

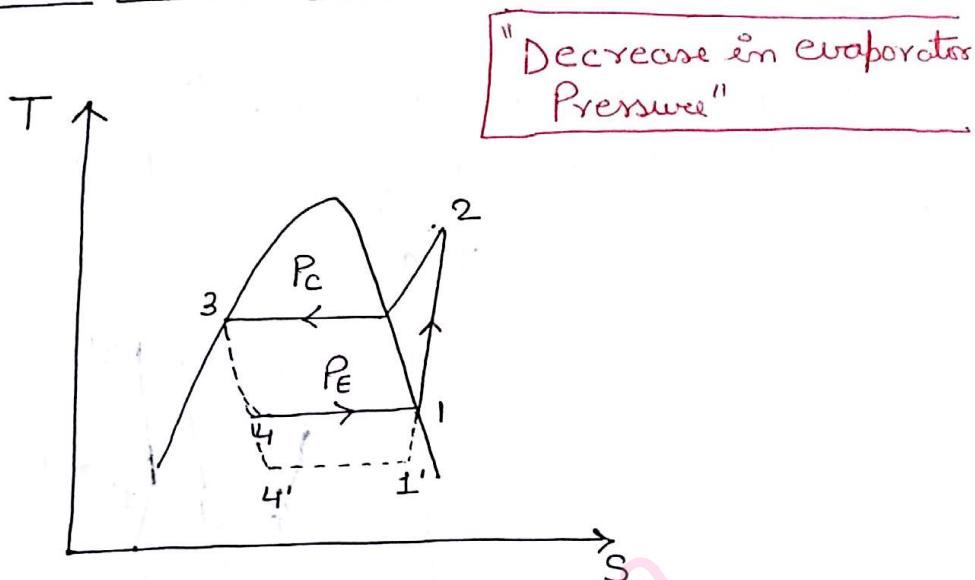
$$(R.E)_{Wet} = h_1 - h_4$$

- 2) The Liquid particle, which is present in the mixture of Refrigerant, may wash away the lubricant and it ↑ the chances of Wear & tear & it also damage the Compressor valve & its Body.

- 3) Wet Compression Represents individually, the incomplete evaporation of Refrigerant.

Effect of Variation in Parameters on Performance of Vapour Compression Refrigeration System (VCRS) :-

1) Case ① → Decrease in evaporator Pressure :-



Process → 1-2-3-4-1

$$1) R.E = h_1 - h_4$$

$$2) \dot{W}_{in} = h_2 - h_1$$

$$3) C.O.P = \frac{R.E}{\dot{W}_{in}}$$

$$4) \frac{P_C}{P_E}$$

Process → 1'-2-3-4'-1'

$$1) R.E \downarrow = h_1' - h_4'$$

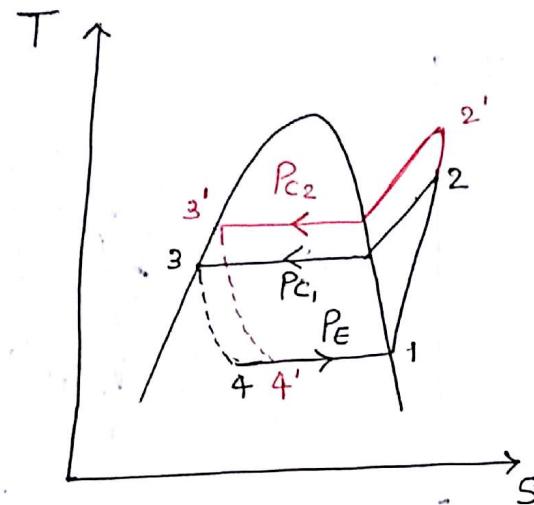
$$2) \dot{W}_{in} = h_2 - h_1'$$

$$3) \downarrow C.O.P = \frac{R.E \downarrow}{\dot{W}_{in} \uparrow}$$

$$4) \boxed{\frac{P_C}{P_E \downarrow}} \uparrow, \eta_v \downarrow$$

$$\eta_v = \left[1 + C - C \left(\frac{P_C}{P_E} \right)^{\frac{1}{m}} \right]$$

2) Case 2 :- Effect of \uparrow in Condenser Pressure - NewtonDesk.com



Process $\rightarrow 1-2-3-4-1$

$$1) R.E = h_1 - h_4$$

$$2) W_{in} = h_2 - h_1$$

$$3) C.O.P = \frac{R.E}{W_{in}}$$

$$4) \frac{P_{C1}}{P_E}$$

Process $\rightarrow 1-2'-3'-4'-1$

$$1) \downarrow R.E = h_1 - h_4'$$

$$2) \uparrow W_{in} = h_2' - h_1$$

$$3) \downarrow C.O.P = \frac{R.E \downarrow}{W_{in} \uparrow}$$

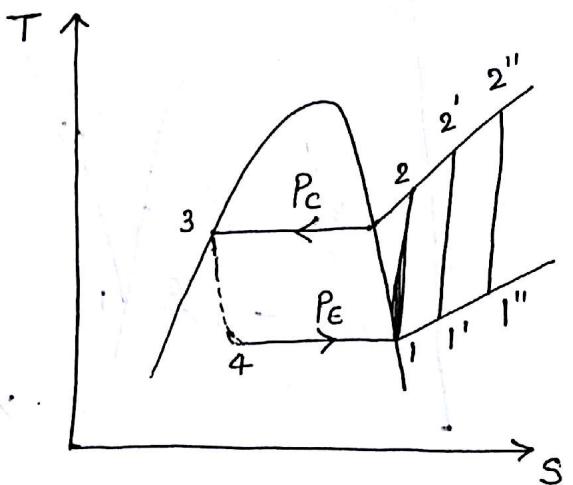
$$4) \left(\frac{P_{C2}}{P_E} \right) \uparrow, \eta_v \downarrow$$

$$\Rightarrow \eta_v = \left[1 + C - C \left(\frac{P_C}{P_E} \right)^{\frac{1}{n}} \right]$$

NOTE :-

- 1) Effect of \uparrow in Condenser pressure and \downarrow in evaporator pressure are adjacently Same.

3) Case-③ → Superheating (Within the Evaporator)



Process → 1-2-3-4-1

$$1) R.E = h_1 - h_4$$

$$2) W_{in} = h_2 - h_1$$

$$3) C.O.P = \frac{R.E}{W_{in}}$$

4) ~~Efficiency~~

Process → 1'-2'-3'-4'-1'

$$1) \uparrow R.E = h_1' - h_4$$

$$2) \uparrow W_{in} = h_2' - h_1'$$

$$3) C.O.P = \frac{\uparrow R.E}{\uparrow W_{in}}$$

Prove that W_{in} is a function of
Turbine

$$W_{in} = n W_{closed}$$

$$W_{in} = n \left[\frac{P_1 V_1 - P_F V_F}{n-1} \right]$$

$$= \frac{n}{n-1} [P_1 V_1 - P_2 V_2]$$

$$P_v = mRT$$

$$= \frac{n}{n-1} (mRT_1 - mRT_2)$$

$$= \frac{n}{n-1} mR(T_1 - T_2)$$

$$= \frac{n}{n-1} mRT_1 \left(1 - \frac{T_2}{T_1}\right) \quad \text{--- (1)}$$

$$Pv^n = C \quad (\text{Polytropic})$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} = \left(\frac{P_c}{P_e} \right)^{\frac{n-1}{n}} \rightarrow ②$$

$$P_3 = P_2' = P_2 = P_c \\ P_4 = P_1 = P_1' = P_e \rightarrow ③$$

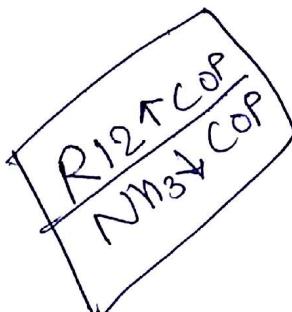
$$W_{in} = \frac{n}{n-1} m R T_1 \left[1 - \left(\frac{P_c}{P_e} \right)^{\frac{n-1}{n}} \right]$$

$W_{in} = f(T_{inlet})$

Effects of Superheating :-

- 1) Refrigeration Effect (R.E) \uparrow , if Superheating occurs in Evaporator.
- 2) W_{in} in the Compressor \uparrow , because it is in the function of inlet temperature to the Compressor. (function of Tenlet)
- 3) (C.O.P) may be \uparrow or \downarrow , depending on Refrigerant.

for example:-

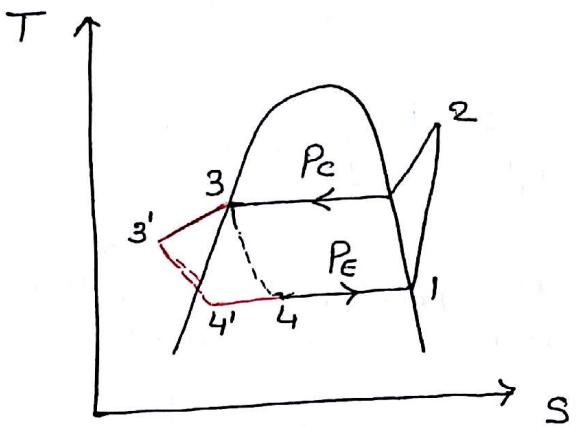


R-12 Refrigerant \uparrow (COP)
(Superheating Would Result $\&$ \uparrow in COP)

NH₃ Ammonia Refrigerant \downarrow (COP)
(Superheating Would Result in \downarrow in C.O.P)

4) Sub Cooling :-

It is the Process of \downarrow the temperature at Constant Pressure below Saturated Liquid.



Process $\rightarrow 1-2-3-4-1$

$$1) R.E = h_1 - h_4$$

$$2) W_{in} = h_2 - h_1$$

$$3) C.O.P = \frac{R.E}{W_{in}}$$

Process $\rightarrow 1-2-3'-4'-1$

$$1) \uparrow R.E = h_1 - h_4'$$

$$2) W_{in} = h_2 - h_1 \text{ (Const)}$$

$$3) \uparrow C.O.P = \frac{\uparrow R.E}{\uparrow W_{in} \text{ (Const)}}$$

To obtain the required subcooling, the inlet fluid must be cooled below its saturation temperature.

The amount of heat added to the system is $Q = m(h_2 - h_1)$.

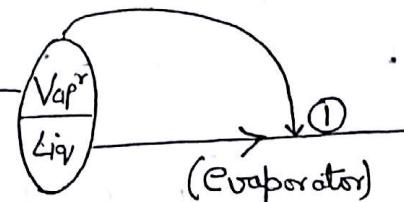
For a given Q , the subcooling depends on m .

Use of Flash Chamber in VCRS :-

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Flash Chamber is a device, which is used to separate liquid Refrigerant from the Vapour, at the entry of evaporator and, it allows only the liquid refrigerant to enter into evaporator which results in absorption of heat.

By the use of Flash chamber
Size of evaporator Reduce
which is good for industrial
Purpose.

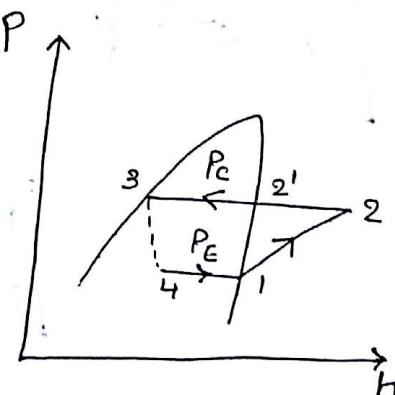
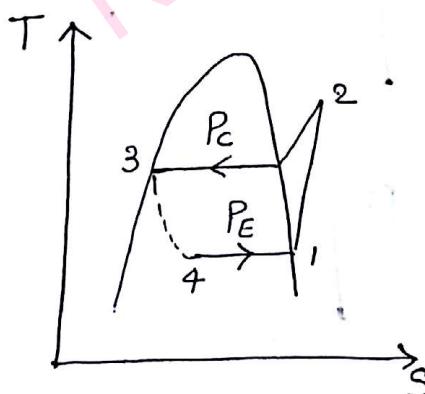


Because density of Water is ↑
and density of Vapours is ↓ low.

NOTE :-

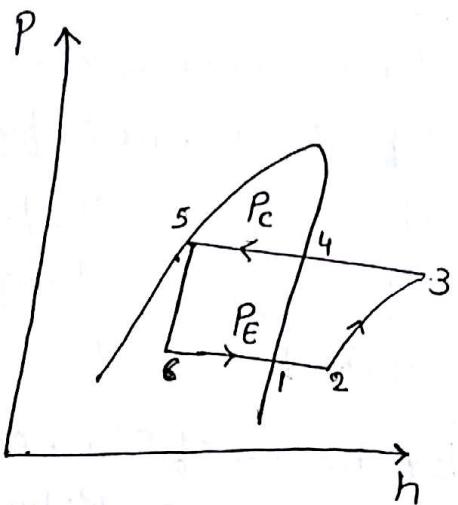
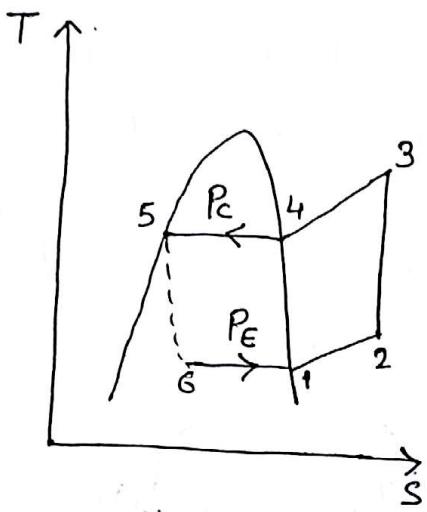
- 1) There is no impact on COP with the use of flash chamber.
- 2) Flash Chamber helps in reducing the Size of evaporator.

NOTE :- (1) Simple VCRS



$$\begin{aligned} P_4 &= P_E = P_1 \\ P_3 &= P_2' = P_2 = P_C \end{aligned}$$

2) Superheating :-

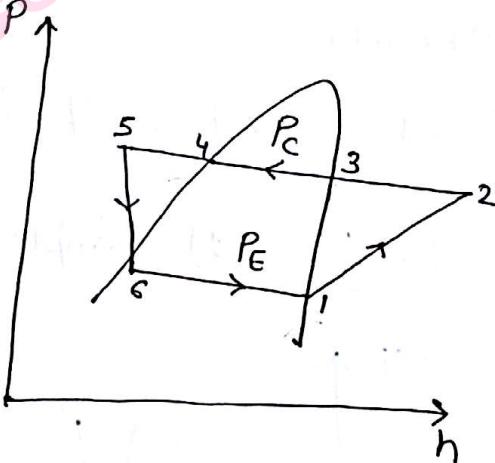
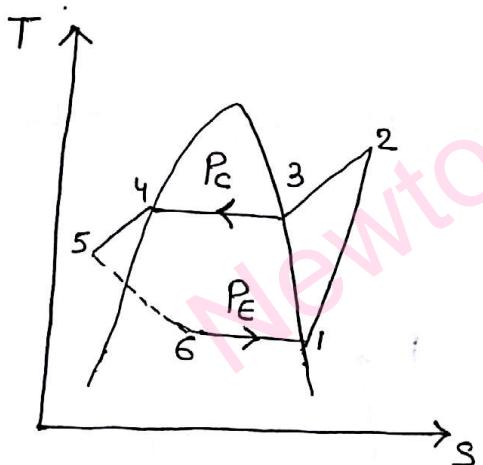


$$P_G = P_1 = P_2 = P_E$$

$$P_5 = P_4 = P_3 = P_c$$

3)

Subcooling :-



$$P_5 = P_4 = P_3 = P_2 = P_c$$

$$P_6 = P_1 = P_E$$

(Qn) A Refrigerant opening/operating on simple VCRS, having enthalpy at the entry of evaporator is 80 KJ/Kg & leaving the evaporator with enthalpy of 180 KJ/Kg. Enthalpy at entry of condenser is 210 KJ/Kg.

Find COP?

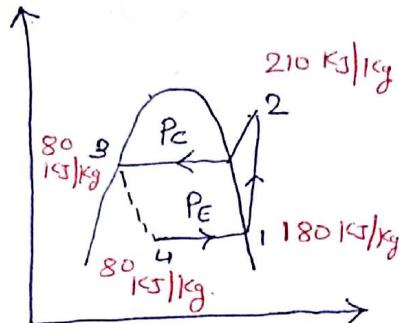
$$\text{Soln) } R.E = h_1 - h_4 \\ = 180 - 80 \\ = 100$$

$$W_{in} = h_2 - h_1 \\ = 210 - 180 \\ = 30$$

$$COP = \frac{R.E}{W_{in}}$$

$$COP = \frac{100}{30}$$

$$COP = 3.33 \quad \text{Ans}$$



Methods To find mass flow Rate \dot{m}

$$① \quad R.C = \dot{m} \times R.E$$

$$② \quad \cancel{P_{in}} = \dot{m} \times W_{in}$$

$$③ \quad N_V = \frac{\dot{m} V_{\text{entry of comp.}}}{\frac{\pi}{4} D^2 L \frac{N \times K}{60}}$$

if there is no value given in Data of K
then it must be understood to take it
as 1

(Qn) In 5 kW Cooling Capacity, Refrigeration System, the Refrigerant enters in evaporator with the enthalpy of 75 kJ/kg. & leaves with the enthalpy of 183 kJ/kg. Compression process is isentropic and the enthalpy at the outlet of the Compressor is 210 kJ/kg. Calculate,

- 1) COP.
- 2) Power Consumption in kW.
- 3) Rate of Heat Rejection across Condenser in kW.

Soln) 1) $R.E = h_1 - h_4$
 $= 183 - 75$
 $= 108$

$$W_{in} = h_2 - h_1$$

 $= 210 - 183$
 $= 27$

$$COP = \frac{R.E}{W_{in}} = \frac{108}{27} = 4$$

$$\boxed{COP = 4}$$

2) $P_{in} = \dot{m} \times W_{in}$

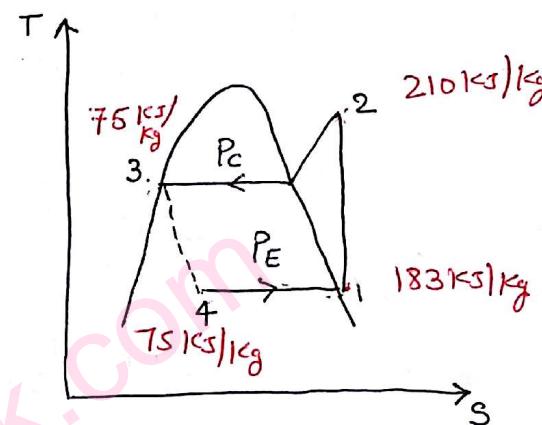
$$\dot{m} = \frac{P_{in}}{W_{in}}$$

$$\dot{m} = 0.04629 \text{ kg/sec}$$

$$\boxed{\dot{m} = 0.04629 \text{ kg/sec}}$$

3) $Q_c = (h_2 - h_3) \dot{m}$
 $= 135 \times 0.04629$

$$\boxed{Q_c = 6.24915 \text{ kW}}$$



$$R.C = \dot{m} \times R.E$$

$$5 = \dot{m} \times 108$$

$$\dot{m} = 0.04629 \text{ kg/sec}$$

$$Q_c = (h_2 - h_3) \dot{m}$$

But it Result Ans in kJ/kg

So to Convert it into kW

We must multiply Q_c with \dot{m} .

$$Q_c = (h_2 - h_3) \dot{m}$$

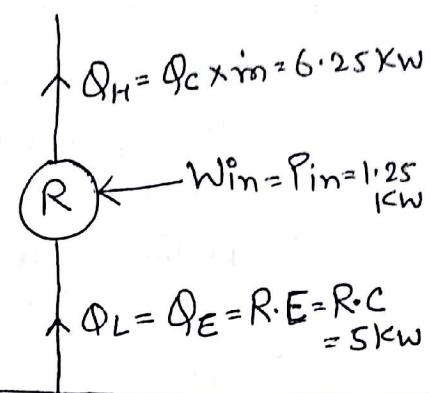
$$\downarrow$$

$\frac{\text{kJ}}{\text{kg}} \times \frac{\text{kg}}{\text{sec}}$	$\frac{\text{kJ}}{\text{sec}} = \text{kW}$
---	--

Another Method to Solve above Question,

$$COP = \frac{RE}{Win} = \frac{RE \times \dot{m}}{Win \times \dot{m}} = \frac{RC}{Pin}$$

$$P = \frac{RC}{COP} = \frac{5}{4} = 1.25 \text{ kW}$$



- Qn) A Refrigeration operating on Simple VCRS has Piston displacement vol (Swept Vol.) of 1.5 L, having 80% volumetric efficiency and 1600 R.P.m. the following Data's are provided,

	$h \text{ kJ/kg}$	$v \text{ m}^3/\text{kg}$
Compressor Inlet	183.2	0.0767
Compressor discharge	222.6	0.0614
Condenser exit	84.9	0.00083

$$1600 \times \text{pm} / 80\% / 1.5 \text{ L}$$

Then find,

- 1) Refrigeration effect in kW
- 2) Power input in kW

$$\begin{aligned} \text{Setn)} \quad R.E &= h_1 - h_4 \\ &= 183.2 - 84.9 \end{aligned}$$

$$RE = 98.3 \text{ kJ/kg}$$

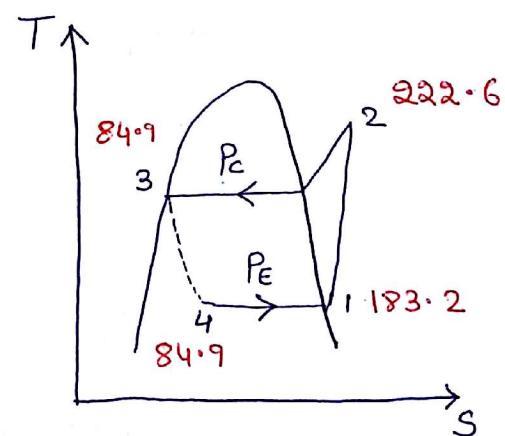
$$\begin{aligned} Win &= h_2 - h_1 \\ &= 222.6 - 183.2 \end{aligned}$$

$$Win = 39.4$$

$$\text{Power Input} = Pin = \dot{m} \times Win$$

$$Pin = 0.4142 \times 39.4$$

$$Pin = 16.319 \text{ kW}$$



$$N_V = \frac{\dot{m} V_{entry}}{\frac{\pi}{4} D^2 L N \times K}$$

$$0.80 = \frac{\dot{m} \times 0.0767}{\frac{1.5 \times 10^3 \times 1600}{60}}$$

$$\dot{m} = 0.4142 \text{ kg/sec}$$

Qn) A Refrigerant operating on Simple VRCS having COP = 6.5.

Enthalpy of Saturated liquid & Saturated Vapour Refrigerant at the operating Condenser temperature of 35°C are 69.55 kJ/kg and 201.50 kJ/kg .

Respectively. The Saturated Refrigerant Vapour leaving the evaporator having enthalpy of 187.53 . The Specific heat of Vapour refrigerant is 0.6155 kJ/kg-K .

Find the Compressor discharge temp in $^{\circ}\text{C}$.

Soln) Given Data,

$$\text{COP} = 6.5$$

$$(C_p)_{\text{Vap}} = 0.6155 \text{ kJ/kg-K}$$

$$\begin{aligned} R.E &= h_1 - h_4 \\ &= 187.53 - 69.55 \\ R.E &= 117.98 \text{ kJ/kg} \end{aligned}$$

$$\text{C.OP} = \frac{R.E}{W_{\text{in}}}$$

$$6.5 = \frac{117.98}{W_{\text{in}}}$$

$$W_{\text{in}} = \frac{117.98}{6.5}$$

$$W_{\text{in}} = 18.150 \text{ kJ/kg}$$

$$\boxed{\text{C.OP} = \frac{R.E}{W_{\text{in}}}}$$

$$W_{\text{in}} = h_2 - h_1$$

$$18.150 = h_2 - 187.53$$

$$h_2 = 205.680 \text{ kJ/kg} \quad \text{Ans}$$

$$h_E = h_{g_2} + (C_p)_{\text{Vap}} (T_2 - T_2')$$

$$h_2 = h_{g_2} + (C_p)_{\text{Vap}} (T_2 - T_2')$$

$$205.680 = 201.50 + 0.6155 (T_2 - 35^{\circ})$$

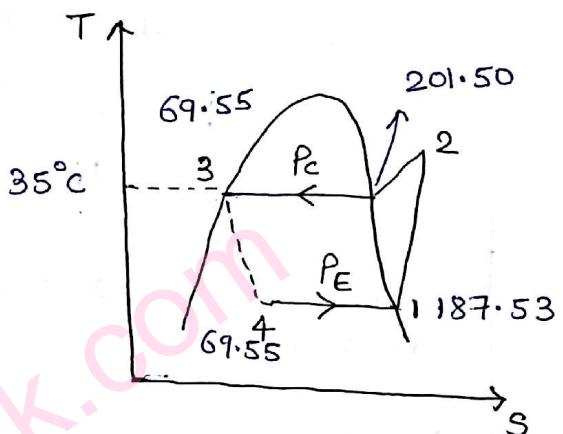
$$4.152 = T_2 - 35^{\circ}$$

$$T_2 = 39.01^{\circ}\text{C} \text{ or } 41.79^{\circ}\text{C}$$

$$4.18 = 0.6155 (T_2 - 35^{\circ})$$

$$6.7912 = T_2 - 35^{\circ}$$

$$T_2 = 41.79^{\circ}\text{C} \quad \text{Ans}$$



Qn) A Refrigerant based on ideal VCRS, operates b/w a temp limits of -20°C & 40°C .

The Refrigerant Enters the Condenser as Saturated Vapour and leaves the Condenser as Saturated Liquid. Then find,

- 1) COP
- 2) Refrigeration ~~effect~~^{Capacity} in kW , if $m = 0.025 \text{ kg/sec}$.

Soln) Given,

$$\text{Temp. limits} = -20^{\circ} \text{ & } 40^{\circ}\text{C}$$

$$m = 0.025 \text{ kg/sec}$$

$t^{\circ}\text{C}$	h_f	h_g	s_f	s_g
-20°	20	180	0.07	0.7366
40°	80	200	0.03	0.67

$$h_1 = h_{f1} + x(h_{g1} + h_{f1})$$

$$h_1 = 20 + x_1(180 - 20)$$

$$h_1 = 20 + x_1(160) \quad \text{--- (1)}$$

$$s_1 = s_2$$

$$s_{f1} + x(s_{g1} - s_{f1}) = s_{g2}$$

$$0.07 + x(0.7366 - 0.07) = 0.67$$

$$x = 0.9$$

Putting value of x in (1)

$$h_1 = 164 \text{ kJ/kg}$$

$$(1) R.E = h_1 - h_4$$

$$= 164 - 80 \\ = 84$$

$$\boxed{R.E = 84}$$

$$(2) W_{in} = h_2 - h_1$$

$$= 200 - 164 = 36$$

$$\boxed{W_{in} = 36}$$

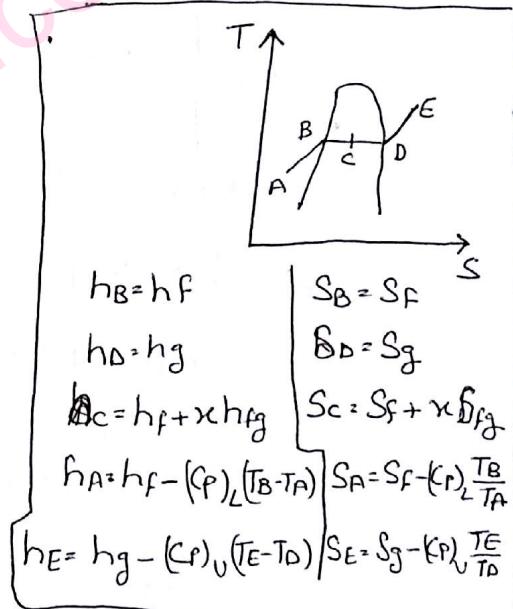
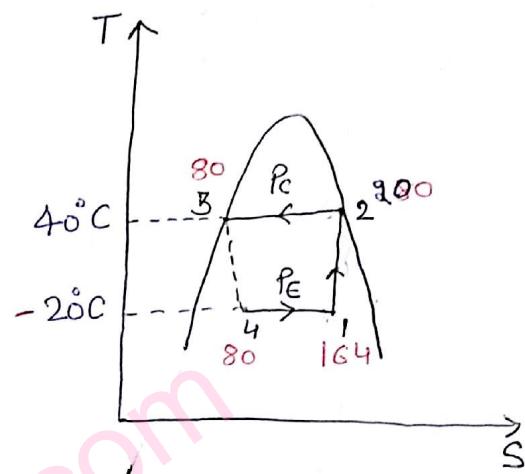
$$C.O.P = \frac{84}{36} = 2.33$$

$$\boxed{C.O.P = 2.33 \text{ Ans}}$$

$$(3) R.C = m \times R.E$$

$$= 0.025 \times 84$$

$$\boxed{R.C = 2.1 \text{ kW} \text{ Ans}}$$



$$h_B = h_f$$

$$h_D = h_g$$

$$h_C = h_f + x h_{fg}$$

$$h_A = h_f - (k_p)_L (T_B - T_A) \quad \boxed{S_A = S_f - (k_p)_L \frac{T_B}{T_A}}$$

$$h_E = h_g - (k_p)_U (T_E - T_D) \quad \boxed{S_E = S_g - (k_p)_U \frac{T_E}{T_D}}$$

Q22) A VCRS System using R-12 is employed to produce 8640 Kg of ice/day. The Condensing & evaporator of refrigerant are 48°C & -20°C. Saturated liquid leaves the condenser and Saturated vapour leaves the evaporator. The compression is isentropic. Water at 35°C is used to form ice and the temp of the ice should be 8°C. Heat flow into the brine tank from surrounding which is 10% of total heat removed from water to form ice. Determine the total power required to drive the compressor in KW.

Assume Specific heat of ice 2.26 kJ/kgK , Latent heat of ice is 334.72 kJ/kg & Specific heat of vapor refrigerant $(C_p)_v = 0.82 \text{ kJ/kgK}$

$t^{\circ}\text{C}$	$P(\text{bars})$	$h_f (\text{kJ/kg})$	$h_g (\text{kJ/kg})$	S_f	S_g
48°	11.64	82.83	205.83	0.2973	0.6802
-20°	1.51	17.82	178.74	0.0731	0.7087

$$\text{Soln) } m_{\text{ice}} = 8640 \text{ Kg/day} = \frac{8640}{24 \times 3600} = 0.1 \text{ kJ/sec}$$

$$h_2 = h_1 + (C_p)_v (T_2 - T_1) \\ = 205.83 + 0.82 (T_2 - 32) - ①$$

$$S_1 = S_2$$

$$Sg_1 = Sg_2 + (C_p)_v \ln \frac{T_2}{T_1}$$

$$0.7087 = 0.6802 + 0.82 \ln \frac{T_2}{32}$$

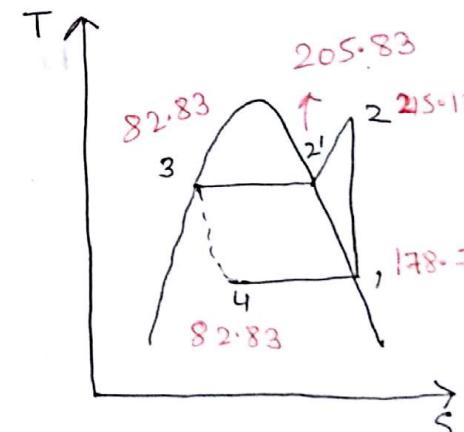
$$T_2 = 332.35 \text{ K}$$

using value of T_2 in ①

$$h_2 = 215.139 \text{ kJ/kg}$$

$$P_{in} = \dot{m} \times h_{in}$$

$$P_{in} = \dot{m} \times h_2 - h_1 \Rightarrow P_{in} = \dot{m} \times 36.34$$



$$35^{\circ}\text{C} - \underset{\text{S.H}}{0^{\circ}\text{C}} - \underset{\text{L.H}}{0^{\circ}\text{C}} - \underset{\text{S.H}}{0^{\circ}\text{C}} - 8^{\circ}\text{C}$$

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 S.H → Temp Change
 L.H → Phase Change

$$R_C = \dot{m} C_{fg} (T_H - T_L) + \dot{m} (LH) + \dot{m} C_{fg} (T_H - T_L)$$

$$= 0.1 \times 4.187 (35 - 0) + 0.1 \times 334.72 + 0.1 \times 2.26 \times (0 - (-8))$$

$$R_C = 49.90 \text{ kW}$$

$$R_C = \dot{m} RE$$

$$R_C = \dot{m} (h_1 - h_4)$$

$$49.90 = \dot{m} 95.91$$

$$\dot{m} = 0.520 \text{ kg/sec}$$

$$R_C = \dot{m} RE$$

$$10\% \text{ of } 49.90$$

$$4.999 \text{ kW}$$

$$54.90 = \dot{m} 95.91$$

$$\dot{m} = 0.572 \text{ kg/sec}$$

Putting \dot{m} in ①

$$= 0.57 (h_2 - h_1)$$

$$= 0.57 (205.34 - 178.74)$$

$$\dot{P}_{in} = 20.85 \text{ kW}$$

$$COP = \frac{RE}{\dot{P}_{in}} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{95.91}{36.39}$$

$$COP = 2.63$$

$$\begin{array}{c} 35^{\circ}\text{C} \\ -8^{\circ}\text{C} \end{array} \rightarrow \begin{array}{l} 49.94 \\ + \\ 4.499 \\ = 54.90 \text{ kW} \end{array}$$

Q. 23 Workbook)

(Q) A Food Storage requires a Refrigeration capacity of 1STR. It works b/w -10°C & 30°C . The Temperature of Refrigerant Superheated as gas in evaporator is -5°C & temperature of Refrigerant Subcooled as liquid in the ~~compressor~~ Condenser is 25°C . No. of cylinders are equal to 2, Stroke is 1.5 times the bore & Speed is 960 RPM. Determine,

- 1) (a) R.E / Kg
(b) mass flow rate (in) of Refrigerant in Kg/min
(c) Theoretical Piston displacement
(d) COP
(e) Bore and Stroke of the Compressor.

2) if the clearance volume is 3% of stroke volume then,

- (a) Determine volumetric efficiency η_v .
- (b) Bore & Stroke of the Compressor.

The specific heat of liquid is taken as 0.963 kJ/kgK & Specific heat of vapour is 0.615 kJ/kgK

$t^{\circ}\text{C}$	$P(\text{bar})$	$h_f(\text{kJ/kg})$	$h_g(\text{kJ/kg})$	S_f	S_g	$V (\text{m}^3/\text{kg})$
-10	2.1928	190.72	347.96	0.96561	1.5632	0.07702
30	7.4458	229.11	364.96	1.0999	1.5481	0.02372

Sohn
Saturated

Given Data,

$$R.C = 15\text{TR}$$

$$R.C = 15 \times 3.5 = 52.5 \text{ kW}$$

$$\text{at } S_g \quad \text{Temp. evaporator} = -10^{\circ}\text{C} = 263\text{K}$$

$$\text{at } S_g \quad \text{Temp. Condenser} = 30^{\circ}\text{C} = 303\text{K}$$

Temp. of Refrigerant Superheated as gas in evaporator is $-5^{\circ}\text{C} = 268\text{K}$

Temp. of Refrigerant Superheated as liquid in

Condenser is $25^{\circ}\text{C} = 298\text{K}$

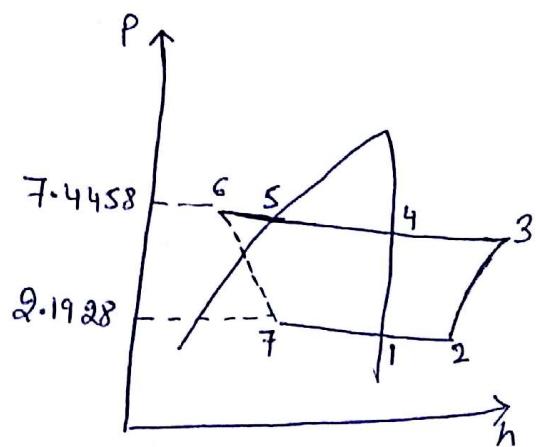
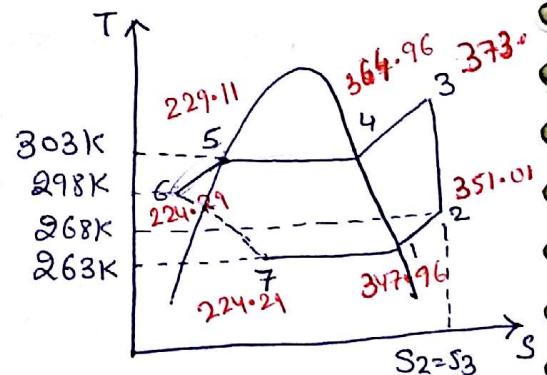
No. of cylinders (K) = 2

Stroke (L) = 1.5 D

Speed (N) = 960 RPM

$(C_p)_V = 0.615 \text{ kJ/kgK}$

$(C_p)_L = 0.963 \text{ kJ/kgK}$



$$h_1 = 347.96$$

$$h_2 = h_{g1} + (C_p)_v (T_2 - T_1)$$

$$h_2 = 347.96 + 0.615 (268 - 263)$$

$$h_2 = 347.96 + 3.075$$

$$h_2 = 351.01 \text{ kJ/kg-K}$$

$$h_4 = 364.96$$

$$h_3 = h_{g4} + (C_p)_v (T_3 - T_4)$$

$$h_3 = 364.96 + 0.615 (T_3 - 303) - ①$$

$$S_2 = S_3$$

$$S_{g1} + (C_p)_v \ln \frac{T_2}{T_1} = S_{g4} + (C_p)_v \ln \frac{T_3}{T_4}$$

$$\cancel{0.96561 + 0.615 \ln \frac{268}{263}} = + \\ 1.5632 + 0.615 \ln \frac{268}{263} = 1.5481 + 0.615 \ln \frac{T_3}{303}$$

$$T_3 = 316.12 \text{ K}$$

On putting value of T_3 in eqn ①

$$h_3 = 364.96 + 0.615 (316.12 - 303)$$

$$h_3 = 364.96 + 0.615 (13.12)$$

$$h_3 = 373.02 \text{ kJ/kg-K}$$

$$h_5 = 229.11$$

$$h_6 = h_{fs} - (C_p)_L (T_5 - T_6)$$

$$h_6 = 229.11 - 0.963 (303 - 298)$$

$$h_6 = 224.29$$

$$h_6 = h_7 = 224.29 \quad \text{Bc3 of Throttling}$$

$$① \frac{R_o E}{R_E} = h_2 - h_7$$

$$R_E = (351.01 - 224.29) \Rightarrow R_E = 126.8 \text{ kJ/kg-K}$$

$$R.C = \dot{m} R.E$$

$$\frac{52.5}{\frac{\text{kg}}{\text{sec}}} = \dot{m} \frac{126.8 - 124.29}{\text{kJ/kg}} \quad \dot{m} = 0.414 \text{ kg/sec} \times 60$$

$$\dot{m} = 24.60 \text{ kg/min}$$

$$\textcircled{1} \text{ (d)} \quad \underline{\text{COP}} = \frac{R \cdot E}{W_{in}} = \frac{126.8}{21.99} \approx 5.76$$

$$W_{in} = (h_3 - h_2) \\ = (373 - 351.01) \\ W_{in} = 21.99 \text{ kJ/kg-K}$$

I(c) Theoretical Piston displacement means
100% volumetric efficiency.

$$\eta_v = 100\% = 1 = \frac{\dot{m}v_2}{\frac{\pi}{4} D^2 L \frac{N}{60} K}$$

$$T_{PD} = \dot{m}v_2 = \frac{\pi}{4} D^2 L \frac{N}{60} K$$

$$T_{PD} = 0.416 v_2 - \textcircled{1}$$

$$T_{PD} = 0.416 \times 0.07702$$

$$T_{PD} = 0.326 \text{ m}^3/\text{sec}$$

$$P_U = mRT \quad P(\frac{V}{m}) = RT \quad VdT$$

$$\frac{V_2}{V_1} = \frac{T_2}{T_1} = \frac{v_2}{0.07702} = \frac{268}{263}$$

$$v_2 = 0.07848 \text{ m}^3/\text{kg}$$

$$T_{PD} = 0.0326 = \frac{\pi}{4} D^2 L \frac{N}{60} \times K$$

$$0.0326 = \frac{\pi}{4} D^2 1.5D \times \frac{960}{60} \times 2$$

$$\frac{m^3}{\text{sec}} = \frac{D^2}{\text{sec}}$$

$$D = 0.095 \text{ m}$$

$$L = 0.1429 \text{ m}$$

2(a)

$$V_C = 30\% V_S$$

$$C = \frac{V_C}{V_S} = 0.03$$

$$V_C = 0.03 V_S$$

$$\eta_v = 1 + C - C \left(\frac{P_3}{P_2} \right)^{\frac{1}{n}} \text{ or } \eta_v = 1 + C - C \left(\frac{T_3}{T_2} \right)^{\frac{1}{n-1}}$$

$$\eta_v = 1 + C - C \left(\frac{V_2}{V_3} \right)^{\frac{1}{n-1}}$$

$$P_3 = P_4 = P_C$$

$$P_2 = P_1 = P_T = P_E$$

$$P_U^n = C$$

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

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

$$\left(\frac{P_3}{P_2} \right)^{\frac{n-1}{n}} = \left(\frac{V_2}{V_3} \right)^{n-1} \Rightarrow \left(\frac{P_3}{P_2} \right)^{\frac{1}{n}} = \frac{V_2}{V_3}$$

$$\eta_v = 1 + 0.03 - 0.03 \left(\frac{0.7848}{V_3} \right) - \textcircled{1}$$

$$V \propto T = \frac{V_3}{V_4} = \frac{T_3}{T_4}$$

$$\frac{V_3}{0.02372} = \frac{316}{303} \Rightarrow V_3 = 0.0247 \text{ m}^3/\text{kg}$$

Putting value of V_3 in $\textcircled{1}$

$$\boxed{\eta_v = 93.5\%}$$

(2)(b)

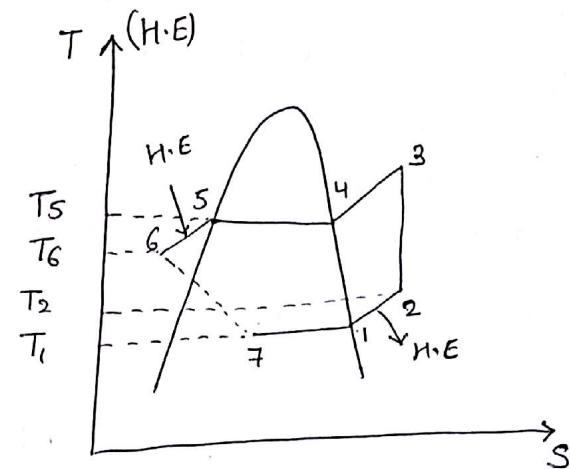
$$\eta_v = \frac{\dot{m}v_2}{\frac{\pi}{4} D^2 L \frac{N}{60} \times K}$$

$$\eta_v = 93.5 = \frac{0.416 \times 0.07848}{\frac{\pi}{4} D^2 \times 1.5D \times \frac{960}{60} \times 2}$$

$$\boxed{D = 0.097 \text{ m}}$$

$$\boxed{L = 0.1459 \text{ m.}}$$

Use Of Heat Exchanger In VCRS :-

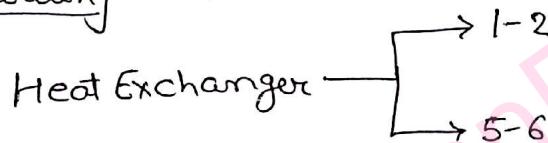


Evaporator $\rightarrow 7 - 1 - \cancel{2} \rightarrow R.E = h_1 - h_7$

Compressor $\rightarrow 2 - 3 \rightarrow W_{in} = h_3 - h_2$

Condenser $\rightarrow 3 - 4 - 5 - \cancel{6} \rightarrow Q_c = h_3 - h_5$

Throttling $\rightarrow 6 - 7 \rightarrow h_6 = h_7$



Qn) A Food Storage Requires a refrigeration Capacity of 50 KW.
It Works b/w a Condenser temperature of 35°C & evaporator temperature of -10°C. It is Sub cooled by 5°C before entering the expansion valve by the dry saturated vapour leaving the evaporator.

The Refrigerant Ammonia is Assuming a Single cylinder, Single acting Compressor, operating at 1000 RPM with Stroke is equal to 1.2 time the Bore. Determine,

- 1) Power Required
- 2) Cylinder dimension

t °C	P (bars)	h (kJ/kg)		S (kJ/kg-K)		v (m³/kg)		Sp. Heat	
		hf	hg	Sf	Sg	Vf	Vg	Lg	V
-10	2.9157	154.05	1450.22	0.82965	5.7550	-	0.4700	-	2.492
35	13.522	366.07	1488.57	1.56605	5.2086	1.7023	0.09562	0.556	2.903

Solⁿ)

$$R.C = 50 \text{ KW} = 50 \times 3.5 = \cancel{175} \text{ KW}$$

$$L = 1.2D$$

$$n = 1000$$

NOTE :-

As There is no information provided Regarding clearance Ratio (q_{mb}) therefore is letill assume 100% volumetric efficiency.

CASCADE :-

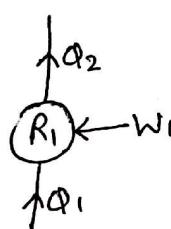
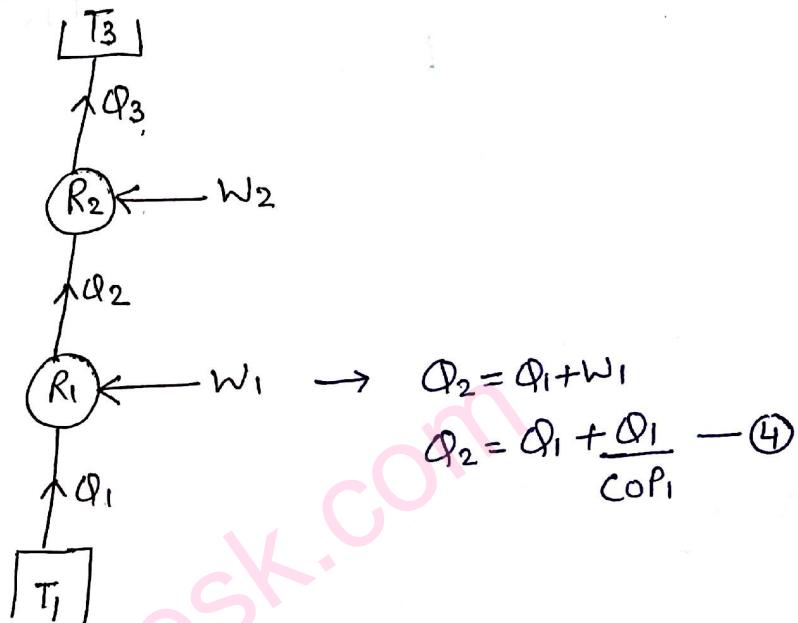
Prove That, COP of Cascade Refrigeration System is

(COP)_{CC} = $\frac{(COP)_1 + (COP)_2}{1 + (COP)_1 + (COP)_2}$

(COP)₁ is COP of first Refrigeration System i.e R₁.
 (COP)₂ is COP of second Refrigeration System i.e R₂.

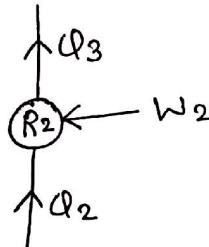
Where (COP)₁ is COP of first Refrigeration System i.e R₁.

(COP)₂ is COP of second Refrigeration System i.e R₂.



$$(COP)_1 = \frac{DE}{W_{in}} = \frac{Q_1}{W_1}$$

$$W_1 = \frac{Q_1}{(COP)_1} \quad \dots \quad (1)$$



$$(COP)_2 = \frac{DE}{W_{in}} = \frac{Q_2}{W_2}$$

$$W_2 = \frac{Q_2}{(COP)_2} \quad \dots \quad (2)$$

$$(COP)_{CC} = \frac{(DE)_{LC}}{(W_n)_{LC} + (W_{in})_{VC}} = \frac{Q_1}{W_1 + W_2} \quad \dots \quad (3)$$

using (1) & (2) in equation (3)

$$(COP) = \frac{Q_1}{\frac{Q_1}{(COP)_1} + \frac{Q_2}{(COP)_2}}$$

$$(COP)_{cc} = \frac{\frac{Q_1}{(COP)_1}}{\frac{Q_1}{(COP)_1} + \frac{Q_1}{(COP)_2}} = \frac{\frac{Q_1}{(COP)_1}}{\frac{Q_1}{(COP)_1} + \frac{Q_1}{(COP)_2} + \frac{Q_1}{(COP)_1 \times (COP)_2}}$$

Goal objective

$$(COP)_{cc} = \boxed{\frac{(COP)_1 (COP)_2}{1 + (COP)_1 + (COP)_2}}$$

Hence Proved.

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(Q13) A Cascade Refrigeration System of 100 TR Capacity uses ammonia & CO₂ Refrigerant. The evaporating & condensing temp of CO₂ are -40°C & 5°C. The evaporating temp of NH₃ is -7°C. The Power Supplied to the NH₃ Compressor is 96.5 kW. In the CO₂ circuit the liquid leaving the Condenser as Saturated liquid, the Vapours leaving the evaporator is dry & Saturated & the compression is isentropic. Calculate the mass flow rate of CO₂ & COP of the total system. Use the following table for CO₂ having (C_P)_v = 0.85 kJ/kg K

t°C	P(bar)	h _f	h _g	s _f	s _g
-40	10.55	332.7	652.8	3.8531	5.2262
5	39.77	431.0	649.8	4.2231	5.0037

Soln) $\dot{m} \times R_C = 100 \text{ TR} = 100 \times 3.5 = 350 \text{ kW} = \dot{m} \times R_E = \dot{m}_{CO_2} \times (h_2 - h_1)$

$$CO_2 \rightarrow T_E = -40^\circ C$$

$$T_c = 5^\circ C$$

$$NH_3 \rightarrow T_E = -7^\circ C$$

$$P_{NH_3} \rightarrow 96.5 \text{ kW}$$

$$R_C = \dot{m} \times R_E$$

$$\therefore 350 = \dot{m}_{CO_2} \times (652.8 - 431)$$

$$350 = \dot{m}_{CO_2} 221.8$$

$$\dot{m}_{CO_2} = \frac{350}{221.8}$$

$$\dot{m}_{CO_2} = 1.577 \text{ kg/sec.}$$

$$P_{CO_2} = \dot{m} \times w_{in}$$

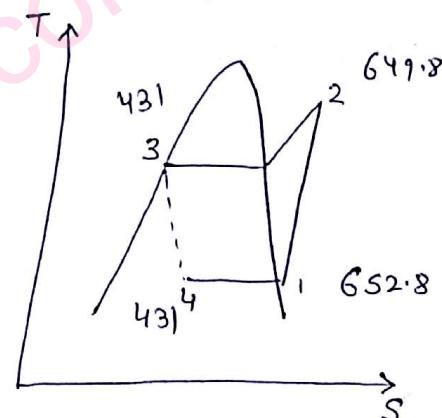
$$= 1.577 \times (h_2 - h_1)$$

$$= 1.577 \times (h_2 - 652.8) \quad \text{--- (1)}$$

$$(COP)_{CC} = \frac{350}{1.577(h_2 - 652.8) + 96.5}$$

$$h_2 = h_{g1} + (C_P)_v (T_2 - T_1)$$

$$h_2 = 649.8 + 0.85(T_2 - 278) \quad \text{--- (2)}$$



$$S_{g1} = S_{g2} + (C_P)_V \ln\left(\frac{T_2}{T_1}\right)$$

$$5.2262 = 5.0037 + 0.85 \ln\left(\frac{T_2}{273}\right)$$

$$T_2 = 361.18 \text{ K}$$

using value of T_2 in eqn ②

$$h_2 = 672.5 \text{ kJ/kg}$$

using value of h_2 in ①

$$\text{CoP} = 1.52$$

Refrigerants

Type of Refrigerant :-

Primary Refrigerant

Secondary Refrigerant

1) Primary Refrigerant :-

Primary Refrigerant are the Working fluid, that undergoing the Cyclic process and extract the heat on the System. There is a Latent heat of Transformation for the Refrigeration.
e.g:- R-11, R-12, R-22, R-134.

2) Secondary Refrigerant :-

Secondary Refrigerants are the Working fluid, which are first cooled by primary Refrigerant & then used for the Cooling at desired place.

e.g:- H₂O, Brine.

Designation of Refrigerant :-

1) CASE I :- When The Refrigerant is Saturated Hydrocarbon.

$$R-(m-1)(n+1)p$$

$$n+p+q = 2m+2$$



Halo Carbons

m → Represent no. of Carbon element.

n → Represent no. of Hydrogen element.

p → Represent no. of Fluorine element.

q → Represent no. of Chlorine element.

1) R-11

R-011

$$R - (m-1)(n+1)P$$

$$m-1=0 \quad ; \quad m=1$$

$$n+1=1 \quad ; \quad n=0$$

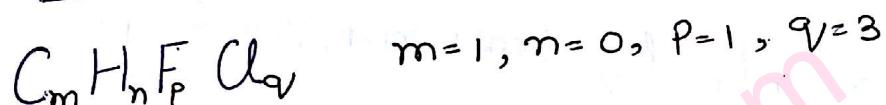
$$P=1 \quad ; \quad P=1$$

$$n+P+qV = 2m+2$$

$$0+1+qV = 2 \times 1 + 2$$

$$1+qV = 4$$

$$\boxed{qV = 3}$$



2) R-12

R-012

$$R - (m-1)(n+1)P$$

$$m-1=0 \quad ; \quad m=1$$

$$n+1=1 \quad ; \quad n=0$$

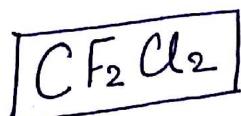
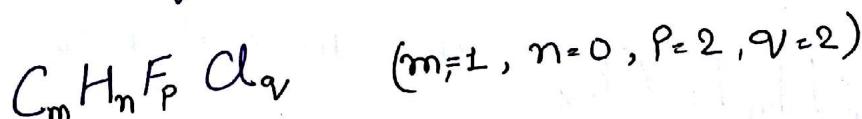
$$P=2 \quad ; \quad P=2$$

$$n+P+qV = 2m+2$$

$$0+2+qV = 2 \times 1 + 2$$

$$2+qV = 4$$

$$qV=2$$



3)

R-22

R-022

$$R - (m-1)(n+1)P$$

$$m-1=0 ; m=1$$

$$n+1=2 ; n=1$$

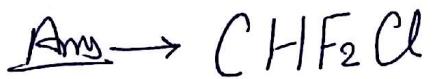
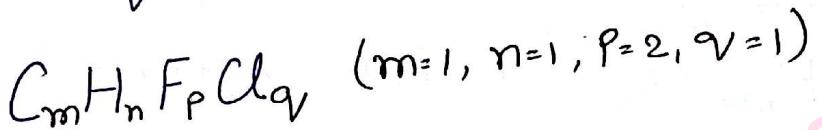
$$P=2 ; P=2$$

$$m+P+q = 2m+2$$

$$1+2+q = 2+2$$

$$3+q = 4$$

$$q = 1$$



4)

R-134

$$R - (m-1)(n+1)P$$

$$m-1=1 ; m=2$$

$$n+1=3 ; n=2$$

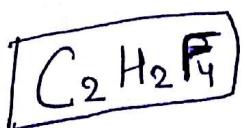
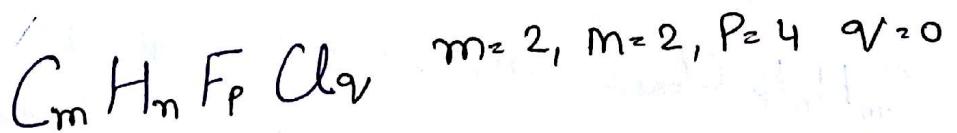
$$P=4 ; P=4$$

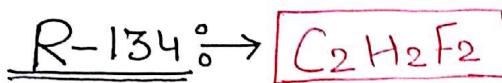
$$m+P+q = 2m+2$$

$$2+4+q = 4+2$$

$$q = 6 - 6$$

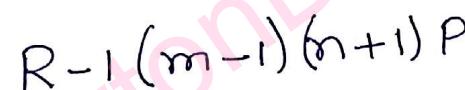
$$\boxed{q=0}$$



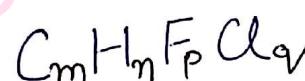


R-134, which is C₂H₂F₂, is Known as ecofriendly. Refrigerant. The Chlorine element which are present in Commonly used Refrigerant attacks the Ozone layer, which is sited in Stratosphere, which prevents us to filter the harmful UV radiation which is emitted by Sun. The Chlorine (Cl) element present in the Commonly use refrigerant, attacks the Ozone layer & reduce Ozone layer thickness. Therefore we are use such refrigerant which have the minimum tendency at reduction in Ozone layer.

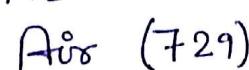
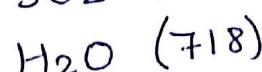
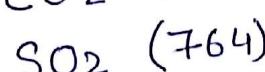
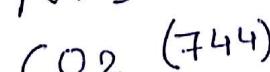
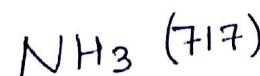
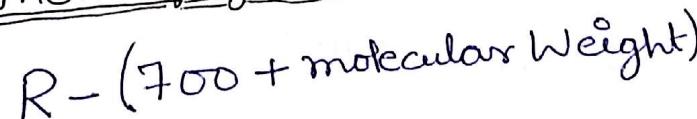
2) CASE II :- When the Refrigerant is unsaturated Hydrocarbon.



$$n+P+q = 2m$$



3) Case III :- When Refrigerant is inorganic Compound.



Selection of Refrigerant (Desirable Property of Refrigerant)

- A — Thermodynamic Property
- B — Chemical Property
- C — Physical Property

A) Thermodynamic Property :-

(i) Critical Temperature :- must be \uparrow as possible

The Critical Temperature of Refrigerants Should be as high as possible for above the Condenser pressure & Temperature.

NOTE :-

The Critical Temperature of CO_2 & Ethylene are almost. For the Indian Summer Ambient Condition.

$$\text{H}_2\text{O} = 314^\circ\text{C}$$

$$\text{SO}_2 = 156.5^\circ\text{C}$$

$$\text{NH}_3 = 132.4^\circ\text{C}$$

$$\text{R-12} = 111.5^\circ\text{C}$$

$$\text{R-22} = 96.5^\circ\text{C}$$

$$\text{R-134} = 101.2^\circ\text{C}$$

ii) Specific Heat :-

The Specific Heat of Vapours Should be high, in order to limit the degree of Superheated, whereas the Specific heat of liquid should be low in order to limit the degree of irreversibility. (Low value of δS). bcz $C_p \propto ds$

iii) Enthalpy of Vaporization :-

It Should be as high as possible because the same Refrigerant Capacity. The mass flow rate (m) Reduce.

$$R_c \rightarrow m \times R.E. \uparrow$$

NOTE :-

Among The Commonly used Refrigerants NH₃ have high Value of the enthalpy of Vaporization.

$$\uparrow \text{H}_2\text{O} - 2261$$

$$\text{NH}_3 - 1369$$

$$\text{R}-11 - 234.7$$

$$\text{R}-12 - 165.7$$

$$\text{R}-134 - 197.3$$

$$R_c \rightarrow \downarrow m \times R.E. \uparrow$$

iv) Thermal Conductivity (K) :- must be as high possible.

It Should be high, Because it help to Reducing the Size of evaporator and Condensor.

$$Q = KA \frac{dT}{dx}$$

$$K \propto \frac{1}{\text{Area}}$$

V) Evaporator and Condenser Pressure :-

Both Should be Positive (+ve). If the evaporator pressure is less than atmospheric pressure, then there is probability for the leakage of air, so the evaporator pressure {grb} Should be Kept almost equal to atmospheric pressure. On the Other Side, the Condenser pressure should be Kept at Some moderate value.

VI) Compression Ratio :-

It is Defined as the Ratio of volume before compression to the volume after compression.

Low Compression Ratio is desirable because the high Compression Ratio results in increase in Work input to the Compressor and ↓ in volumetric efficiency.

VII) Freezing Point :-

Low Freezing Point is desirable.

Freezing Point of $\text{NH}_3 \rightarrow -77^{\circ}\text{C}$

Freezing Point of $\text{H}_2\text{O} \rightarrow 0^{\circ}\text{C}$

NOTE :-

Freezing Point of Water is 0°C . below 0°C it Convert into Solid State and its flow is not possible.

$\text{R}-22 \rightarrow -160.5^{\circ}\text{C}$

$\text{R}-12 \rightarrow -157.4^{\circ}\text{C}$

$\text{NH}_3 \rightarrow -77^{\circ}\text{C}$

$\text{R}-134 \rightarrow -101.2^{\circ}\text{C}$

viii) Compressor Discharge Temperature :-

NH₃ Compressor are Water Cooled Compressor.

Because of its high Compressor discharge temperature
Where as

R-11

R-12

NH₃ — Water Cooled Comp^r
R-11, R-12 — Air Cooled Comp^r

Compressor are air cooled.

↓η_v

ix) Coefficient of Performance (COP) :-

It represent the Running Cost of the equipment.

Higher the COP, Lower will be the running cost.

$$\uparrow \text{COP} = \downarrow \text{Running Cost}$$

NOTE :-

- Almost all of the Refrigerant are having similar value of COP, when operating between same temperature limit.
- Even though, the Latent heat of vaporization for NH₃, Refrigerant is having high value, but it doesn't help to improve in COP because of it, high Work input to the Compressor.

$$R-11 \rightarrow 4.04$$

$$NH_3 \rightarrow 4.06$$

$$R-12 \rightarrow 4.12$$

Compressor	Pressure	Volume	Refrigerant
Screw or Reciprocating Compressor	✓	✗	NH ₃ , CO ₂
Rotary or Centrifugal Compressor	✗	✓	R-11, R-113

B) Chemical Property :-

1) Toxicity :-

Refrigerant Should be non-Toxic.

NOTE :-

NH_3 is Non Toxic in Nature.

2) Flamability :-

Refrigerant Should be non flammable in nature.

NOTE :-

NH_3 is both Non-Toxic and non flammable in nature.

3) Action With Oil :-

R + fully miscible with oil. R-11, R-12

R + Fully immiscible with oil. NH_3 , CO_2

R + Partially miscible with oil. R-22

There are some Refrigerant, fully miscible with oil and some Refrigerant fully immiscible with oil, doesn't create any Problem but refrigerant which is partially miscible with oil like R-22, create problem. Choking problem occurs in Condenser.

Therefore Synthetic oil is used in Case of

NOTE :-

- 1) Oil Separator is installed b/w Compressor & Condenser.
- 2) oil separator, which no Requirement to install, when Refrigerant & oil are immiscible at Condenser pressure & Temperature.
- 3) Sensing bulb is placed at the exit of evaporator.

4) Action With material of Construction :-

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NH₃ attacks Copper (Cu), so preferable Wrough iron

Whereas Hydrocarbon Compound attacks aluminium (Al)
Prefreable with Copper (Cu)

NH₃ Corrodes Copper, Suitable for Wrough iron
Hydrocarbon Corrodes Aluminum Suitable for Copper

c) Physical Property :-

(i) Cost :-

It should be Low.

Viscosity ↑

ii) Leak Detection :-

First of All it Should be not be leakage of Rego Refrigerant at any cost but if it leaks out, then its detection should be as faster as possible by the Simplest Methods.

For example :-

i) Feron leak or Halocarbon leak :-

(I.E.S)
Objective

ii) Halide Torch Method :-

If Feron leaks then Colour of light changes from blue to bluish green. (ii) Soap bubble Method.

iii) NH₃ leak :- (Burning Sulphur Candle)

iv) Sulphur stick Method :-

The presence of NH₃ leak, which forms of ammonium Sulphides are formed, When Burning Sulphur Candle.

v) SO₂ leak :-

NH₃ Swab Test.

Leakage	Detected by
NH ₃	Burning Sulphur Candle
Halocarbon, "	Halide Torch test
Hydrocarbon & Propane	Soap and Water Test
SO ₂	NH ₃ , Swab Test
Refrigeration equipment	Electronic Leak detector (high Sensivity)

Azeotropes :-

It is mixture of Refrigerants, which behaves like a Pure System.
Their designation are started with R-500.

Azeotropes \rightarrow R-500

Mix of Refrigerant behave like pure System

~~BE~~

Refrigerant And their Application :-

R-11 \rightarrow Central Air Conditioning

R-12 \rightarrow Domestic Refrigerator, Water Cooler

R-22 \rightarrow Window A/C

NH₃ \rightarrow Cooling Storage Plant

CO₂ \rightarrow Direct Contact freezing of food.
used as dry ice in transport.

Brine \rightarrow Milk Chilling Plants

Air \rightarrow Gas liquidification, Air craft

Refrigeration System

Refrigerant in ↑ order of Normal Boiling Point :-

R-11 (-23.7°C) > R-12 (-21°C) > NH₃ (-33.3°C) > R-22 (-41°C) > CO₂ (-73.6°C)

Refrigerant in ↑ order of freezing Point :-

CO₂ < NH₃ < R-11 < R-12 < R-22

Refrigerant in ↑ order of Critical temp. :-

R-11 > NH₃ > R-12 > R-22 > CO₂

Refrigerant in ↓ order of Critical Pressure :-

NH₃ (113-86) > CO₂ (73.8) > R-22 > R-11 > R-12 (41.2)

Refrigerant in ↓ of COP :-

R-11 > NH₃ > R-12 > R-22 > CO₂

Vapour Absorption Refrigeration System :- (VARS)

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- 1) The Compressor which is used in (VCRS) is Replaced With Absorber, Pump & Generator.
- 2) Solar Absorption Refrigeration System is Working on the Principal of (VARS).
- 3) VARS System is generally Preferred in Remote locations & where the Cost of electricity is high.
- 4) Waste heat Can be effectively utilized in (VARS) System.
- 5) The COP of VARS System is Low & and it generally lies b/w 0.3 to 0.5.
- 6) Heat Rejection Occurs in Condensor and Absorber.
- 7) The Commonly used Absorber Refrigerant pair is,

(A) Ammonia & Water ($\text{NH}_3 - \text{H}_2\text{O}$) :-

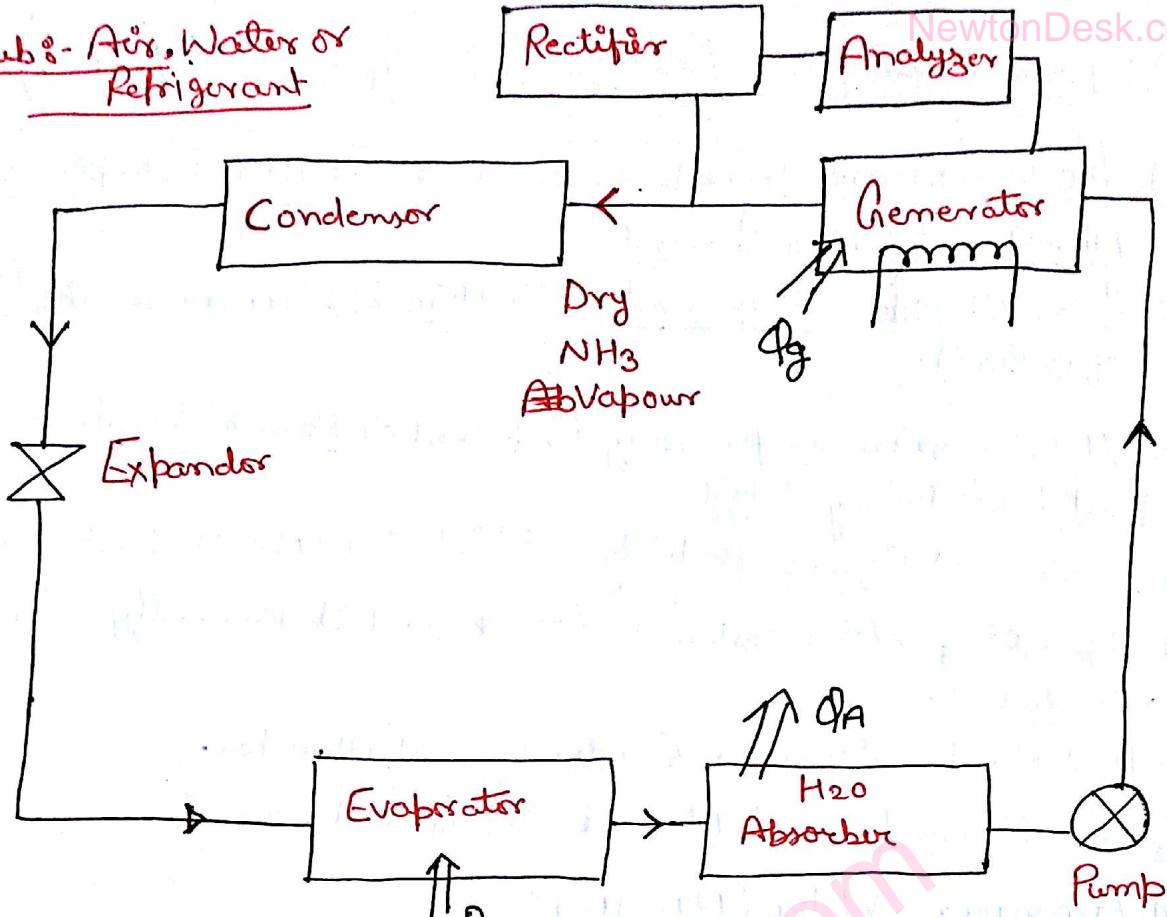
In this Ammonia (NH_3) is used as the Refrigerant & Water is used as a Absorber. In order to Remove Water Particles from the ammonia Vapour Analyser & Rectifier Assembly is used. Here, Water is Removed in two Stages. The Complete elimination of Water Particles occurs in Rectifier & it Will produce dry Ammonia Vapours.

(B) Lithium Bromide & Water ($\text{LiBr} - \text{H}_2\text{O}$) :-

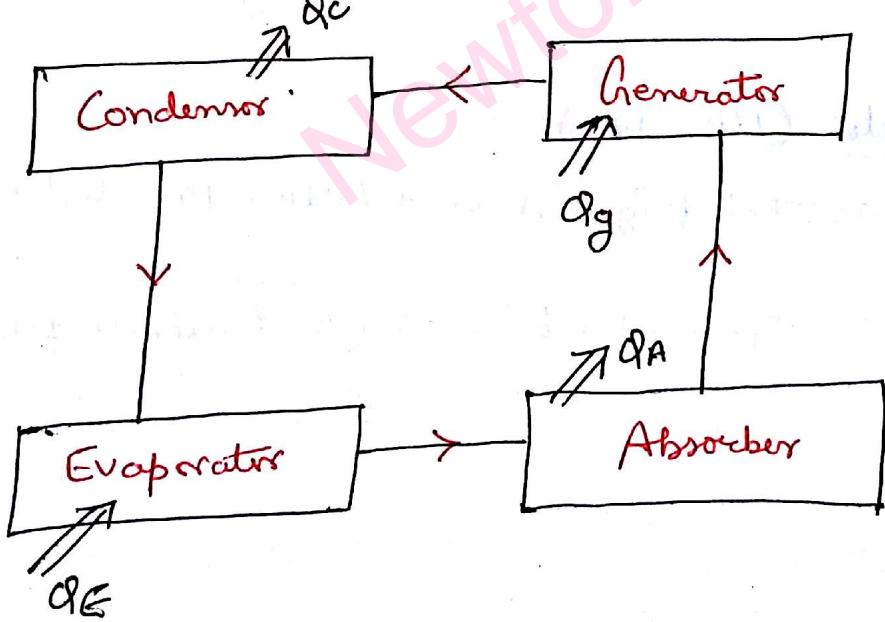
In this Water is used as the Refrigerant and Lithium Bromide (LiBr) is used as the Absorber. The Above Combination is not practicable below 0°C (The freezing Pt. of H_2O 0°C)

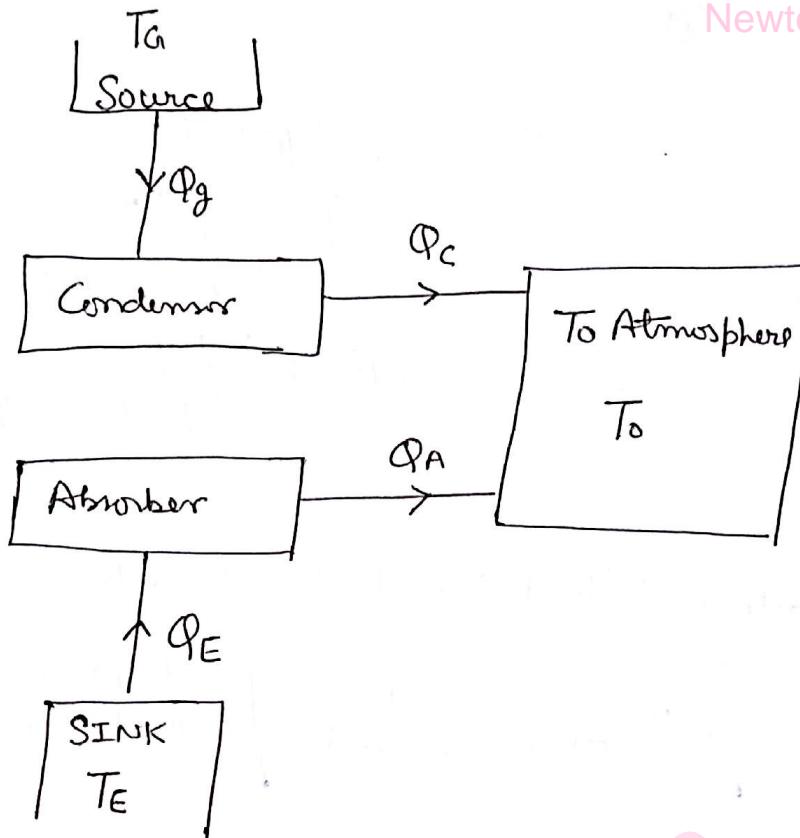
Working Sub :- Air, Water or Refrigerant

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COP of VARS :-





$$Q_E + Q_G = Q_C + Q_A \quad - \textcircled{1} \quad (\text{from 1st Law of Thermodynamics})$$

$$\frac{Q_E}{T_E} + \frac{Q_G}{T_G} = \frac{Q_C}{T_0} + \frac{Q_A}{T_0} \quad - \textcircled{2}$$

$$\frac{Q_E}{T_E} + \frac{Q_G}{T_G} = \frac{Q_C + Q_A}{T_0} = \frac{Q_E + Q_G}{T_0} = \frac{Q_E}{T_0} + \frac{Q_G}{T_0}$$

$$\frac{Q_E}{T_E} - \frac{Q_E}{T_0} = \frac{Q_G}{T_0} - \frac{Q_G}{T_E}$$

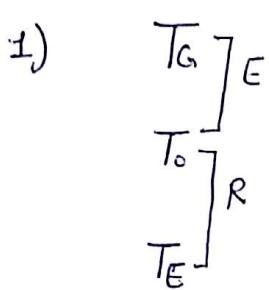
$$Q_E \left(\frac{1}{T_E} - \frac{1}{T_0} \right) = Q_G \left(\frac{1}{T_0} - \frac{1}{T_E} \right)$$

$$Q_E \left(\frac{T_0 - T_E}{T_E T_0} \right) = Q_G \left(\frac{T_E - T_0}{T_E T_0} \right)$$

$$COP = \frac{Q_E}{Q_G} = \frac{T_E - T_0}{T_E} \times \frac{T_E}{T_0 - T_E}$$

Objectives

$$(COP)_{VARS} = \frac{T_E}{T_G} = \frac{T_E - T_0}{T_0 - T_E}$$

NOTE :-

$$\begin{aligned}
 (\text{COP})_{\text{VARS}} &= \eta_E \times (\text{COP})_R \\
 &= \left(1 - \frac{T_0}{T_G}\right) \cdot \left(\frac{T_E}{T_0 - T_E}\right) \\
 &= \left(\frac{T_G - T_0}{T_G}\right) \left(\frac{T_E}{T_0 - T_E}\right) = \frac{T_G}{T_G} \left(\frac{T_G - T_0}{T_0 - T_E}\right)
 \end{aligned}$$

2) $(\text{COP})_{\text{Actual}}$, Actual COP of (VARS) System is,

$$(\text{COP})_{\text{Actual}} = \frac{\dot{Q}_E}{W_p + \dot{Q}_G}$$

[if Question Said to Consider Pump Work.]

$$W_p = -V_f \int dP \quad (V_f \text{ is very small})$$

$$(\text{COP})_{\text{VARS}} = \frac{\dot{Q}_E}{\dot{Q}_G}$$

(Assumption neglect Pump Work)

(if Question Said to neglect Pump Work)

VCRS

- 1) Compressor is used.
- 2) It is a Work Operated Unit.
Or Runs on high grade energy.
- 3) Heat Rejection Occurs in Condenser only.
- 4) Noise Related Problem is having more serious impact or dangerous in VCRS.
- 5) Chances for the leakage of Refrigerant are high.
- 6) It has higher COP, generally varies from 3-5.
- 7) Creates More noise Pollution.

Spend Money bz ↑ COP

VARs NewtonDesk.com

- 1) Compressor is Replaced With Absorber, Pump & Generator
- 2) It is a Heat operated unit.
Or
Runs on Low Grade energy.
- 3) Heat Rejection Occurs in Condenser as well absorber.
- 4) Relatively Lesser Problem.
- 5) Relatively lesser chances.
- 6) It has Relatively Lower (COP). Generally varies from 0.3 - 0.5.
- 7) Relatively Less noisy.

less money & COP can be Considered

Electrolytic Refrigerators :- [No use of Pump]

- i) The main Aim, of using this Refrigerator System, is to Create noiseless operation. (i.e) no use of Pump. ~~**~~
- ii) It is a three fluid System: i.e Ammonia, Water & Hydrogen.

<u>NH₃</u>	Refrigerant
<u>H₂O</u>	Absorber
<u>H₂</u>	(Low Partial Pressure of Ammonia Vapour) used to

NH₃ is used as the Refrigerant.

H₂O is used as the Absorber.

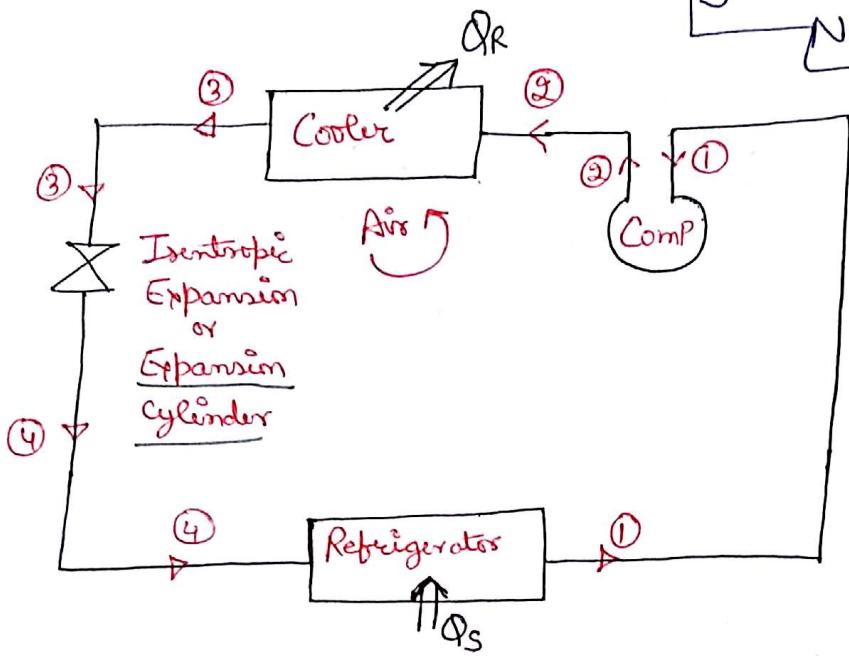
H₂ is used to Create Low Partial Pressure of NH₃ Vapour

Reversed Brayton Cycle / Bell-Coleman Cycle :-

Foult Cycle

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q is for air only
No phase change



Reversed Brayton Cycle / Bell Coleman Cycle

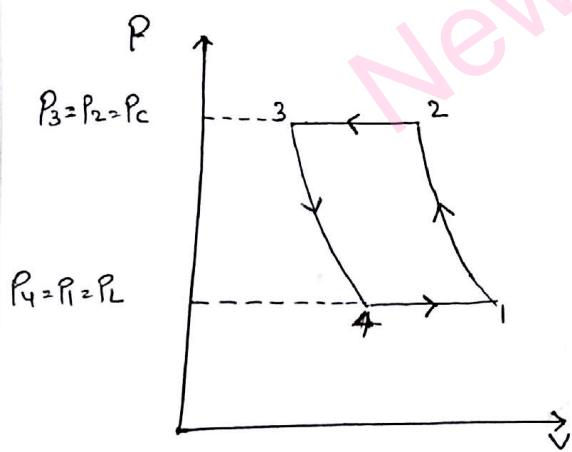
Process (1-2) \rightarrow Isentropic / Reversible Adiabatic Compression.

Process (2-3) \rightarrow Heat Rejection at Constant Pressure.

Process (3-4) \rightarrow Isentropic / Reversible Adiabatic expansion.

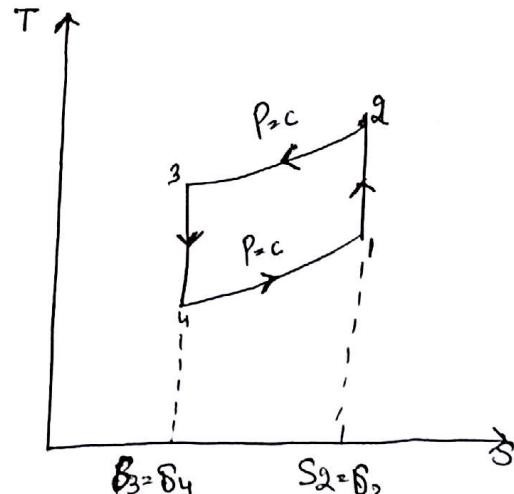
Process (4-1) \rightarrow Heat addition at Constant Pressure

Processes



$$\text{Let } r_p \text{ be Pressure Ratio : - } \frac{P_4}{P_L}$$

(P-v curve)



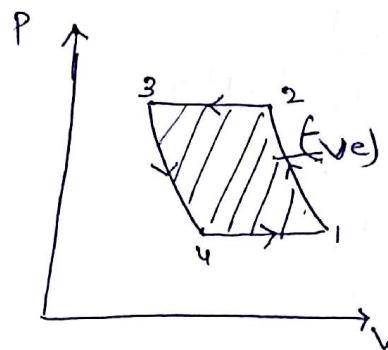
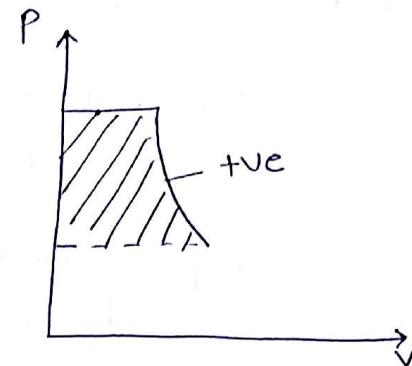
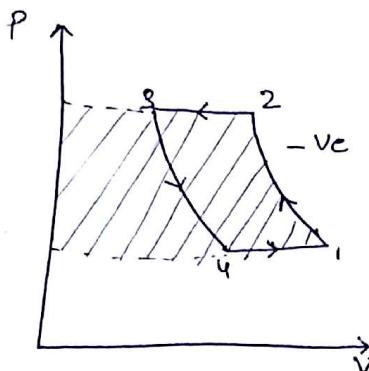
(T-S) Curve

COP of Reversed Brayton Cycle :-

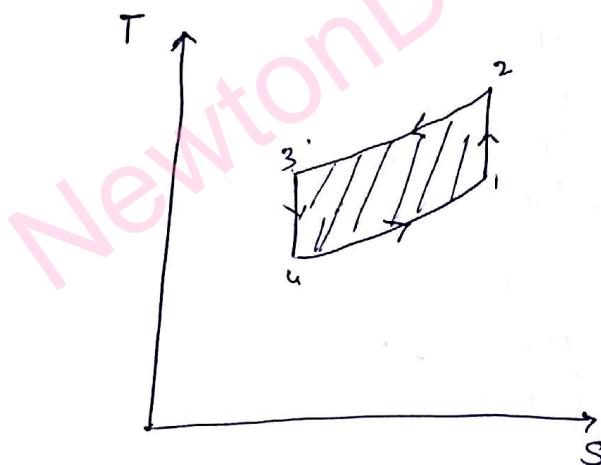
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(Q-1)

$$COP = \frac{R.E}{W_{net}}$$



for T-S



$$\begin{aligned} Q_{NET} &= -ve \\ W_{net} &= Q_{net} \end{aligned}$$

$$COP = \frac{R \cdot E}{W_{in}}$$

~~$COP = \frac{R \cdot E}{R_E - R}$~~

$$COP = \frac{R \cdot E}{W_C - W_T} \quad - \text{Reason } \underline{\text{bcz}} \text{ R.E is taken as +ve}$$

$$COP = \frac{(h_1 - h_4)}{(h_2 - h_1) - (h_3 - h_4)}$$

$$COP = \frac{h_1 - h_4}{(h_2 - h_1) - h_3 + h_4}$$

$$COP = \frac{h_1 - h_4}{h_2 - h_3 - h_1 + h_4}$$

$$COP = \frac{(h_1 - h_4)}{(h_2 - h_3) - (h_1 - h_4)}$$

$$COP = \frac{1}{\left(\frac{h_2 - h_3}{h_1 - h_4}\right) - 1}$$

Air \rightarrow $\frac{Pv = mRT}{h = CpT}$ Entropy is funⁿ of temp for ideal gas

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

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

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

Process 1-2 $P_V^\gamma = C$

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

Assuming $\frac{\gamma-1}{\gamma} = \kappa$ & Pressure Ratio $\gamma_P = \frac{P_h}{P_L}$

Process 3-4 — $P_V^\gamma = C$ b.c. (Adiabatic)

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^\kappa \quad \text{--- (3)}$$

Process (2-3) :- $P_2 = P_3$] — (4) using eqn (4) in (3)

Process (4-1) :- $P_1 = P_4$]

$$\frac{T_3}{T_4} = \left(\frac{P_2}{P_1}\right)^\kappa \quad \text{--- (5)}$$

using eqn (2) & (5)

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

Objective

$$\boxed{\frac{T_2 T_4}{T_1 T_3} = \frac{\text{even}}{\text{odd}}} \quad \text{--- (6)}$$

grb Objective for Otto and
more cycle.

$$\begin{bmatrix} I_C \\ T_D \\ P_P \end{bmatrix}$$

using (6) in eqn (1)

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

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

use eqn No (2) :- $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = (\gamma_P)^{\frac{\gamma-1}{\gamma}}$

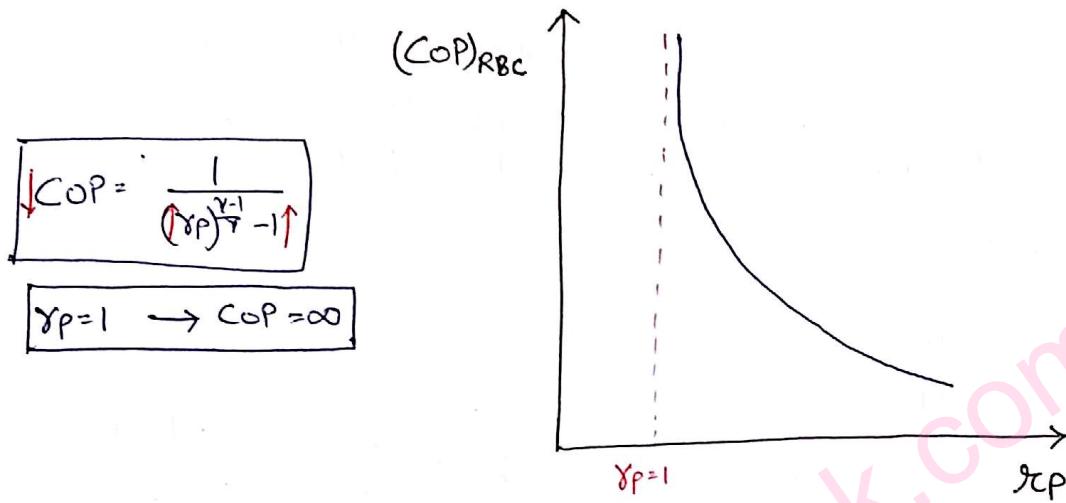
$$\text{Let } \gamma_P = \frac{P_h}{P_L} = \frac{P_2}{P_1}$$

grb Objective
$$\boxed{(COP)_{RBC} = \frac{1}{(\gamma_P)^{\frac{1}{\gamma}} - 1}}$$

The COP of Reversed Brayton Cycle is a function of Pressure Ratio.

Assumptions :-

- 1) There is Only one Assumption taken in deriving the expression for COP of Reversed Brayton Cycle is Both Compressing & expansion are isentropic.



NOTE :-

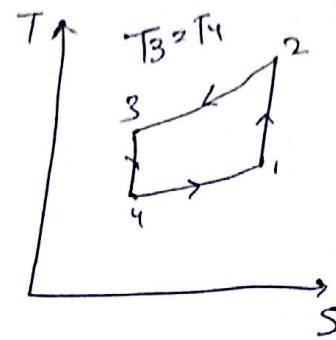
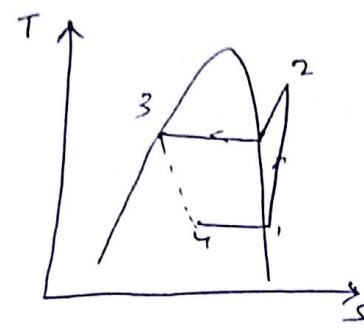
- 1) Air → is the Working fluid used because of Low WT / TON of Refrigeration.
- 2) The Expansion Work is not Negligible in Comparison to the Compression Work. Because Both equipment (Compressor & turbine) are handling same state of the Working fluid that is gaseous Phase.

$$COP = \frac{R.E}{W_c - W_E}$$
$$\downarrow$$
$$\int V_g dP \cdot \int V_g dP$$

V_f can be neglected
but b_g is not

$$V_g \gg V_f$$

- Qn) Why isenthalpic expansion is not preferable in Reversed Brayton Cycle?
- Ans) Air is Treated As ideal gas, & for an ideal gas enthalpy is function of temp
So in the Case of isenthalpic expansion, there is no drop in temp taken place if instead of heat absorbing it will Releasing Heat. Therefore isentropic expansion is preferable.



$$\Delta h_{\text{irr}} = P \nu_2 m R T$$

$$h_2 - c_p T$$

$$h_3 = h_4$$

$$\cancel{c_p T_3} = \cancel{c_p T_4}$$

$$\boxed{T_3 = T_4}$$

Qn) A Bell-Coleman Refrigeration Plant operating with Air as a Working fluid, having 1 bar pressure and 10°C temperature is compressed to a Pressure of 5 bar. Air is then cooled in the cooler to a temperature of 25°C. Before expanding in the expansion cylinder, where the Cold Pressure of 1 bar is maintained. Determine

- 1) Theoretical COP
- 2) Refrigeration Effect per Kg, Assuming both Compression & expansion to be ~~isentropic~~ isentropic, having value of $\gamma = 1.4$, & Specific heat $C_p = 1.005 \text{ kJ/kgK}$.
- 3) If Compression follows $P_v^{1.35} = C$ (Compressor) and expansion $P_e^{1.3} = C$

Then Calculate

- (a) COP
- (b) Refrigeration Effect per Kg.

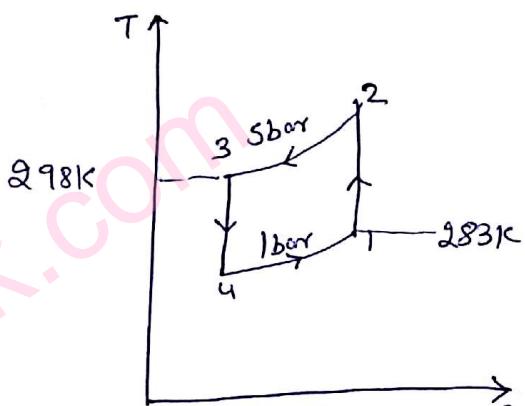
Soln)

$$\gamma_p = \frac{P_2}{P_1} = \frac{P_2}{P_1} = \frac{5}{1} = 5$$

Pressure Ratio

(i) Theoretical COP

$$\frac{1}{(5)^{\frac{0.4}{1.4}} - 1} = 1.71$$



(ii) R.E./kg = $h_1 - h_4$ enthalpy is fun of temp.

$$= C_p(T_1 - T_4)$$

$$= 1.005(283 - T_4) \quad \textcircled{1}$$

$$= 1.005(283 - 188.15)$$

$$= 95 \text{ kJ/kg}$$

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

$$\frac{298}{T_4} = (5)^{\frac{0.4}{1.4}} \Rightarrow T_4 = 188.15 \text{ K}$$

$$\text{iii)} P_v^{1.35} = C \rightarrow \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow \frac{T_2}{283} = \left(\frac{5}{1}\right)^{\frac{1.35-1}{1.35}} = T_2 = 429.3 \text{ K}$$

$$P_v^{1.3} = C \rightarrow \frac{298}{T_4} = \left(\frac{5}{1}\right)^{\frac{1.35-1}{1.35}} \Rightarrow T_4 = 205 \text{ K.}$$

$$\begin{aligned} \text{(b)} \quad R.E./kg &= h_1 - h_4 = C_p(T_1 - T_4) \\ &= 1.005(283 - 205) \\ &= 77.8 \frac{\text{kJ}}{\text{kg}} \end{aligned}$$

$$\boxed{PV^{1.35} = C} = m \left(\frac{P_1 V_1 - P_2 V_2}{n-1} \right)$$
$$= \frac{n}{(n-1)} (P_1 V_1 - P_2 V_2)$$

As it is case of ideal gas

$$PV = mRT$$
$$= \frac{n}{n-1} (mRT_1 - mRT_2)$$
$$= \frac{n}{n-1} mR(T_1 - T_2)$$

W_{1-2} (Compress) must be -ve.

$$W_{1-2} = \left(\frac{1.35}{1.35-1} \right) \times 1 \times 0.287 (283 - 429)$$
$$= -162 \frac{\text{kJ}}{\text{kg}}$$

$$W_{3-4} = \left(\frac{n}{n-1} \right) mR (T_3 - T_4)$$

$$PV^{1.3} = C$$
$$= \left(\frac{1.3}{1.3-1} \right) \times 1 \times 0.287 (298 - 205)$$
$$= +114.98 \frac{\text{kJ}}{\text{kg}}$$

$$W_{net} = -162 + 114.98 = -47 \text{ kJ/kg}$$

$$W_{in} = 47 \text{ kJ/kg}$$

$$COP = \frac{R.E}{W_{in}}$$

$$\boxed{(COP) = \frac{77.8}{47} = 1.64}$$

(Qm) Air is used as a Refrigerant in Reversed Brayton Cycle.
 Draw P-V & T-S diagram for the cycle & derive the expression for COP in terms of Pressure Ratio.

If the temperatures at the end of Heat absorption & Heat rejection are 0°C and 30°C respectively and pressure ratio (γ_p) = 4.

Then determine the temperature of all other points and volume flow rate of the inlet of compressor & exit of expander for 1 TN Cooling Capacity.

Assuming inlet pressure (P_1) to the compressor is 1 bar.

Soln

$$\gamma_p = 4$$

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

$$\frac{T_2}{273} = (4)^{\frac{0.4}{1.4}} \rightarrow T_2 = 405\text{K}$$

$$\frac{303}{T_4} = (4)^{\frac{0.4}{1.4}} \rightarrow T_4 = 203.9\text{K}$$

~~$P_1 V_1 = P_2 V_2$~~

$$P_1 V_1 = m R T_1$$

$$V_1 = \frac{m R T_1}{P_1} \Rightarrow V_1 = \frac{m \times 0.287 \times 273}{1 \times 10^5} = 0.039 \text{ m}^3/\text{sec}$$

$$R_C = m \times R \cdot E \Rightarrow 3.5 = m(h_1 - h_4)$$

$$R_C = m c_p (T_1 - T_4)$$

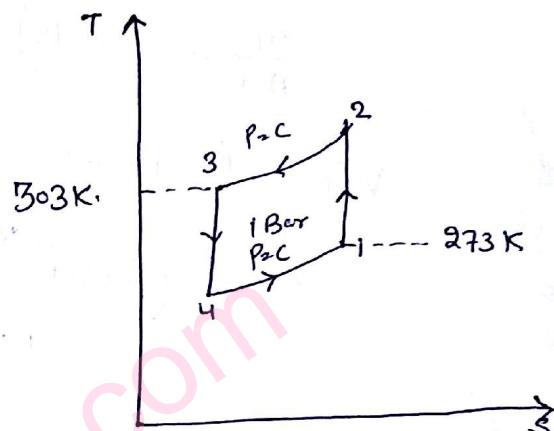
$$3.5 = m \times 1.005 (273 - 203.9)$$

$$m = 0.05 \text{ kg/sec}$$

$$\dot{V} \propto T$$

$$\frac{\dot{V}_4}{\dot{V}_1} = \frac{T_4}{T_1}$$

$$\frac{\dot{V}_4}{0.039} = \frac{203.9}{273} \quad \dot{V}_4 = 0.29 \text{ m}^3/\text{sec}$$



Qn) It is desire to make the COP of a Carnot Refrigerator System NewtonDesk.com equal to 3.5. If the operating b/w -40°C & $+40^{\circ}\text{C}$ is equal to 3.5 , by changing the Temperature. The decrease in higher temperature is equal to \uparrow in lower temperature. Then Determine the new temperatures in Kelvin.

Solⁿ

$$T_{L_1} = (40^{\circ}\text{C}) - = 233\text{ K}$$

$$T_{L_2} = +40^{\circ}\text{C} = 313\text{ K.}$$

$$T_{L_2} = T_{L_1} + x = 233 + x = 238.875\text{ K}$$

$$T_{H_2} = T_{H_1} - x = 313 - x = 307.125\text{ K.}$$

$$3.5 = \text{COP} = \frac{T_{H_2}}{T_{H_2} - T_{L_2}} = \frac{T_{L_1} + x}{(T_{H_1} - x) - (T_{L_1} + x)} = \frac{233 + x}{80 - 2x}$$

$$x = 0.5875$$

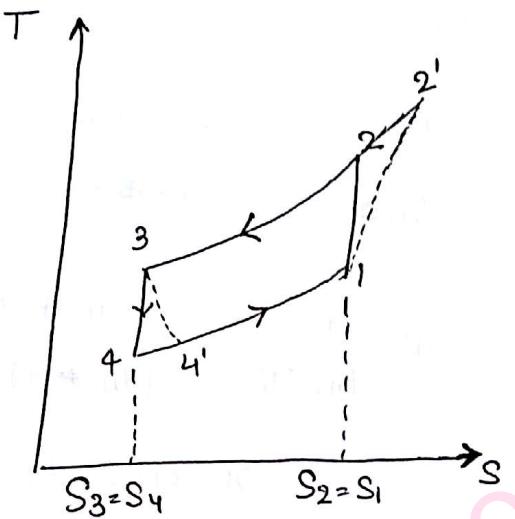
Isentropic Efficiency Of Compressor and Turbine

Isentropic Efficiency of Compressor is defined as the Ratio of Ideal enthalpy rise to the actual enthalpy rise.

Whereas, isentropic efficiency of turbine is defined as the Ratio of Actual enthalpy drop to that of ideal enthalpy drop.

$$(\eta_{is})_C = \frac{\text{Ideal}}{\text{Actual}}$$

$$(\eta_{is})_T = \frac{\text{Actual}}{\text{Ideal}}$$



(use only when Ideal gas bcz $h = f(T)$)

$$(\eta_{is})_C = \frac{h_2 - h_1}{h_2' - h_1} = \frac{c_p(T_2 - T_1)}{c_p(T_2' - T_1)} = \frac{T_2 - T_1}{T_2' - T_1}$$

$$(\eta_{is})_T = \frac{h_3 - h_4'}{h_3 - h_4} = \frac{c_p(T_3 - T_4')}{c_p(T_3 - T_4)} = \frac{T_3 - T_4'}{T_3 - T_4}$$

$\eta_{\text{isentropic}}$

- ↳ Rev. Adiabatic
- irr. Adiabatic $\rightarrow ds = \dot{S}_{gen} + \frac{dT}{T}$

$\boxed{\eta \rightarrow \text{Loss}}$

$$\text{Actual } W_c = \frac{\text{Ideal } W_c}{\eta_c}$$

Compressor is used to Compress the gas, So we need that more & more Compression takes Place Or ↑ in W_c . So We divide by η_c and η_c is less than 1.

$$\text{Actual } W_T = \text{Ideal } W_T \times \eta_T$$

$$\text{Actual Power output} = \frac{\text{Ideal Power output}}{\eta_{\text{mech.}}}$$

(IP)

$$\text{Actual } \underline{Q_s} = \text{Ideal } \underline{Q_s} \times \eta_{cc}$$

Here multiply With η indicates loss.

(Qn) In belt-Coleman Refrigeration plant, air enters the Compressor at a pressure of 0.1 MPa and temperature of 4°C. It is then compressed to pressure of 0.3 MPa, with an isentropic efficiency of 72%. It is then cooled in the cooler to a temperature of 55°C and then expanded to a pressure of 0.1 MPa, with an isentropic efficiency of 78%. Assuming Air to be an Ideal Gas and the Lower temp air, Absorbs Cooling load of (3 TR).

Determine;

- 1) mass flow Rate in kg/sec.
- 2) Power Consumption in kW.
- 3) COP

Soln

$$\begin{array}{l} \text{Ideal} \rightarrow 1-2-3-4-1 \\ \text{Actual} \rightarrow 1-2'-3-4'-1 \end{array}$$

$$RC = \dot{m} \times RE$$

$$RC = \dot{m} \times (h_1 - h_4)$$

$$RC = \dot{m} \times C_p (T_1 - T_4)$$

$$\dot{m} = 0.58 \text{ kg/sec.}$$

$$\frac{T_2}{277} = \left(\frac{0.3}{0.1} \right)^{\frac{(0.4)}{1.4}}$$

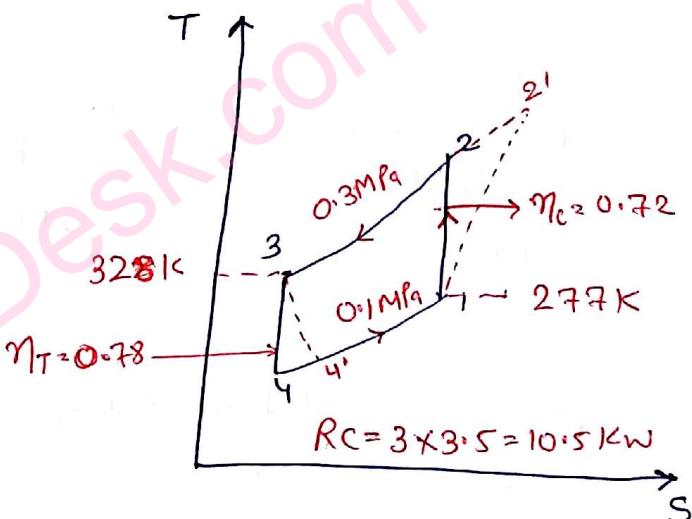
$$T_2 = 379 \text{ K}$$

$$\eta_c = \frac{T_2 - T_1}{T_{2'} - T_1}$$

$$0.72 = \frac{379 - 277}{T_{2'} - 277}$$

$$T_{2'} = 418.86 \text{ K}$$

As it is isentropic Process



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

$$\frac{328}{T_4} = \left(\frac{0.3}{0.1} \right)^{\frac{0.4}{1.4}}$$

$$\boxed{T_4 = 239 \text{ K}}$$

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

$$0.78 = \frac{328 - T_4'}{328 - 239}$$

$$\boxed{T_4' = 259 \text{ K}}$$

$$P = m (w_c - w_T)$$

$$P = m (h_2' - h_1) - (h_3 - h_4')$$

$$P = m c_p (T_2' - T_1) - (T_3 - T_4')$$

$$P = 0.58 \times 1.005 (418.86 - 297) - (328 - 259)$$

$$\approx 42.5 \text{ kW}$$

$$\boxed{COP = \frac{R.C}{P_m} = \frac{10.5}{42.5} = 0.247}$$

Heat Rejection Ratio :-

It is defined as the Ratio of Heat Rejected across condenser to the Refrigeration Effect.

If the Value of Heat Rejection Ratio = 1

then it violates Clausius Statement Of Thermodynamic.

Therefore the Value of Heat Rejection Ratio is always greater than one.

$$\boxed{HRR = \frac{Q_c}{R.E}}$$

Qn) If the Value of Heat Rejection Ratio is 1.2 & the Heat absorbed across evaporator is 2000 KJ/min, then calculate the Heat Rejected across Condenser in KJ/min & COP.

$$H.RR = 1.2$$

$$R.E = 2000 \text{ KJ/min}$$

$$\uparrow H.RR = \frac{Q_c}{R.E} \downarrow$$

So first two are neglected

A) ~~2100, 4~~

B) ~~2100, 5~~

C) ~~2520, 4~~

D) ~~2520, 5~~

$$1.2 = \frac{Q_c}{2000}$$

$$1.2 = \frac{Q_c}{}$$

$$Q_c = 2520 \text{ KJ/min}$$

$$\boxed{H.RR = \frac{Q_c}{R.E}}$$



$$W_{in} = 420 \text{ KJ/min}$$

$$COP = \frac{2100}{420}$$

$$COP = 5$$

Qn) Prove that Heat Rejection Ratio,

$$HRR = 1 + \frac{1}{COP}$$

$$\begin{aligned} COP &= \frac{D \cdot E}{W_{in}} = \frac{\dot{Q}_L}{\dot{Q}_H - \dot{Q}_L} \\ &= \frac{1}{\left(\frac{\dot{Q}_H}{\dot{Q}_L} - 1\right)} \end{aligned}$$

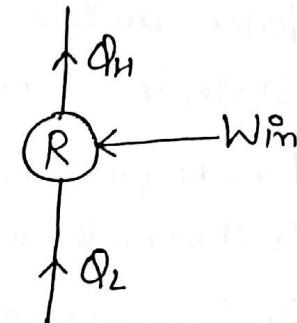
$$= \frac{1}{HRR - 1}$$

$$HRR - 1 = \frac{1}{COP}$$

Objective

$$H.R.R = \frac{1}{COP} + 1$$

Objective



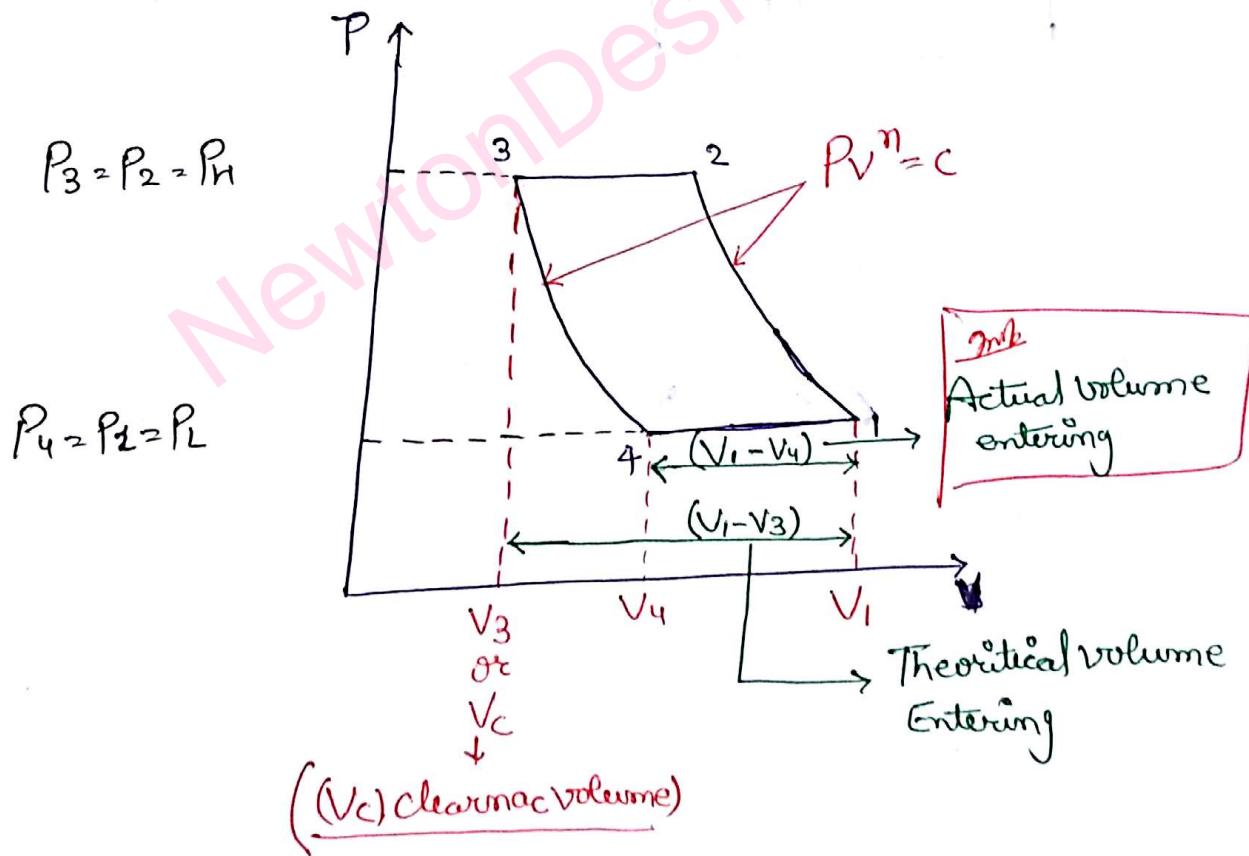
Refrigeration Equipment

Function Of Compressor :-

- i) Take Suction of Refrigerant generally in Saturated Vapour State, from the evaporator.
- ii) Discharge the Refrigerant generally in Superheated State. to the Condenser.
- iii) It increases the pressure & temperature of the Refrigerant.

Qn) Prove That Volumetric Efficiency is ,

$$\eta_v = 1 + c - c \left(\frac{P_h}{P_L} \right)^{\frac{1}{n}}$$



$\eta_V = \frac{\text{Actual volume entering}}{\text{Swept volume.}}$

$$\eta_V = \frac{V_1 - V_4}{V_1 - V_3}$$

$$\eta_V = \frac{V_1 - V_4 - V_3 + V_3}{V_1 - V_3} \quad \text{multiply by } -V_3 + V_3$$

$$\eta_V = \frac{V_1 - V_3 + V_3 - V_4}{V_1 - V_3}$$

$$\eta_V = \frac{V_1 - V_3}{V_1 - V_3} + \frac{V_3}{V_1 - V_3} - \frac{V_4}{V_1 - V_3}$$

$$\eta_V = 1 + \frac{V_3}{V_S} - \frac{V_4}{V_S}$$

$$\boxed{V_3 = V_C \\ V_S = V_1 - V_3}$$

$$\eta_V = 1 + C - \frac{V_4}{V_S} \times \frac{V_C}{V_C}$$

$$\eta_V = 1 + C - C \frac{V_4}{V_C} \quad \text{--- (1)}$$

Process (3-4) Polytropic

$$P V^n = C$$

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

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

$$\frac{V_4}{V_3} = \left(\frac{P_3}{P_4}\right)^{\frac{1}{n}} \Rightarrow \left(\frac{P_H}{P_L}\right)^{\frac{1}{n}} \quad \text{--- (2)}$$

$$\boxed{P_3 = P_2 = P_H \\ P_4 = P_1 = P_L}$$

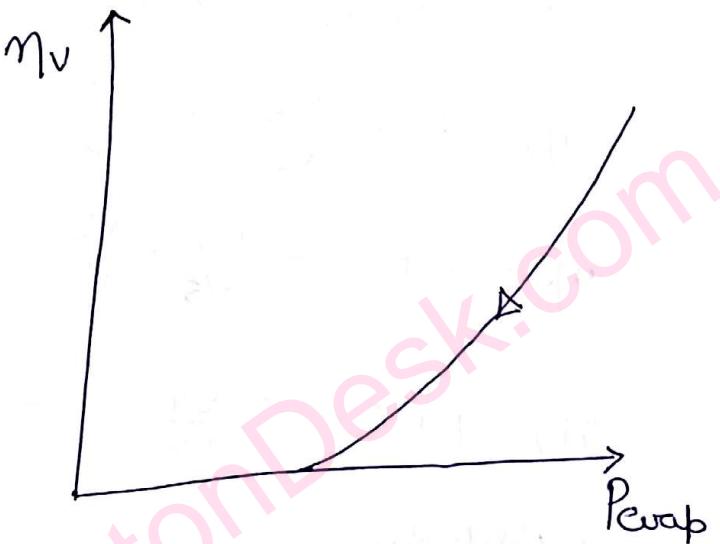
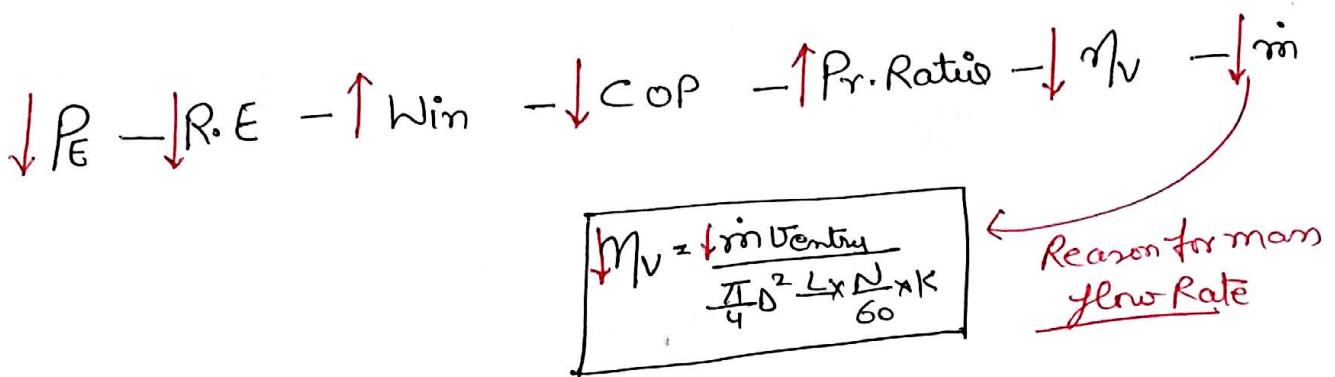
Putting (2) in (1)

Objectiv

$$\boxed{\eta_V = 1 + C - C \left(\frac{P_H}{P_L}\right)^{\frac{1}{n}}}$$

Performance Parameters :-

1) Effect of evaporator Pressure :-



Volumetric Efficiency v/s evaporator Pressure

Here graph is Plotting

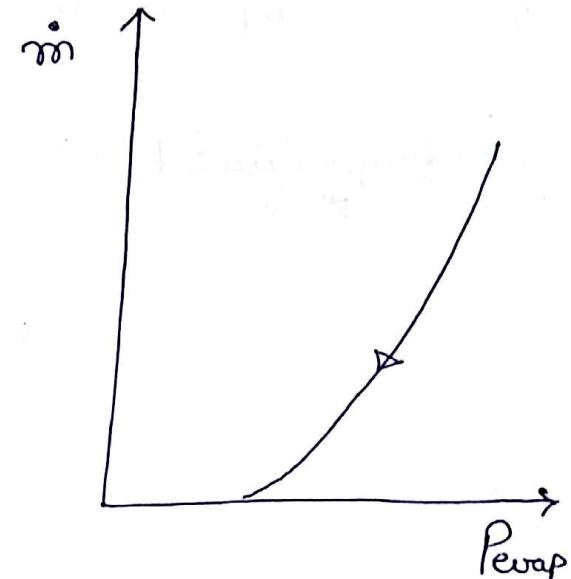
$P_2 = 1$

Bcz Evaporator must be
 Same or equal to evaporator
 Pressure bcz, Below
 P_Eva it becomes Vacuum

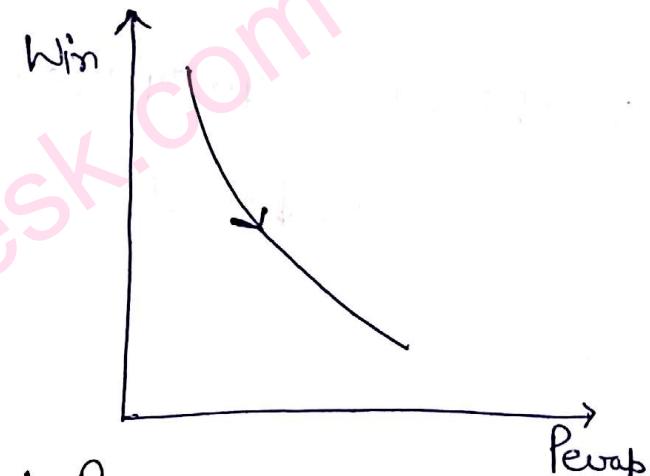
2) Mass flow Rate v/s evaporator pressure :-

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$$\downarrow \dot{m}_v = \frac{\dot{m}_{\text{Ventry}}}{\frac{\pi D^2 L N}{60} \times K}$$



3) Work in to Compressor v/s P_{evap} :-

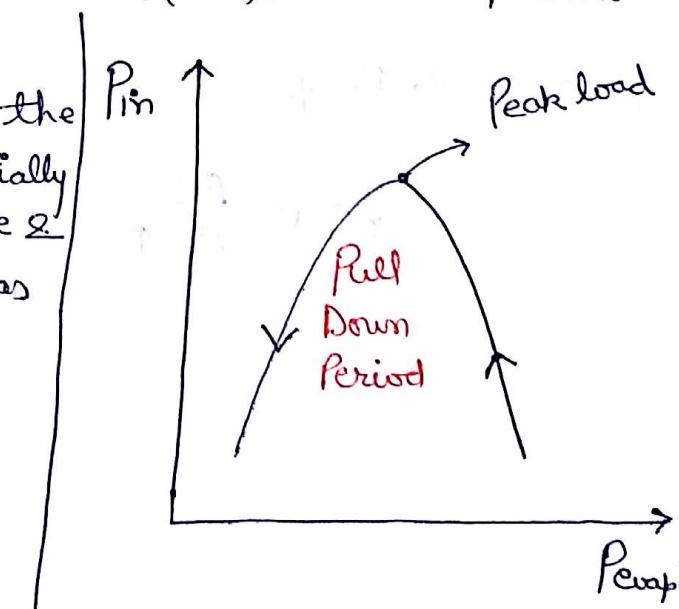


4) Power Input to the Compressor v/s P_{evap} :-

With the \downarrow P_{evap} , the mass flow Rate \dot{m} & (W_{in}) to the Compressor increases.

Therefore, initially with the \downarrow in P_{evap} , the Power input to the Compressor is initially increases, then reaches to its peak value & finally decreases. This Period is known as **Pull Down Period**

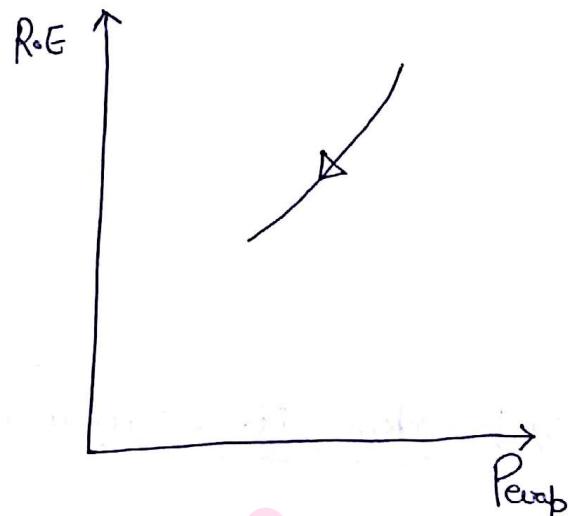
$$P_{\text{in}} = \dot{m} \times W_{\text{in}}$$



NOTE:-

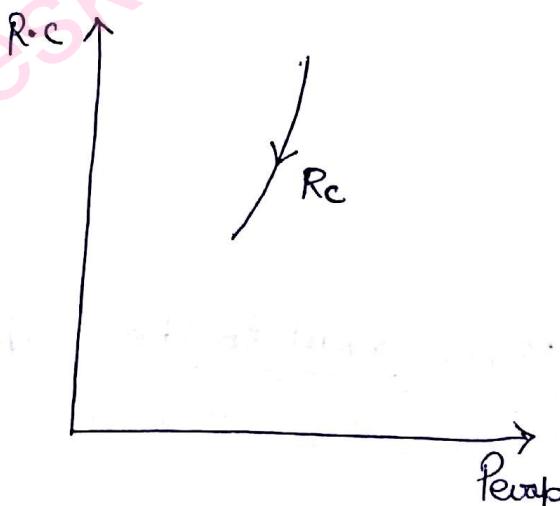
1) The Compressor should be design for Peak loads/peak hours.

5) Refrigeration Effect v/s evaporation (Evaporator) Pressure :-



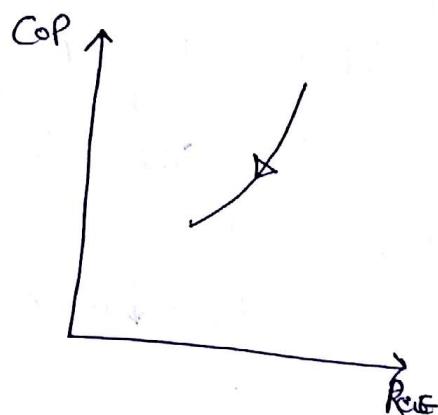
6) Refrigeration Capacity v/s evaporation Pressure:-

$$R.C = \downarrow \text{min} \times \downarrow R.E$$



7) COP v/s P_evp

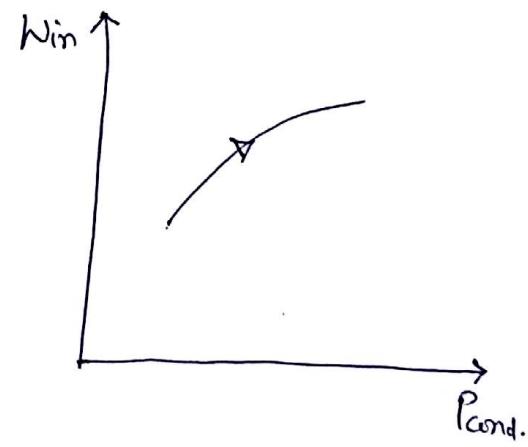
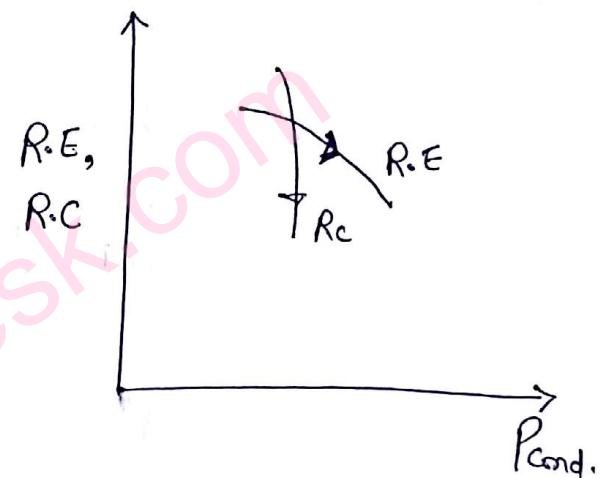
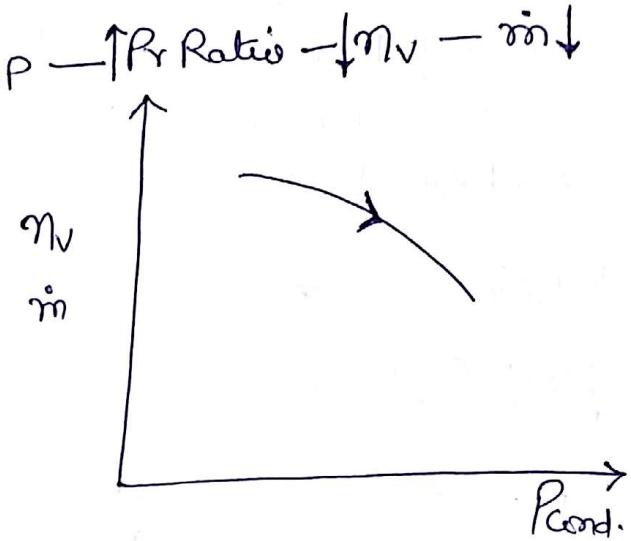
$$\text{COP} = \frac{\text{R.E}}{\text{R.E} + \text{P}_e}$$



* Effect of Evaporator Pressure:-

$\downarrow P_E \rightarrow \uparrow P_c \rightarrow \downarrow R.E - \uparrow W_{in} - \downarrow COP \rightarrow \uparrow \text{Pr Ratio} \rightarrow \uparrow \eta_v - \dot{m} \downarrow$

$\rightarrow \eta_v, \dot{m} \text{ v/s } P_{\text{cond}}$



NOTE :-

1) Effect of \uparrow in P_{cond} and \downarrow in P_{evap} are exactly same.
 but we are more sensitive towards evaporator pressure because
 of Desired Condition which is Refrigeration.

NOTE :-PURGING :-

It is the Removal of Air, from the Condenser.
 Air is non Condensable Gas. and it has poor heat Transfer Coefficient.
 Therefore it offers more thermal Resistance and hence Reduces the
 Performance of VCRS.

$$\downarrow Q = \downarrow KA \frac{dT}{dx}$$

$$\uparrow R_{th} = \frac{1}{\downarrow KA}$$

Types of Reciprocating Compressor :-

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1) Open Type :-

In this Type both Compressor and motor are the separate units and are connected by the main source means of open belt drive. The chances for the leakage of Refrigerant are high but its maintenance is very easy. Because the Compressor and Motor are the separate units.

2) Semi hermetically Sealed :-

In this, the Compressor and motor are placed in a cylinder shell with a flexible or removable cover.

3) Hermetically Sealed :-

In this, the Compressor and motor are placed in the welded Steel Shell.

The chances for the leakage of Refrigerant are negligible but its maintenance is complex.

Disadvantage of Hermetically Sealed Compressor :-

- Its heat Rejection Ratio is high: $HRR = 1 + \frac{1}{COP}$ because of its lower COP.

$$HRR \uparrow = 1 + \uparrow \left(\frac{1}{COP} \right)$$

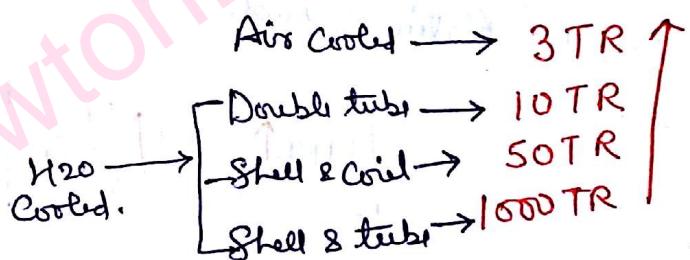
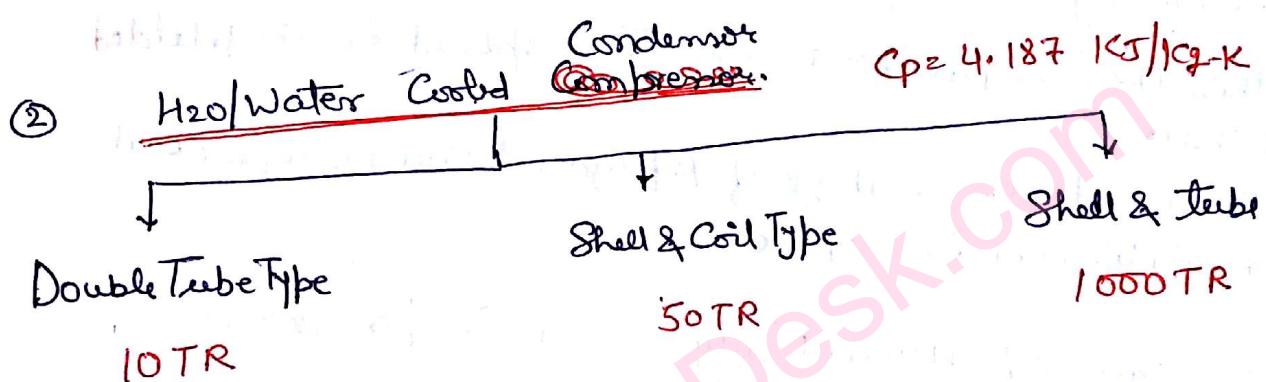
Condensor And Evaporator :-

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- Both are the Heat exchanger, with the same refrigerant as a common medium.
- In Condenser, Refrigerants Rejects its heat.
Whereas, In evaporators Refrigerants absorbs the heat.

Types of Condenser :-

1) Air Cooled Condenser. 3TR $C_p = 1.005 \text{ kJ/kg-K}$



③ Evaporative Type Condenser :-

These are generally preferred when Water is not available in Large Quantity or when there is Scarcity of Water.

In this type, First Absorbs Heat from Refrigerant & then Water in turn Rejects its heat to Air.

For example → Cooling Tower.

Expansion Device :-

- The Function Of the Expansion Device, is To Reduce the Pressure from Condenser to evaporator.
- It Will supplies the flow of Refrigerant to the evaporator as per desired capacity.

Types of Expansion Device :-

1) Constant Area Type :-

Example; Capillary Tube.

It is a narrow tube of Constant Crosssection Area.

It is used for Low Capacity Application.

e.g.; Domestic Refrigerator, Water Cooler & Window AC.

The Pressure drop in the Capillary tube is directly Proportional to the Length of Capillary tube and Inversely Proportional to the diameter of Capillary tube. The pressure drop in the Capillary tube is achieve through frictional Resistance and acceleration of the fluid in the tube.

2) Constant Volume Type :-

① Automatic Expansion Device :-

It is used to maintain Constant pressure in the evaporator irrespective of load.

② Thermostatic :-

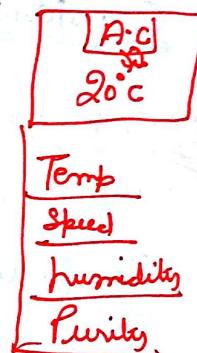
It is used to main, Constant degree of Superheat in the evaporator irrespective of Load.

Air Conditioning

- ① Temperature of Air
- ② Purity
- ③ Velocity
- ④ humidity

Air Conditioner

use → to control/maintain lower
Temperatures
→ Purity of Air
→ velocity of Air
→ humidity



Cooler → temp maint +

→ Purity ↑

→ accels ↑

→ hum ✓↑

Air Conditioning :-

New Topic

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It is the Simultaneous Control of the temperature of Air, Purity of Air, velocity of air and humidity of air.

Psychrometry :-

It is the Branch of the Science, which deals with the Study, Properties of Moist air.

Moist Air is the Composition of Dry Air and Water Vapour.

Dry Air is the Pure Substance. But Moist air is impure Substance. Because the % of Water Vapour Content varies from place to place. As we have seen that at some places, there is high humidity and at some places there is low humidity.

NOTE:-

Generally moist air is in Superheated State.

Various Psychrometric Terms :-

1) Specific humidity :- / Humidity Ratio :- (W)

→ It is defined as the Ratio of Mass of Water Vapour per kg wt. of dry Air in a given volume and at a same Temperature.

(kg/kg of d.A)

gmb

$$W = \frac{m_v}{m_a} = \frac{0.622 P_v}{P - P_v}$$

$$\frac{m_v}{m_a} = \frac{V_v}{V_a} = V$$

$$P_v = m R T$$

$$\frac{P_v}{P_a} = \frac{m_v R_v T_a}{m_a R_a T_a}$$

$$\frac{P_v}{P_a} = \frac{m_v}{m_a} \frac{R_v}{R_a}$$

$$\frac{m_v}{m_a} = \frac{P_v}{P_a} \times \frac{R_a}{R_v}$$

$$\frac{m_v}{m_a} = \frac{P_v}{P_a} \times \left(\frac{\bar{R}}{\bar{R}} / \text{mole. Wt.} \right)$$

$$\frac{m_v}{m_a} = \frac{P_v}{P_a} \left[\frac{\text{mole. Wt. O}_2}{\text{mole. Wt. A}} \right]$$

$$\frac{m_v}{m_a} = \frac{18}{29} \times \frac{P_v}{P_a}$$

Mole. Wt. Vapour = 18

Molecular Wt. Air = 29

[which is for dry as well atmospheric air]

gmb GATE

$$g_m/\text{kg of d.A} = 10^{-3} \text{ kg/kg of d.A}$$

$$(P = P_a + P_v) \quad \text{Dalton's Law of Partial Pressure.}$$

2) Relative humidity ϕ :- (ϕ)

It is defined as the Ratio Of Mass of Water Vapour to the mass of Water Vapour under Saturated Condition in a given volume and at a same temperature.

Dmt
objective

$$\phi = \frac{m_v}{m_{vs}} = \frac{P_v}{P_{vs}}$$

NOTE :-

The Specific humidity indicates the actual amount of Water Vapour present in the air.

Whereas

Relative humidity indicates indirectly the moisture absorption capacity of the Present air.

3) Dry Bulb Temperature °

It is the temperature of moist air, measured by ordinary Thermometer.

4) Wet Bulb Temperature °

It is the temperature shown by Thermometer whose bulb is covered with wet cloth.

5) Wet Bulb Depression °

It is the difference b/w DBT & WBT.

6) Dew Point Temperature :-

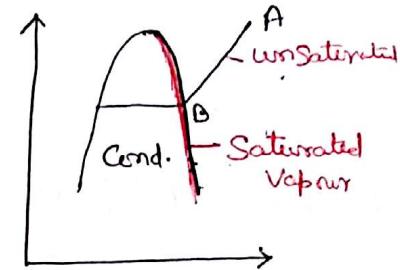
It is the Saturation temperature, corresponding to the initiation of Condensation or Water Particles just start to Condense.
OR

It is the Saturation Temperature corresponding to the Partial Pressure of Water Vapour.

NOTE :-

i) In Case of unsaturated air.

$$DBT > WBT > DPT$$



ii) In case of Saturated air, all the temperatures are equal.

$$DBT = WBT = DPT$$

$$\phi = 1 \text{ or } 100\%$$

iii) When the air is fully Saturated, the Value of Relative humidity is 1 or 100%.

iv) In Case of Saturated air, Value of ~~Wet Bulb~~ depression is Zero.

Sling

v) Sling Psychrometer measures Both DBT as well as WBT.

7) Degree of Saturation / Percent humidity: (μ)

Objective

$$\mu = \frac{W}{W_s} = \frac{P_v}{P_{vs}} \left(\frac{P - P_{vs}}{P - P_v} \right)$$

$$\mu = \frac{W}{W_s} = \frac{\frac{0.622 P_v}{P - P_v}}{\frac{0.622 P_{vs}}{P - P_{vs}}} = \frac{P_v}{P_{vs}} \left(\frac{P - P_{vs}}{P - P_v} \right)$$

8) Enthalpy of Moist Air :-

$$h_{mA} = 1.005t + \omega(2500 + 1.88T) \text{ KJ/kg of d.a.}$$

$t \rightarrow \text{DBT } (\text{°C})$

$\omega \rightarrow \text{Kg/Kg of d.a}$

9) APJON Formula :-

It is used to calculate the Partial pressure of Water Vapour.

Objective

$$P_v = P'_v - \frac{1.8 P(t - t')}{2700}$$

NOTE :-

- 1) $t \rightarrow$ Dry Bulb temperature taken in °C.
- 2) $t' \rightarrow$ Wet Bulb Temperature taken in °C
- 3) $P_v \rightarrow$ Partial Pressure of Water Vapour corresponding to P_v , the Saturation temperature, provides the values of Dew Point temperature.
- 4) $P'_v \rightarrow$ It is the Saturation Pressure corresponding to Wet Bulb temperature.
- 5) $P_{vs} \rightarrow$ Partial Pressure of Water Vapour under Saturated Conditions, Corresponding to P_{vs} , the Saturation Temperature provides the value of dry Bulb temperature.
- 6) $P \rightarrow$ If it is the total Pressure or if total Pressure not provided then taken as atmospheric Pressure.

$P = \text{Total Pressure}$

$P_{atm} = 1.01325 \text{ bar}$

101.325 kPa

$1.01325 \times 10^5 \frac{\text{N}}{\text{m}^2}$ or Pascal

(Qn) The Dry Bulb Temperature and Wet Bulb Temperature of air are 30°C and 20°C respectively. The atmospheric Pressure is 740 mm of Mercury (Hg). Determine, (2 mark fixed on hate)

i) Partial Pressure of Water Vapour

ii) Specific humidity (w)

iii) Relative humidity (ϕ)

iv) Degree of Saturation (H)

v) Enthalpy of Moist Air (h_{ma})

vi) Vapour density.

	Sat. Temp	(Bar) Sat. Pressure
Hg-D.BT	30°C	0.04242
WBT	20°C	0.02337

$$w = \frac{m_v}{m_a} = \frac{0.622 P_v}{P - P_v}$$

$$H = \frac{W}{W_s} = \frac{P_v}{P_{vs}} \left(\frac{P - P_{us}}{P - P_v} \right)$$

$$\phi = \frac{m_v}{m_{vs}} = \frac{P_v}{P_{vs}}$$

$$P_v = P' + \frac{1.8 P (t - t')}{2700}$$

$$h_{ma} = 1.005 t + w(2500 + 1.88t)$$

Soln) DBT = 30°C

WBT = 20°C

P atm = 740 mm

$$P_v = 0.02337 - \frac{1.8 \times P (30 - 20)}{2700}$$

$$P_v = 0.02337 - \frac{1.8 \times 0.9875 (10)}{2700}$$

$$= 0.02337 - 0.006583$$

$$P_v = 0.0167 \text{ bar.}$$

$t \rightarrow$ Dry Bulb temp

$t' \rightarrow$ Wet Bulb Temp

$P_v \rightarrow$ Partial pressure \rightarrow DPT

$P'_v \rightarrow$ Saturation Pressure \rightarrow WBT

$P_{vs} \rightarrow$

$P = \text{TP.}$

$$P = \rho g h$$

$$= 13.6 \times 1000 \times 9.81 \\ \times 740 \times 10^{-3}$$

$$= 0.9875 \times 10^5 \text{ N/m}^2$$

$$= 0.9875 \text{ bar}$$

ii) $w = \frac{m_v}{m_a} = \frac{0.622 P_v}{P - P_v}$

Specific humidity

$$w = \frac{0.622 \times 0.0167}{0.9875 - 0.0167} = \frac{0.01044}{0.9708} = 0.01075$$

$$w = 0.01075$$

iii) Relative humidity $\phi = \frac{P_v}{P_{vs}}$

$$\phi = \frac{0.0167}{0.04242}$$

$$\boxed{\phi = 0.3936}$$

iv) Degree of Saturation $\rightarrow H$

$$H = \phi \left(\frac{P - P_{vs}}{P - P_v} \right)$$

$$H = 0.3936 \left(\frac{0.9875 - 0.04242}{0.9875 - 0.0167} \right)$$

$$H = 0.385$$

v) Enthalpy of moist air, (KJ/kg)

$$\begin{aligned} h &= 1.005t + w(2500 + 1.88t) \\ &= 1.005 \times 30 + 0.01075(2500 + 1.88 \times 30) \\ &= 54.14 \text{ KJ/kg} \end{aligned}$$

vi) Vapour Density :-

$$P_v = mRT$$

$$P = \frac{(m)RT}{V}$$

$$\boxed{P = PRT}$$

$$P = \frac{P}{RT}$$

$$P_v = w \left(\frac{P_a}{R_a T_a} \right)$$

$$w = \frac{m_v/v}{m_a/v}$$

$$\boxed{w = \frac{P_v}{P_a}}$$

$$\boxed{P_v = w P_a}$$

$T \rightarrow \text{in Kelvin}$

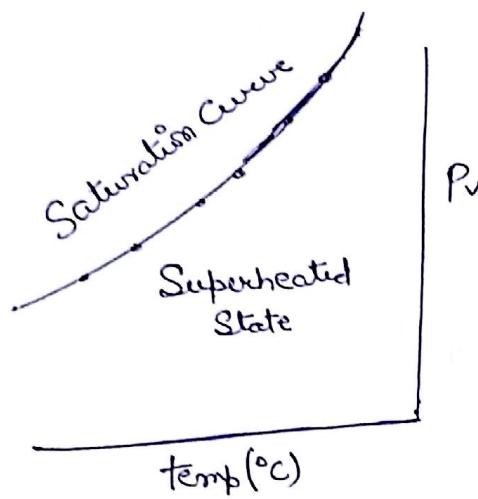
N/m^2

Dalton's law

$$\begin{aligned} P &= P_a + P_v \\ P_v &= w \left(\frac{P - P_a}{R_a T_a} \right) = 0.0107 \frac{(0.9875 - 0.0167)}{0.287 \times 10^3 \times (273 + 30)} = 0.0119 \text{ kg/m}^3 \end{aligned}$$

Psychrometry Chart :-

We know that, as a temperature (Saturation) \uparrow , the saturation pressure also \uparrow . So the plot b/w saturation temperature & pressure is,



$$w = \frac{0.622 Pv}{P - Pv}$$

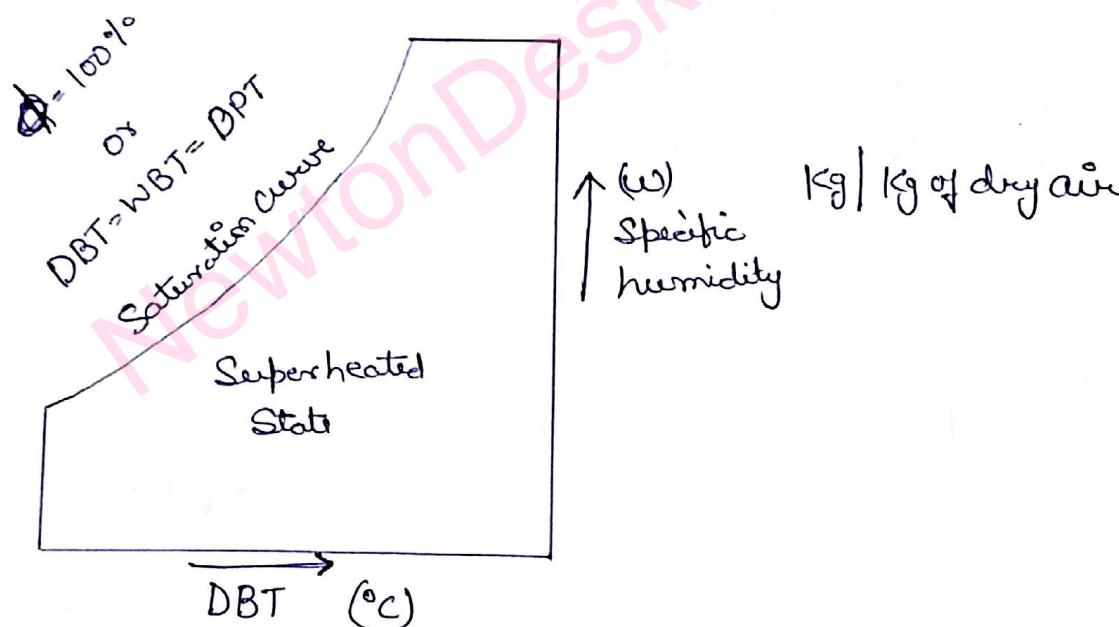
$$w = f(Pv)$$

For Superheated

$$PV = mRT$$

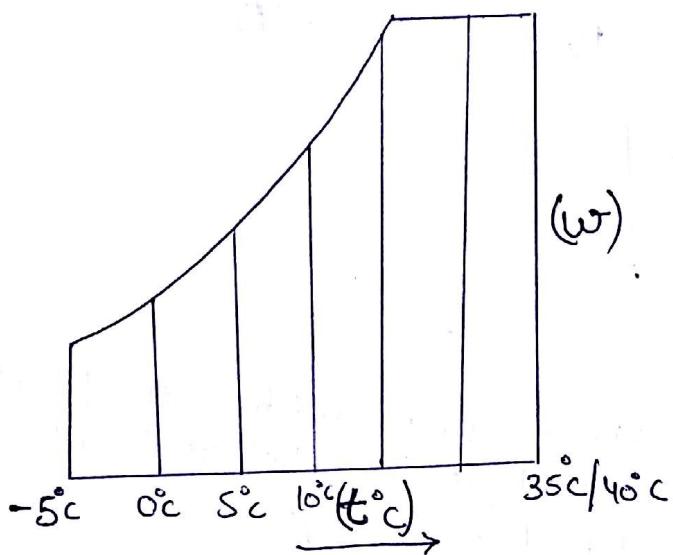
$$P \propto T$$

Later on, we found that the specific humidity is the function of partial pressure of water vapour, therefore in the original Psychrometry chart (Pv) is replaced with (w) specific humidity.



Representation of Different Constant Parameters ON Psychrometric Chart :-

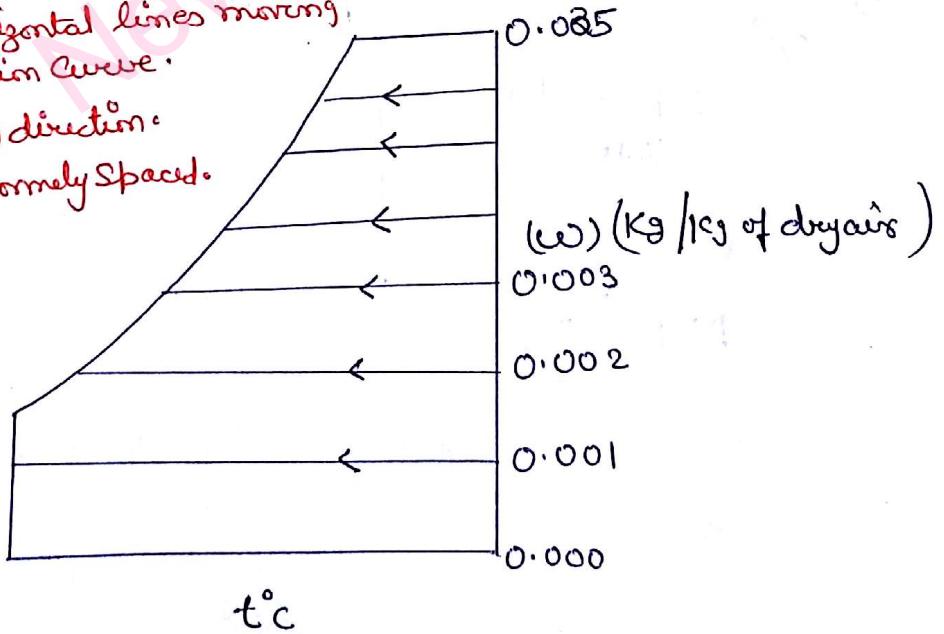
1) Constant Dry Bulb Temperature Line DBT :-



- These are the vertical lines.
- Increasing order is $(+x)$ direction.
- These are uniformly Spaced.

2) Constant Specific humidity lines :- (w)

- These are Horizontal lines moving towards Saturation Curve.
- ↑ order in $(+y)$ direction.
- These are uniformly Spaced.

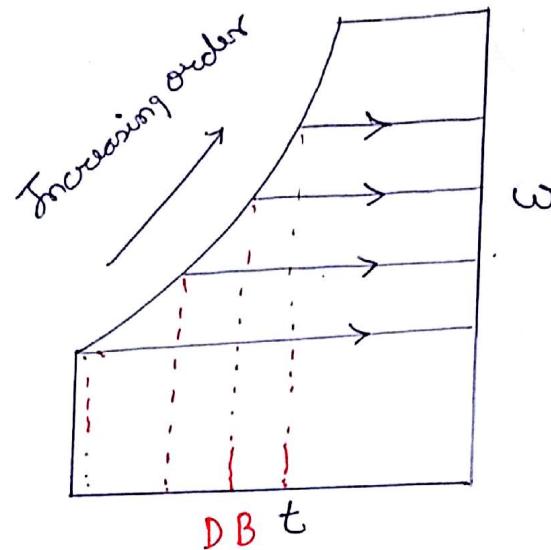


3) Constant Dew Point Temperature Lines DPT :- NewtonDesk.com

→ These are the Horizontal lines moving away from Saturation Curve.

→ These are non uniformly Spaced.

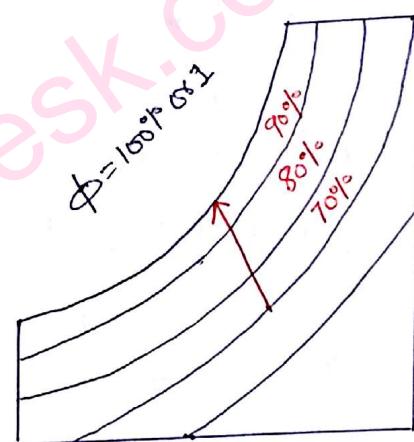
→ Increasing order



4) Constant Relative humidity Curve :-

1) These are Parallel to Saturation Curve.

2) increasing order in North-West direction.



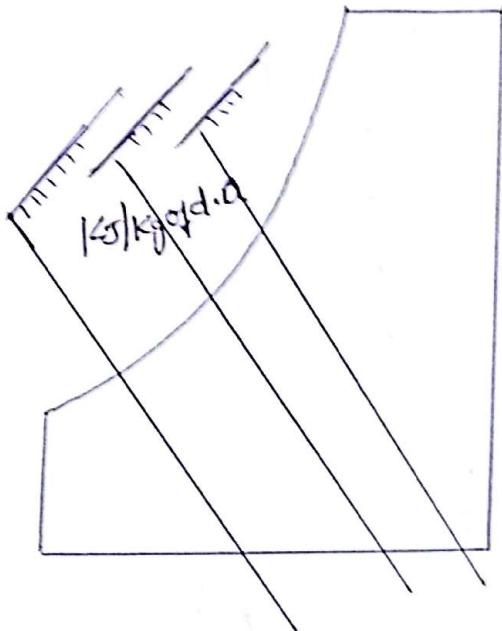
5) Constant Enthalpy lines, Constant Wet Bulb temperature line, Constant Specific volume lines :-

$$1) \quad h / WBT / v$$

$$\begin{array}{c} \downarrow \\ \text{kJ/kg} \end{array} \quad \begin{array}{c} \downarrow \\ 0^\circ\text{C} \end{array} \quad \begin{array}{c} \downarrow \\ \text{m}^3/\text{kg} \end{array}$$

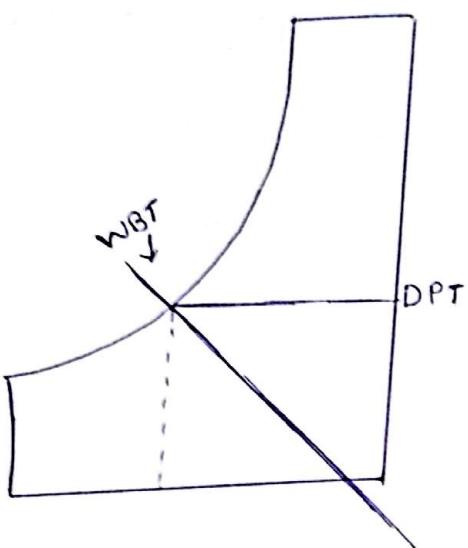
②

R



③

W.B.T



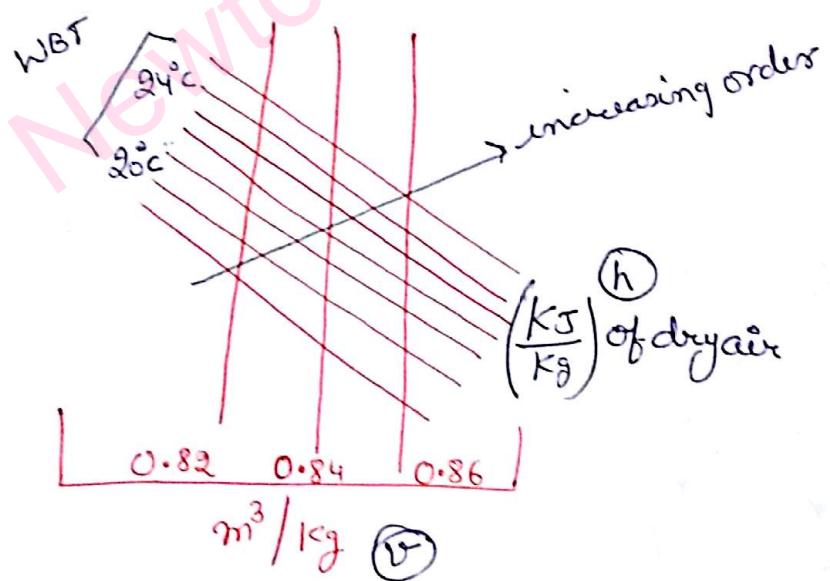
④

$h \rightarrow$ Same degree of Inclination
W.B.T.

$v =$ highest degree of Inclination

⑤

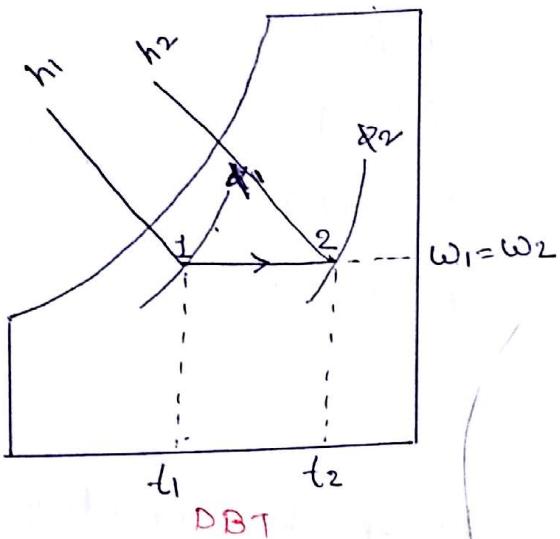
$h \rightarrow$ uniformly Spaced.
W.B.T. \rightarrow Non uniformly Spaced.



Basic Psychrometry Process :-

1) Sensible Heating :-

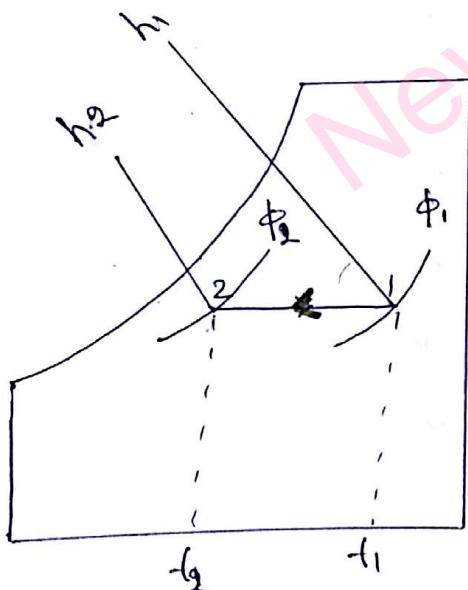
It is the process of \uparrow the dry bulb temperature at constant specific humidity.



- ① $t \uparrow$
- ② $w \text{ const}$
- ③ DPT const
- ④ $\varphi \downarrow$
- ⑤ $h \uparrow$
- ⑥ WB T \uparrow
- ⑦ $v \uparrow$

2) Sensible Cooling :-

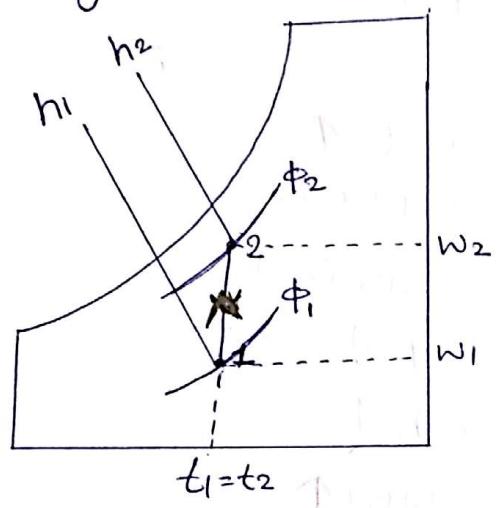
It is the process of \downarrow the temperature at constant specific humidity.



- ① $t \downarrow$ (DBT)
- ② $w \text{ const}$
- ③ DPT const
- ④ $\varphi \uparrow$
- ⑤ $h \downarrow$
- ⑥ WB T \downarrow
- ⑦ $v \downarrow$

③ Humidification :-

It is the process of \uparrow the specific humidity at constant dry bulb temperature.



① t Const

② $w \uparrow$

③ DPT \uparrow Dew Point Temp

④ $\phi \uparrow$

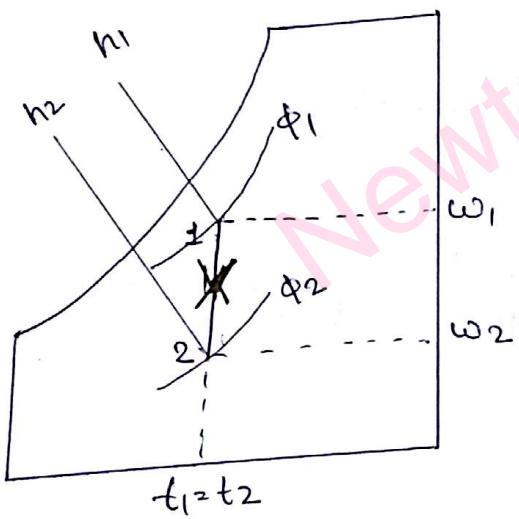
⑤ $h \uparrow$

⑥ WBT \uparrow

⑦ $v \uparrow$

④ Dehumidification :-

It is the process of decreasing the specific humidity at constant dry bulb temperature.



① t Constant

② $w \downarrow$

③ DPT \downarrow

④ $\phi \downarrow$

⑤ $h \downarrow$

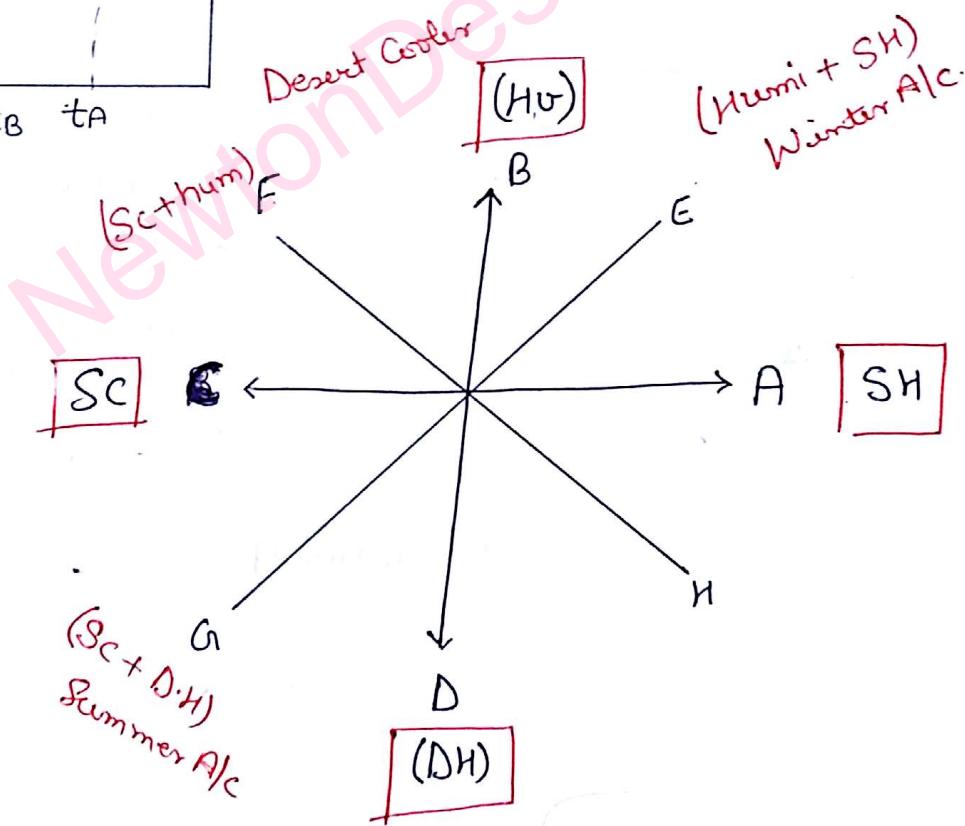
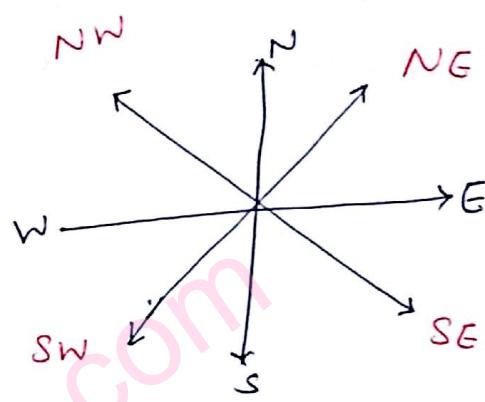
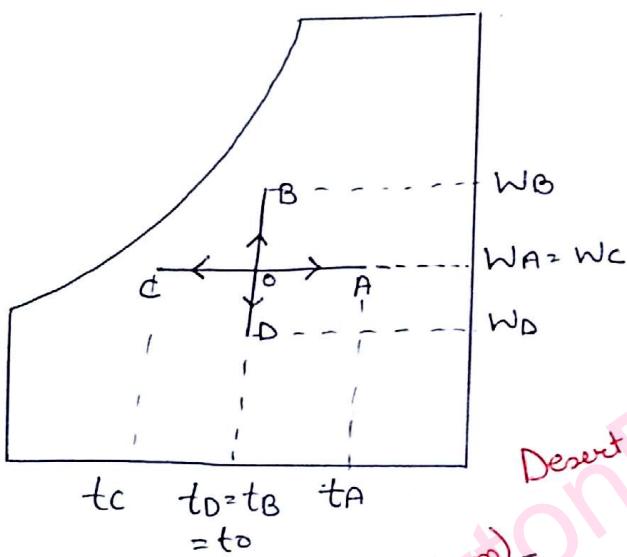
⑥ WBT \downarrow

⑦ $v \downarrow$

NOTE :-

Pure humidification & Dehumidification are impossible to achieve practically.
Therefore these are combined either with sensible heating or sensible cooling.

Representation of all the above process on same Psychrometric chart :-

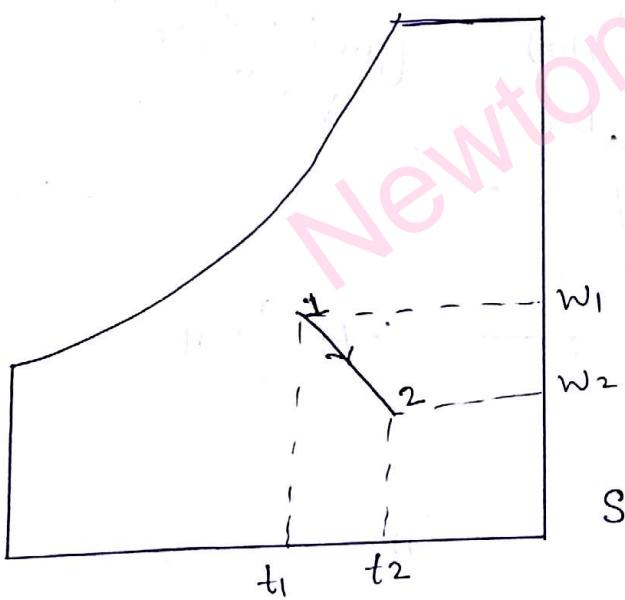


NOTE:-

In Case of Summer air Conditioning the process of Cooling & Dehumidification.

Whereas in case of Winter air Conditioning, the Process of heating & humidification occurs.

- In Case of desert cooler the process of Cooling & humidification or Adiabatic Saturation process occurs
- Desert Coolers are most effective when the Value of Wet bulb depression is, high. (Important in terms of question / Interview)
- 4. Point



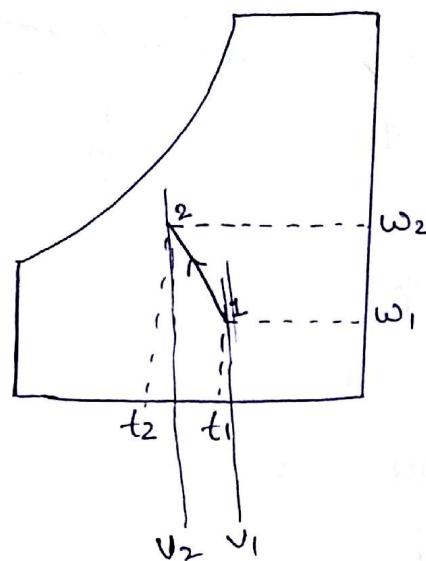
- ① $t \uparrow$
 - ② $w \uparrow$
 - ③ DPT \downarrow
 - ④ $\phi \downarrow$
 - ⑤ h
 - ⑥ WBT
 - ⑦ v
- We Can't Say

S.H + Dehumidification

Adiabatic or Chemical humidification :-

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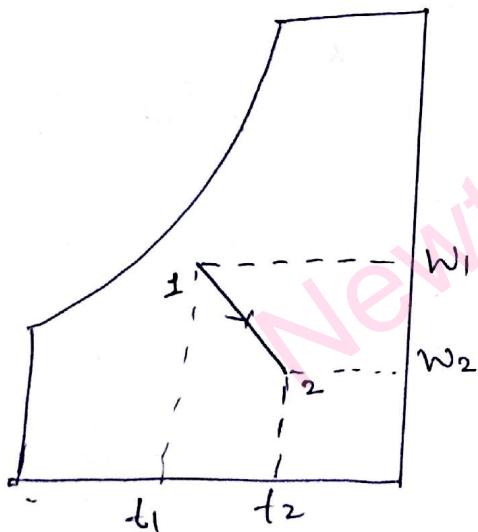
Adiabatic humidification $\rightarrow h \rightarrow \text{Constant}$
 $h_u/DH \rightarrow \text{Decides direction}$



- ① t ↑
- ② w ↑
- ③ DPT ↑
- ④ φ ↑
- ⑤ h Const
- ⑥ WB T Const
- ⑦ v ↑

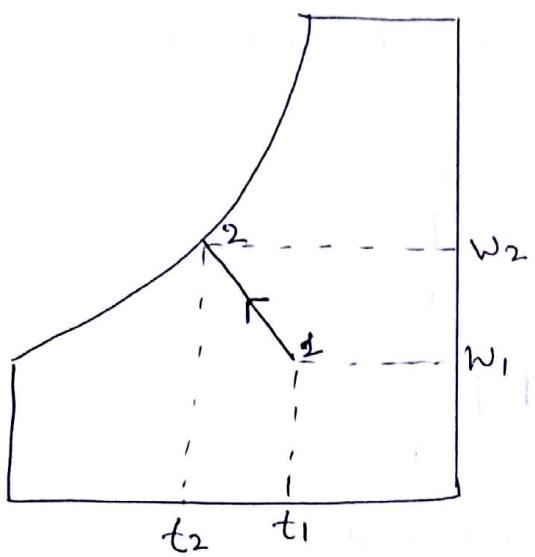
Adiabatic chemical Dehumidification :-

Ad/DH $\rightarrow h \rightarrow \text{Constant}$
DH \rightarrow decides direction

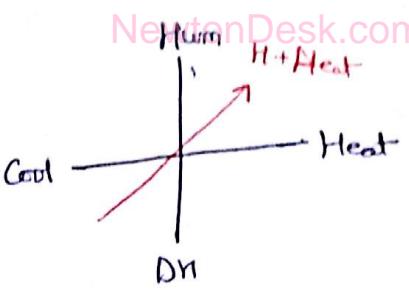


- ① t ↑
- ② w ↓
- ③ DPT ↓
- ④ φ ↓
- ⑤ h Const
- ⑥ WB T Const
- ⑦ v ↑

Adiabatic Saturation :-



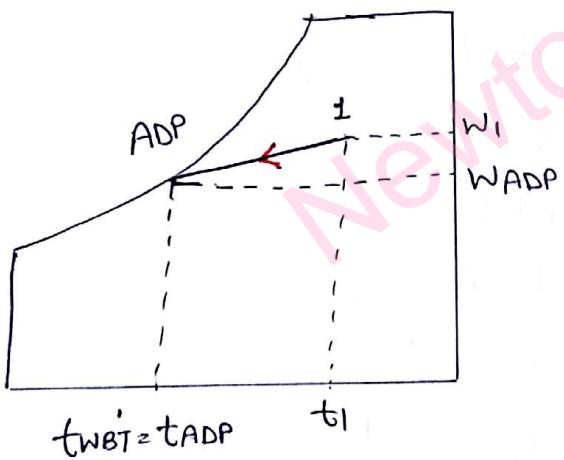
- ① $t \downarrow$
- ② $w \uparrow$
- ③ DPT \uparrow
- ④ $\phi \uparrow$
- ⑤ $h \text{ Const}$
- ⑥ ~~WBT~~ Const
- ⑦ $v \downarrow$



Apparatus Dew Point - (ADP)

It is the Point obtained by the intersection of Cooling and dehumidification with the saturation curve.

Three cases are formed

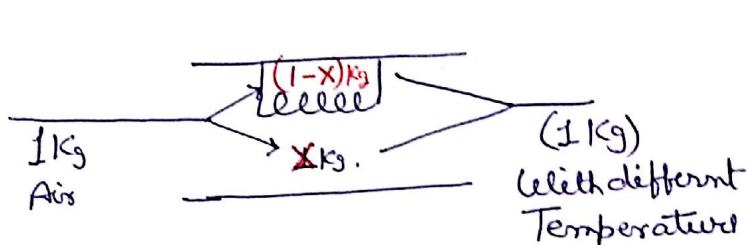


- ① Cooling & Dehumidification
- ② Saturation Curve touch and at Saturation Curve
- ③ $\phi_{APP} = 1$

By-Pass Factor :- (C)

It simply represent the loss.

It represents the uncontaminated air / it represents the fractional part of inlet air which is not coming in contact with the coil.

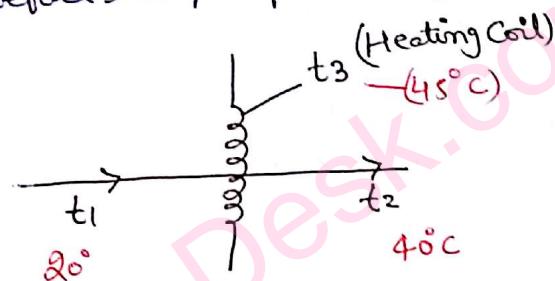


$$\boxed{\eta = 1}$$

$$\boxed{\eta = 1 - \text{BPF} \downarrow}$$

By-Pass factor of Heating Coil :-

Let, t_1 be the inlet temp. of air, t_2 be the outlet temp. of air and t_3 be the surface temp. of heating coil.



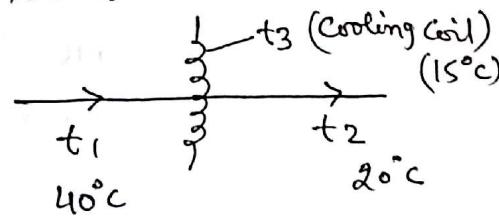
$$\boxed{(\text{BPF})_{\text{HC}} = \frac{t_3 - t_2}{t_3 - t_1}}$$

Loss
diff

$$\boxed{(\eta)_{\text{HC}} = 1 - (\text{BPF})_{\text{HC}}}$$

By Pass factor of Cooling Coil :-

Let t_3 be surface temp. of Cooling coil.



Important

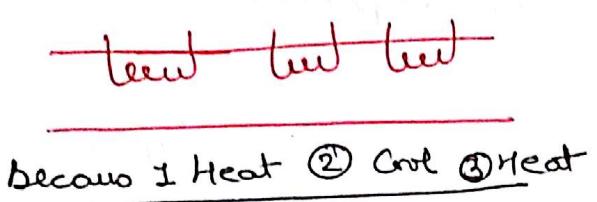
$$\boxed{(\text{BPF})_{\text{CC}} = \frac{t_2 - t_3}{t_1 - t_3}}$$

$$\boxed{\eta_{\text{CC}} = 1 - (\text{BPF})_{\text{CC}}}$$

NOTE

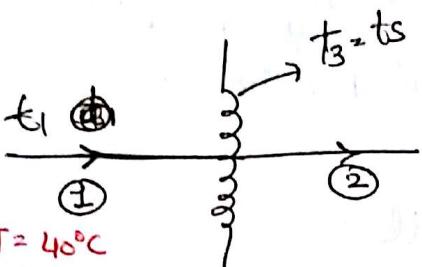
→ By Pan factor in case of Combined coil (when there is more than one Rows of coil)

[No such case]



$$X^N = N - \text{Total no. of coil}$$

→



$$DBT = 40^\circ C$$

$$DPT = 20^\circ C$$

$SH \rightarrow DBT$
 $SC \rightarrow DPT$

Humidification $\rightarrow H_2O$
dehumidification $\rightarrow DPT$

ts

①

$50^\circ C$

②

$50^\circ C H_2O$

③

Steam ($100^\circ C$)

④

$30^\circ C$

⑤

$20^\circ C$
or
 $19^\circ C$

outlet temp

SH

SH + Hu

SH + Hu

SC

~~SC + Hu~~

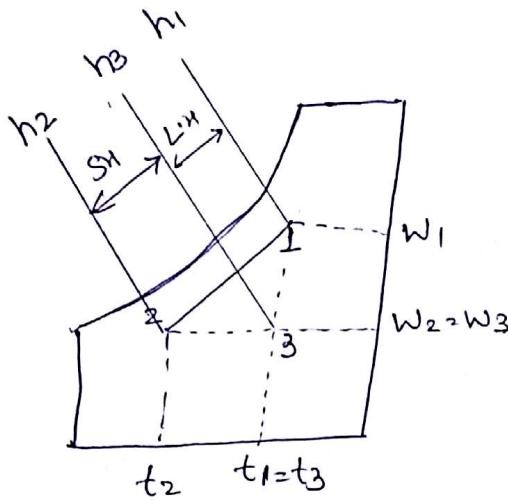
SC + DH

Sensible Heat Factor :-

It is defined as the Ratio of Sensible heat to the total heat.

~~Total heat~~

Total Heat is the Summision of (SH) & (LH).



$$SHF = \frac{SH}{LH} = \frac{SH}{SH+LH}$$

$$= \frac{h_3 - h_2}{(h_3 - h_2) + (h_1 - h_3)}$$

$$SHF = \frac{h_3 - h_2}{h_1 - h_2}$$

grub

Value of Sensible Heat factor for different Places :-

Residence & P.T. office	0.9
Restaurant & Busy office	0.8
Auditorium & Cinema hall	0.7
Dancehall room	0.6

Effective Temperature :-

It is the temperature of Saturated Air at which human being can / would feel same level of comfort as in Actual environment. It includes comfort temperature, humidity, Acceleration of air & velocity.

Psychometry

Factors Affecting effective Temperature :-

(1) Climate and Seasonal Differences :-

People living in Colder climate feeling comfortable at lower effective temperatures than the people living in Warmer Region.

In Summer optimum effective temperature is 21.6°C

Whereas in Winter effective temp is 20°C

(2) Age and Gender :-

Childrens and old aged Persons needs ~~too~~ $2-3^{\circ}\text{C}$ higher effective temperature than Adults.

Similarly in the case with Womens. Which need $2-3^{\circ}\text{C} \uparrow$.

(3) Kind of Activity :-

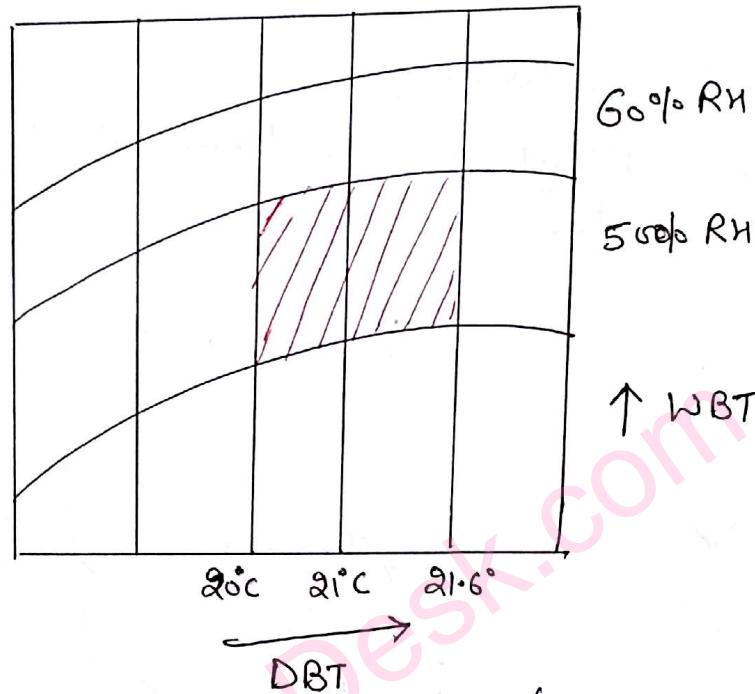
If a Person is involved in Activities like dancing, foundry shop etc. means/needs lower effective temp.

than the person who are in rest condition.

4) Density of Occupants :-

Highly Density occupied areas needs lower effective temps than the less density occupied area.

5) Comfort Chart :-



This chart is Developed by ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers).

By Conducting a Survey on different Kinds of People Subjected to wide range of environmental temperature Condition, humidity and air velocity.

This Chart is developed b/w DBT & WBT which are taken on X & Y axis Respectively.

→ If the Value of Relative humidity is above 50%, then there is tendency of Sticky Sensation develops. whereas as if the Value of Relative humidity is below 50% then the skin is too dry.

Ventilation Air :-

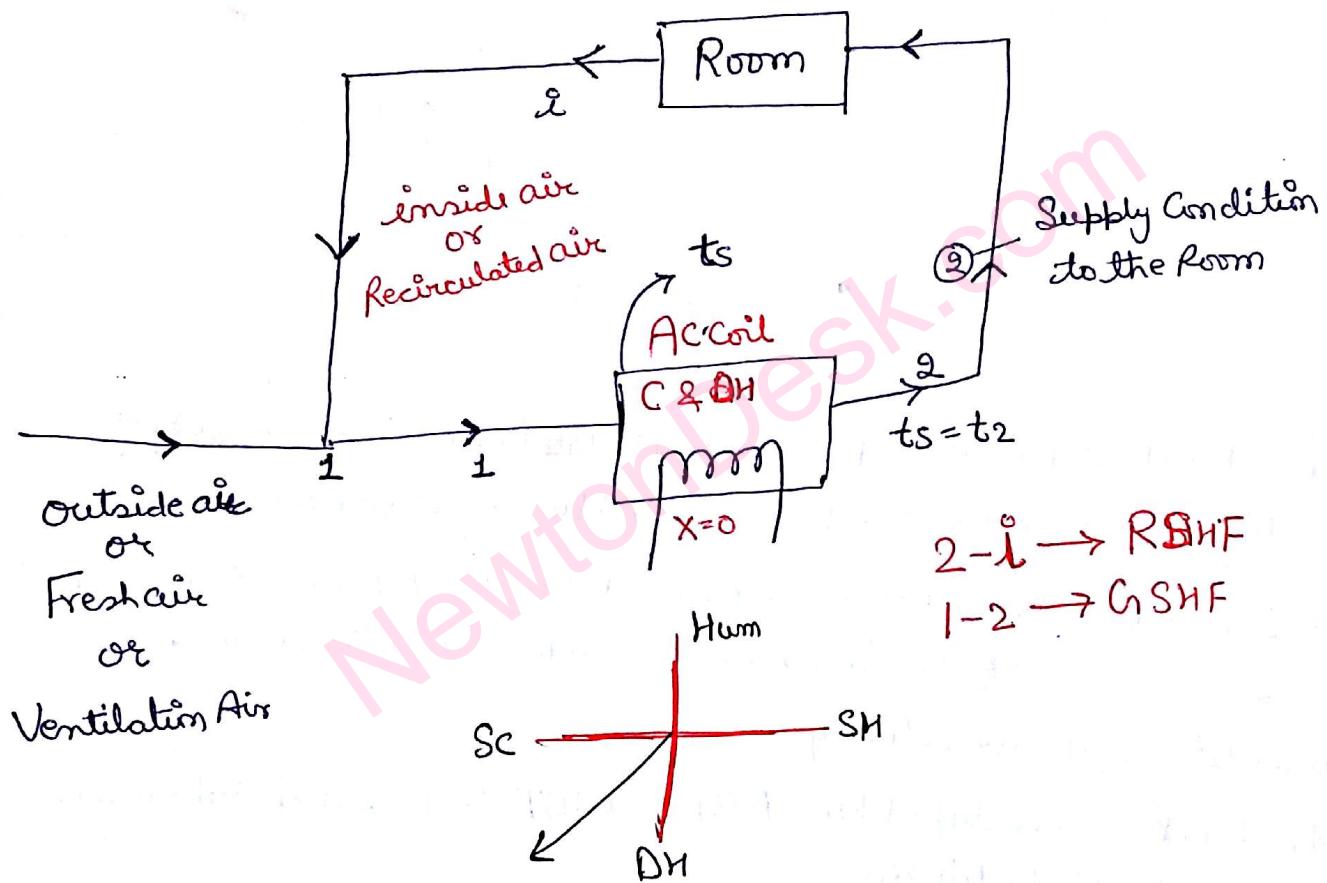
It is the amount of fresh air which is supplied to the A/c coil, in order to maintain its purity.

NOTE:-

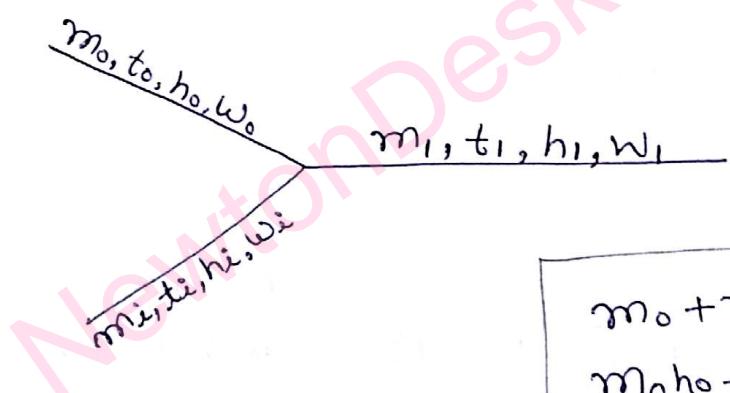
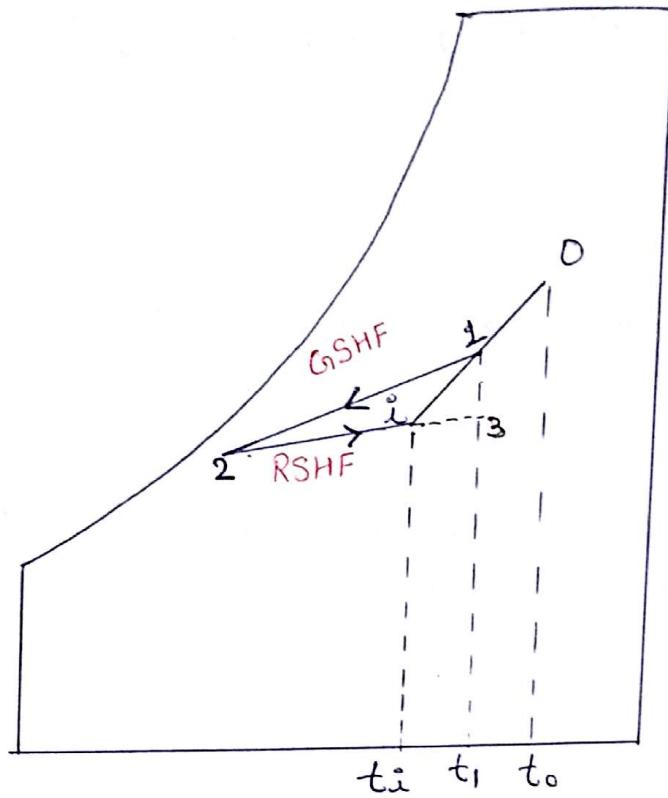
In Case of operation theatre / ICU, 100% outside air is supplied.

Summer Air Conditioning :-

Air is passing through cooling & dehumidification coil with (0 BPF)
Zero By-Pass factor.



in Summer
outer temp ↑



$$\begin{aligned}
 m_0 + m_i &= m_1 \\
 m_0 h_0 + m_i h_i &= m_1 h_1 \\
 m_0 t_0 + m_i t_i &= m_1 t_1 \\
 m_0 w_0 + m_i w_i &= m_1 w_1
 \end{aligned}$$

GSHF :-

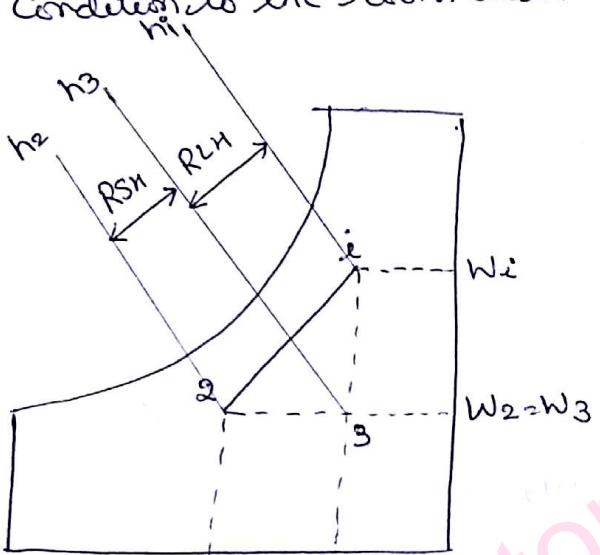
It is the line or curve obtained by the joining of inlet & outlet of the coil.

R SHF :-

It is defined as the Ratio of room sensible heat to the room total heat.

or

It is the line or curve which is obtained by joining the Supply Condition to the room with the inside condition.



$$R_{SHF} = \frac{R_{SN}}{R_{TH}} = \frac{R_{SN}}{R_{SN} + R_{2H}} = \frac{h_3 - h_2}{(h_3 - h_2) + (h_1 - h_3)}$$

$$\boxed{R_{SHF} = \frac{h_3 - h_2}{h_1 - h_2}}$$

NOTE :-

$$\textcircled{1} \quad R_{SH} = 0.0204 \text{ Cmm } \Delta t (\text{Kw})$$

(Room Sensible Heat)

$$\textcircled{2} \quad R_{LH} = 50 \text{ Cmm } \Delta w (\text{Kw})$$

Qmb Cmm = _____

 m^3/min

note it must be in this unit

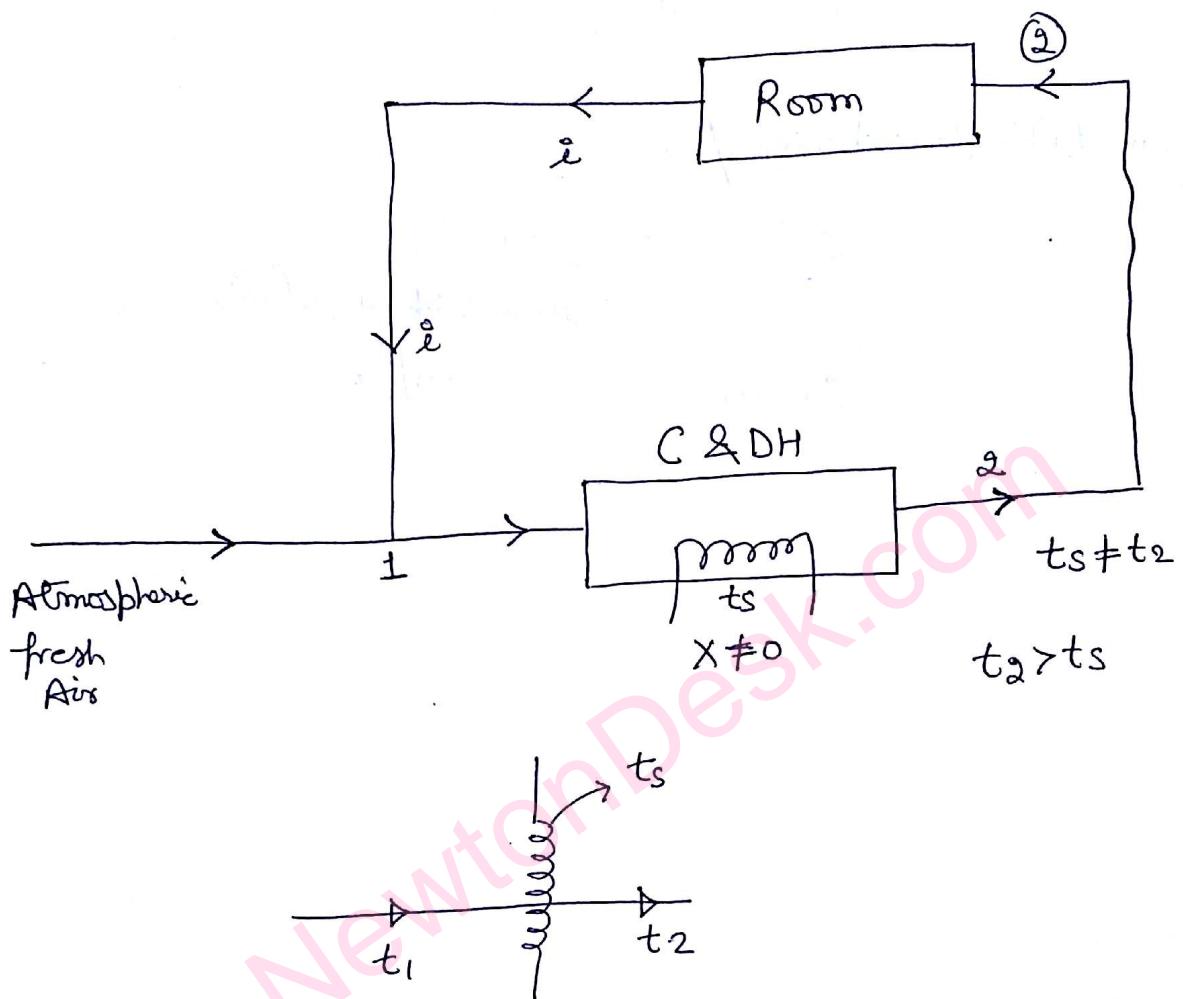
$$\textcircled{3} \quad \text{No. of Airflow changes/hr}$$

$$= \frac{\text{Cmm}}{\text{Volume of Room (m}^3)}$$

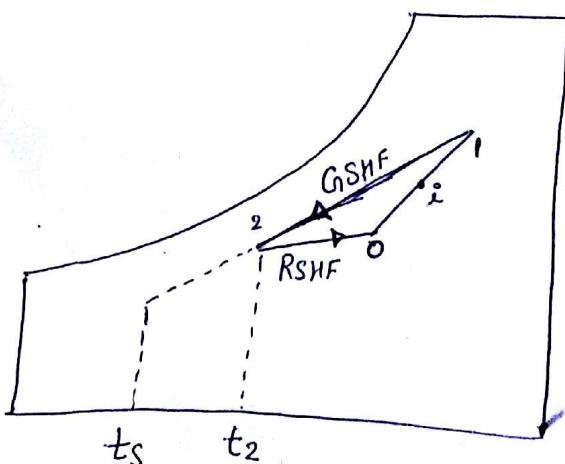
$$\text{Cmm} = \text{_____ m}^3/\text{hr}$$

Summer Air Conditioning :-

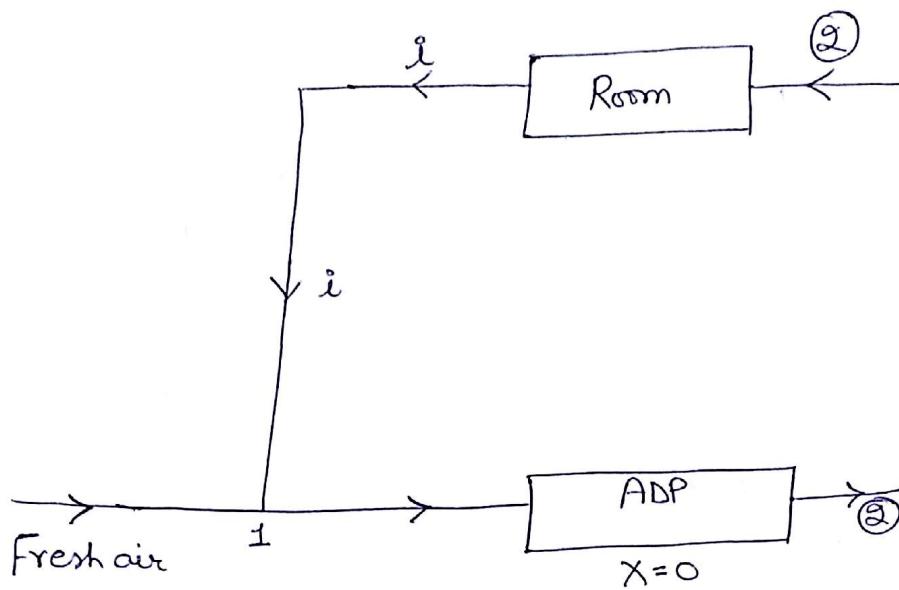
Air is Passing Through a Cooling and dehumidification coil with non zero By Pass factor.



$$X = \frac{t_2 - t_s}{t_1 - t_s} = \frac{h_2 - h_s}{h_1 - h_s} = \frac{w_2 - w_s}{w_1 - w_s}$$

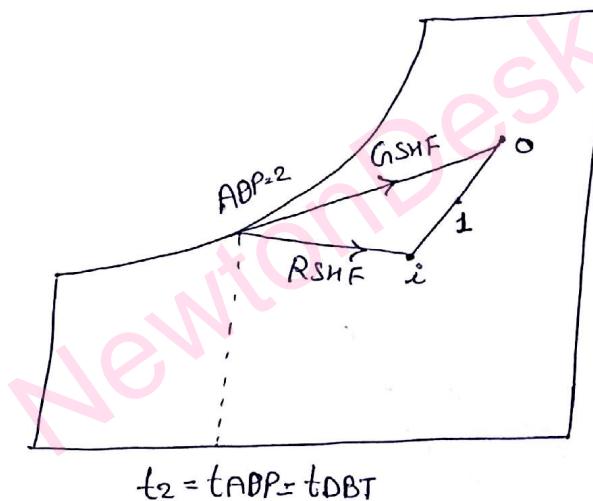


Air Is Passing Through a Coil having Some Given Value of ADP
(Apparatus dew Point) With zero By Pass factor:-



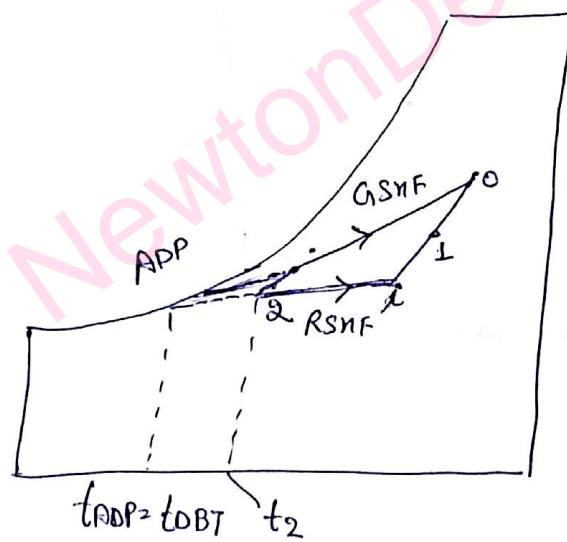
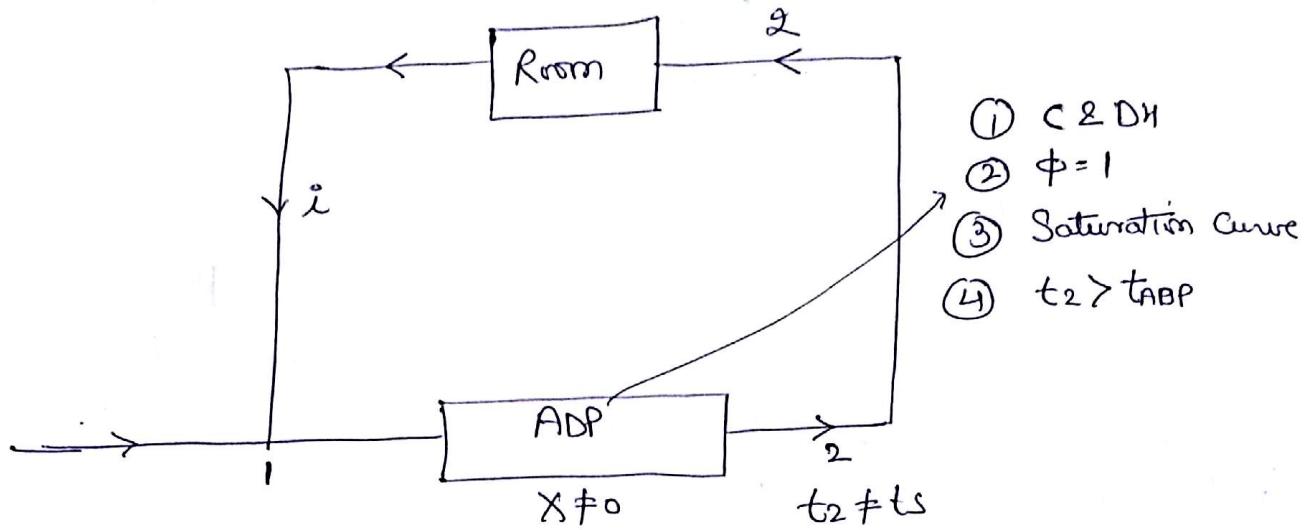
Summaries

- ① C & DH
- ② Saturation Curve (ADP)
Apparatus Dew Pt.
- ③ $\phi_{ADP} = 1$
- ④ $t_2 = t_{ADP}$



Case 4

Air is passing through a coil having some given value of ADP with non-zero by pass factor :-



NOTE :-

→ Human beings are feeling Comfort b/w $24 - 26^{\circ}\text{C}$ DBT and 50 - 60% Relative humidity.

→ The Degree of Freedom of moist air is,

$$P + F = C + 2$$

$$1 + F = 2 + 2$$

$$\boxed{F = 3}$$

The degree of freedom of moist air is 3, but we can locate or fix the state of moist air on the chart by using two variables, because the chart is developed for the particular pressure, that is atmospheric pressure.

→ During the compression of moist air or when moist air is heated in a air tight vessel, then the specific humidity Remains Constant.

→ Air Washer ⁺ filter can be used as humidifier, Dehumidifier and filter.