

Amish  
5/2

\* Refrigeration :- It is a process of maintaining in a space at a lower temperature compared to the surrounding.

The working fluid circulated for maintaining the refrigeration is called refrigerant.

\* Refrigeration effect :- The amount of heat absorbed from the refrigerated space is called refrigeration effect.

It is generally calculated in kilojoule/kilogram ( $\text{kJ/kg}$ ).

\* Refrigeration capacity :- The rate of heat absorbed from the refrigeration space is called refrigeration capacity.

It is generally calculated in kilojoule/second (or) kilowatt. ( $\text{kJ/sec}$  (or)  $\text{kW}$ ).

formula  $\boxed{RC = \dot{m} \times RE}$  <sup>relation</sup> unit  $[\text{kJ/sec}]$

where,

$RC$  = Refrigeration capacity ( $\text{kJ/sec}$ )

$\dot{m}$  = mass per second ( $\text{kg/sec}$ )

$RE$  = Refrigeration effect ( $\text{kJ/kg}$ )

15/09/25

\* Heat effect & Heating capacity :-

The amount of heat rejected is called heating effect and is generally calculated as  $\text{kJ/kg}$ .



The rate of Heat Rejection is called Heating capacity. and it is generally calculated as KW (or) KJ/sec.  
relation  $\frac{KW}{KJ/sec}$   $(HC = \dot{m} \times HE)$

\* Ton of Refrigeration (TR) :- It is the rate of Heat removal which is required to convert 906 kg (1 Ton) of water at 0°C to 1 Ton of ice at 0°C in 24 hours.

$1 TR = 3.5167 KW$   
(OR)

$1 TR = 211 KJ/min$  (OR)  $1 TR = 4.2 Joule$   
(OR)

Latent Heat of solidification in water =  $1 TR = 50.4 Kcal/min$   
 $[334 KJ/kg]$

Latent Heat of liquidation in water :-  $1 kg ice - LHS = 334$   
 $[2257 KJ/kg]$   
 $\frac{1 \times 334}{24 \times 60 \times 60}$

$1 kg ice = 3.5167 KW$

Unit-2.

\* ~~Refrigeration~~ Refrigeration cycle :- ~~Vapour~~

(i) (VCRS)  $\Rightarrow$  Vapour compression Refrigeration system.

• Sequence of component of VCRS  $\Rightarrow$

compressor  $\rightarrow$  condenser  $\rightarrow$  Throttle valve  $\rightarrow$  Evaporator



push  
size

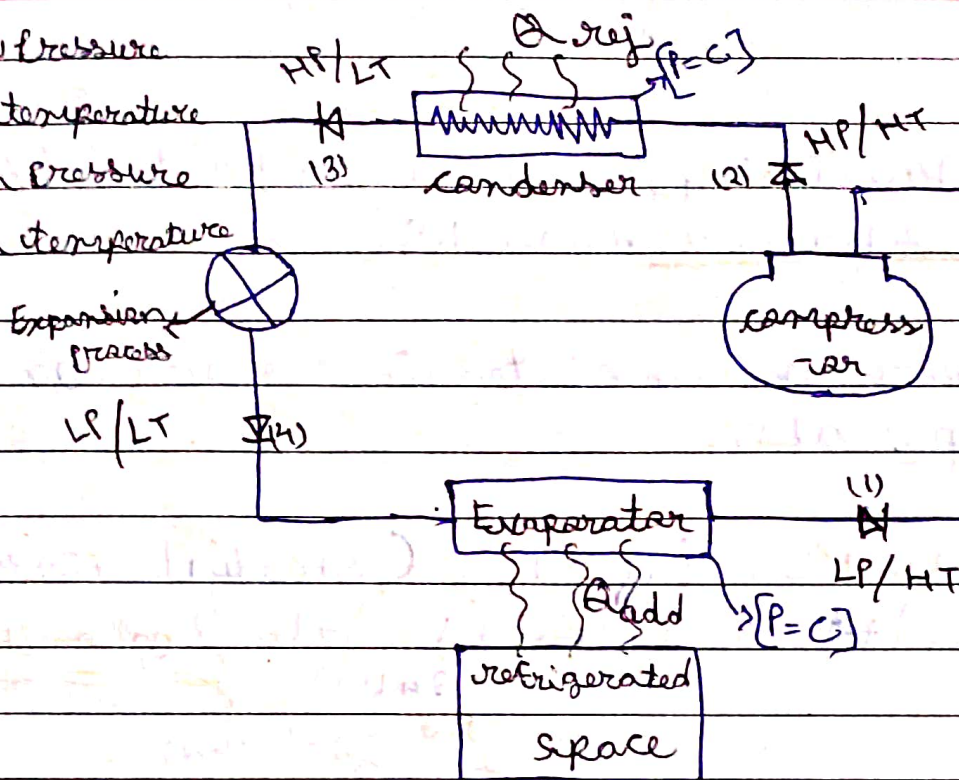
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LP = Low Pressure

LT = Low Temperature

HP = High Pressure

HT = High Temperature



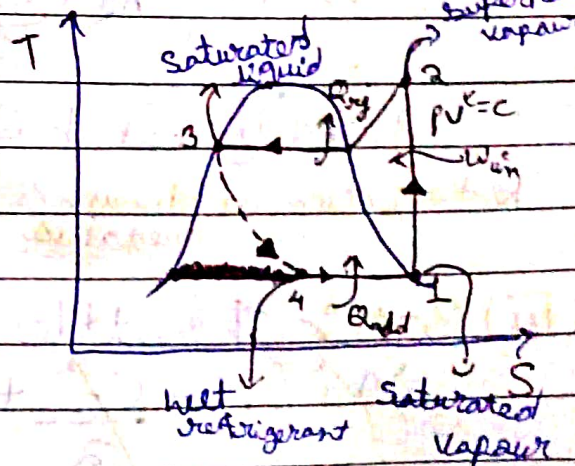
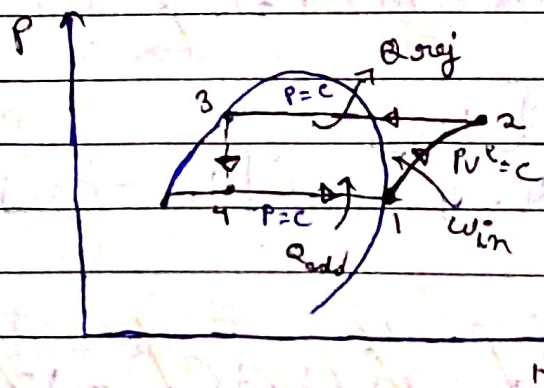
1-2:- compression:- Isentropic process. ( $PV^k=c$ )

2-3:- condenser:- Pressure = constant ( $P=c$ ); and heat rejection ( $Q_{rej}$ ).

3-4:- Throttle valve; Expansion / Throttling:- Isenthalpic process ( $h=c$ ) constant

4-1:- Evaporation:- constant Pressure ( $P=c$ ); and heat addition ( $Q_{add}$ ).

16/09/25





⇒ In Am. oil separator incorporated b/w compressor & condenser in VCRS.

\* Expansion device is connected in between condenser and evaporator.

:- Analysis of VCRS:- By SFEE (steady flow energy equation)  

$$\left\{ m \left( h_1 + \frac{C_1^2}{2} + gz_1 \right) + Q = m \left( h_2 + \frac{C_2^2}{2} + gz_2 \right) + W \right\} \text{ eqn. of SFEE}$$

(i) 1-2:- Compressor:-

$$\Rightarrow m \left( h_1 + \frac{C_1^2}{2} + gz_1 \right) + Q = m \left( h_2 + \frac{C_2^2}{2} + gz_2 \right) + W$$

$$\Rightarrow m [h_1] = m [h_2] + W_{in}$$

work input is always negative ⇒  $W_{in} = m [h_1 - h_2] \text{ } (-ve)$

(ii) 2-3:- condenser:-

$$\Rightarrow m \left( h_2 + \frac{C_2^2}{2} + gz_2 \right) + Q = m \left( h_3 + \frac{C_3^2}{2} + gz_3 \right) + W$$

$$\Rightarrow m [h_2] + Q = m [h_3]$$

heat rejection is always negative ⇒  $Q_{rej} = m [h_3 - h_2] \text{ } (-ve)$

(iii) 3-4:- Throttle Valve:-

$$\Rightarrow m \left( h_3 + \frac{C_3^2}{2} + gz_3 \right) + Q = m \left( h_4 + \frac{C_4^2}{2} + gz_4 \right) + W$$



$$\Rightarrow \{ h_3 = h_4 \}$$

(iv) 4-1 :- Evaporator :-

$$\Rightarrow m' (h_4 + C_p \frac{2}{2} + g \frac{2}{2}) + Q = m' (h_1 + C_p \frac{2}{2} + g \frac{2}{2}) + W$$

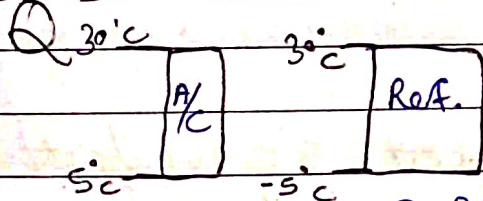
$$\Rightarrow m' [h_4] + Q = m' [h_1]$$

$$\Rightarrow \{ Q = m' [h_1 - h_4] \}$$

heat absorb by the evaporator  $\rightarrow$  KJ/sec (Watt)  $\rightarrow$  kg/sec  $\rightarrow$  KJ/kg

:- Application of VCRS :- commercial ice plant.

Interview Most Imp.



Sol,  $Cop = \frac{\text{Desired effect}}{\text{Working input}}$

where,  $Cop$  = coefficient of performance.

$$COP/A/C = \frac{5 + 273}{25}$$

$$COP/Ref = \frac{273 - 5}{35}$$

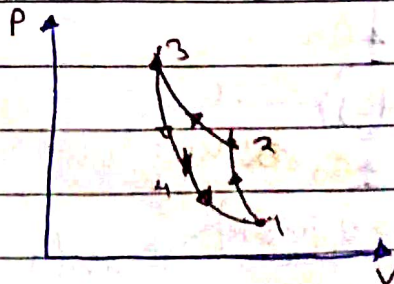
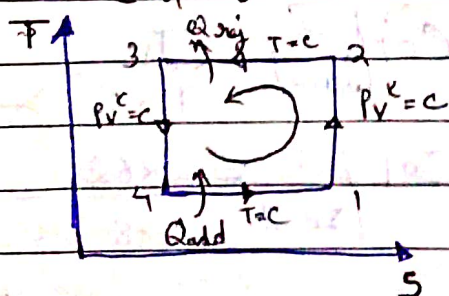
$$COP/A/C \approx 11.2$$

$$COP/Ref \approx 7.65$$

$$\text{most imp } \{ COP/A/C > COP/Ref \}$$

17/09/25

\* Ideal VCRS system :- (Carnot cycle)





- 1-2 :- Rev. adiabatic process : compression ( $PV^k = c$ )  
 2-3 :- Rev.  $T = C$  process -  $Q_{rej}$  ( $PV = c$ )  
 3-4 :- Rev. adiabatic process : Expansion ( $PV^k = c$ )  
 4-1 :- Rev.  $T = C$  process -  $Q_{add}$  ( $PV = c$ )

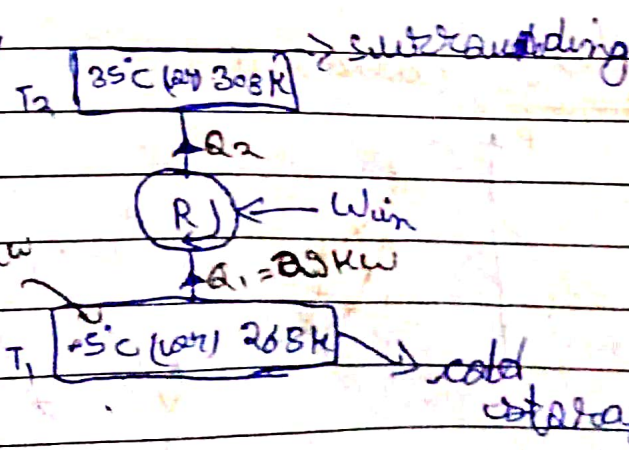
$$\text{COP}_{\text{ideal Ref.}} = \frac{\text{Desired Effect}}{W_{in}} = \frac{T_1}{T_2 - T_1}$$

$$\text{COP} = \frac{1}{\frac{T_2}{T_1} - 1}$$

$$\text{COP}_{\text{ideal Ref.}} \text{ of } f(\text{max. strain temp.})$$

18/3/25  
 Q. A cold storage is to be maintained at  $-5^\circ\text{C}$  while the surroundings are at  $35^\circ\text{C}$ . The leakage from the surrounding into the cold storage is estimated to be  $29\text{ kW}$ . The actual COP of the refrigeration plant is one third of an ideal plant working b/w the same temperatures. Find the power required to drive the plant.

Sol,



$$\left\{ \text{COP}_{\text{act}} = \frac{1}{3} \times \text{COP}_{\text{ideal}} \right\}$$

$$\left\{ \text{COP}_{\text{ideal}} = \frac{T_1}{T_2 - T_1} \right\}$$

$$\text{COP}_{\text{ideal}} = \frac{268}{308 - 268} = 6.7$$



$$\left\{ \text{COP}_{\text{act}} = \frac{1}{3} \times \text{COP}_{\text{Ideal}} \right\} \Rightarrow \text{COP}_{\text{act}} = \frac{1}{3} \times 6.70 = [2.233]$$

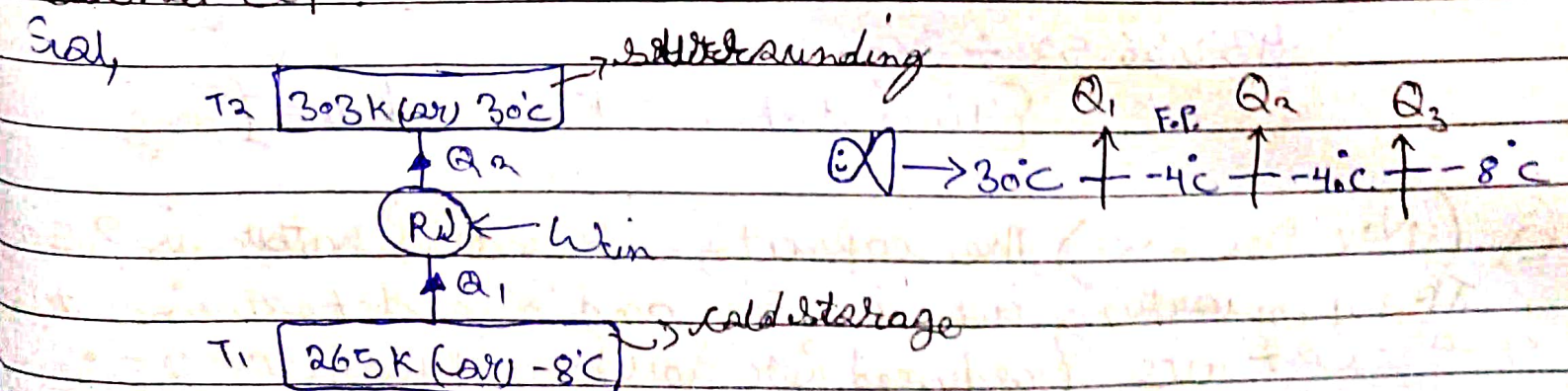
$$\text{COP} = \frac{T_1}{T_2 - T_1} = \frac{Q_1}{W_{\text{in}}} \rightarrow \text{Actual}$$

Ideal/Reversible

$$\text{COP}_{\text{act}} = \frac{Q_{\text{add}}}{W_{\text{in}}} \Rightarrow W_{\text{in}} = \frac{Q_{\text{add}}}{\text{COP}_{\text{act}}} \Rightarrow \frac{29}{2.233}$$

$$[W_{\text{in}} = 12.98 \text{ kW}] \text{ Ans.}$$

Q. A cold storage plant is required to store 20 tonnes of fish is supplied at a temperature of  $30^\circ\text{C}$  the specific heat of fish above freezing point is  $2.93 \text{ kJ/kg K}$  which is maintained at  $-8^\circ\text{C}$  a freezing. The specific heat below freezing point is  $1.26 \text{ kJ/kg K}$ . The fish is stored in cold storage which is maintained at  $-8^\circ\text{C}$  the freezing point of fish is  $-4^\circ\text{C}$  the latent heat of fish is  $235 \text{ kJ/kg}$ . If the plant requires  $75 \text{ kW}$  to drive it find (i) The capacity of the plant and 2 time taken to achieve cooling assume actual COP of the plant as 0.3 of the Carnot COP?





$$\left\{ \text{COP}_{\text{ideal}} = \frac{T_1}{T_2 - T_1} \right\} \Rightarrow \frac{265}{303 - 265} = [6.97]$$

$$\text{COP}_{\text{act}} = 0.30 \times \text{COP}_{\text{ideal}} \Rightarrow 0.30 \times 6.97 \Rightarrow [\text{COP}_{\text{act}} = 2.09]$$

$$\{ Q_1 = m_i C_{p,i} \Delta T \} \Rightarrow 20 \times 10^3 \times 2.93 \times (30 - (-4)) = [1.99 \times 10^6]$$

$$\{ Q_2 = m_i h_{fg} \} \Rightarrow 20 \times 10^3 \times 235 = [0.101 \times 10^6]$$

$$\{ Q_3 = m_i C_{p,i} \Delta T \} \Rightarrow 20 \times 10^3 \times 1.26 (-4 - (-8)) = [4.7 \times 10^6]$$

$$\{ Q_{\text{remove}} = Q_1 + Q_2 + Q_3 \} \Rightarrow Q_{\text{remove}} = (1.99 + 0.101 + 4.7) \times 10^6 \text{ kJ}$$

$$\{ Q_{\text{remove}} = 6.793 \times 10^6 \text{ kJ} \} \text{ Ans.}$$

$$\left\{ \text{COP}_{\text{act}} = \frac{Q_{\text{remove}}}{W_{\text{in}}} \right\} \Rightarrow 2.09 = \frac{Q_{\text{remove}}}{W_{\text{in}}}$$

$$Q_{\text{remove}} = 2.09 \times 75 \times 10^3 \text{ W}$$

$$\{ Q_{\text{remove}} = 156.75 \text{ kJ/sec} \} \text{ Ans.}$$

$$\text{Time taken} = \frac{6.793 \times 10^6 \text{ kJ}}{156.75 \text{ kJ/sec}} \Rightarrow [43336.52 \text{ sec}]$$

$$43336.52 \div 3600$$

$$\{ \text{Time taken} = 12.037 \text{ hour} \} \text{ Ans.}$$

Q. (Nov-Dec 2022) The capacity of refrigerator is 250 TR. When working between  $-5^\circ\text{C}$  and  $25^\circ\text{C}$  determine the mass of ice produced per day from water at  $25^\circ\text{C}$



Also find the power required to drive the unit assume that the cycle operates on a reversible Carnot cycle and latent heat of ice is  $335 \text{ kJ/kg}$ ?

Sol given  $LH_{ice} = 335 \text{ kJ/kg}$   
 $Cp_{water} = 4.18 \text{ kJ/kgK}$   
 $Cp_{ice} = 2.09 \text{ kJ/kgK}$   
 $RC = 250 \text{ TR}$

$Q_{TR} = 3.5167 \text{ kW}$   $RC = 250 \times 3.5167$

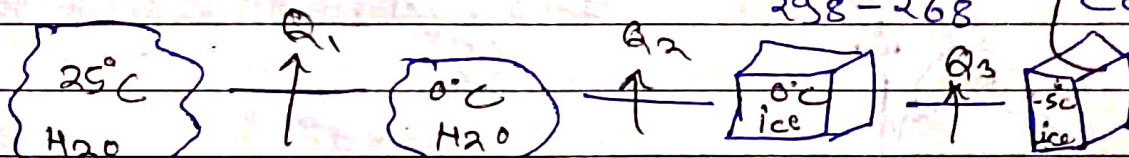
$RC = 879.175 \text{ kW}$  Ans.

$\left\{ \frac{COP}{Ref} = \frac{T_1}{T_2 - T_1} \right\}$

$COP_{Ref} = \frac{268}{298 - 268}$

$\left\{ \frac{COP}{Ref} = 8.933 \right\}$  Ans.

$\left\{ \dot{m}_i = 1 \text{ kg/sec} \right\}$   
Assume



$\left\{ Q_1 = \dot{m} C_{p_{water}} \Delta T \right\} \Rightarrow 1 \times 4.18 \times (25) \Rightarrow [Q_1 = 104.5 \text{ kJ/kg}]$

$\left\{ Q_2 = \dot{m} L_{H_{ice}} \right\} \Rightarrow 1 \times 335 \text{ kJ/kg} \Rightarrow [Q_2 = 335 \text{ kJ/kg}]$

$\left\{ Q_3 = \dot{m} C_{p_{ice}} \Delta T \right\} \Rightarrow 1 \times 2.09 \times (5) = [10.45 \text{ kJ/kg}]$

$\left\{ Q_A = Q_1 + Q_2 + Q_3 \right\} \Rightarrow Q_A = 104.5 + 335 + 10.45$   
 $[Q_A = 449.95 \text{ kJ/kg}]$  Ans.

$\left\{ \text{Time} = \frac{RC}{Q_A} \right\} = \frac{879.175 \text{ kW (or) kJ/sec}}{449.95 \text{ kJ/kg}}$

$[ \text{Time} = 1.95 \text{ kg/sec} ]$



but

24 hours. than

Sec. min. hour

$$\text{Time} = 1.95 \times 60 \times 60 \times 24$$

$$\text{Time} = 168480 \text{ kg/day}$$

$$\text{Time} = 168.48 \text{ Toner kg}$$

(can)

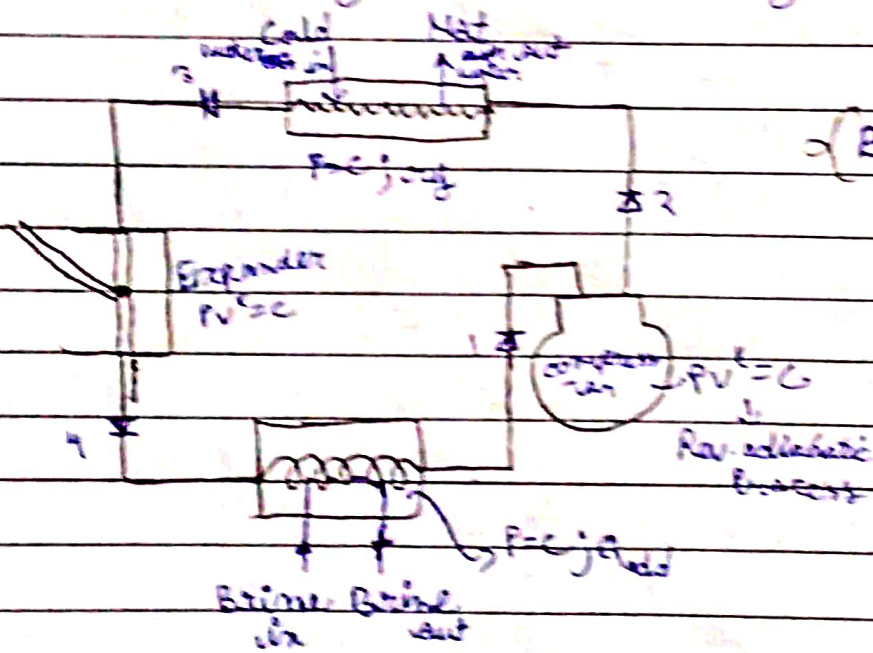


## \* Air refrigeration cycle:-

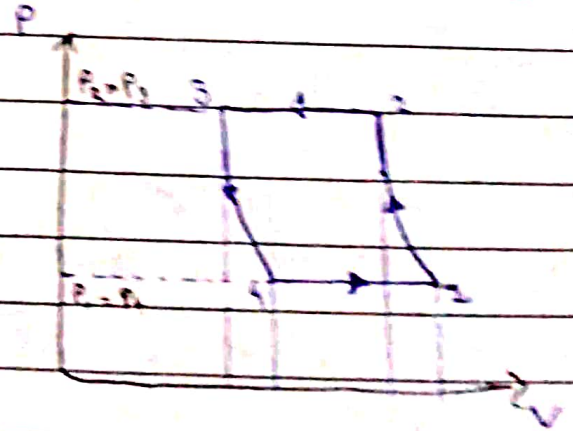
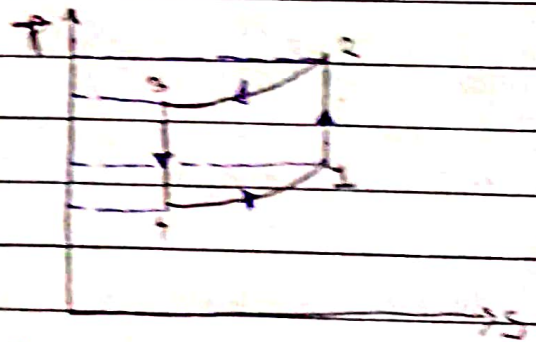
→ \* इस चक्र में चार्ज में प्रवेश करने से

## \* Bell-Coleman / Reversed / Brayton cycle / Joule cycle:-

- Compressor
- Heat exchanger (Condenser)
- Expander
- Refrigerating section / cooling Heat exchanger



{ Brine solution = Salt water }



→ Compressor:- 1-2:-

$$\left\{ W_c = \frac{P_1 V_1 - P_2 V_2}{(k-1)} \right\}$$

→ Heat exchanger:- 2-3:-

$$\left\{ Q_{rej} = m \cdot c_p [T_3 - T_2] \right\}$$



→ Expander :- 3-4 :-

$$\left\{ W_c = \frac{K}{K-1} [P_3 V_3 - P_4 V_4] \right\}$$

→ Refrigerating section :- 4-1 :-

$$\left\{ Q_{add} = m c_p [T_1 - T_4] \right\}$$

$$\therefore \left\{ COP = \frac{\text{Desired effect}}{\text{work input}} \right\} \quad \frac{m c_p [T_1 - T_4]}{m c_p [T_1 - T_4] + m c_p [T_3 - T_4]}$$

$$COP = \frac{Q_{add}}{W_c - W_E} \Rightarrow \frac{h_1 - h_4}{(h_2 - h_1) - (h_3 - h_4)}$$

∵ Air is used as refrigerant & Air acting as an Ideal gas  
 $\Rightarrow h = f(T)$

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

$$\Rightarrow \frac{T_1 - T_4}{T_2 - T_3 - T_1 + T_4}$$

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

$$\therefore \left\{ \frac{T_2}{T_1} = \left( \frac{P_2}{P_1} \right)^{\frac{K-1}{K}} = \frac{T_3}{T_4} \right\} \quad \text{Carnot eqn}$$

$$\left\{ \frac{T_2}{T_1} = \frac{T_3}{T_4} \right\} \quad \left\{ \frac{T_2}{T_3} = \frac{T_1}{T_4} \right\}$$

$$\left\{ \left( \frac{P_2}{P_1} \right)^{\frac{K-1}{K}} = \left( \frac{P_3}{P_4} \right)^{\frac{K-1}{K}} \right\} \quad \text{Pressure ratio}$$



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

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

$$\Rightarrow \text{COP} = \frac{1}{\frac{T_3}{T_4} - 1}$$

main formula

$$\text{COP} = \frac{1}{\gamma_P^{\frac{\gamma-1}{\gamma}} - 1}$$

→ comp<sup>o</sup> & Exp<sup>n</sup> both must be S=C process

\* relation between COP &  $\gamma_P$  :-

$$\text{COP} = \frac{1}{(\gamma_P)^{\frac{\gamma-1}{\gamma}} - 1}$$

$$\left[ \text{COP} \propto \frac{1}{(\gamma_P)} \right] \text{ condition } \gamma = \text{constant}$$

$$\text{COP} = \frac{1}{(\gamma_P)^{\frac{\gamma-1}{\gamma}} - 1}$$

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

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

If comp<sup>o</sup> & Expander follows:-  
polytrophic process  $PV^n = C$

$$\text{COP} = \frac{Q_{\text{add}}}{W_C - W_E}$$

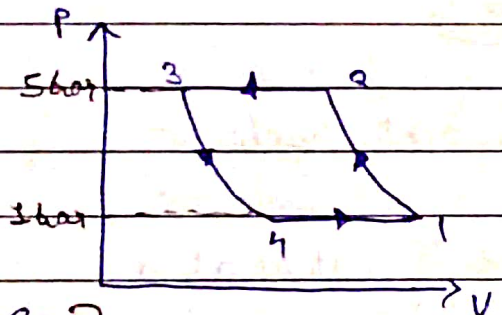
$$\left[ \text{COP} = \frac{n C_P (T_1 - T_4)}{\frac{n}{n-1} (P_1 V_1 - P_2 V_2) - \frac{n}{n-1} (P_3 V_3 - P_4 V_4)} \right]$$



Ans

Q. In a refrigeration plant working on Bell Coleman cycle air is compressed to 5 bar from 1 bar its initial temperature is  $10^{\circ}\text{C}$ . After compression the air is cooled up to  $20^{\circ}\text{C}$  in a cooler before expanding back to a pressure of 1 bar. Determine the theoretical COP of the plant and net refrigerating effect. Take  $C_p = 1.005 \text{ kJ/kg K}$  and  $C_v = 0.718 \text{ kJ/kg K}$ .

Sol,



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

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

$$C_p = 1.005 \text{ kJ/kg K}$$

$$C_v = 0.718 \text{ kJ/kg K}$$

$$\left\{ \gamma = \frac{C_p}{C_v} \right\} \Rightarrow \gamma = \frac{1.005}{0.718} \Rightarrow [\gamma = 1.40]$$

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

$$\left( \frac{5}{1} \right)^{\frac{0.40}{1.40}} = \frac{T_2}{283} \Rightarrow T_2 = 283 \times \left( \frac{5}{1} \right)^{\frac{0.40}{1.40}}$$

$$[T_2 = 448.22 \text{ K}] \text{ Ans.}$$

$\therefore$  In R.B.C. when comp<sup>n</sup> & Expansion takes place at S=C process

$$\left\{ \frac{T_2}{T_1} = \frac{T_3}{T_4} \right\} \quad T_4 = \frac{293}{448.22} \times 283$$

$$[T_4 = 184.99 \text{ K}] \text{ Ans}$$



$$\left\{ \text{COP} = \frac{1}{(\frac{P_2}{P_1})^{\frac{\gamma-1}{\gamma}} - 1} \right\} \Rightarrow \frac{1}{(5)^{\frac{1.4-1}{1.4}} - 1}$$

[COP = 1.713] Ans.

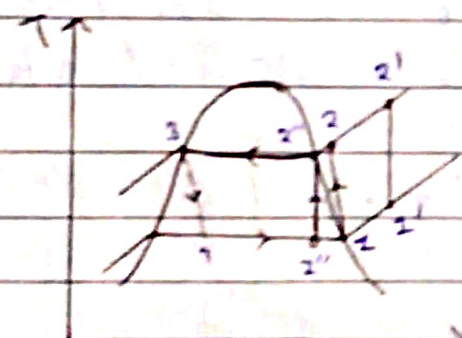
$$\{ RE = m C_p dT \} \Rightarrow m C_p [T_1 - T_4]$$

$$= 1 \times 1.005 \times [283 - 184.99]$$

[RE = 98.50 KJ/kg] Ans.

10/10/25

\* Vapour compression refrigerant cycle :-



$\Rightarrow 1-2$  :- Saturated  
 $\Rightarrow 1'-2'$  :- Superheated  
 $\Rightarrow 1''-2''$  :- Wet

:-  $W_{in} / RE / Q_{add} / Q_{rej} / \eta_{comp} / \text{COP} :-$

$\Rightarrow$  Saturated :-

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

$$Q_{add} = h_2 - h_4$$

$$RE = h_1 - h_4$$

$$Q_{rej} = h_2 - h_3$$

$$\left\{ C = \frac{V_e}{V_s} \right\}$$

$$\eta_{comp} = 1 + C - C \left( \frac{P_2}{P_1} \right)^{1/\eta_e}$$

$$\text{COP} = \frac{RE}{W_{in}}$$

$W_{in}$

$C$  = clearance ratio.

$\eta$  = Polytrophic index for expansion



W<sub>reg</sub> ↓ / RE ↓

$$\eta_{\text{comp}} = \text{same}$$

$$\text{COP} = \frac{\text{RE} \downarrow}{\text{W}_{\text{in}} \downarrow} \quad (\text{can't say})$$

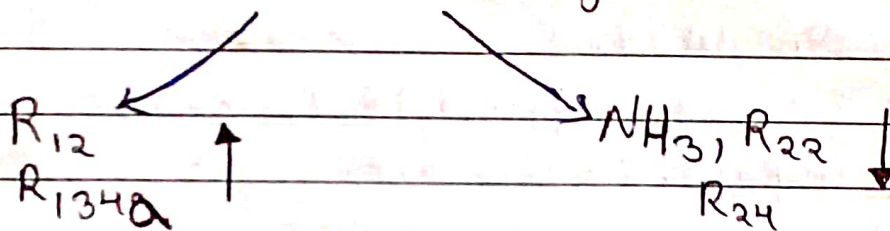
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⇒ superheated :-

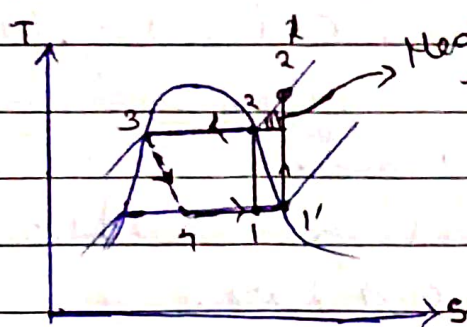
$$\begin{aligned} W_{\text{in}} &= h_2' - h_1' && \uparrow \\ Q_{\text{add}} &= h_1' - h_4 && \uparrow \\ \text{RE} &= h_1' - h_4 && \uparrow \\ Q_{\text{rej}} &= h_2' - h_3 && \downarrow \\ \eta_{\text{comp}} &= 1 + C - \left( \frac{P_2'}{P_1'} \right)^{1/\gamma_{\text{re}}} && (\text{same}) \\ \text{COP} &= \frac{\text{RE} \uparrow}{W_{\text{in}} \uparrow} \Rightarrow (\text{can't say}) \end{aligned}$$

\*\*\*\*\*

\* COP Depended on Refrigerant :-



\* Wet, & Dry, Superheated :-  
compression



1-2 ⇒ Wet compression  
1'-2' ⇒ Dry compression  
⇒ In actual refrigeration system, the compressor handles vapour only & hence this process is commonly referred to as Dry compression.

⇒ In wet compression both refrigeration effect & work input is less than as in dry compression hence the COP may be higher or lower compare to dry compression, depending on the refrigerant.



most imp.

Wet compression is not preferred in the reciprocating compression because:-

- (i) Liquid molecules of the refrigerant damage the valves of the compressor.
- (ii) Liquid molecules of the refrigerant wash away the lubricating oil hence resulting in wear & tear of compressor.

Generally, EOP is higher with wet compression hence whenever wet compression is used, rotary compressions are used.

NOTE:- Refrigerant supplied to the compressor must be superheated vapour refrigerant.

→ Reciprocating refrigerant compressor are very suitable for small displacement & high condensing pressure.

→ Centrifugal compressor require large displacement & low condensing pressure, hence use for large tonnage application (more than 200 TR).

NOTE:- Dry compression is preferred due to less change of damage to compare.

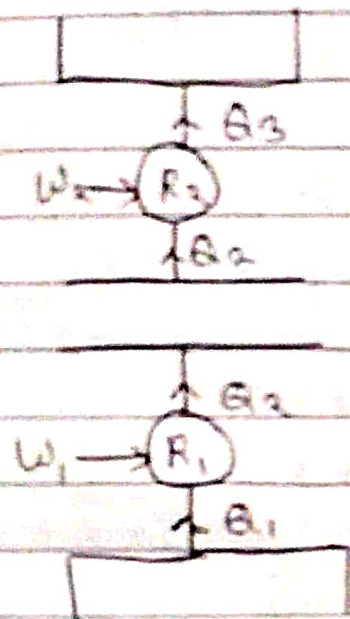
\* Cascade Refrigeration system:-

If the required refrigeration temp<sup>s</sup> are very low than the use of a single refrigeration cycle will result in very low evaporator pressure & hence high pressure ratio which will reduce the volumetric efficiency.



drastically.

To avoid this we use cascade refrigeration system.



cascade :-  $COP_2 = \frac{Q_1}{W_1}$

$COP_2 = \frac{Q_2}{W_2}$

$(COP)_{overall} = \frac{Q_1}{W_1 + W_2}$

(or)  $(COP)_{overall} = \frac{COP_1 COP_2}{1 + COP_1 + COP_2}$

\* NOTE :- The Cascade Refrigeration System uses two kinds of refrigerant making different B.P which runs through their own independent freezing cycle & are joined a heat exchanger this system is employed to obtain  $-40^\circ C$  to  $-80^\circ C$  or ultra low temp than these.

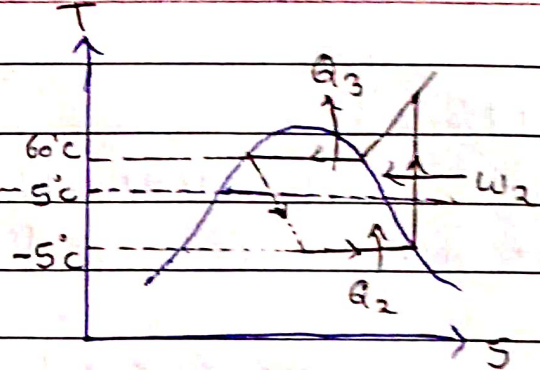
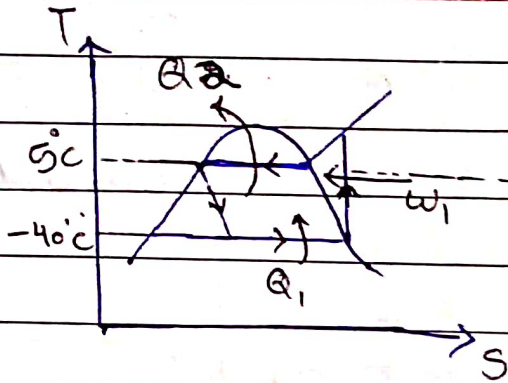
\* NOTE :- Mass flow rate in high stage compressor is smaller than that in low stage compressor.

In two stage Cascade system, the optimum cascade temp<sup>o</sup> at which  $COP$  will be max<sup>m</sup>

is :-  $\left[ \sqrt{T_{high} \times T_{lower}} \right]$  &  $T$  in Kelvin

$\left[ \sqrt{T_{high} \times T_{low}} \right]$





Q. Prove that  $COP = \frac{COP_1 \cdot COP_2}{1 + COP_1 + COP_2}$

Sol,  $COP = \frac{Q}{W_1 + W_2} \times \frac{W_1}{W_2}$   $1 + COP_1 + COP_2$

$$COP = COP_1 \times \frac{W_1}{W_1 + W_2}$$

$$\therefore COP_2 = \frac{Q_2}{W_2}$$

$$COP = COP_2 \times \frac{W_1}{W_1 + Q_2}$$

$$COP = COP_1 \cdot COP_2 \times \frac{W_1}{W_1 \cdot COP_2 + Q_2}$$

$$Q_2 = Q_1 + W_1$$

$$COP = COP_1 \cdot COP_2 \times \frac{W_1}{W_1 \cdot COP_2 + Q_1 + W_1}$$

Dividing by  $W_1$

$$COP = \frac{COP_1 \cdot COP_2}{COP_2 + COP_1 + 1}$$



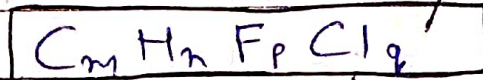
# Unit - 3

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\* Refrigerant (or) Freon (F) :-

Representation

\* Saturated refrigerant :-



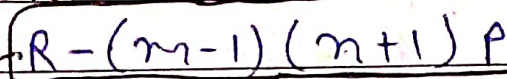
C = Carbon

H = Hydrogen

F = Fluorine

Cl = Chlorine

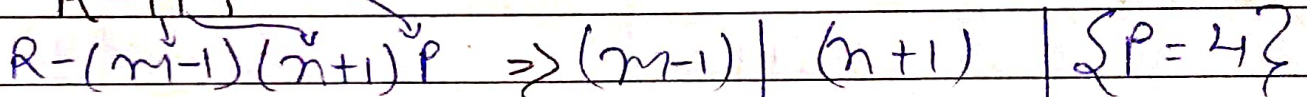
chemical formula



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

Relation b/w subscript

Ex:- R-114



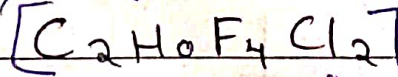
$$n+p+q = 2m+2$$

$$\{m=2\} \quad \{n=0\}$$

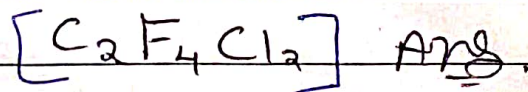
$$4+q = 2 \times 2 + 2$$

$$4+q = 6$$

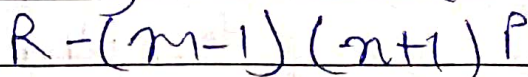
$$\Rightarrow q = 6 - 4 \quad [q=2]$$



H<sub>0</sub> is not chemical present in refrigerant.



\* Ex:- R-12 ; R-012



$$m=1 ; n=0 ; P=2$$

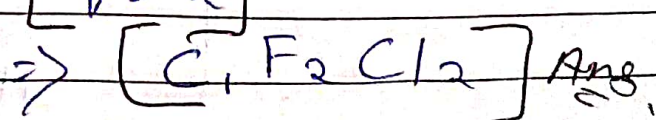
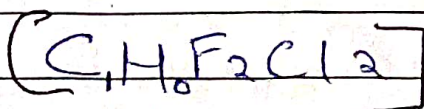
$$n+p+q = 2m+2$$

$$2+q = 2 \times 1 + 2$$

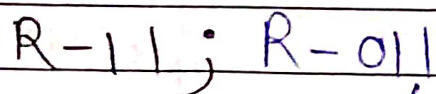
$$2+q = 4$$

$$\Rightarrow q = 4 - 2$$

$$[q=2]$$







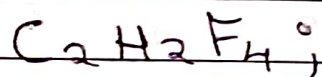
$$(m-1)(n+1)P$$

$m=1; n=0; P=1$   
 $m+p+q = 2m+2$

$$1+q = 2 \times 1 + 2 \Rightarrow 1+q = 4$$

$$q = 4 - 1$$

$$[q=3] \quad [C, F, Cl_3] \text{ Ans.}$$



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

$m=2; n=2; P=4$

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

$$2 \times 2 + 2 = 2 + 2 + q$$

$$6 = 4 + q \Rightarrow q = 6 - 4$$

$$[R-134] \quad [q=2]$$

Ans.

\* Symmetric and asymmetric nature:-

Symmetric nature

134

F

|



|

H

F

|

|

H

Asymmetric nature

134a

a = Asymmetric nature.

F

|



|

H

F

|

|

F



Representation

\*  $\Rightarrow$  Unsaturated refrigerant :-  $C_m H_n F_p Cl_q$   
 Relation b/w subscript  $R-1(m-1)(n+1)p$   
 $n+p+q = 2m$  chemical formula

Ex:  $C_2H_4$  ;  $m=2$  ;  $n=4$  ;  $p=0$   
 $n+p+q = 2m \Rightarrow 4+q = 2 \times 2$   
 $4+q = 4$

$$q = 4 - 4 \Rightarrow q = 0 \text{ Ans.}$$

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

$$R-1(2-1)(4+1)0$$

$$[R-1150] \text{ Ans.}$$

\* NOTE :- Maximum chlorine element compound leads to maximum Ozone potential Depletion (~~POPD~~)

$\rightarrow$  Free end group of refrigerants are - Halocarbon refrigerant.

\* Inorganic and Organic refrigerant :-

| Inorganic refrigerant                                                                                  | Organic refrigerant                                                              |
|--------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Formula.<br>$R-700 + (\text{Molecular mass})$                                                          | <div> <div>Saturated Hydrocarbon</div> <div>Unsaturated Hydrocarbon</div> </div> |
| $\Delta NH_3 = N = 7 \times 2 = 14$<br>$H = 1 \times 3 = 3$<br>$14 + 3 = 17$ <del>700 + 17 = 717</del> |                                                                                  |



700 + 17  $\Rightarrow$  R-717.

2)  $\text{CO}_2 = 12 + 32 = 44$   
700 + 44  $\Rightarrow$  R-744.

3)  $\text{H}_2\text{O} = 2 + 16 = 18$   
700 + 18  $\Rightarrow$  R-718.

4) Air = R - (700 + 29)  
R-729

R-22

R-22 refrigerant is better  
Used in refrigerant in  
R-12.

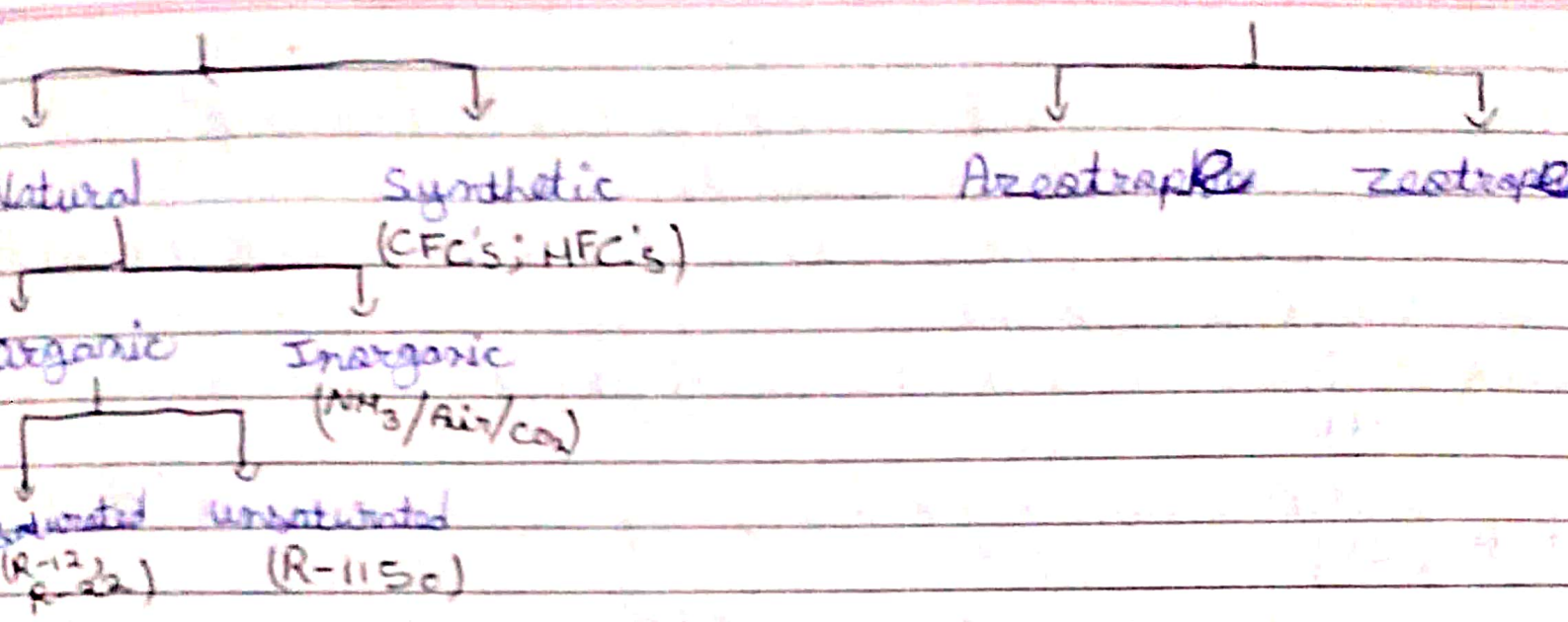
:- Advantage :- Freon as refrigerant  
 $\rightarrow$  Easy to run & maintain.  
 $\rightarrow$  Easier repair in case of failure.  
 $\rightarrow$  Relatively low investment cost.

:- Disadvantage :- Freon as refrigerant.  
 $\rightarrow$  Freon refrigerant has the negative effect on the environment.  
 $\rightarrow$  Lower COP than other refrigerant.

\* NOTE :- Moisture in Freon refrigeration system  
cause freezing of regulation Automatic valve

\* Refrigerant  
 Pure refrigerant      Mixture refrigerant





\* Azetropic refrigerant:- Mixture of refrigerant behaving as pure substance are known as Azetropic refrigerant.

Ex :- ex:- {R-502}

\* NOTE :- Use of non azetropic mixture used as the refrigerant in VCRS improve COP.

\* Zeotropic refrigerant:- Mixture of refrigerant almost behaving as azetropic is called Zeotropic refrigerant.

~~Ex:- R-12 is a zeotropic refrigerant which is mixed with R-115c~~

\* NOTE:- The chlorine element present in the refrigerant dissociates in presence of sunlight, the chlorine element reacts with the Ozone layer which is situated in stratosphere hence causing Ozone layer depletion.

Ozone layer filters have harmful ultraviolet rays



from reaching the earth surface hence depletion of Ozone layer is undesirable.

Therefore, we have replaced the refrigerant's containing element.

:- eg :- R-12 in domestic refrigerator has been replaced with R-134a.

R-22 in window A/c are replaced by R-410A ( $C_2Cl_2$ )  
[ $CHF_2Cl$ ]

ODP = Ozone Depletion Potential.

CFC = chloro fluoro carbon.

GWP = Global warming potential.

\* Refrigerant and it's uses :-

| <u>Refrigerant</u>  | <u>Uses</u>                                                                                  |
|---------------------|----------------------------------------------------------------------------------------------|
| 1) R-11             | ⇒ central A/c, large capacity centrifugal compressor.                                        |
| 2) R-12             | ⇒ Domestic refrigerator (Household refrigerator) reciprocating compressor of small capacity. |
| 3) R-22             | ⇒ window type A/c, reciprocating compressor of large capacity.                               |
| 4) $NH_3$ (Ammonia) | ⇒ cold storage, ice plant, large industries.                                                 |
| 5) Air              | ⇒ Air craft.                                                                                 |



- 6) Brine solution  $\Rightarrow$  Milk chilling plant.
- 7)  $\text{CO}_2$  (carbon dioxide)  $\Rightarrow$  Direct contact freezing of foods.
- 8)  $\text{H}_2\text{O}$  (water)  $\Rightarrow$  Li-Br absorption system.
- 9) R-134a  $\Rightarrow$  Domestic refrigerator.
- 10) R-113  $\Rightarrow$  A/C (Air conditioner).

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\* Primary refrigerant & Secondary refrigerant :-

Primary  $\Rightarrow$  The refrigerant which circulates through the refrigeration equipment is called Primary refrigerant.

Secondary  $\Rightarrow$  The refrigerants which absorb heat for the refrigerant space and rejected to the primary refrigerant is called secondary refrigerant.

:- Ex:- of secondary refrigerant.

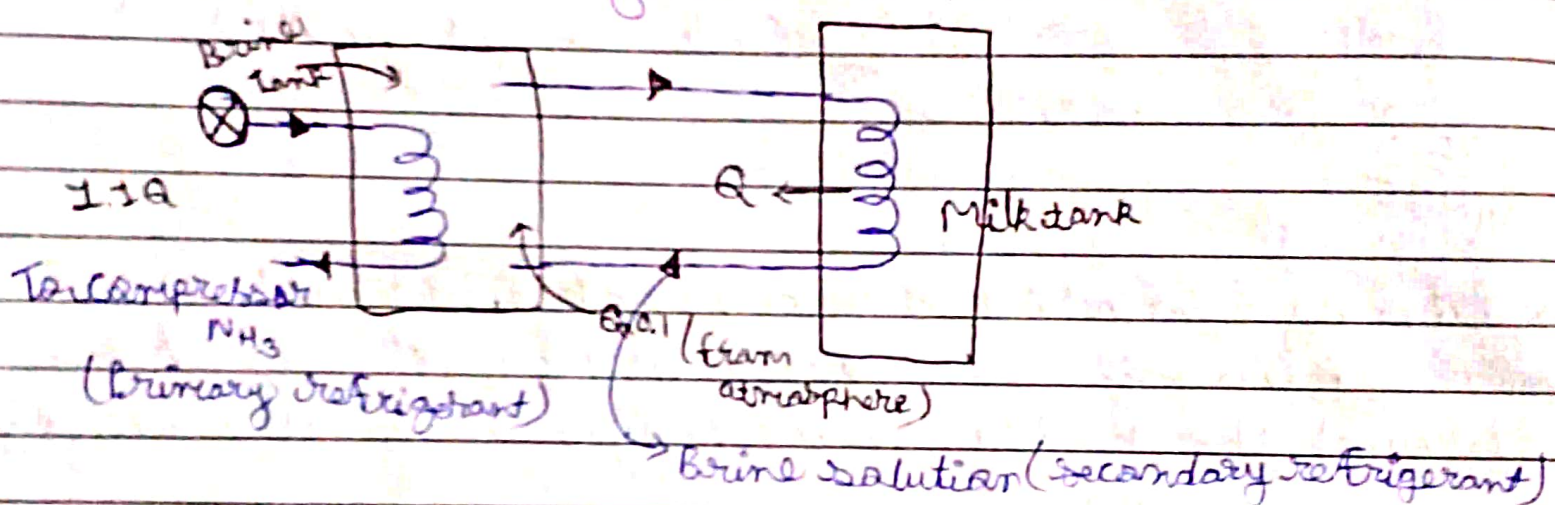
In air conditioner application Air acts as the secondary refrigerant where as the refrigerant which flows inside the Air conditioner system is called primary refrigerant. Similarly in milk chilling plant, Brine solution act as secondary refrigerant and Ammonia ( $\text{NH}_3$ ) act as primary refrigerant.

:- Importance of secondary refrigerant :-

The use of secondary refrigerant helps in reducing the refrigeration cost due to it.



- 1) Reduction in the cost associated with the amount of refrigerant in ~~the~~ circulation.
- 2) It is unable to use primary refrigerant with good thermodynamic properties.



∴ Actual heat removed is that heat which the primary refrigerant is removing, not 2<sup>nd</sup>ary refrigerant is 1.18

Properties of a refrigerant:-

1) Normal Boiling Point:- • The boiling point corresponding to 1 atm pressure is called the normal Boiling Point.

• It is desirable to keep the evaporator pressure slightly above atmospheric pressure to avoid air leaking inside the system. Air leaking in the system brings water vapour which freezes at low temperature & chokes the system, hence air entry is undesirable. [Critical temp. of water is among the highest in commonly used refrigerants]



Low normal boiling point refrigerant are preferred for the refrigeration purpose.

Low normal boiling point refrigerant are called high pressure refrigerants & high normal boiling point refrigerant are called low pressure refrigerant.

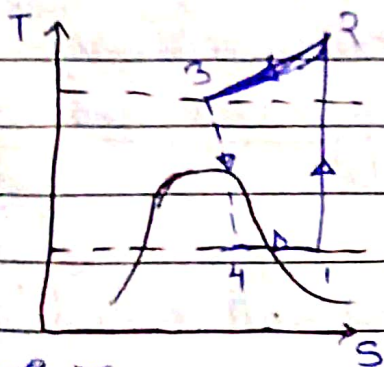
Low freezing point refrigerant are preferred.

\* Burging :- The process of removal of trapped air from the condensed is called burging.

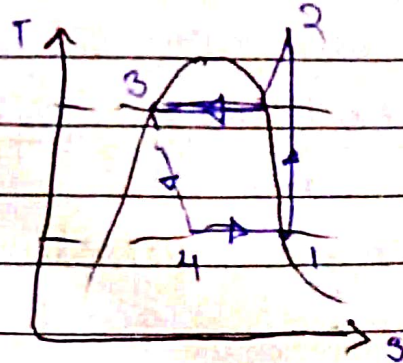
The air trapped in the condenser can be detected by the following :-

- 1) Increased condenser pressure.
- 2) Increased power consumption.
- 3) Increased temp. of cooling water.

3) Critical temperature :- Critical temp. is the highest temp. at which a substance can exist as liquid i.e. it cannot be turned into liquid by applying pressure above this temperature.



If  $T_{critical}$  is high



If  $T_{critical}$  is low.



$$\{R.C = \eta_i \times R.E\} \quad T_{cs} \downarrow \rightarrow \eta_i \uparrow \rightarrow V_{ol} \uparrow \rightarrow W_{s/p} \uparrow \rightarrow R.E \downarrow$$

$$\rightarrow C.O.P. \downarrow$$

- The Critical temp<sup>n</sup> of the refrigerant should be much higher than the required condensing temperature.
- The Critical temp<sup>n</sup> of  $CO_2$  & Ethylene is much lower than the ambient summer temp<sup>n</sup> in India hence they are not used as refrigerants.

\* Latent heat (or) specific heat :-  $\left[ \Delta h_{fg} \downarrow \rightarrow \eta_i \uparrow \right]$  ↗ Not desirable

- The latent heat of refrigerant should be high as it results in lower mass flow rates.

- The latent heat of ammonia is very high.

The specific heat of the liquid refrigerant should be low so that degree of subcooling will be large leading to smaller amount of flash gas at evaporator inlet.

\* Compressor Discharge temperature :-

The compressor discharge temp<sup>n</sup> should be low to avoid overheating of compressor. Ammonia ( $NH_3$ ) has high compressors are water cooled.

\* Freezing temperature :-

The refrigerant should have low freezing temperature.

Water has very high freezing temperature.



hence not used as refrigerant in most of the applications.  
Although it has high critical temp.

\* Viscosity :- The viscosity should be low to avoid viscous losses.

\* Toxicity & flammability :- should be non toxic & non flammable. Ammonia has good thermodynamic property but is not used as refrigerant in domestic application because of its toxic & flammable nature.

### Unit-3

<sup>most imp.</sup> \* Vapour Absorption Refrigeration system (VARS) :- (VAS) (or)  
→ VARS works on low grade energy (heat), hence the COP is less ( $0.3 \approx 0.5$ ). VCRS works on high grade energy hence the COP is higher.

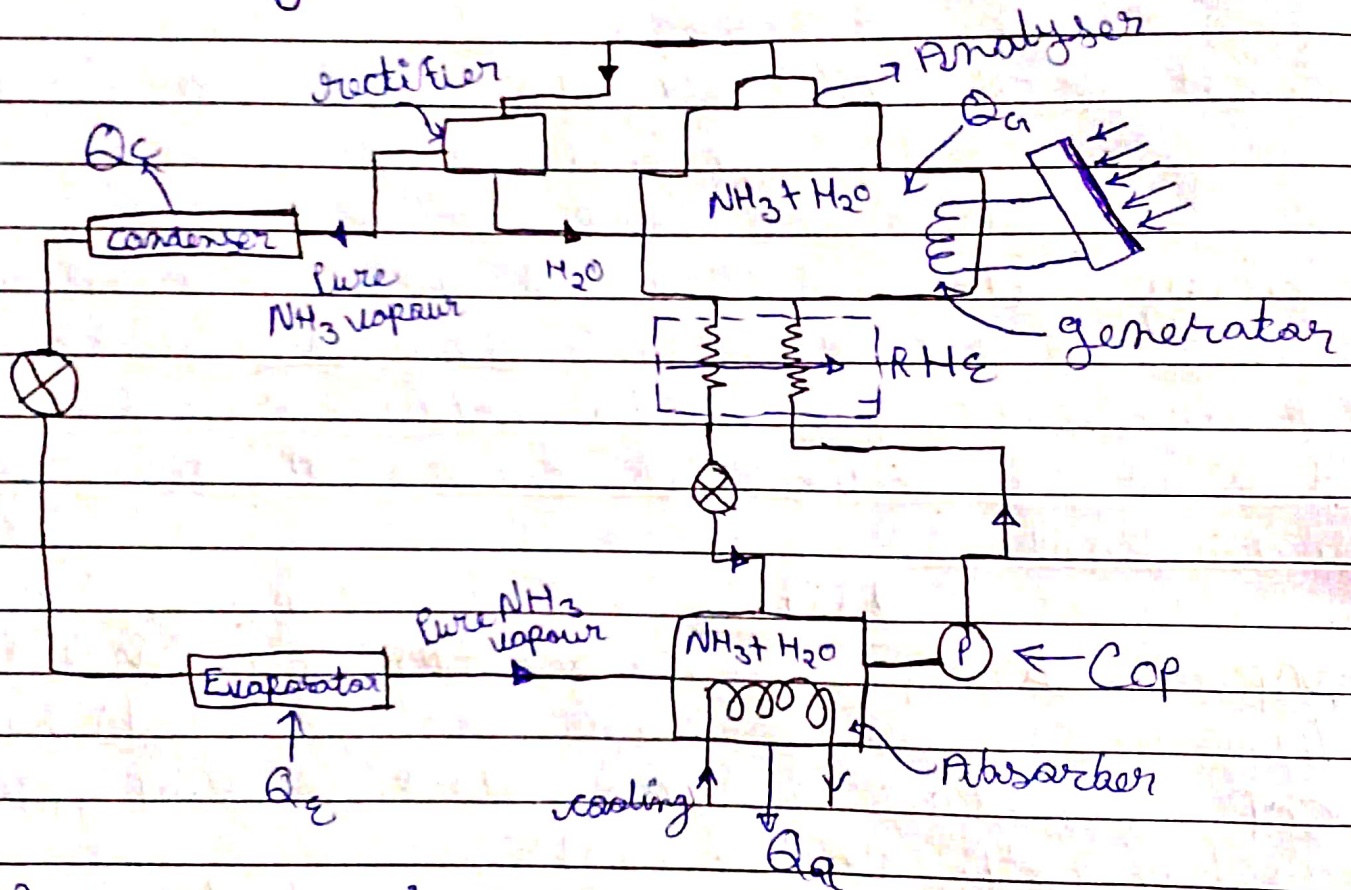
→ VARS is used when the cost of electricity is very high or large ammonia waste energy is available. Solar refrigeration system & geothermal refrigeration system is based on VARS. (VAS)

→ The most common VARS is ammonia-water system. here  $\text{NH}_3$  acts as refrigerant & water acts as absorbent.

→ Other common VARS are  $\text{H}_2\text{O} - \text{LiBr}$  &  $\text{H}_2\text{O} - \text{LiCl}$ . Here water acts as refrigerant. Hence the use of this is limited to A/C application only.



→ Heat is absorbed in generator & evaporator where as heat is rejected in condenser & absorber.



Pure Ammonia Vapour enters the absorber, where it gets absorbed in water. This is exothermic & lot of heat is released. The solubility of Ammonia is inversely proportional to the temp<sup>o</sup> of the solution hence cooling water is continuously circulated to maintain low temp<sup>o</sup> of the solution.

The solution rich in ammonia is pumped to generator where it is heated & ammonia separates from water forming high pressure ammonia vapours. Analyser helps in condensing the water vapours present with



ammonia. For complete removal of water vapour rectifier is installed.

→ Regenerative heat exchanger is used to exchange heat between the weak & rich solution. Regenerative hx improves the COP of the system.

$$COP = \frac{R/E}{W_{in}} = \frac{R/E}{E_{input}} \Rightarrow$$

$$COP = \frac{Q_E}{W_P + Q_G} \Rightarrow \text{Work Pump Negl.}$$

$$COP_{VAS} = \frac{Q_E}{Q_G} \Rightarrow \text{Work Pump} = \text{Negl.}$$

Q. In ammonia water absorption system, heat is supplied to generator by condensing steam at 0.2 MPa the initial state of the steam is at a dryness fraction of 0.8 & the final state of steam after condensing is saturated liquid the temp<sup>o</sup> to be maintained in the refrigerator is -10°C & the surrounding temp<sup>o</sup> is 30°C find:

- the max<sup>m</sup> COP of refrigerator.

② If the actual COP is 40% of max COP & the refrigeration load is 20 TR, what will be the required flow rate of steam. At 0.2 MPa;  $T_{sat} = 120.2^\circ\text{C}$ ;  $h_{fg} = 2201.9 \text{ kJ/kg}$

Sol, given,

generator 0.2 MPa,  $T_{sat} = 120.2^\circ\text{C}$

$h_{fg} = 2201.9 \text{ kJ/kg}$

$$T_{sat} = T_g \Rightarrow 120.2^\circ\text{C} + 273 = 393.2 \text{ K}$$

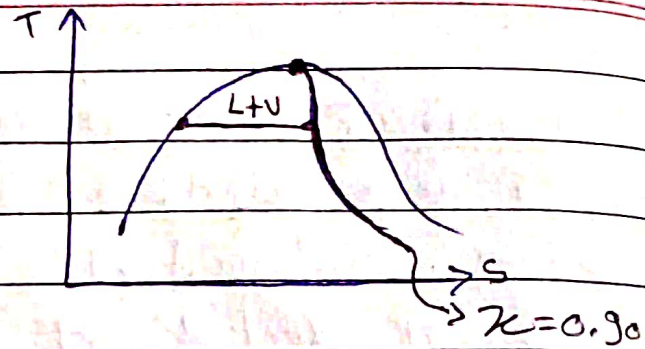


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$$T_a = T_c = T_o = 30^\circ\text{C} \Rightarrow 303\text{K}$$

$$T_e = T_{\text{ref}} = -10^\circ\text{C} \Rightarrow 263\text{K}$$



$$\left\{ \text{max}^m \text{COP} = \frac{Q_e}{Q_a} \right\}$$

$$\frac{Q_e}{Q_a} = \frac{T_a - T_o}{T_a} \times \frac{T_e}{T_o - T_e}$$

$$\Rightarrow \frac{393.2 \times 303}{393.2} \times \frac{263}{303 - 263}$$

$$[\text{COP}_{\text{max}} = 1.508] \text{ Ans.}$$

$$\left\{ \text{RC} = 20 \text{TR} \right\} \Rightarrow 20 \times 3.5167 \Rightarrow [70.334 \text{ kJ/sec}]$$

$$\left\{ 1 \text{TR} = 3.5167 \text{ kJ/sec} \right\}$$

$$\left\{ \text{COP}_{\text{act}} = 0.40 \times \text{COP}_{\text{max}} \right\}$$

$$[\text{COP}_{\text{act}} = 0.6032] \text{ Ans.}$$

$$\left\{ \text{COP}_{\text{act}} = \frac{Q_e}{Q_a} \right\}$$

$$\Rightarrow Q_a = \frac{Q_e}{\text{COP}_{\text{act}}}$$

$$Q_a = \frac{70.334}{0.6032}$$

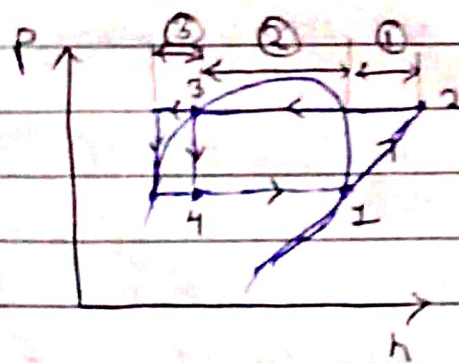
$$[Q_a = 116.60 \text{ kW}] \text{ Ans.}$$



\* **Condensers**:- The condenser is an important device used in the high pressure side of refrigeration system. Its function is to remove heat of the hot vapour refrigerant discharged from the compressor.

The heat from the hot vapour refrigerant in a condenser is removed first by transferring it to the walls of the condenser tubes and from the tubes to the condensing or cooling medium.

The selection of a condenser depends upon the capacity of the refrigerating system, the type of refrigerant used and the type of cooling medium available.



① = Desuperheating

② = condensation

③ = Subcooling

:- Factors Affecting the condenser capacity:-

The Heat transfer capacity of a condenser depend upon the following factors:-

① **Material**:- The size of a condenser of a given capacity can be varied by selecting the right material. It may be noted that higher the ability of a material to transfer heat, the smaller will size of condenser.

② **Area of contact**:- This can be done by varying the



Surface area of the condenser and the rate of flow of the condensing medium over the condenser surface.

(3) Temp<sup>d</sup> difference :- As the temp<sup>d</sup> difference increases the heat transfer rate increases the therefore the condenser capacity increases. Generally, this temp<sup>d</sup> difference cannot be controlled.

\* Heat Rejection factor :- (HRF) The Heat rejected in a condenser. The load on the condenser per unit refrigeration capacity is known as heat rejection factor. The load on the condenser  $Q_c$  is given by? formula.

$$HRF = \frac{\text{Load on condenser}}{(RC) \text{ Refrigeration capacity}}$$

where,

:- Load on condenser = RC + work done in compressor.

$$HRF = \frac{RC + \text{work done in compressor}}{RC}$$

$$\Rightarrow HRF = \frac{RC}{RC} + \frac{W_{in}}{RC} \Rightarrow 1 + \frac{W_{in}}{RC}$$

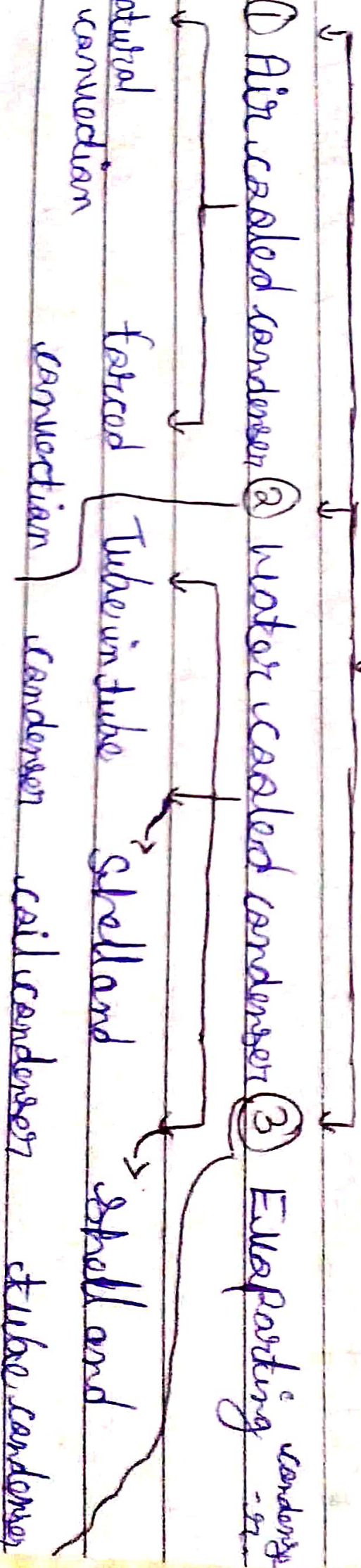
$$\frac{1 + \frac{1}{\frac{RC}{W_{in}}}}{\frac{RC}{W_{in}}} \Rightarrow \left[ HRF = 1 + \frac{1}{COP} \right] \text{ Heat SRF}$$



Unit - 2

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## \* Classification of Condensers :-





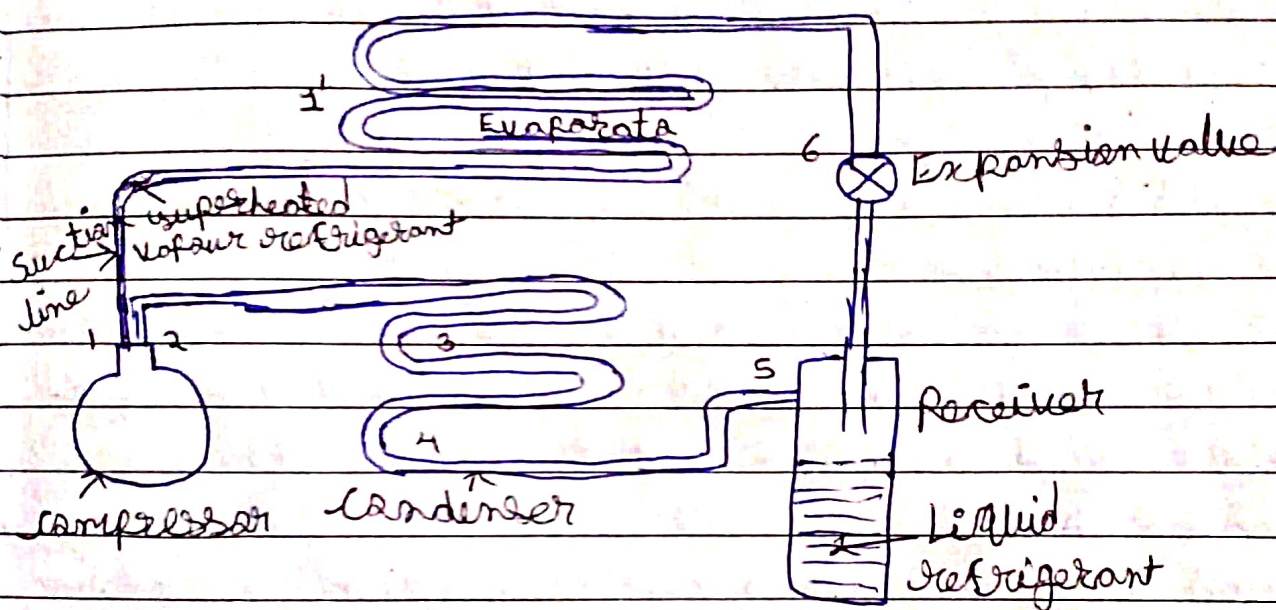
\* Evaporators:- The refrigerant at point 1 is still colder than the medium being cooled, therefore the vapour refrigerant continues to absorb heat.

This heat absorption causes an increase in the sensible heat (or temp<sup>s</sup>) of the vapour refrigerant. The vapour temperature continues to rise until the vapour reaches the evaporator to the suction line at point 1. At this point



## Unit-2

the temperature of the vapour is above the saturation temp<sup>o</sup> and the vapour refrigerant is superheated.



**\*NOTE:-** The heat absorbed by the refrigerant, while it is evaporating accounts for most of the cooling accomplished by the evaporator. In other words, the cooling is due to the evaporation of the refrigerant, rather than its increase in the refrigerant's sensible heat.

**% Capacity of an evaporator:-** The capacity of an evaporator is defined as the amount of heat absorbed by it over a given period of time. ~~The~~

$$Q = UA(T_2 - T_1) \quad \text{W (or) J/sec}$$

where,

$U$  = overall heat transfer coefficient in  $\text{W/m}^2 \text{ } ^\circ\text{C}$

$A$  = Area of evaporator surface in  $\text{m}^2$ .



$T_2$  = Temp<sup>o</sup> of medium to be cooled (or) temp<sup>o</sup> outside the evaporator) °C

$T_1$  = Saturation temp<sup>o</sup> of refrigerant at Evaporator Pressure (or) temp<sup>o</sup> inside the evaporator) °C.

:- Factors Affecting the Heat transfer capacity of an Evaporator :-

1) Material :- The material used for the construction of an evaporator coil should be a good conductor of heat. Metal does not conduct heat, therefore they are always used for evaporators. Iron and steel can be used with all common refrigerants. Aluminium should not be used with Freon.

2) Temperature difference :- It may be noted that a too low temp<sup>o</sup> difference (below 2°C) may cause slime on certain products such as meat & poultry. A too high temp<sup>o</sup> difference causes excessive dehydration.

3) Velocity of refrigerant :- Velocity of refrigerant flowing through the evaporator increases, the overall heat transfer coefficient also increases. Increased velocity will cause greater pressure loss in the evaporator. Only recommended velocities for different refrigerants which give high heat transfer and allowable



pressure loss should be used.

1) Thickness of the evaporator coil wall:- Thickness of the evaporator coil wall also affects the heat transfer capacity of the evaporator. The thicker the wall is, the rate of heat transfer. Thickness has only a slight effect on total heat transfer capacity because the evaporators are usually made from highly conductive material.

2) Contact surface area:- Surface available b/w the walls of evaporator coil and the medium being cooled. The amount of contact surface is, in turn, depends basically on physical size and shape of the evaporator coil.

\* Heat transfer During Boiling:- The boiling occurs in the following two ~~ways~~ ways:-

- 1) Pool boiling.
- 2) Flow boiling or forced convection boiling.

• Pool boiling:- A necessary condition for the occurrence of pool boiling is that the temp<sup>s</sup> of the heating surface exceeds the saturation temp<sup>s</sup> of liquid.

• Flow boiling (or) forced convection boiling:- Occurs in a flowing stream and the boiling surface may itself be a portion of the flow passage.



:- Types of Evaporators:-

1) A/c to the type of construction:-

- (a) Bare tube coil evaporator,
- (b) Finned tube evaporator,
- (c) Plate evaporator,
- (d) Shell and tube evaporator,
- (e) Shell and coil evaporator,
- (f) Tube-in Tube evaporator

2) A/c to the manner in which liquid refrigerant is fed

- (a) flooded evaporator,
- (b) Dry ~~connection~~ <sup>expansion</sup> evaporator,

3) A/c to the mode of heat transfer:-

- (a) Natural convection evaporator,
- (b) forced convection evaporator,

4) A/c to a Refracting condition:-

- (a) frosting evaporator
- (b) Non-frosting evaporator
- (c) Defrosting evaporator.

~~Def~~



Unit - 4Psychrometry

\* Psychrometry:- It is the study of mixture of dry air and water vapour.

$$\text{Moist air} = \text{Dry air} + \text{water vapour}$$

# Dalton's law of partial pressure:-

It's states that the total pressure of the mixture of non reacting gas is the sum of the partial pressure of the individual gases.

$$\left\{ \begin{array}{l} \text{Total Pressure} = \sum P_{\text{mix}} \\ \text{(or)} P_1 + P_2 + P_3 + \dots \end{array} \right.$$

Where,  $P_1, P_2, P_3$  are the components of gases present in it.

\* NOTE:- Assumption  $\Rightarrow$  gases are Ideal and Non-reacting.

\* Partial pressure:- It is the pressure exerted on the surface when a given substance is Indivisible kept in the container at same temperature as that ~~partial pressure is~~ when all the particles kept in the container. Partial pressure is depended on the number of molecules.

\* Vapour pressure:- It is the pressure exerted by the vapour on a liquid surface when



Vapours are in equilibrium in liquid.

It is the function of internal energy of liquid and temperature of liquid.

\*

Atmospheric Air

Dry air  $\rightarrow O_2, N_2, CO_2$

water vapour

Atm. air / moist air = mix of dry air & water vapour

Atm air

$$m = m_a + m_v$$

$$P = P_a + P_v$$

$$T = T_a = T_v$$

$m$  = mass of moist air / atm air

$m_a$  = mass of dry air.

$m_v$  = mass of water vapour.

$P$  = Partial Pressure of moist air / atm

$P_a$  = Partial Pressure of dry air.

$P_v$  = Partial Pressure of water vapour.

central volume  $\Rightarrow (v=c)$   $T = T_a = T_b = \text{Temp}^\circ$  of atm air / moist air.

$$V = V_a = V_v$$

\* Specific Humidity / moisture content / Humidity ratio / vapour density :- ( $W$ ) :- specific

Humidity is the mass of water vapour present in per kg of dry air in a given moist air.

:- range :- <sup>min</sup> 5 - <sup>max</sup> 20 gm / kg of dry air.  $\left\{ W = \frac{m_v}{m_a} \right\}$



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:- Unit :-  $\frac{\text{kg of dry air}}{\text{kg}}$  /  $\frac{\text{kg of water vapour}}{\text{kg of dry air}}$

formula

$$W = 0.620 \frac{P_v - P_a}{P_a}$$

\* 10%

$$W = f(P_v)$$

partial pressure of water vapour

W is the linear function of partial pressure

partial pressure of water vapour

$$W = 0.622 \frac{P_v}{P_a - P_v}$$

$$P_t = P_a + P_v$$

\* Relative Humidity (RH):- It is defined as the ratio of partial pressure of water vapour in unsaturated air to the partial pressure of water vapour when this air is got saturated at same temperature. It is represented by  $\phi$ .

:- Unit of RH = % (Percentage)

✓ :- At saturation condition  $\Rightarrow \{RH = 100\}$

$$RH = \frac{P_v}{P_{v/sat}}$$

:- At unsaturation condition  $\Rightarrow 0 < RH < 100\%$

$$\phi = \frac{P_v}{P_{v/sat}}$$

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\* Dry bulb temperature (DBT):- It is the temperature of the air measured by an ordinary thermometer.

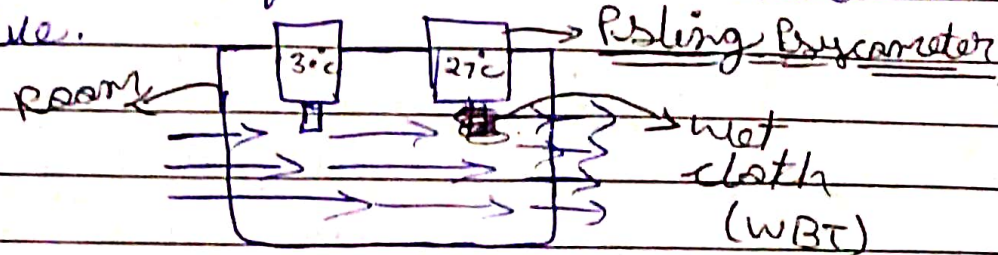
\* Wet bulb temperature (WBT):- Wet Bulb Temp



Summer =  $30^{\circ}\text{C} - 40^{\circ}\text{C} = \text{RH}/\text{min} \times (100)(\%)$   
Winter =  $30^{\circ}\text{C} - 40^{\circ}\text{C} > \text{RH} > 50\%.$

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is the temperature of a wet cloth measured by thermometer when equilibrium condition are achieved.



Wet Bulb temp<sup>o</sup> is the min<sup>m</sup> temp<sup>o</sup> up to which :-

- 1) Water can be cooled in an Earthen pot (HEKA, ghada).
- 2) Water can be cooled in cooling tower.
- 3) Air can be cooled in Desert cooler (घर का cooler/ यकस वाला).

\* Dew bulb temperature / Dew Point temperature :-

(DPT) :- It is the temp<sup>o</sup> up to which the air should be cooled so that the water vapour in the air start condensing (cooled at pressure is equal to constant (P=c)).

It can be understood as the temp<sup>o</sup> at which the partial pressure of water vapour become saturation than only become said that Dew Point temp<sup>o</sup> (DPT) is reached.

\* NOTE :- fog change will occur and Dew Point temperature.

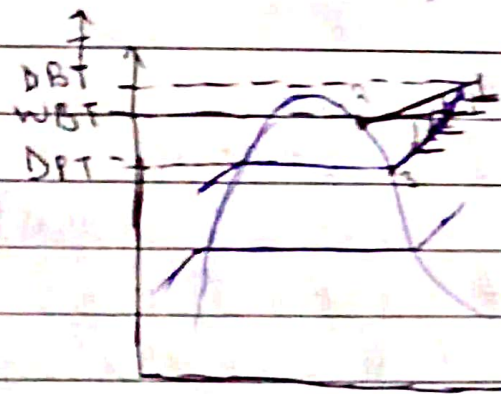


\* Wet Bulb Depression (or) Dry Bulb Depression:-  
Difference of DBT & WBT is known as (WBD).

$$WBD = DBT - WBT$$

This will depend / RH (Relative Humidity) In Directly.

- For RH = 100; WBD tends to min<sup>m</sup>.
- For RH = 0; WBD tends to max<sup>m</sup> (WBD  $\rightarrow$  zero).



$$DBT > WBT > DPT$$

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| Saturated Air                                                                            | Unsaturated Air                                                                                                      |
|------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>• RH = 100%</li> <li>• DBT = WBT = DPT</li> </ul> | <ul style="list-style-type: none"> <li>• <math>0 &lt; RH &lt; 100</math></li> <li>• DBT &gt; WBT &gt; DPT</li> </ul> |
| $WBD = 0$                                                                                | $WBD \neq 0$                                                                                                         |

\* Absolute Humidity:- The Mass of water vapour Present in  $1m^3$  of Dry air is known as Absolute Humidity.

\* Degree of saturation / ~~Percentage~~ Percentage Humidity:- (u):- It is the ratio of specific Humidity under unsaturated condition to the specific Humidity under saturated condition. It is denoted by (u).



$$\{\phi = RH\}$$

SH = Sensible Heat

LH = Latent Heat

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formula.

$$\left\{ u = \frac{w}{w_{sat}} \right\} \quad \left\{ u = \frac{\phi \times P - P_{v/sat}}{P - P_v} \right\}$$

$$u \approx \phi$$

∴ Physical meaning of Degree of saturation :-

It is the ratio of actual mass of water vapour in a unit mass of dry air to the mass of water vapour in the same mass of dry air when it is saturated at same temp<sup>o</sup> and pressure.

\* Enthalpy (H) :-

$$\left\{ \frac{m_v}{m_a} = w \right\} = m_a h_a + m_v h_v$$

$$= m_a \left[ h_a + \frac{m_v}{m_a} \cdot h_v \right]$$

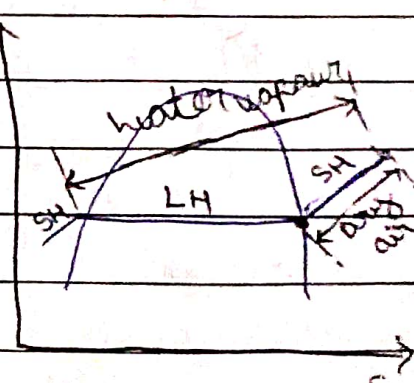
$$H_{mixture} = m_a [h_a + w \cdot h_v]$$

$$H = m_a [1.005 dt_a + w \times 1.88 dt_v]$$

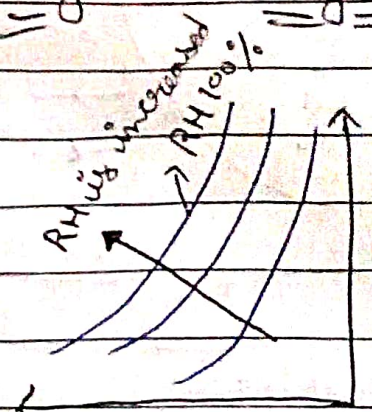
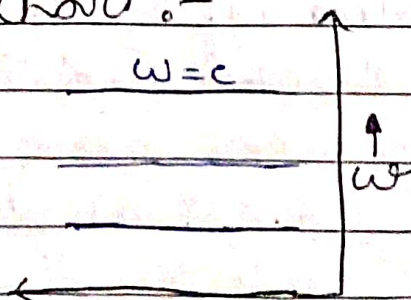
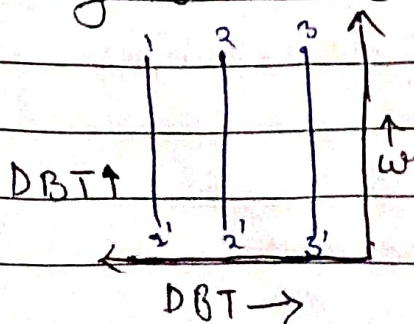
and

$$h = 1.005 dt + w [2500 + 1.88 t]$$

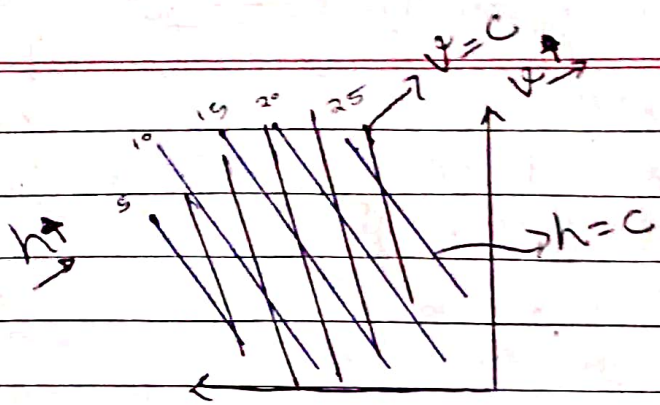
unit.  
KJ/Kg for dry air



\* Psychrometric chart :-





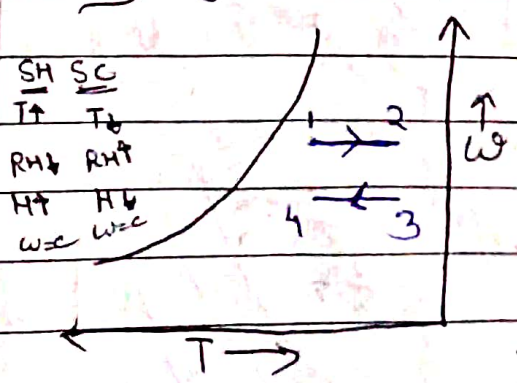


Slope of  $w$  & slope of  $h$  are different.

**\* NOTE :- WBT :-** There is a slight difference at constant WBT line and constant Enthalpy line but for all practical application these lines are taken as same at the psychrometric chart.

- :- Psychrometric Process :-**
- 1) Sensible Heating & sensible cooling.
  - 2) Humidification & dehumidification.
  - 3) Heating & Humidification.
  - 4) cooling & Humidification.
  - 5) cooling & dehumidification.
  - 6) Heating & dehumidification.

**1) Sensible Heating & sensible cooling :-**



The Heating (or) cooling of air without changing specific humidity is known as sensible Heating & sensible cooling.

$W=C$   
sensible

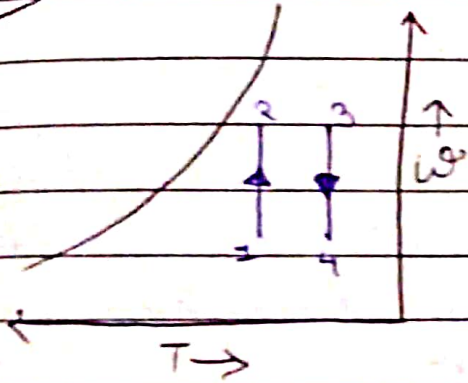
- 1-2 :- Sensible heating  
3-4 :- Sensible cooling



:- application :- 1) sensible heating take place in electric room heater.

2) sensible cooling take place in air conditioners.

3) Humidification & dehumidification :-



$\Rightarrow$  Humidification is the process of increasing the amount of water vapour in the air under constant temperature.

$\Rightarrow$  humidification is used to make the dry air more comfortable.

1-2 :- humidification :- method :- 1) Misting system

3-4 :- Dehumidification 2) Steam vaporizers.

\* Dehumidification :- The process of reducing the amount of water vapour in the air under constant temperature.

$\Rightarrow$  This process is generally use in Hot & Humid climate.

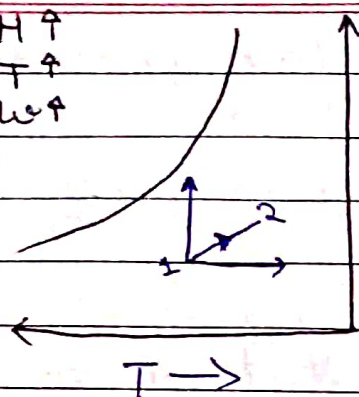
:- method :- 1) Refrigerants 2) Desiccants.

\* NOTE :- Partially Humidification and Dehumidification can not occur at constant temperature.

3) Heating and Humidification :- It is a process in which simultaneously increase both temp<sup>o</sup> (DBT) and amount of water vapour (Humidity ratio) in the air.



H ↑  
T ↑  
w ↑



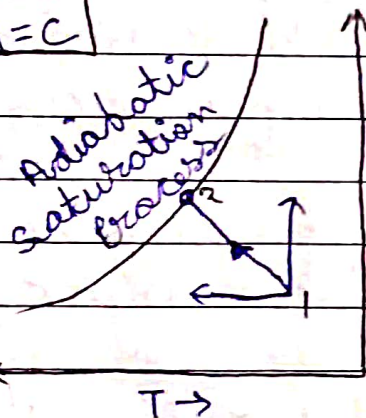
⇒ This process is seen in winter air conditioning Equipment.

Method :- Adding steam with higher temp.

RH (can't say) ↑ (or) ↓ Depend on temp of steam adding.

4) Cooling and Humidification :- It is a process that simultaneously decrease air temp and increase its moisture content by passing the air over a water spray.

$h = c$



⇒ cooling & Humidification process is also known Evaporative cooling.

⇒ Desert cooler undergoes cooling & Humidification process.

⇒ This process is an example of adiabatic saturation process. during adiabatic saturation Enthalpy and WBT of air.

\* NOTE :- Thermodynamic Wet Bulb temp ( $T_{WBT}$ ) :- The temp corresponding to the line where Adiabatic saturation line intersects the saturation curve is called thermodynamic wet Bulb temp (or) Adiabatic saturation temp ( $T_{WBT}$ ).

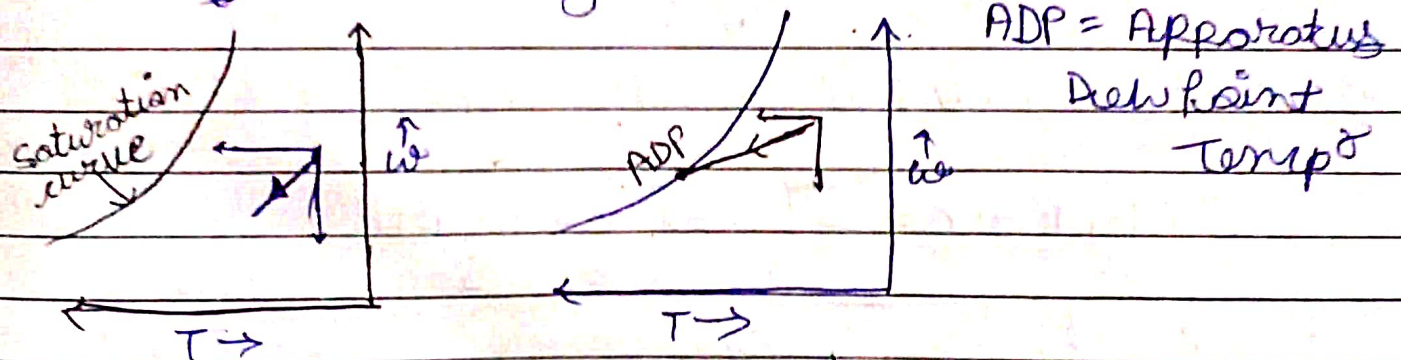


| Summer | Winter |                                                                                        |
|--------|--------|----------------------------------------------------------------------------------------|
| DBT    | DBT    | $T \uparrow \rightarrow P_v \uparrow \rightarrow W \uparrow \rightarrow RH \downarrow$ |
| $W$    | $W$    | $RH \propto \frac{1}{W}$                                                               |
| RH     | RH     |                                                                                        |

5) Cooling & Dehumidification:- It is a process of sensible cooling the air while insulating it, thereby removing the moist from it.

⇒ These process takes place when the temp<sup>o</sup> of coil is less than Dew point temperature of air.

⇒ These process is followed in summer air conditioning.

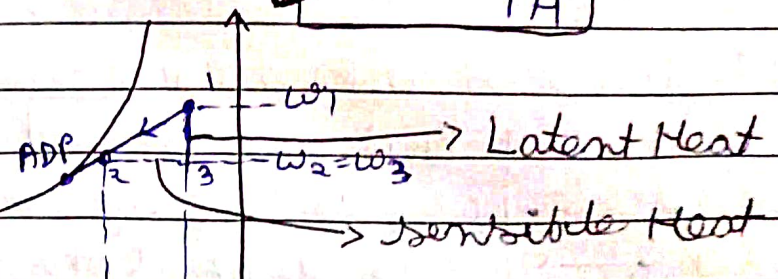


:- Sensible Heat Factor (SHF) :-  $SHF = \frac{SH}{TH}$

SH → Temp<sup>o</sup> change

LH → Phase change

$W_2 < W_3$  Dehumidification



Total Heat = SH + LH

:- Latent Heat Factor (LHF)

$$LHF = \frac{LH}{TH}$$

Derive  $TH = h_1 - h_3 + h_3 - h_2$

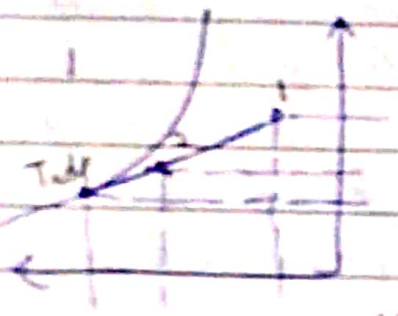
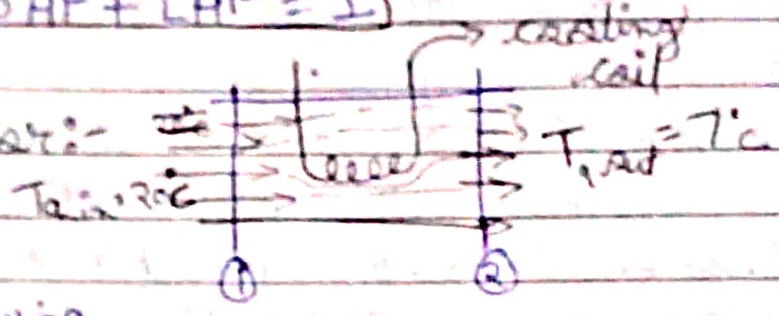
$$TH = h_1 - h_2$$



Sensible heat factor is the ratio of sensible heat to the total heat.

$$SHF + LHF = 1$$

\* By Pass factor:-



$$BPF = \frac{t_{a2} - t_{co}}{t_{a1} - t_{co}} = \frac{h_2 - h_{co}}{h_1 - h_{co}} = \frac{W_2 - W_{co}}{W_1 - W_{co}}$$

$$\% \text{ heating } BPF = \frac{t_{a2} - t_2}{t_1 - t_2}$$

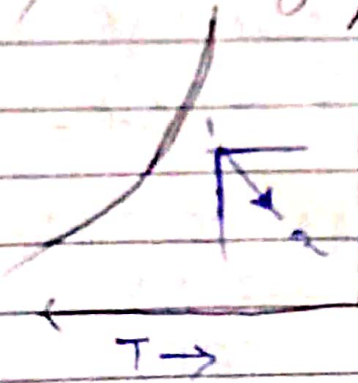
\* Contact ratio (X) / coil efficiency ( $\eta$ ):-

$$BPF + X = 1 \Rightarrow X = 1 - BPF$$

$$X = 1 - \frac{t_2 - t_{co}}{t_1 - t_{co}}$$

$$X = \frac{t_1 - t_2}{t_1 - t_{co}}$$

6) Heating & dehumidification:- The act of removing

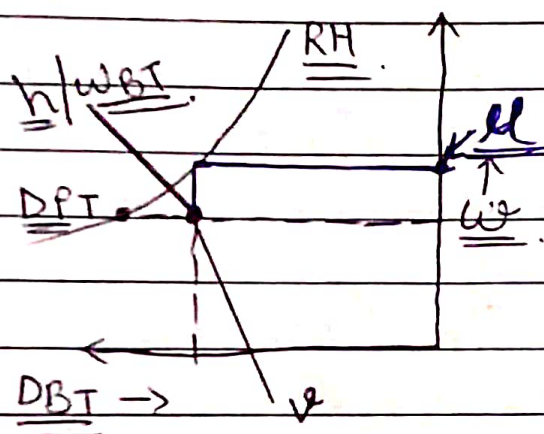


moist water vapour from the air while increasing its DBT. This process is known as Heating & dehumidification. These processes are also known as Adiabatic chemical dehumidification process.



⇒ Aluminium and silica gel like chemicals are generally used for this type of process.

\* Main chart :- Psychrometric



The Psychrometric chart reading method.

Q. In winter air conditioning system  $100 \text{ m}^3$  of air per min at  $15^\circ\text{C}$  DBT  $80\%$  RH heated until its DBT is  $22^\circ\text{C}$  with constant specific humidity find the heat added to the air per min?

Sol, given  $V_{\text{air}} = 100 \text{ m}^3/\text{min}$

$$\omega_1 = \omega_2$$

DBT =  $15^\circ\text{C}$   $\Delta$  DBT =  $22^\circ\text{C}$  } Assume: graph Heating  
RH =  $80\%$  } & sensible heating.

\* Heat added to the air/min

$$h_1 = 37 \text{ kJ/kg}$$

$$h_2 = 45 \text{ kJ/kg}$$

$$Q = m_a (h_2 - h_1)$$

$$\left\{ \begin{array}{l} m_a = \frac{\text{Volume of air}}{\text{Sp. Volume of air}} \end{array} \right\} \begin{array}{l} \rightarrow \text{m}^3/\text{min} \\ \rightarrow \text{m}^3/\text{kg} \end{array} \rightarrow \text{kg/min}$$

$$m_a = \frac{100}{0.825}$$

$$m_a = 121.21 \text{ kg/min}$$

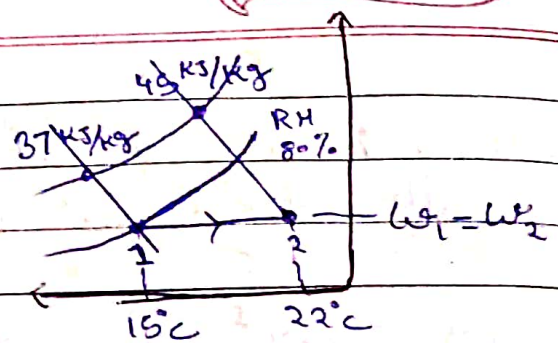
Ans.



$$Q = \dot{M}_a (h_2 - h_1)$$

$$Q = 121.21 (45 - 37)$$

$$[Q = 969.68 \text{ kJ/min}] \text{ Ans}$$

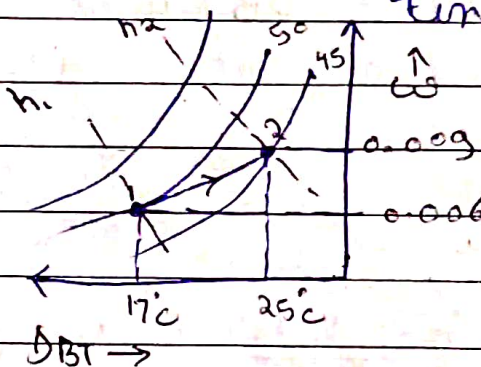


Q. Air is supplied to a condition room at  $17^\circ\text{C}$  DBT and  $50\%$  RH. The air leaves the room at  $25^\circ\text{C}$  DBT during which RH ~~is~~ decreased by  $5\%$ . Find 1) DPT of supply air 2) change in enthalpy during the process 3) change in vap. Humidity during process?

Sol,

Given Initial  $\Rightarrow 17^\circ\text{C}$  DBT &  $50\%$  RH

Final  $\Rightarrow 25^\circ\text{C}$  DBT &  $45\%$  RH



$$\text{DPT} \approx 6^\circ\text{C}$$

$$H = H_2 - H_1$$

$$H_1 = 33 \text{ kJ/kg}$$

$$H_2 = 48 \text{ kJ/kg}$$

$$H = H_2 - H_1 \Rightarrow 48 - 33$$

$$\Delta W = W_2 - W_1$$

$$0.009 - 0.006 \Rightarrow [W = 0.003 \text{ kg/kg da}] \text{ Ans}$$

$$[H = 15 \text{ kJ/kg}] \text{ Ans}$$

Q. Atmospheric air at DBT of  $16^\circ\text{C}$  and  $25\%$  RH passes through a humidifier is such way that final DBT is  $30^\circ\text{C}$  and RH is  $50\%$ . Find the heat added



to air 2) moisture added to air SHF of the process?

Sol, given

Air  
DBT =  $16^{\circ}\text{C}$  Humidification  $\longrightarrow$  DBT =  $30^{\circ}\text{C}$   
RH = 25% RH = 50%

①  $h_1 = 24 \text{ kJ/kg}$   
 $h_2 = 65 \text{ kJ/kg}$

$\{Q_{\text{add}} = h_2 - h_1\}$   
 $65 - 24 = \Rightarrow [Q_{\text{add}} = 41 \text{ kJ/kg}] \text{ Ans}$

②  $w_1 = 0.0029$

$w_2 = 0.0135$

Moisture added =  $\Delta w = w_2 - w_1$

$0.0135 - 0.0029$

$[\Delta w = 0.0106 \text{ kg/kg da}] \text{ Ans}$

③

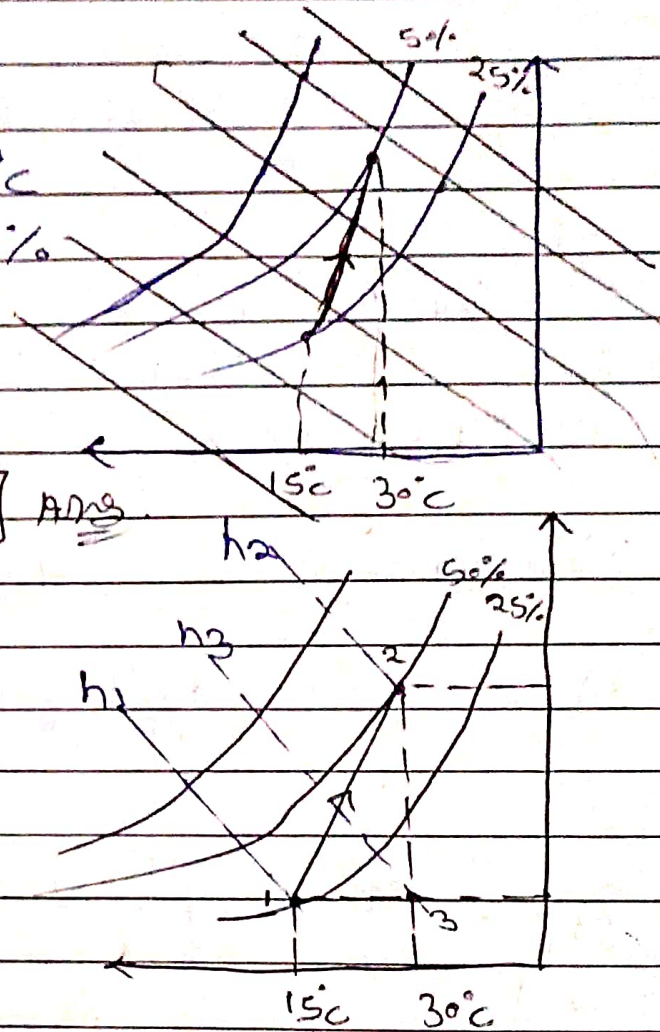
$\{SHF = \frac{SH}{TH}\}$

$h_3 = 37 \text{ kJ/kg}$   
 $\{SHF\} = \frac{h_3 - h_1}{h_2 - h_1} = \frac{37 - 24}{65 - 24} \Rightarrow [SHF = 0.317] \text{ Ans}$

Unitless quantity

$\{LHF + SHF = 1\} \Rightarrow LHF = 1 - 0.317$

$[LHF = 0.683] \text{ Ans}$





Ans. short data.

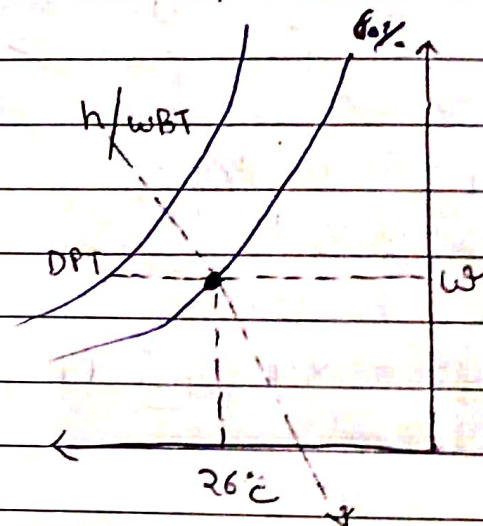
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Q. With the help of Psychrometric chart find the following properties of air, if air is at  $26^\circ\text{C}$  DBT and 60% RH find :- 1) DPT 2) WBT 3) sp. Volume of Air 4) Enthalpy of air 5) sp. Humidity of Air?

Sol,

Given DBT =  $26^\circ\text{C}$

RH = 60%



1) DPT =  $17.5^\circ\text{C}$  Ans

2) WBT =  $21^\circ\text{C}$  Ans

3)  $V = 0.86 \text{ m}^3/\text{kg}$  Ans

4)  $h = 58 \text{ kJ/kg}$  Ans

5)  $W = 0.0129 \text{ kg/kg da}$  Ans

✓

\*  
not  
Imp  
Point

Atmospheric Pressure = 760 mm of Hg (mercury)

$h = 760 \text{ mm}$

$P = 13600 \text{ kg/m}^3$  (or)  $13.6 \text{ kg/mm}^3$

$g = 9.81 \text{ m/s}^2$

$\Rightarrow 13.6 \times 1000 \times 9.81 \times 760$

$\Rightarrow [101396.16 \text{ Pa}]$  Ans

$\Rightarrow [101.396 \text{ kPa}]$  Ans

$\Rightarrow [1.013 \text{ bar}]$  Ans



\* Arrhenius's formula :- Use to find out partial pressure of water vapour. ( $P_v$ ).

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

$$t = \text{DBT } \left\{ \begin{array}{l} \text{centigrade} \\ \text{Fahrenheit} \end{array} \right.$$

$$t' = \text{WB T}$$

where,

$P_v$  = Partial pressure of water vapour.

$P$  = Atmospheric pressure / Barometric pressure.

$P_v'$  = Saturation pressure corresponding to WB T.

Find out from steam table.