Refrigeration & Air Conditioning

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5th Semester Diploma

Department of Mechanical Engineering

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CHAPTER-1

22/09/22 **Air Refrigeration Cycle**

Learning Resources

1) RAC by R.K. Rajput
2) RAC by R.S. Khurmi
3) RAC by C.P Arora
4) RAC by Arora and Domkundwar
5) RAC by P.L Ballaney

Definition of refrigeration :-

(i) Refrigeration is a process of removing heat from a substance under controlled conditions.

(ii) In air refrigeration cycle, air is used as working fluid absorbing heat from low temperature system and discharging the heat to a high temperature system which is done by air.

(iii) Since air doesn't change its phase, that is it remains gaseous throughout the cycle so, the heat carrying capacity per kg of air is very small as compare to vapour absorption system.

(iv) Air cycle refrigeration became obsolete because of low COP (coefficient of performance) and high operating cost and power requirement.

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(v) With the advancement in air flight and appling air conditioning system to the aeroplane so, now a days air refrigeration system continues to be favoured because of low weight and volume of equipment.

(vi) The basic elements of air refrigeration system are
(i) compressor
(ii) cooler or condenser
(iii) Expander
(iv) Evaporator

So, refrigeration means continuous extraction of heat from a body whose temperature is below the temperature of its surrounding.

(vii) the substance which works to extract heat from a cold body and deliver its to a hot body is called refrigerant.

(viii) Application :-

(a) Manufacture of ice.
(b) cooling storage chamber in which perish Food, drinks, medicines are stored.
(c) Rockets, air craft, submarine ship, domestic refrigerator etc.

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Unit of refrigeration :-

The unit of refrigeration is tonne of refrigeration.

Refrigeration unit is tonne

Imp: A tonne of refrigeration is defined as the amount of refrigeration effect produced by the the uniform melting of 1 tonne of ice from and at 0°C in 24 hours.

As latent heat of ice = 335 KJ/Kg

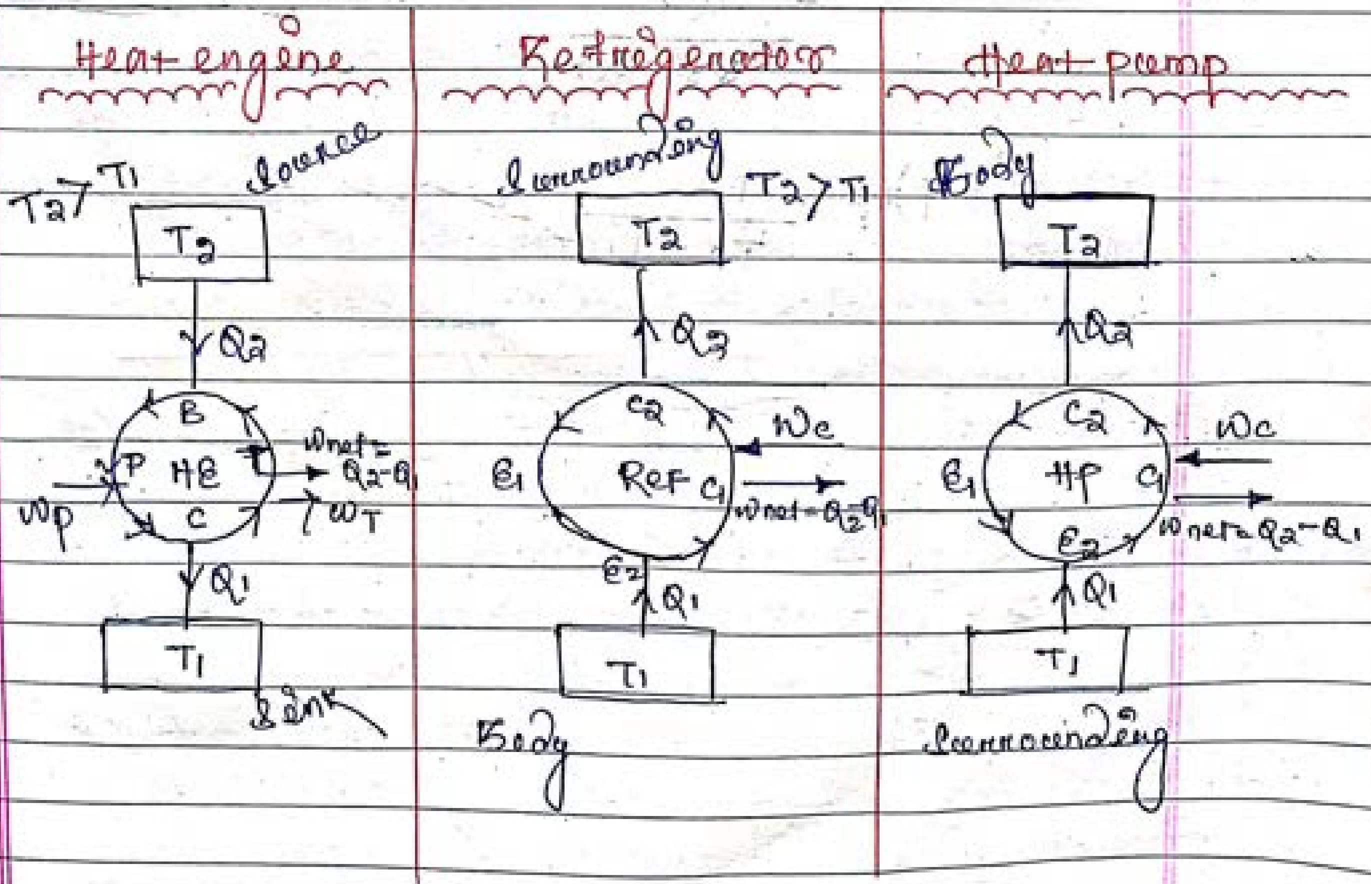
So, ∴ 1 tonne of refrigeration = 1000 × 335 KJ in 24 hrs.

$$= \frac{1000 \times 335}{24 \times 60}$$

∴ 1 tonne = 232.6 KJ/min

∴ 1 Tonne ≃ 210 KJ/min

1 TR ≃ 3.5 KJ/s



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Heat engine :-

B-T-C-P

imp

$$\eta_{HE} = \frac{W_{net}}{\text{Heat input}}$$

$$= \frac{W_T - W_P}{Q_2}$$

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

$$= \frac{T_2 - T_1}{T_2}$$

Refrigerator :- (Evaporator)

C1-C2-E1-E2

imp

$$(COP)_{REF} = \frac{RE}{W_{net}}$$

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

$$= \frac{T_1}{T_2 - T_1}$$

Body temp^r Higher than the surrounding

Heat pump :-

$$(COP)_{HP} = \frac{\text{Desired effect}}{W_{net}}$$

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

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

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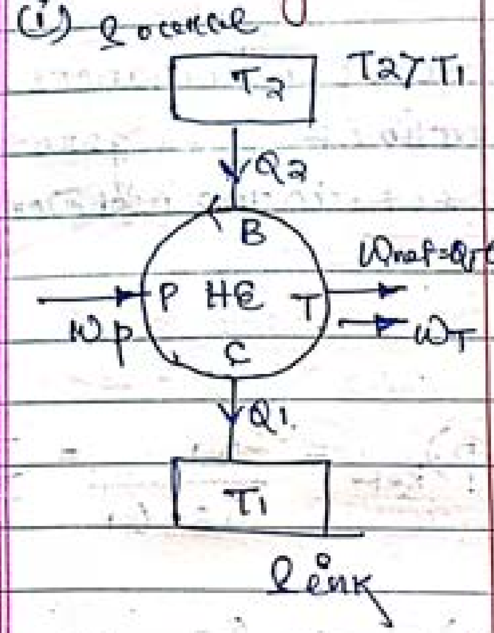
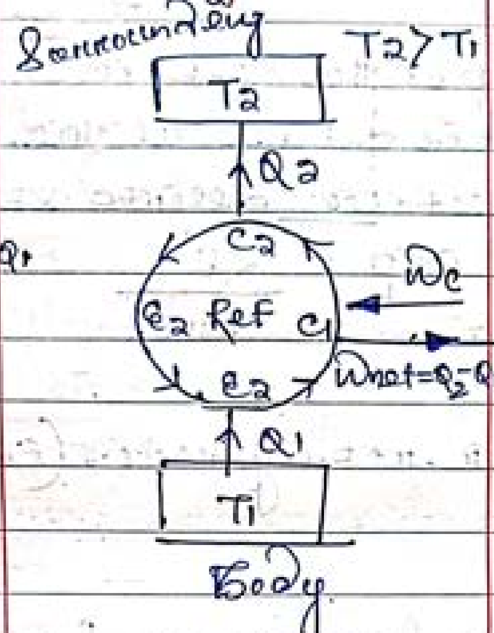
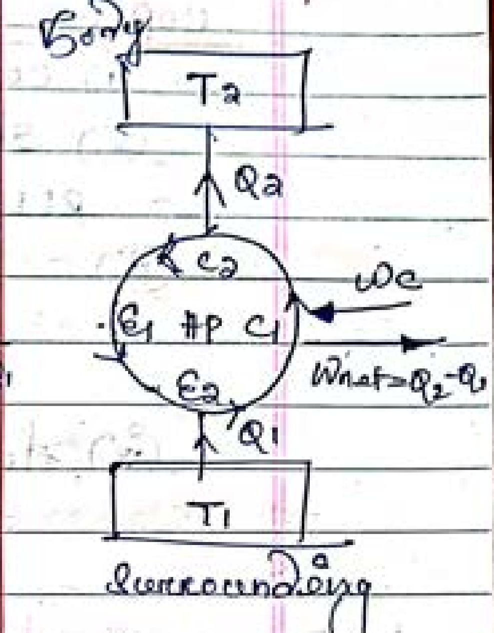
Heat engine	Refrigerator	Heat Pump
(i) 		
(ii) A heat engine is a system that converts heat to mechanical energy which can then be used to do mechanical work. (HE → ME)	(ii) It is a continue controlled process which extracts heat from a body which temp^r is below than its surrounding temp^r.	(ii) A heat pump is a device operating in a cycle that maintains a space at a higher temp^r than the surrounding.
(iii) The performance of Heat engine is measured by efficiency of heat.	(iii) The performance of refrigerator is measured by COP of refrigerator.	(iii) The performance of heat pump is measured by COP of heat pump.
(iv) It is denoted $\eta_{th}\,HE = \frac{Q_2 - Q_1}{Q_2}$ or $\frac{T_2 - T_1}{T_2}$	(iv) It is denoted as $(COP)_{Ref} = \frac{Q_1}{Q_2 - Q_1}$ or $\frac{T_1}{T_2 - T_1}$	(iv) It is denoted as $(COP)_{Ref} = \frac{Q_2}{Q_2 - Q_1}$ or $\frac{T_2}{T_2 - T_1}$

Heat transfer cold body to hot body

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Cop :-

(i) cop is the coefficient of performances.

(ii) It is defined as the ratio of Refrigerating effect or desired effect to the net work done

(iii) $cop = \frac{RE}{W_{net}}$

(iv) for refrigerator $(COP)_{Ref} = \frac{Q_1}{Q_2 - Q_1} = \frac{T_1}{T_2 - T_1}$

for heat pump $(COP)_{HP} = \frac{Q_2}{Q_2 - Q_1} = \frac{T_2}{T_2 - T_1}$

(v) so it is known as theoretical cop.

(vi) the ratio of actual cop to the theoretical cop is known as relative cop.

$\therefore$ Relative cop = $\frac{\text{Actual cop}}{\text{Theoretical cop}}$

Imp →

$$(COP)_{Reln.} = \frac{(COP)_{act}}{(COP)_{theo}}$$

(vii) Cop may be less than or greater 1 in refrigerator.

★ Refrigerating effect is that amount of heat which is related to the body.
Refrigerating effect, occurs at the evaporator.

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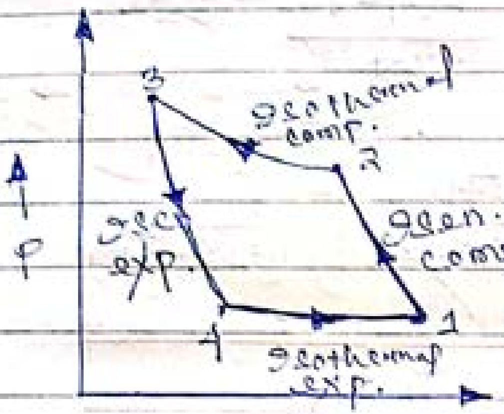
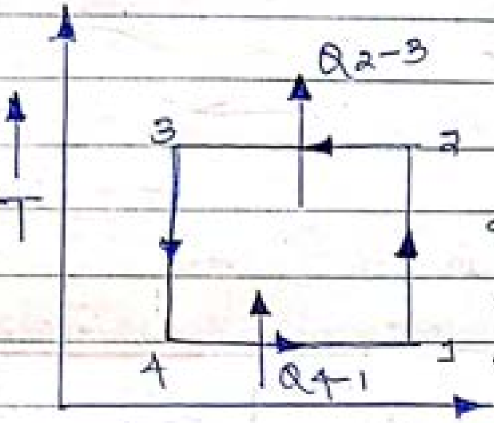
Reversed Carnot cycle:





$ds = \frac{dQ}{T}$

$\Rightarrow dQ = T\,ds$

$\Rightarrow Q_{2-3} = T_2(s_2 - s_3)$

$s_1 = s_2$

In a refrigerating system; the carnot cycle consider as reversed carnot cycle, where using air as working medium.

Heat absorbe by the refrigerating effect.

$\therefore Q_{2-3} = T_2(s_2 - s_3)$

$Q_{4-1} = T_4(s_1 - s_4)$

$= T_1(s_2 - s_3)$

Now the workdone during the cycle

$W = Q_{2-3} - Q_{4-1}$

$= T_2(s_2 - s_3) - T_1(s_2 - s_3)$

$$\boxed{W = (s_2 - s_3)(T_2 - T_1)}$$

Now the cop of the refrigeration system working on reversed Carnot cycle

$$(COP)_{\text{Rev. carnot cycle}} = \frac{\text{Heat absorbed}}{W}$$

$$= \frac{Q_{4-1}}{W}$$

$$= \frac{T_1(s_2 - s_3)}{(s_2 - s_3)(T_2 - T_1)}$$

$$\Rightarrow \boxed{(COP)_{\text{Rev. carnot}} = \frac{T_1}{T_2 - T_1}}$$

N.B

Why carnot cycle cannot be used in Practice as it serves as ideal cycle?

Ans :-

Though the reversed Carnot cycle is the most efficient between the Fixed temperature limits, yet no refrigerator has been made using this cycle. This is due to the reason that the isentropic processes of the cycle requires high speed while the isothermal process requires extreamly low speed.

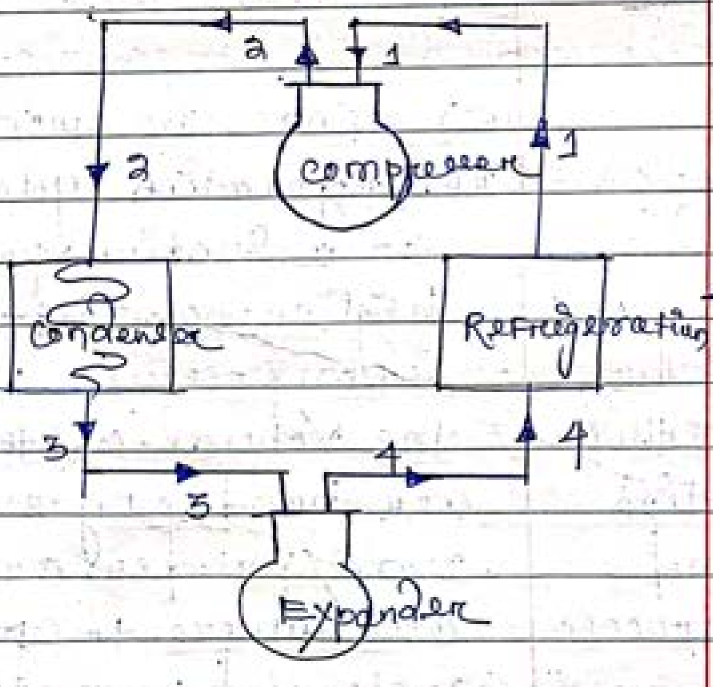
So this Variation in speed of air is not practically. Hence the carnot cycle cannot be used in practice.

Bell coleman air refregeration cycle :-

(i) Air refregeration cycle is based on working on Bell & coleman cycle or reversed Brayton cycle or Joule cycle.

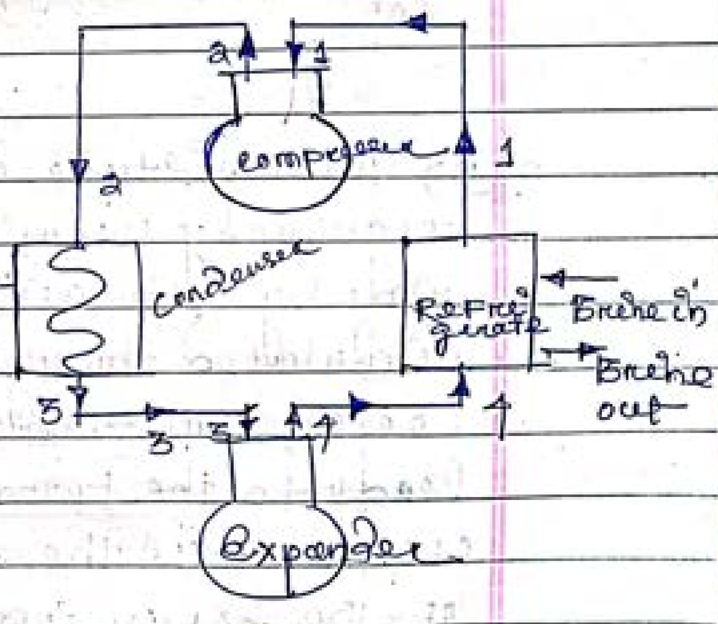
(ii) It is of two types
  (a) open Bell coleman cycle or open air ref. cycle
  (b) closed Bell coleman cycle or closed air refregeration cycle :- (Dense)

Open Bell coleman cycle



(i) In open Bell coleman cycle, air is directly led to space to be cooled that is a refrigerator allowed to circulate

closed Bell coleman cycle



(i) In a closed or dense Bell coleman cycle, the air is passed through the pipes and component parts of the system at

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through the cooler and then returned to the compressor to start another cycle.

(ii) Since the air is supplied to the refrigerator at atmospheric pressure, therefore the volume of air handed by the compressor and expander is larged, thus the size of compressor and expander should be larged.

(iii) The moisture is regularly carried away by the air circulated through the cooled space. Thus this leads to the formation of frost at the end of the expansion process and clog the line.

(iv) In open system a dryer should be used for this reason.

all times and the air in the ~~flow~~ closed system doesn't come in contact directly with the space to be cooled.

(ii) The air in the system is used for absorbing heat from other fluid or brine and this cooled brine is circulated into the space to be cooled.

(iii) Since the closed air refrigeration cycle work at a suction pressure higher than that of the atm. pressure, so the volume of the air handle by the comp. and expander are smaller as compare to open cycle and no moisture contents.

(iv) No ..... Need of dryer, and the operating pressure ratio can be reduced which results in higher COP.

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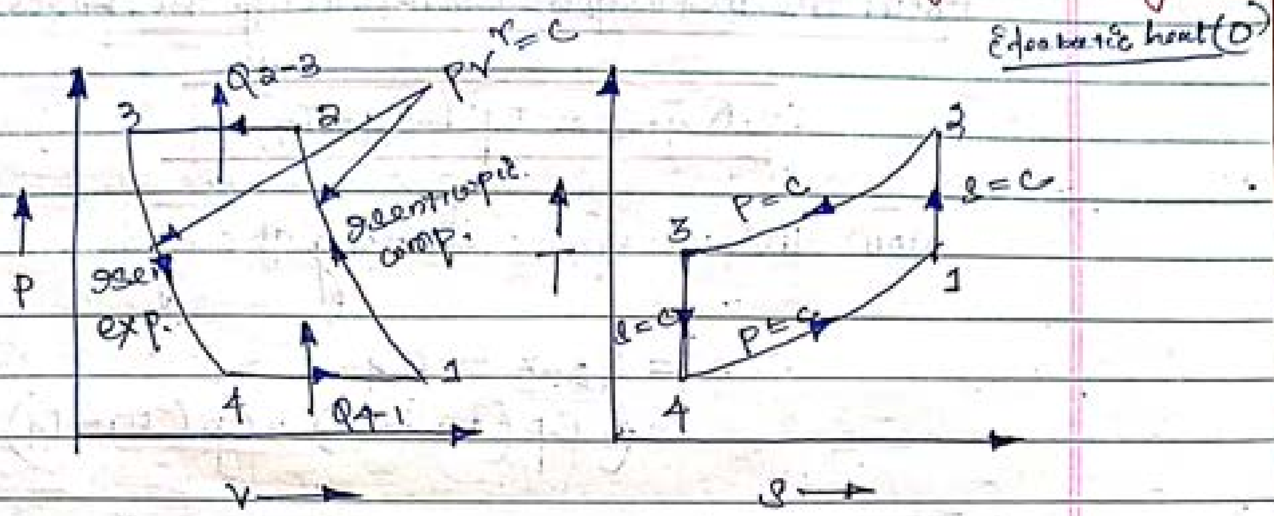
Calculation of COP of Bell-Coleman refrigeration cycle:



(i) It is known as reversed Brayton cycle or Joule cycle.

(ii) It is a modification of reversed Carnot cycle, consists of compressor, cooler or condenser and expander and a refrigerator or evaporator.

(iii) This cycle is used in refrigerator in ship carrying frozen meat.

(iv) It consists of two reversible adiabatic and two reversible constant pressure process.

The heat rejected by the air during constant pressure per kg of air during the process 2-3.

$$\therefore \boxed{Q_{2-3} = c_p(T_2 - T_3)}$$

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The heat absorbed by the air or heat extracted from the refrigerator during the process 4-1.

$$\therefore \boxed{Q_{4-1} = C_p(T_1 - T_4)}$$

Now the workdone during the cycle.

$$\therefore W = Q_{2-3} - Q_{4-1}$$
$$= C_p(T_2 - T_3) - C_p(T_1 - T_4)$$

Now, coefficient of performance

$$COP = \frac{\text{Heat absorbed}}{\text{Workdone}}$$
$$= \frac{C_p(T_1 - T_4)}{C_p(T_2 - T_3) - C_p(T_1 - T_4)}$$

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

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

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

Adiabatic index γ
Adiabatic eqn
$P^{\gamma-1}$

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Now for the process 1-2

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

for the process 3-4

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

$$\Rightarrow \boxed{\frac{T_3}{T_4} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}} \longrightarrow (iii)$$

from eqn (ii) and (iii) we get,

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

$$\Rightarrow \boxed{\frac{T_2}{T_3} = \frac{T_1}{T_4}} \longrightarrow (iv)$$

Putting the value of eqn 4 in eqn (1)

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

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

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

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

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

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

Imp

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

where, $r_p = \frac{P_2}{P_1} = \frac{P_3}{T_4}$, is known as expansion or compression ratio.

★ If the compression and expansion processes takes place according to the law $pv^n = C$ (polytropic process) then for the process 1-2

Workdone by the compression during process 1-2 per kg of Air

$$W_{1-2} = \frac{n}{n-1}(P_2v_2 - P_1v_1)$$

$$= \frac{n}{n-1}(RT_2 - RT_1)$$

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Now for the process 3-4, the workdone by the expander

$$W_{3-4} = \frac{n}{n-1}(P_3V_3 - P_4V_4)$$
$$= \frac{n}{n-1}(RT_3 - RT_4)$$

Now, the net workdone during the cycle

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

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

Imp

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

Now, the COP = $\frac{\text{Heat absorved}}{W_{net}}$

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

$$\Rightarrow COP = \frac{C_p(T_1 - T_4)}{\frac{n}{n-1} \times C_v(\gamma - 1)[(T_2 - T_1) - (T_3 - T_4)]}$$

$$\Rightarrow COP = \frac{\gamma(T_1 - T_4)}{\frac{n}{n-1} \times (\gamma - 1)[(T_2 - T_1) - (T_3 - T_4)]}$$

Imp

$$\Rightarrow COP = \frac{(T_1 - T_4)}{\frac{n}{n-1} \times \frac{\gamma - 1}{\gamma}[(T_2 - T_1) - (T_3 - T_4)]}$$

$C_p - C_v = R$

$C_p = \frac{\gamma R}{\gamma - 1}$

$C_v = \frac{R}{\gamma - 1}$

$\frac{C_p}{C_v} = \gamma (1.4)$

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N.B

If n = γ then,

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

Home Work
2.2, 2.3, 2.4 (44 Page)

Example - 2.2
A machine working on a Carnot cycle operates between 305 K and 260 K. Determine the C.O.P when it is operated as: 1. a refrigerating machine
2. a heat pump and 3. a heat engine.

Ans :- Given Data
$T_2 = 305 K$
$T_1 = 260 K$

(1). COP of a refrigerating machine
we know that C.O.P of a refrigerating machine,

$$(C.O.P)_{Ref} = \frac{T_1}{T_2 - T_1}$$
$$= \frac{260}{305 - 260}$$
$$= 5.777 \text{ (Ans)}$$

(2) COP of a heat pump
we know that COP of a heat pump.

$$(C.O.P)_{pump} = \frac{T_2}{T_2 - T_1} = \frac{305}{305 - 260} = 6.777 \text{ (Ans)}$$

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(3) COP of a heat engine.

We know that C.O.P of a heat engine.

$$(C.O.P)_{HE} = \frac{T_2 - T_1}{T_2}$$

$$= \frac{305 - 260}{305} = 0.147 \text{ (Ans)}$$

Example - 2.3

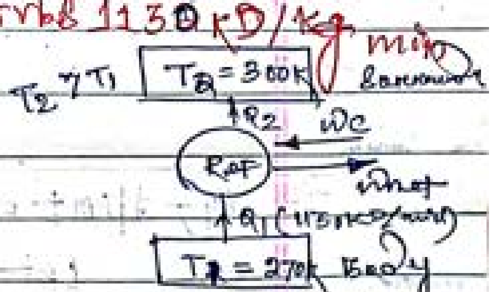
A carnot refrigeration cycle absorbs heat at 270K and rejects it at 300K.

(1) Calculate the co-efficient of performance of this refrigeration cycle.

(2) If the cycle is absorbing 1130 KJ/min at 270K, how many KJ of work is required per second ?

(3) If the Carnot heat pump operates between the same temperature as the above refrigeration cycle, What is the coefficient of performance.

(4) How many KJ/min will the heat pump deliver at 300K if it absorbs 1130 KJ/kg at 270K. (Ans)-



(Ans) - Given Data :-

$T_1 = 270K$

$T_2 = 300K$

(1) Coefficient of performance of Carnot refrigeration cycle -

We know that coefficient of performance of Carnot refrigeration cycle,

$$(COP)_{Ref} = \frac{T_1}{T_2 - T_1} = \frac{270}{300 - 270} = 9 \text{ (Ans)}$$

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(2) Work required per second

Let W_R = Work required per second

Heat absorbed at 270 K (T_1),

$$Q_1 = 1130 \text{ KJ/min}$$

$$= \frac{1130}{60} = 18.833 \text{ KJ/s}$$

We know that

$$(COP)_{Ref} = \frac{Q_1}{W_R}$$

$$\Rightarrow 9 = \frac{18.833}{W_R}$$

$$\Rightarrow W_R = \frac{18.833}{9}$$

$$\Rightarrow W_R = 2.09 \text{ KJ/s (Ans)}$$

(3) Coefficient of performance of Carnot heat pump

We know that coefficient of performance of a Carnot heat pump,

$$(COP)_{HP} = \frac{T_2}{T_2 - T_1} = \frac{300}{300 - 270} = 10 \text{ (Ans)}$$

(4) Heat delivered by heat pump at 300K

Let Q_2 = Heat delivered by Heat pump at 300 K.

Heat absorbed at 270 K (T_1)

$$Q_1 = 1130 \text{ KJ/min}$$

We know that

$$(C.O.P)_{HP} = \frac{Q_2}{Q_2 - Q_1}$$

$$\Rightarrow 10 = \frac{Q_2}{Q_2 - 1130}$$

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ideal (Reversible no Losses)

$\Rightarrow 10Q_2 = Q_2 - 1130$

$\Rightarrow 10Q_2 - 1130 = Q_2$

$\Rightarrow Q_2 = 1256$ KJ/min (Ans)

Example:- 2.4

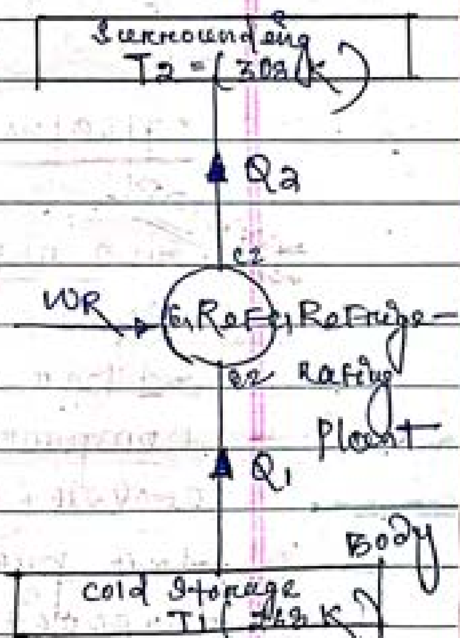
A cold storage is to be maintained at $-5°C$ while the surroundings are at $35°C$. The heat leakage from the surroundings into the cold storage is estimated to be 29 KW. The actual C.O.P of the refrigeration plant is one-third of an ideal plant working between the same temperatures. Find the power required to drive the plant.

Ans- Given Data :-

$T_1 = -5°C = -5 + 273 = 268K$;

$T_2 = 35°C = 35 + 273 = 308K$;

$Q_1 = 29$ KW;



$(COP)_{actual} = \frac{1}{3}(COP)_{ideal}$

The refrigerating plant operating between the temperatures T_1 and T_2 is shown in Figure.

Let W_R = Work required to drive the plant.

We know that the coefficient of performance of an ideal refrigeration plant.

$$(COP)_{ideal} = \frac{T_1}{T_2 - T_1} = \frac{268}{308 - 268} = 6.7$$

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∴ Actual coefficient of performance,

$$(COP)_{actual} = \frac{1}{3}(COP)_{ideal}$$

$$= \frac{1}{3} \times 6.7 = 2.233$$

We also know that

$$(COP)_{actual} = \frac{Q_1}{W_R}$$

$$\Rightarrow W_R = \frac{Q_1}{(COP)_{actual}}$$

$$\Rightarrow W_R = \frac{29}{2.233}$$

$$\Rightarrow W_R = 12.987 \text{ KW} \text{ (Ans)}$$

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v.v.imp

In a refrigeration plant working on Bell-coleman cycle, air is compressed to 5 Bar from 1 bar. Its initial temp. is 10°c. After compression the air is cooled up to 20°c in a cooler (condenser) before expanding back to a pressure of 1 bar. Determine the theoretical C.O.P of the plant and net refrigerating effect. take Cp = 1.005 KJ/Kg.K and Cv = 0.718 KJ/Kg.K.

Ans :- Given Data :-

$C_p = 1.005$ KJ/Kg.K, $C_v = 0.718$ KJ/Kg.K

$P_2 = 5\text{bar} = 5 \times 10^5 \text{ N/m}^2$

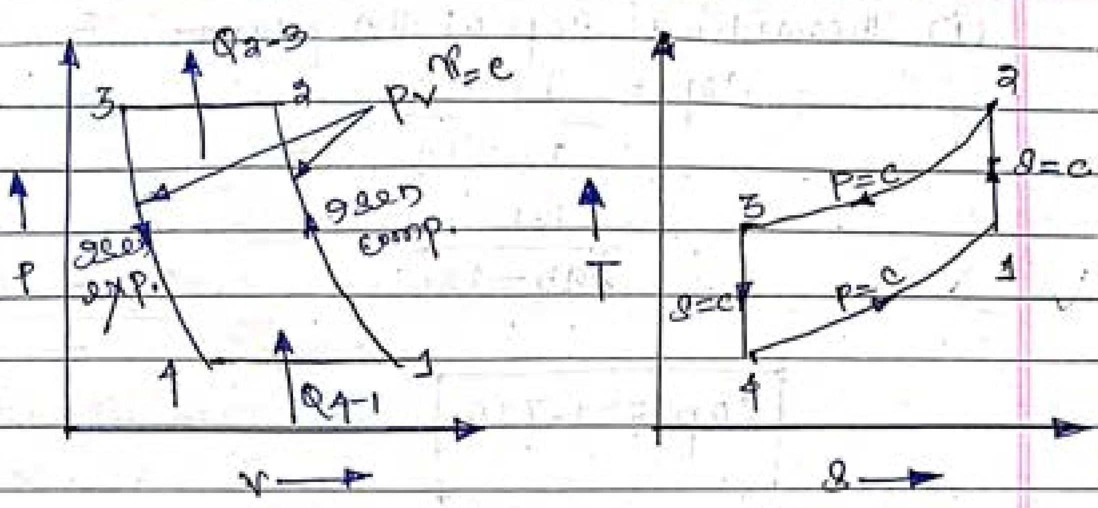
$P_1 = 1\text{bar} = 1 \times 10^5 \text{ N/m}^2$

$T_1 = 10°C = 10 + 273 = 283°K$

$T_3 = 20°C = 20 + 273 = 293°K$

COP = ?
RE = ?

(Cp) - Specific heat and constant pressure
(Cv) - Specific heat and constant volume



Now $\gamma = \frac{Cp}{Cv}$

$= \frac{1.005}{0.718}$

$= 1.399$ or 1.4

$\Rightarrow \gamma = 1.4$

Now for the process 3-4

$$\frac{T4}{T3} = \left(\frac{P4}{P3}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow \frac{T4}{T3} = \left(\frac{P1}{P2}\right)^{\frac{\gamma-1}{\gamma}} \quad \left(\because P4 = P1,\ P3 = P2\right)$$

$$\Rightarrow T4 = T3 \times \left(\frac{P1}{P2}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow T4 = 293 \times \left(\frac{1\times10^5}{5\times10^5}\right)^{\frac{1.4-1}{1.4}}$$

$$\Rightarrow \boxed{T4 = 184.995\,K}$$

(i) Theoretical cop of the plant

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

$$= \frac{185}{293 - 185}$$

$$\boxed{COP = 1.713}$$

(ii) Net refrigerating effect

$$Q_{4-1} = m c_p (T_1 - T_4)$$

$$= 1 \times 1.005 \times (283 - 184.995)$$

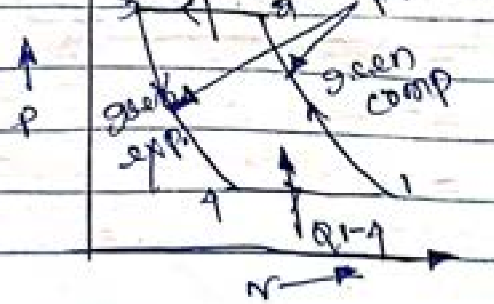
$$\boxed{Q_{4-1} = 98.49 \text{ KJ/kg}} \quad \text{(Ans)}$$

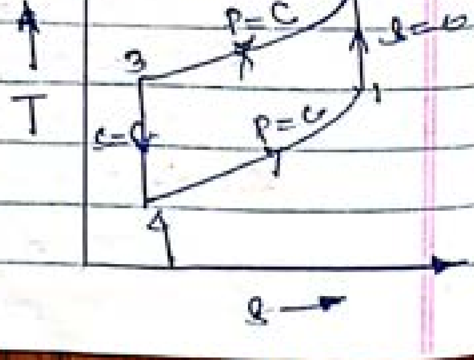
Homework -
2.12

Example-2.12

A refrigerator working on Bell-coleman cycle operates between pressure limits of 1.05 bar and 8.5 bar. Air is drawn from the cold chamber at 10°C, compressed and then it is cooled to 30°C before entering the expansion cylinder. The expansion and compression follows the law $PV^{1.3} = C$. Determine the theoretical cop of the system.

Ans -





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Given Data :-

$P_1 = 1.05 \text{ bar} = 1.05 \times 10^5 \text{ N/m}^2$

$P_2 = 8.5 \text{ bar} = 8.5 \times 10^5 \text{ N/m}^2$

$T_1 = 10°C = 10 + 273 = 283 K$

$T_3 = 30°C = 30 + 273 = 303 K$

we know that,

• Process 1-2 :-

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

$$\Rightarrow \frac{T_2}{283} = \left(\frac{8.5 \times 10^5}{1.05 \times 10^5}\right)^{\frac{1.4-1}{1.4}}$$

$$\Rightarrow T_2 = 283 \times \left(\frac{8.5}{1.05}\right)^{\frac{1.4-1}{1.4}}$$

$$\Rightarrow \boxed{T_2 = 514.37 K}$$

Now, process 3-4

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

$$\Rightarrow \frac{T_4}{T_3} = \left(\frac{P_1}{P_2}\right)^{\frac{n-1}{n}} \quad \left(\because P_1 = P_4,\ P_3 = P_2\right)$$

$$\Rightarrow \frac{T_4}{303} = \left(\frac{1.05}{8.5}\right)^{\frac{1.3-1}{1.3}}$$

$$\Rightarrow T_4 = 187 K$$

(iii) Cop ratio of theoretical coefficient of performance.

$$Cop = \frac{T_1 - T_4}{\frac{n}{n-1} \times \frac{\gamma-1}{\gamma}\left[(T_2 - T_3) - (T_1 - T_4)\right]}$$

$$= \frac{283 - 187}{\frac{1.3}{1.3-1} \times \frac{1.4-1}{1.4}\left[(458.5 - 303) - (283 - 187)\right]}$$

$\Rightarrow 1.80$ (Ans)

$\boxed{Cop = 1.80}$ (Ans)

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v.v.imp Problem - 2.13

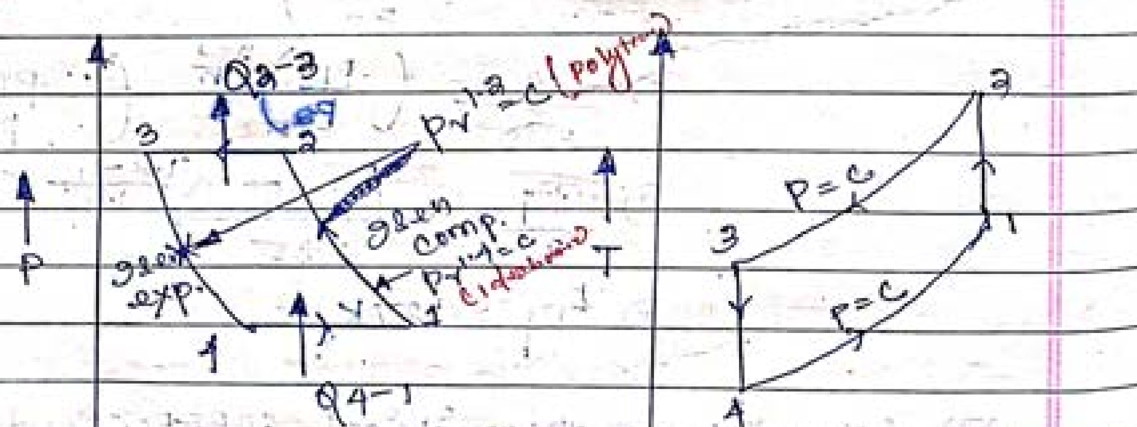
The atmospheric air at pressure 1 bar and temp $-5°C$ is drawn in the cylinder of the compressor of a Bell-coleman refrigerating machine. It is compressed isentropically to a pressure of 5 bar, in the cooler the compressed air is cooled to 15 °C, the pressure remaining the same it is then expanded to a pressure of 1 bar in an expansion cylinder from where it is passed to the cold chamber. find

(i) the workdone per kg of air.

(ii) Cop of the plant.

For air assume law for expansion $pv^{1.2} = C$, law of compression $pv^{1.4} = C$ and the specific heat of air at constant pressure = 1 KJ/kgK.

Ans:-



Given Data:-

$P_1 = P_4 = 1 \text{ bar} = 1 \times 10^5 N/m^2$

$T_1 = -5°C = -5 + 273 = 268 K$

$P_2 = P_3 = 5 \text{ bar} = 5 \times 10^5 N/m^2$

$T_3 = 15°C = 15 + 273 = 288 K$

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For the process 1-2

$$\left(P v^{1.4} = c\right)$$

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

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

$$\Rightarrow T_2 = 268 \times \left(\frac{5\times10^5}{1\times10^5}\right)^{\frac{1.4-1}{1.4}}$$

$$\Rightarrow T_2 = 424.46 K$$

Now for the process 3-4 $\left(P v^{1.2} = c\right)$

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

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

$$\Rightarrow T_4 = 288 \times \left(\frac{1\times10^5}{5\times10^5}\right)^{\frac{1.2-1}{1.2}}$$

$$\Rightarrow T_4 = 220 K$$

Now, workdone for the process 1-2

$$W_c = W_{1-2} = \frac{\gamma}{\gamma-1} \times (P_2 v_2 - P_1 v_1)$$

$$= \frac{\gamma}{\gamma-1} R (T_2 - T_1)$$

$$= \frac{1.4}{1.4-1} \times 0.287(421.46 - 268)$$

$$\boxed{W_c = W_{1-2} = 157.16 \text{ KJ/Kg}}$$

Again, for the process 3-4

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

$$= \frac{n}{n-1} \times R(T_3 - T_4)$$

$$= \frac{1.2}{1.2-1} \times 0.287(288 - 220)$$

$$W_E = W_{3-4} = 117.09 \text{ KJ/Kg}$$

(i) The net workdone per kg of air.

$$W_{net} = W_c - W_E$$

$$= 157.16 - 117.09$$

$$= 40.07 \text{ KJ/Kg}$$

(ii) The heat abstracted during the process 4-1 is,

$$Q_{4-1} = RE = C_p(T_1 - T_4)$$

$$= 1 \times (268 - 220)$$

$$= 48 \text{ KJ/Kg}$$

$$\therefore COP = \frac{\text{Heat absorbed}}{W_{net}}$$

$$= \frac{48}{40.06}$$

$$\boxed{COP = 1.198} \text{ (Ans)}$$

V.V.Imp Problem - 2.15

An air refrigerator works between the pressure limits of 1 bar and 5 bar. The temperature of air entering the compressor and expansion cylinder are 10°c and 25°c. The expansion and compression follow the law $Pv^{1.3} = C$. Find —

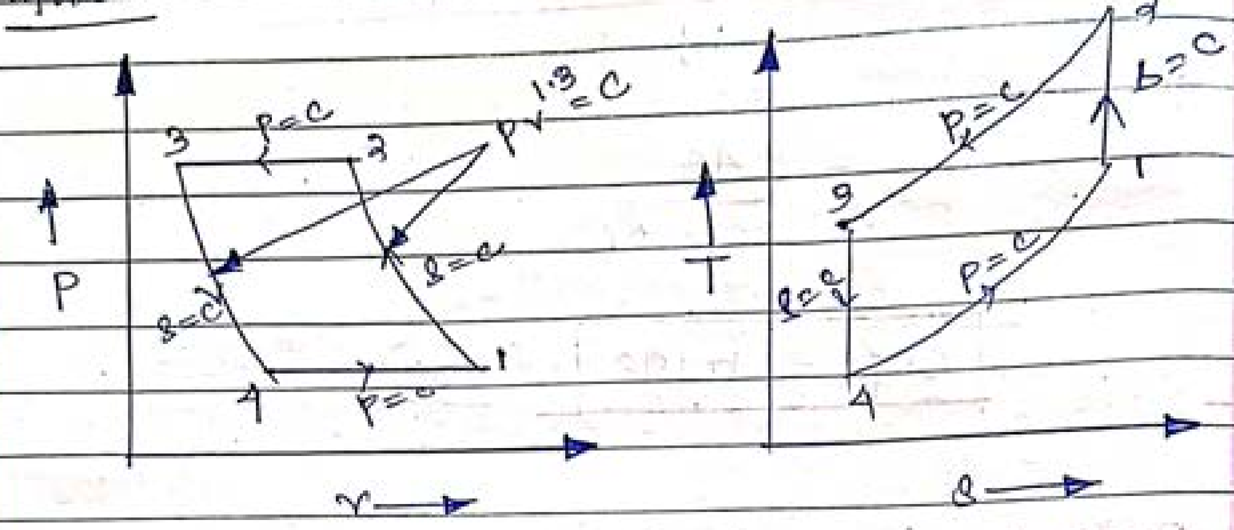
(i) the theoritical COP of the refrigerating cycle.

(ii) If the load on the refrigerating machine is tonne (TR), find the amount of air circulated per minute through the system assuming that the actual cop is 50% of theoretical cop.

(iii) The stroke length (L) and the piston diameter of single acting compressor if the comp. runs at 300 RPM. and the volumetric efficiency is 85%. take $\frac{L}{d} = 1.5$, $Cp = 1.005 \, KJ/kgK$

$Cv = 0.71 \, KJ/KgK$.

Ans :-



Given Data :-

$P_1 = P_4 = 1 \text{ bar} = 1 \times 10^5 \text{ N/m}^2$

$P_2 = P_3 = 5 \text{ bar} = 5 \times 10^5 \text{ N/m}^2$

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

$T_3 = 25^\circ C = 25 + 273 = 298 \text{ K}$

$pv^{1.3} = c, \; n = 1.3$

For the process 1-2

we know $\dfrac{T_2}{T_1} = \left(\dfrac{P_2}{P_1}\right)^{\frac{n-1}{n}}$

$\Rightarrow T_2 = T_1 \times \left(\dfrac{P_2}{P_1}\right)^{\frac{n-1}{n}}$

$\Rightarrow T_2 = 283 \times \left(\dfrac{5 \times 10^5}{1 \times 10^5}\right)^{\frac{1.3-1}{1.3}}$

$\Rightarrow T_2 = 410.28 \text{ K}$

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For the process 3-4

we know that $\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{n-1}{n}}$

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

$= T_4 = 298 \times \left(\frac{1\times10^5}{5\times10^5}\right)^{\frac{1.3-1}{1.3}}$

$= \boxed{T_4 = 205.54\ K}$

for the process 3-4

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

$= \frac{n}{n-1} \times R(T_3 - T_4)$

$= \frac{1.3}{1.3-1} \times 0.287(298 - 205.54)$

$\boxed{W_E = W_{3-4} = 114.98\ kJ/kg}$

for the process 1-2

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

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

$= \frac{1.3}{1.3-1} \times 0.287(410.28 - 283)$

$\boxed{W_C = W_{1-2} = 158.29\ kJ/kg}$

1 tonne = 210 kJ

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The net workdone per kg of air.

$$W_{net} = W_C - W_E$$

$$= 158.29 - 114.98$$

$$W_{net} = 43.31 \text{ KJ/Kg}$$

The heat abstracted during the process 4-1

$$Q_{4-1} = RE = C_P(T_1 - T_4)$$

$$= 1.005(283 - 205.54)$$

$$Q_{4-1} = RE = 77.847 \text{ KJ/Kg}$$

$$\therefore COP = \frac{\text{Heat absorbed}}{W_{net}}$$

$$= \frac{77.847}{43.31}$$

$$COP = 1.797 \text{ (Ans)}$$

(ii) given

$$(COP)_{act} = 50\% (COP)_{th}$$

So the actual heat extracted

$$= 0.5 \times 77.847$$

$$= 38.92 \text{ KJ/Kg}$$

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Refrigerating capacity = 10 TR
$= 10 \times 210 = 2100$ KJ/min

Mass of air $= \frac{2100}{39}$ = 2100 KJ/min

$m_a = 53.84$ Kg/min

(iii) $L/d = 1.5$, $N = 300$

we known $\eta_v = \frac{V_a}{V_S}$ —— ①

Now actual volume, $P_1V_1 = m_a R T_1$

$$V_a = V_1 = \frac{m_a R T_1}{P_1} \quad (R = c_p - c_v)$$

$$\Rightarrow V_1 = \frac{53.84 \times 0.295 \times 10^3 \times 283}{1 \times 10^5}$$

$$\Rightarrow \boxed{V_1 = V_a = 44.94 \ m^3/min}$$

Now swept volume

$$V_s = \frac{\pi}{4} d^2 L N$$

According eqn ①

$$\eta_v = \frac{V_a}{V_S} = \frac{V_1}{\pi/4 \, d^2 L N}$$

$$\Rightarrow \eta_v = \frac{4 V_1}{\pi d^2 (1.5 d) N}$$

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$$\Rightarrow d^3 = \frac{4 v_1}{\pi \eta_v N}$$

$$\Rightarrow d^3 = \frac{4 \times 44.94}{\pi \eta_v \times 300}$$

$$\Rightarrow d = 0.53\,m = 530\,mm$$

$$L = 795\,mm$$

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CHAPTER-2

Vapour Compression Refrigeration System

(i) A vapour compression refrigeration system is an improved type of air refrigeration system in which a suitable working substance is known as Refrigerant is used.

(ii) The refrigerant used are amonia (NH_3), Carbon-dioxide (CO_2), Sulphur dioxide (SO_2), R-12 (Dichlorodifluoro methane) (CCl_2F_2), R-22 (Monochlorodifluoro methane) ($CHClF_2$) R-134a (Tetrafluoro ethane) (CF_3CH_2F) etc.

(iii) The vapour compression refrigeration system is used for all purpose of refrigeration, air conditioning plant, water cooler, cold storage plant, refrigerator etc.

(iv) The refrigerant used doesn't leave the system but is circulated throughout the system alternately condensing and evaporating.

(v) In evaporating, the refrigerant absorbs all its latent heat from the brine solution (salt water solⁿ) which is used for circulating it around the cold chamber.

(vi) While condensing, it gives out its latent heat to the circulating (water) or air of the cooler.

(vii) The vapour compression refrigeration system is therefore a latent heat pump as its pumps the heat from brine and delivers to the coolers.

Advantages and disadvantages of vapour compression refrigeration system over the air refrigeration system :-

Advantages :-

(I) It has smaller size for the given capacity of refrigeration.

(II) It has less running cost.

(III) The cop. is quite high.

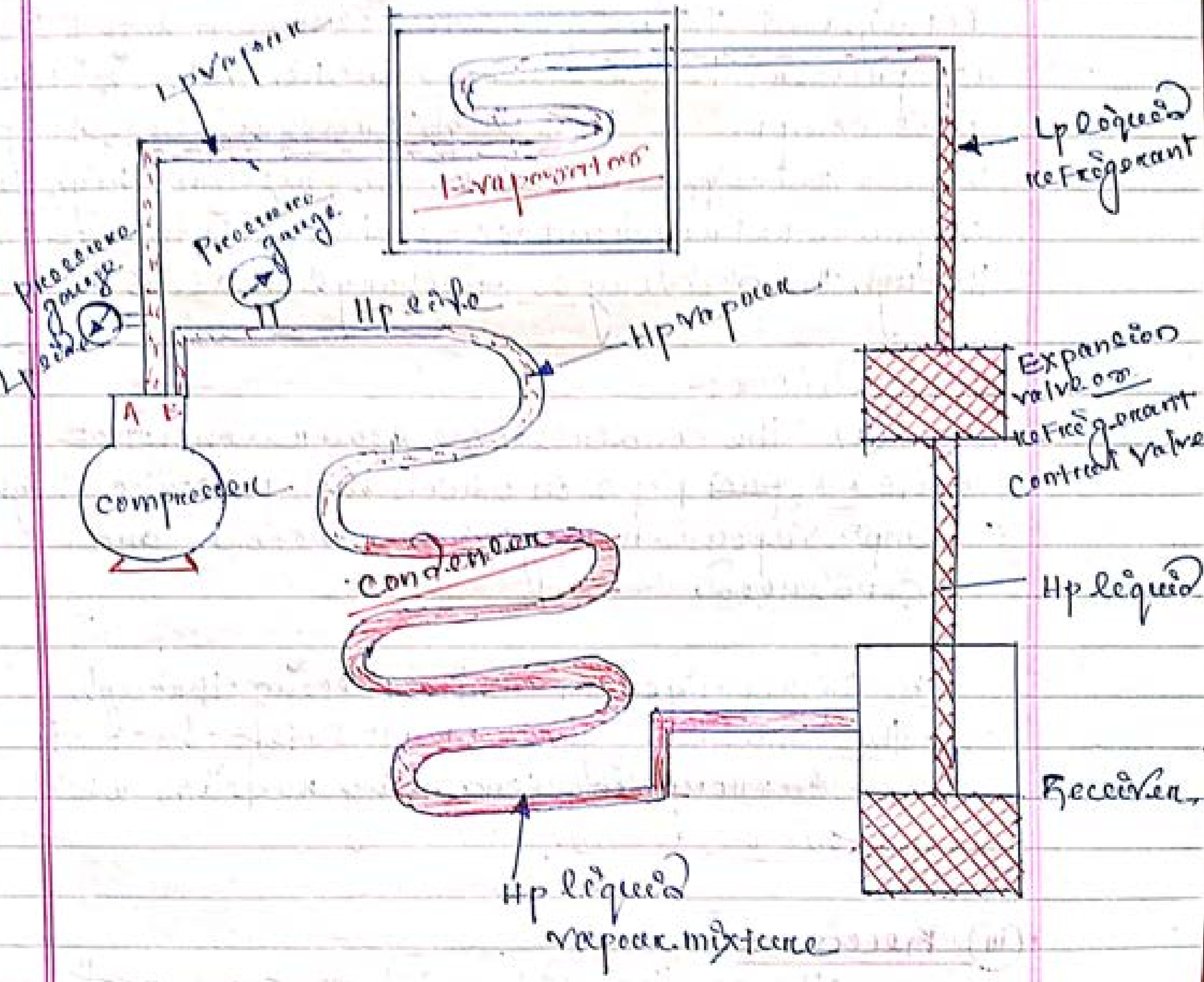
(IV) It can be employed over a large range of temperature.

Disadvantages :-

(I) Initial cost is high.

(II) The prevention of leakage of the refrigerant is the measure problem in vapour compression system.

Simple Vapour Compression Refrigeration System :-



A simple vapour compression refrigeration system consist of 5 parts :-

(I) Compresser
(II) Condenser
(III) Receiver
(IV) Expansion valve (or throttle valve)
(V) Evaporator

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Working Principles :-

(i) Compressor :-

The low pressure, low temperature vapour refrigerant from evaporator is drawn into the compressor to the inlet or suction valve "A" where it is compressed to a high pressure, high temp. vapour refrigerant. the high pressure, high temp vapour refrigerant is discharge into condenser through the delivery or discharge valve "B".

(ii) Condenser :-

(a) The condenser or cooler consist of coils or pipe in which high pressure, high temp vapour refrigerant is cooled and condensed.

(b) the refrigerant while passing through the condenser gives up its latent heat to the surrounding condensing medium which is air or water.

(iii) Receiver :-

The condensed liquid refrigerant from the condenser is stored in a vessel known as receiver from where it is supply to the evaporator through the expansion valve.

(iv) Expansion valve :-

It is also known as throttle valve or refrigerant control valve. the function of expansion valve is to allow the liquid refrigerant under high pressure and temperature to pass at a control rate after reducing its pressure and temperature.

(v) Evaporator :-
It consist of coil of pipe in which the liquid vapour refrigerant at low pressure and temp^r is evaporated and changed into vapour refrigerant at low pressure and temperature. In evaporating the liquid vapour refrigerant absorb its latent heat of vapourisation from the medium which is to be cooled.

N.B
(I) The high pressure side includes the discharge line of compressor, Condenser, Receiver and expansion valve.

(II) low pressure side includes evaporator piping from expansion valve and suction line of compressor.

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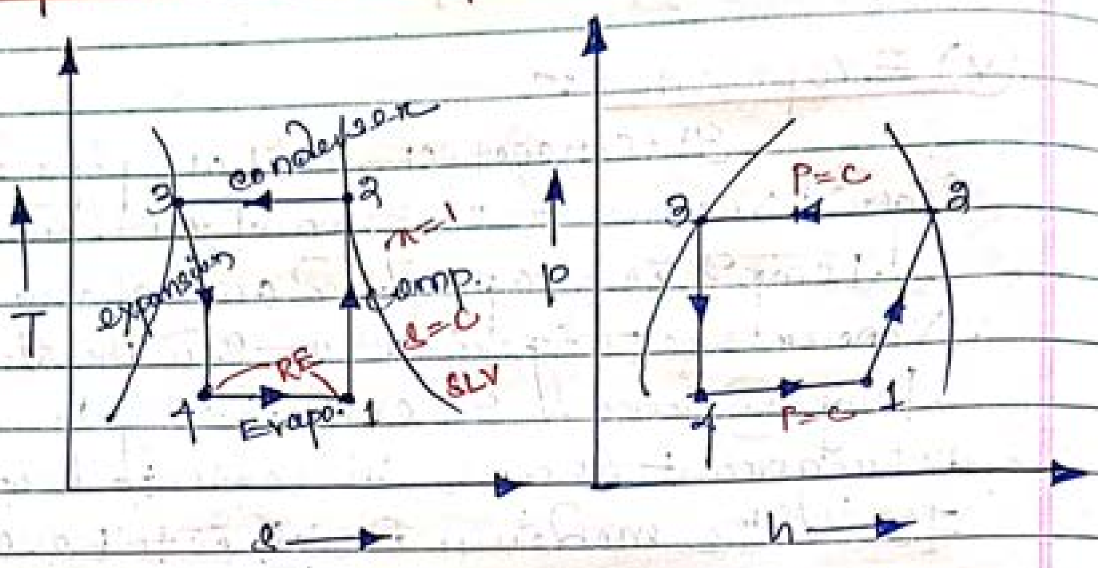
Types of vapour compressor cycle :-
(i) cycle with dry saturated vapour after compression.

(ii) cycle with wet vapour after compression.
(iii) cycle with superheated vapour after compression.
(iv) cycle with superheated vapour before compression
(v) cycle with under cooling or soft cooling of refrigerant.

(1) Vapour compression cycle with dry saturated vapour after compression.



Process 1-2

Reversible adiabatic compression process that is $s = C$,

$$s_1 = s_2$$

Process 2-3

Constant pressure cooling process.

Process 3-4

Throttling process that is isenthalpic (iso + enthalpy), $h_3 = h_4$ process.

Process 4-1

Reversible constant process that extraction process. refrigerating effect.

dry saturated vapour

$$x = 1$$

Compressor work

$$W_c = h_2 - h_1$$

Heat rejected by the condenser

$$Q_c = h_2 - h_3$$

heat absorbed or refrigerating effect at the evaporator.

$$RE = h_1 - h_4$$

Now $COP = \frac{RE}{W_{net}}$

imp

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

v.v. imp.

Problem:-

The tempr limits of an ammonia refrigerating system are 25°c and −10°c. If the gas is dry at the end of compression, calculate COP of the cycle assuming no under cooling of the liquid ammonia. Use the following table for the properties of ammonia.

Tempr (°c)	liquid heat (h_F) (KJ/kg)	latent heat (h_{fg}) (KJ/kg)	liquid (s_f) entropy (KJ/kg)
25°c	298.9	1166.94	1.1242
−10°c	135.37	1297.68	0.5443

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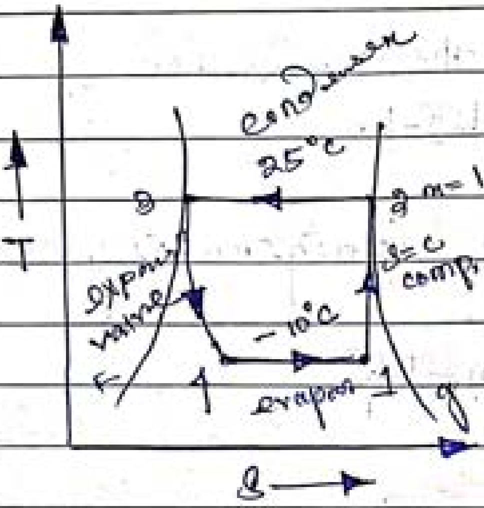
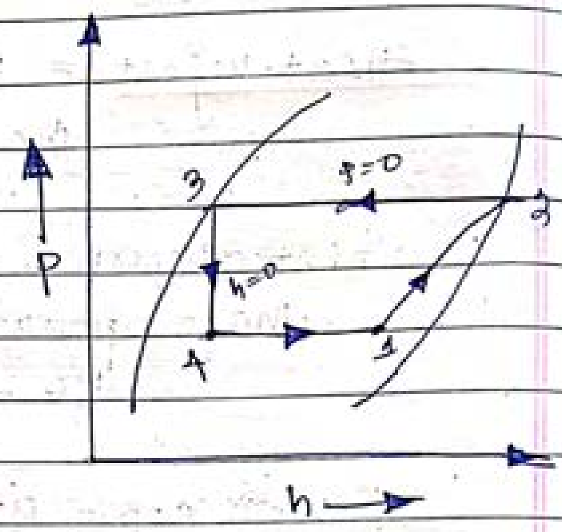
$\therefore ds = \frac{\delta Q}{T}$

$s_{fg} = \frac{h_{fg}}{T}$

Given Data :-





$T_1 = T_4 = -10°C = -10 + 273 = 263\ K$

$T_2 = T_3 = 25°C = 25 + 273 = 298\ K$

$h_{f1} = 135.37\ KJ/Kg$

$s_{f1} = 0.5443\ KJ/kg \cdot K$

$h_{fg1} = 1297.68\ KJ/Kg$

$h_{f2} = h_{f3} = 298.9\ KJ/Kg$

$h_{fg2} = 1166.94\ KJ/Kg$

$s_{f2} = 1.1243\ KJ/Kg \cdot K$

$x_2 = 1$ (as dry saturated at the end of compression)

For the process 1-2 (Rev. adiabatic comp. process)

i.e.

$s_1 = s_2$ —— (i)

Now

$s_1 = s_{f1} + x_1 \times s_{fg_1}$

$\Rightarrow s_1 = s_{f1} + x_1 \times \frac{h_{fg_1}}{T_1}$ —— (ii)

Similarly

$s_2 = s_{f2} + x_2 \times s_{fg_2}$

$\Rightarrow s_2 = s_{f2} + x_2 \times \frac{h_{fg_2}}{T_2}$ —— (iii)

equating eqn (ii) and (iii)

$\therefore s_{f1} + x_1 \times \frac{h_{fg_1}}{T_1} = s_{f2} + x_2 \times \frac{h_{fg_2}}{T_2}$

$\Rightarrow 0.5443 + x_1 \times \frac{1297.68}{263} = 1.1242 + 1 \times \frac{1166.94}{298}$

$\Rightarrow 0.5443 + x_1 \times 4.934 = 5.0401$

$\Rightarrow x_1 = \frac{5.0401 - 0.5443}{4.934}$

$\Rightarrow \boxed{x_1 = 0.911}$

Now $h_1 = h_{f1} + x_1 \times h_{fg_1}$

$= 135.37 + 0.911 \times 1297.68$

$= 1317.55$ KJ/Kg

$h_2 = h_{f2} + x_2 \times h_{fg_2}$

$= 298.9 + 1 \times 1166.94 = 1465.84$ KJ/Kg

Now cop of the cycle = $\frac{RE}{W_{net}}$

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

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

$$= \frac{1317.55 - 278.7}{1465.81 - 1317.55}$$

$$= 6.869$$

H.W ex - 1.3, 1.4   cop = 6.869

Example :- 1.3

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

(1) c.o.p of the cycle ; and

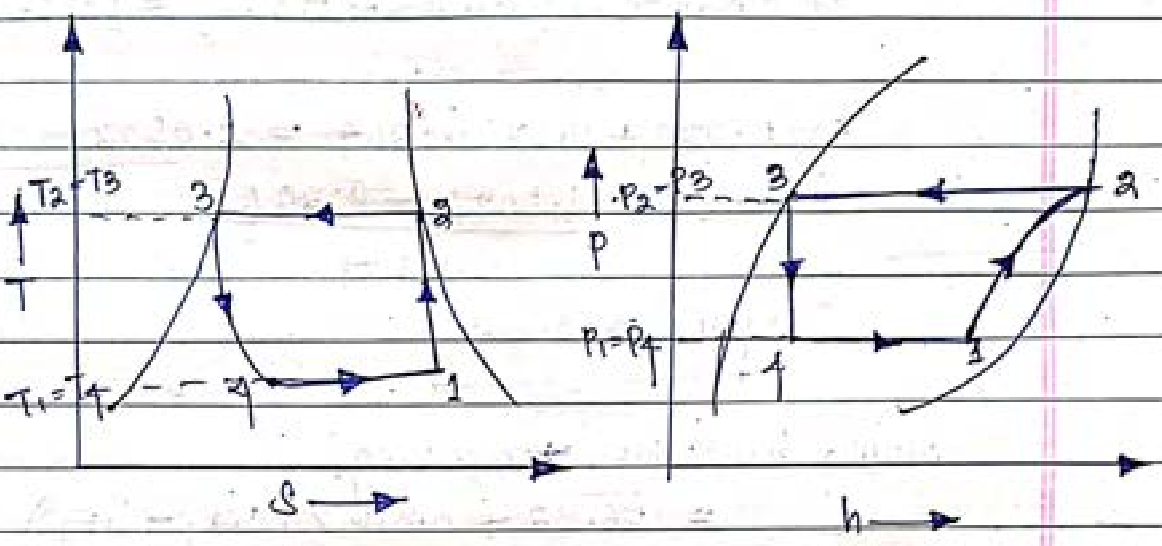
(2) capacity of the refrigerator if the fluid flow is at the rate of 5 kg/min.

Data :-

Pressure (bar)	Saturation temperature (K)	Enthalpy (kJ/kg)		Entropy (kJ/kg K)	
		Liquid	Vapour	Liquid	Vapour
60	295	151.96	293.29	0.554	1.0332
25	261	56.82	322.58	0.226	1.2114

Sol :- Given Data

$P_1 = P_4 = 25$ bar
$P_2 = P_3 = 60$ bar
$T_1 = T_4 = 261$ K
$T_2 = T_3 = 295$ K



$h_{f4} = h_{f2} = 151.96$ KJ/Kg $= h_{f3}$
$h_{g_2} = 293.29$ KJ/Kg
$s_{f2} = 0.554$ KJ/Kg.K
$s_{g_2} = 1.0332$ KJ/Kg.K

$h_{f1} = 56.32$ KJ/Kg
$h_{g_1} = 322.58$ KJ/Kg
$s_{f1} = 0.226$ KJ/Kg.K
$s_{g_1} = 1.2464$ KJ/Kg.K
$x_2 = 1$

For the process 1-2 :-

$$s_1 = s_2 \quad \text{--- (i)}$$

Now

$$s_1 = s_{f1} + x_1 \times s_{fg_1}$$

$$\Rightarrow s_1 = s_{f1} + x_1 (s_{g_1} - s_{f1}) \quad \text{--- (ii)}$$

Similarly $s_2 = s_{F2} + x_2 \times s_{Fg_2}$

$s_2 = s_{F2} + x_2 (s_{g_2} - s_{F2})$ ——— (iii)

Equating eqn (ii) and (iii)

$$s_{F1} + x_1 (s_{g_1} - s_{F1}) = s_{F2} + x_2 (s_{g_2} - s_{F1})$$

$$\Rightarrow 0.226 + x_1 (1.2464 - 0.226) = 0.554 + 1 (1.0332 - 0.534)$$

$$\Rightarrow 0.226 + x_1 \times 1.0204 = 1.0532$$

$$\Rightarrow x_1 = \frac{1.0532 - 0.226}{1.0204}$$

$$\Rightarrow \boxed{x_1 = 0.810}$$

Now, $h_1 = h_{F1} + x_1 \times h_{Fg_1}$

$= 56.32 + 0.810 \times (h_{g_1} - h_{F1})$

$= 56.32 + 0.810 \times (322.58 - 56.32)$

$$\boxed{h_1 = 271.99 \text{ KJ/Kg}}$$

$\therefore h_2 = h_{F2} + x_2 \times h_{Fg_2}$

$= h_{F2} + x_2 \times (h_{g_2} - h_{F2})$

$= 151.96 + 1 \times (293.29 - 151.96)$

$$\boxed{h_2 = 293.29 \text{ KJ/Kg}}$$

(i) COP of the cycle $= \dfrac{h_1 - h_4}{h_2 - h_1}$

$$= \frac{271.99 - 151.96}{293.29 - 271.99}$$

$$\boxed{COP = 5.635}$$

(ii) The heat extracted per kg of refrigerant
$= h_1 - h_{f3} = 211.99 - 101.96 = 120.03$ KJ/kg
The fluid flows in at the rate of 5 kg/min
Total heat extracted $= 5 \times 120.03$
$= 600.15$ KJ/min

Capacity of the refrigerator $= \dfrac{600.15}{210}$
$= \boxed{2.74 \, TR}$ (Ans)

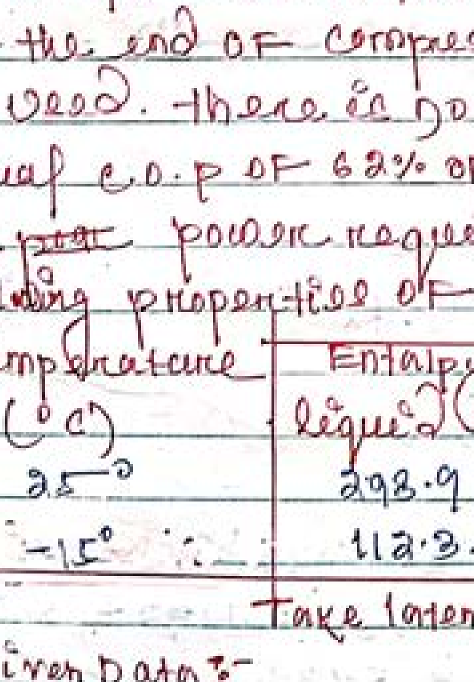
Example - 1.4

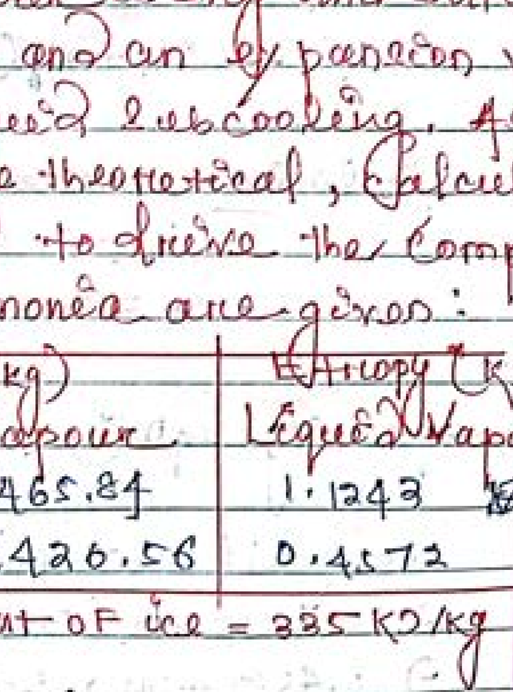
28 tonnes of ice from and 0°C is produced per day in an ammonia refrigerator. The temperature range in the compressor is from 25°C to −15°C. The vapour is dry and saturated at the end of compression and an expansion valve is used. There is no liquid subcooling. Assuming actual C.O.P of 62% of the theoretical, calculate the power required to drive the compressor. Following properties of ammonia are given:

Temperature (°C)	Enthalpy (KJ/kg) liquid	Enthalpy (KJ/kg) vapour	Entropy (KJ/kg·K) liquid	Entropy (KJ/kg·K) vapour
25	298.9	1465.84	1.1243	5.0390
−15°	112.34	1426.56	0.4572	

Take latent heat of ice = 335 KJ/kg

Given Data:-





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$T_1 = T_4 = -15°C = -15 + 273 = 258\ K$

$T_2 = T_3 = 25°C = 25 + 273 = 298\ K$

$h_{F2} = 298.9\ KJ/kg = h_4 = h_{F3}$

$h_{F1} = 112.34\ KJ/kg$

$h_{g_1} = 1426.54\ KJ/kg$

$S_{F1} = 0.4572\ KJ/kg\,K$

$S_{g_1} = 5.5490\ KJ/kg.K$

$h_{g_2} = h_2 = 1465.84\ KJ/kg.K$

$S_{F2} = 1.1242\ KJ/kg.K$

$S_{g_2} = S_2 = 5.0391\ KJ/kg.K$

Ice produced = 28 tonne/day

For the process 1-2.

$$S_1 = S_2 \quad \text{——— (i)}$$

Now

$$S_1 = S_{F1} + x_1 \times S_{Fg_1}$$

$$\Rightarrow S_1 = S_{F1} + x_1 (S_{g_1} - S_{F1}) \quad \text{——— (ii)}$$

Similarly.

$$S_2 = S_{F2} + x_2 \times S_{Fg_2}$$

$$\Rightarrow S_2 = S_{F2} + x_2 (S_{g_2} - S_{F2}) \quad \text{——— (iii)}$$

equating eqn (ii) and (iii)

$$S_{F1} + x_1 (S_{g_1} - S_{F1}) = S_{F2} + x_2 \times (S_{g_2} - S_{F2})$$

$$\Rightarrow 0.4572 + x_1 (5.5490 - 0.4572) = 1.1242 + 1 \times (5.0391 - 1.124$$

$$\Rightarrow 0.4572 + x_1 \times 5.0918 = 5.0391$$

$$\Rightarrow x_1 = \frac{5.0391 - 0.4572}{5.0918}$$

$$\Rightarrow \boxed{x_1 = 0.899}$$

Now $h_1 = h_{f1} + x_1 \times h_{fg_1}$

$= h_{f1} + x_1 \times (h_{g_1} - h_{f1})$

$= 112.34 + 0.899 \times (1426.54 - 112.34)$

$\Rightarrow \boxed{h_1 = 1293.80 \text{ KJ/Kg}}$

Again

$h_2 = h_{f2} + x_2 \times h_{fg_2}$

$= h_{f2} + x_2 \times (h_{g_2} - h_{f2})$

$= 298.9 + 1 \times (1465.84 - 298.9)$

$\boxed{h_2 = 1465.84 \text{ KJ/Kg}}$

The theoretical cop of the cycle $= \dfrac{h_1 - h_4}{h_2 - h_1}$

$= \dfrac{1293.80 - 298.9}{1465.84 - 1293.80}$

$\boxed{Cop_{theo} = 5.782}$

Hence, Cop_{act} is 62% of Cop_{theo}.

$Cop_{act} = 0.62 \times 5.782$

$\boxed{Cop_{act} = 3.584}$

We know that ice produced from and at 0°c

$= 28 \text{ tonne/day} = \dfrac{28 \times 1000}{24 \times 3600}$

$\Rightarrow 28 \text{ tonne/day} = 0.324 \text{ kg/s}$

Given latent heat of ice is = 335 KJ/Kg

∴ Refrigeration effect produced

$= 0.324 \times 335 = 108.56 \text{ KJ/s}$

wet vapour ↓ within the dome

We also know that C.O.P

$3.584 = \frac{\text{Ref. effect}}{W_{net}}$

$\Rightarrow 3.584 = \frac{108.54}{W_{net}}$

$\Rightarrow W_{net} = \frac{108.54}{3.584}$

$\Rightarrow \boxed{W_{net} = 30.28 \text{ KJ/s}}$ (Ans)

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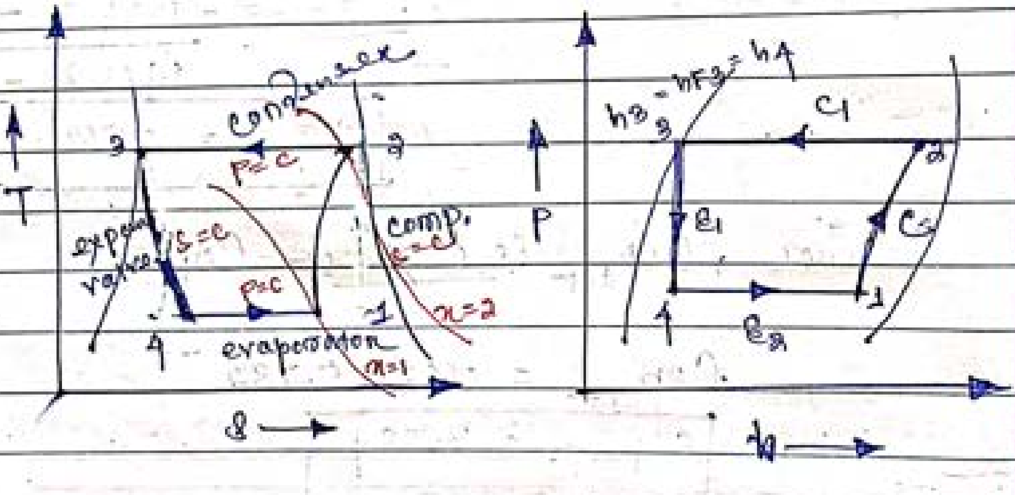
(2) Vapour Compression cycle with wet vapour after Compression :-



$h_1 = h_{f1} + x_1 \times h_{fg_1}$

$h_2 = h_{f2} + x_2 \times h_{fg_2}$ $s_1 = s_2$

$s_1 = s_{f1} + x_1 \times s_{fg_1}$

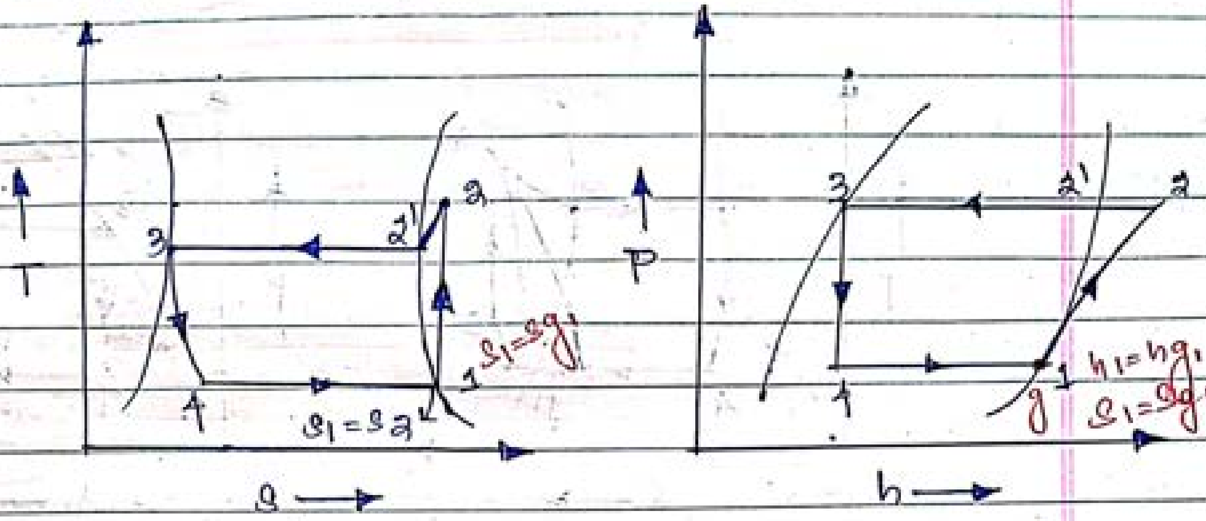
$s_2 = s_{f2} + x_2 \times s_{fg_2}$

So,

$COP = \frac{RE}{W_{net}}$

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

(3) Theoretical vapour compression cycle with superheated vapour after compression :-



Superheating increases the refrigerating effect and the amount of workdone in the compressor. Hence, the increase in refrigerant is less in compare to workdone, the net effect of superheating ∴ is to have low C.O.P.

$$\therefore C.O.P = \frac{RE}{W_{net}}$$

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

Imp

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

$$s_2 = s_2' + c_p \ln \left(\frac{T_2}{T_2'} \right)$$

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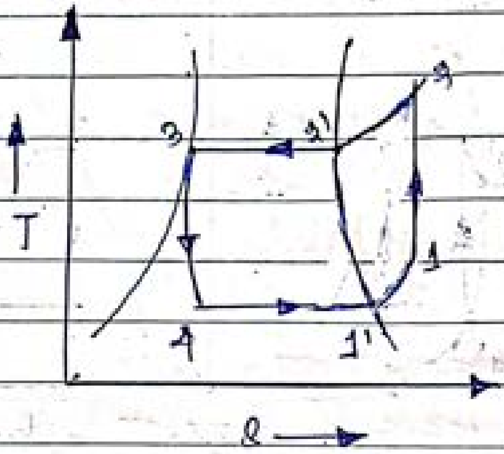
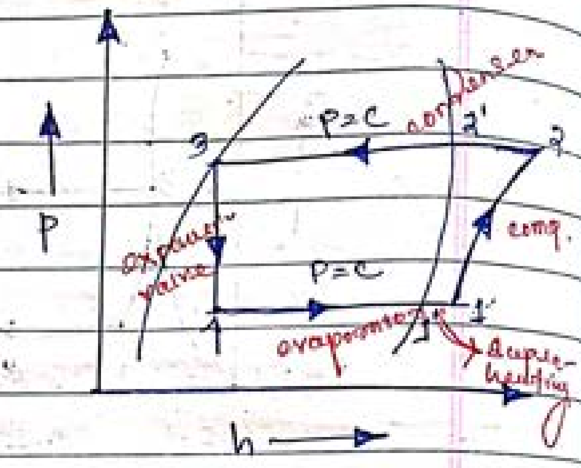
(4) The cycle Vapour Compression cycle with superheated vapour before compression :-





$$COP = \frac{RE}{W_{net}}$$

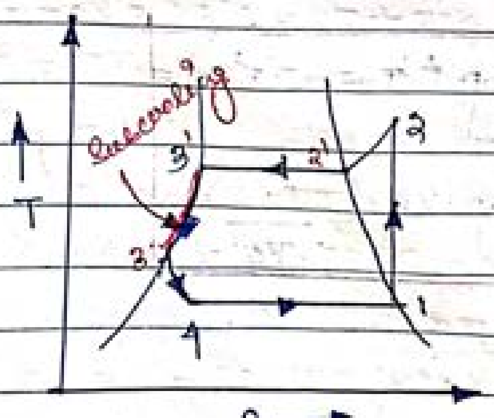
$$= \frac{h_1 - h_4}{h_2 - h_1}$$

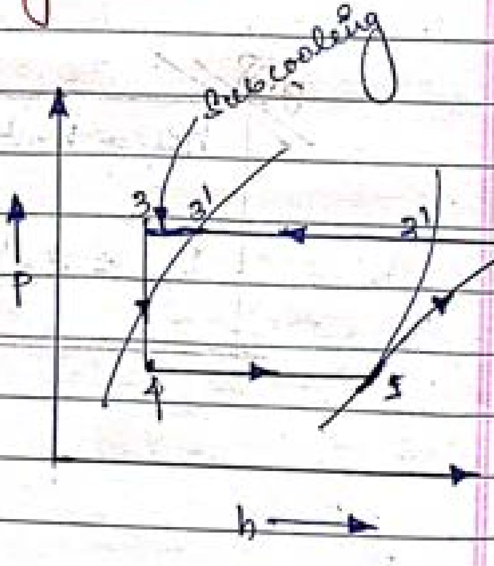
$$= \frac{h_1 - h_{F3}}{h_2 - h_1}$$

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

$$s_2 = s_2' + c_p \ln\left(\frac{T_2}{T_2'}\right)$$

(5) Vapour compression cycle with under cooling or subcooling of Refrigerant :-





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$$h_2 = h_2' + c_p (T_2 - T_2)$$
$$s_2 = s_2' + c_p \ln\left(\frac{T_2}{T_2'}\right)$$

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

(i) The refrigerant after condensation process 2', 3' is cooled below the saturation temperature (T_3') before expansion by throttling such a process is called undercooling or subcooling of the refrigerant, and lie on liquid line.

(ii) The effect of undercooling is to increased the value of C.O.P.

(iii) Undercooling is done by
(a) circulating more cooling water through the condenser
(b) by using a heat exchanger.
(c) by using water cooler with the main circulating water.

H.W :- Ex- 4.5, 4.7, 4.12, 4.13

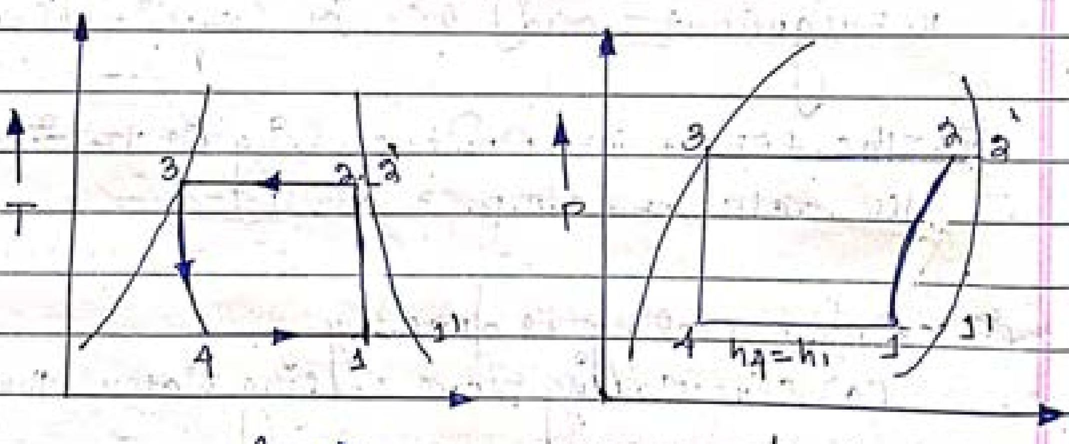
Homework

Problem - 4.5

Find the theoretical C.O.P for a CO_2 machine working between the temperature range of 25°C and -5°C. The dryness fraction of CO_2 gas during the suction stroke is 0.6. Following properties of CO_2 are given:-

Temp. °C	Liquid enthalpy KJ/kg	Liquid Entropy KJ/kg.K	Vapour Enthalpy KJ/kg	Vapour Entropy KJ/kg.K	latent heat KJ/kg
25	164.77	0.5978	282.23	0.9918	117.46
-5	72.57	0.2862	321.33	1.2146	248.76

Sol:- Given Data:



$T_{2'} = T_2 = 25°C = 25 + 273 = 298\ K$

$T_1 = T_4 = -5°C = -5 + 273 = 268\ K$

$x_1 = 0.6$

$h_{F3} = h_{F2} = 164.77\ KJ/Kg$

$h_{F1} = h_{F4} = 72.57\ KJ/Kg$

$s_{F2} = 0.5978\ KJ/Kg.K$

$s_{F1} = 0.2862\ KJ/Kg.K$

$h_{2'} = 282.23\ KJ/Kg$

$h_{1'} = 321.33\ KJ/Kg$

$s_{2'} = 0.9918\ KJ/Kg.K$

$s_{1'} = 1.2146\ KJ/Kg.K$

$h_{Fg_2} = 117.46\ KJ/Kg$

$h_{fg_1} = 248.76\ KJ/Kg$

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$\therefore s_1 = s_2$ —— (i)

So, $s_1 = s_{f1} + x_1 \times s_{fg_1}$

$= s_{f1} + x_1 \times \frac{h_{fg_1}}{T_1}$ —— (ii)

$s_2 = s_{f2} + x_2 \times s_{fg_2}$

$= s_{f2} + x_2 \times \frac{h_{fg_2}}{T_2}$ —— (iii)

Equating the eq^n (ii) and (iii) we get

$$s_{f1} + x_1 \times \frac{h_{fg_1}}{T_1} = s_{f2} + x_2 \times \frac{h_{fg_2}}{T_2}$$

$$\Rightarrow 0.2862 + 0.6 \times \frac{248.76}{268} = 0.5978 + x_2 \times \frac{117.46}{298}$$

$$\Rightarrow 0.8431 = 0.5978 + x_2 \times 0.3941$$

$$\Rightarrow x_2 = \frac{0.8431 - 0.5978}{0.3941}$$

$$\Rightarrow \boxed{x_2 = 0.622}$$

We know that

$h_1 = h_{f1} + x_1 \times h_{fg_1}$

$= 72.57 + 0.6 \times 248.76$

$= 221.826$ KJ/Kg

$h_2 = h_{f2} + x_2 \times h_{fg_2}$

$= 164.77 + 0.622 \times 117.46$

$= 242.528$ KJ/Kg

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Now we also know that

theoretical ... $COP = \frac{RE}{W_{net}}$

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

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

$= \frac{221.826 - 164.77}{237.88 - 221.826}$

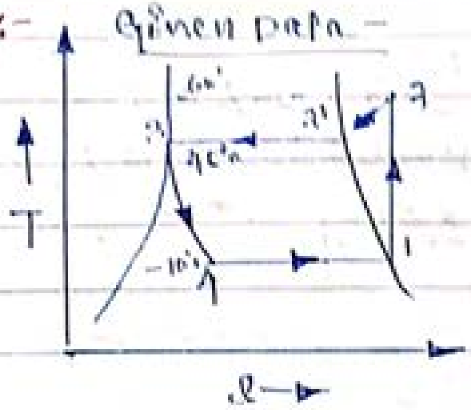
$\boxed{COP = 3.56}$ (Ans)

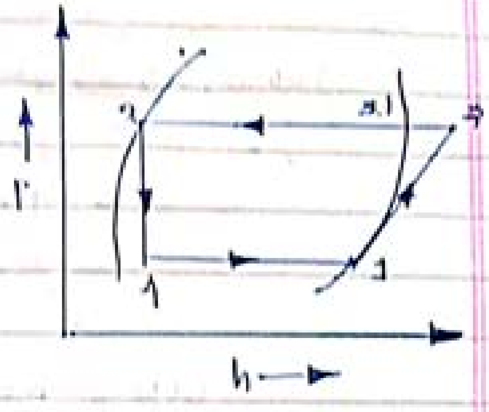
Problem - 4.7

A vapour compression refrigerator uses methyl chloride (R-40) and operates between temp^r. limits of $-10°C$ (T_1) and $45°C$ (T_2). At entry to the compressor the refrigerant is dry saturated and after compression it acquires a temp^r. of $60°C$. Find the COP of the refrigerator. The relevant properties of methyl chloride are as follows:

Sat. temp^r in °C	Enthalpy in KJ/kg liquid h_f	Enthalpy in KJ/kg vapour h_g	Entropy in KJ/kg liquid s_f	Entropy in KJ/kg vapour s_g
-10	45.4	460.7	0.183	1.637
45	133.0	483.6	0.485	1.587

Sol^n :- Given Data -





$T_1 = T_4 = -10°C = -10+273 = 263 K$

$T_{2'} = T_3 = 45°C = 45+273 = 318 K$

$T_2 = 60°C = 60+273 = 333 K$

$h_{f1} = 45.4$ KJ/Kg

$h_3 = h_4 = h_{f2} = 183$ KJ/Kg

$h_{g_1} = h_1 = 460.7$ KJ/Kg

$h_{2'} = 482.6$ KJ/Kg

$s_{f1} = 0.183$ KJ/Kg.K

$s_{f2} = 0.485$ KJ/Kg.K

$s_{g_1} = s_1 = s_2 = 1.637$ KJ/Kg

$s_{g_2} = s_{2'} = 1.587$ KJ/Kg.K

~~$s_2 = s_{2'} + 2.3\, cp \log\left(\frac{T_2}{T_{2'}}\right)$~~

Now $s_2 = s_{2'} + 2.3\, cp \log\left(\frac{T_2}{T_{2'}}\right)$

$\Rightarrow 1.637 = 1.587 + 2.3\, cp \log\left(\frac{333}{318}\right)$

$\Rightarrow \ldots \; 1.637 - 1.587 = 2.3\, cp \log\left(\frac{333}{318}\right)$

$\Rightarrow 0.05 = cp\, 0.046$

$\Rightarrow cp = \frac{0.05}{0.046}$

$\Rightarrow \boxed{cp = 1.086}$

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Now $h_2 = h_{2'} + c_p (T_2 - T_{2'})$
$= 483.6 + 1.086 (323 - 313)$
$= 499.89 \text{ KJ/kg}$

$\therefore COP = \frac{RE}{W_{net}}$
$= \frac{h_1 - h_4}{h_2 - h_1}$
$= \frac{h_1 - h_{f3}}{h_2 - h_1}$
$= \frac{460.7 - 133}{499.89 - 460.7}$

$COP = 8.36$ (Ans)

Problem – 4.8 :-

A simple refrigerant 134a (tetrafluroethane) heat pump for space heating, operates between temperature limits of 15°C and 50°C. The heat required to be pumped is 100 mJ/h. Determine: 1. the dryness fraction of refrigerant entering the evaporator; 2 – the discharge temperature (assuming the specific heat of vapour as 0.996 KJ/kg.K; 3 – the theoretical piston displacement of the compressor; 4. The theoretical power of the compressor; and 5 – the c.o.p. The specific volume of refrigerant 134a saturated vapour at 15°C is 0.04185 m3/kg. The other relevent properties of R-134a are given below:

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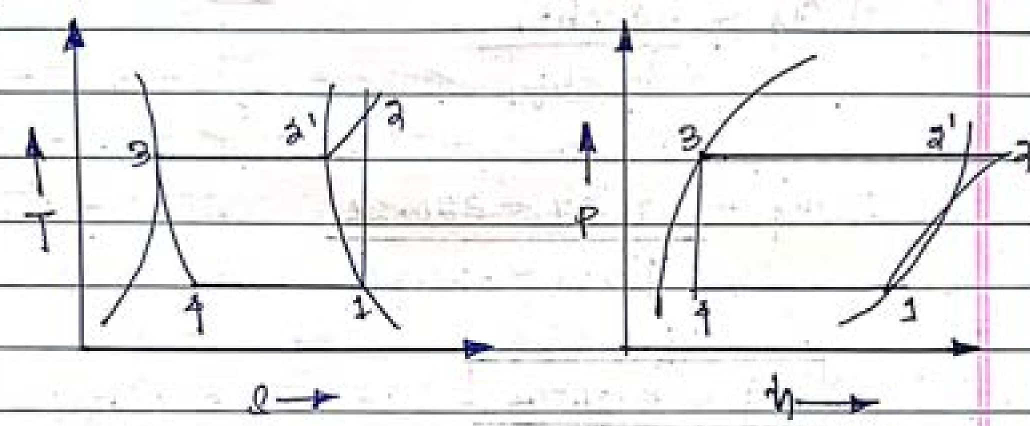
Sat. temp °C	Pressure bar	Specific enthalpy liquid h_f	vapour h_g	Specific entropy liquid s_f	Vapour s_g
15	4.887	220.26	413.6	1.0729	1.7439
50	13.18	271.97	430.4	1.2410	1.7312

Sol^n :-



$T_1 = T_4 = 15°C = 15 + 273 = 288 K$

$T_{2'} = T_3 = 50°C = 50 + 273 = 323 K$

$Q = 100 MJ/h = 100 \times 10^3 KJ/h$

$C_p = 0.996 KJ/kg.K$

$v_1 = v_g = 0.04185 m^3/kg$

$h_{f_1} = 220.26 KJ/kg$ h_{f_4}

$h_{g_1} = 413.6 KJ/kg$ h_{g_4}

$s_{f_1} = 1.0729 KJ/kg.K$

$s_{g_1} = 1.7439 KJ/kg.K$

$h_{f_3} = 271.97 KJ/kg$

$h_{g_{2'}} = 430.4 KJ/kg$ $h_{2'}$

$s_{f_3} = 1.2410 KJ/kg.K$

$s_{2'} = s_{g_{2'}} = 1.7312 KJ/kg.K$

$\therefore h_3 = h_4$

$\Rightarrow h_{f_3} = h_{f_4} + x_4 \times h_{fg_4}$

$\Rightarrow h_{f_3} = h_{f_4} + x_4 \times (h_{g_4} - h_{f_4})$

$\Rightarrow h_{f_3} - h_{f_4} = x_4 \times (h_{g_4} - h_{f_4})$

$\Rightarrow x_4 = \dfrac{h_{f3} - h_{f4}}{h_{g4} - h_{f4}}$

$\Rightarrow x_4 = \dfrac{h_{f3} - h_{f1}}{h_{g1} - h_{f1}}$

$\Rightarrow x_4 = \dfrac{h_4 - h_{f1}}{h_1 - h_{f1}}$

$\Rightarrow x_4 = \dfrac{271.97 - 220.26}{418.6 - 220.26}$

$\Rightarrow \boxed{x_4 = 0.2674}$

(ii) For the process 1-2

$s_1 = s_2 = s_{g1}$
$= 1.7439 \text{ KJ/kg.K}$

$s_{2'} = s_{g2'}$
$= 1.7312 \text{ KJ/kg.K}$

Now $s_2 = s_{2'} + c_p \ln\left(\dfrac{T_2}{T_{2'}}\right)$

$\Rightarrow c_p \ln\left(\dfrac{T_2}{T_{2'}}\right) = s_2 - s_{2'}$

$\Rightarrow 0.996 \ln\left(\dfrac{T_2}{323}\right) = 1.7439 - 1.7312$

$\Rightarrow \ln\left(\dfrac{T_2}{323}\right) = \dfrac{1.7439 - 1.7312}{0.996}$

$\Rightarrow \ln\left(\dfrac{T_2}{323}\right) = 0.0127$

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$$\Rightarrow \left(\frac{T_2}{323}\right) = e^{0.0127}$$

$$\Rightarrow \frac{T_2}{323} = 0.0128$$

$$\Rightarrow T_2 = 323 \times 0.0128$$

$$\Rightarrow \boxed{T_2 = 327.13\ K} \text{ or } 54.13^\circ C$$

(iii) The enthalpy at the discharge

$$h_2 = h_{2'} + C_p \times (T_2 - T_{2'})$$

$$= 430.4 + 2.996 \times (327.13 - 323)$$

$$\boxed{h_2 = \ldots\ (434.50\ KJ/kg)}$$

Now the heat required to be pumped

$$Q = m(h_2 - h_3)$$

$$\Rightarrow Q = m(h_2 - h_{f3})$$

$$\Rightarrow m = \frac{Q}{h_2 - h_{f3}}$$

$$\Rightarrow m = \frac{100 \times 10^3\ KJ/h}{434.5 - 271.97}$$

$$\Rightarrow m = 615.27\ kg/h$$

$$\Rightarrow m = \frac{615.27}{60}$$

$$\Rightarrow \boxed{m = 10.254\ kg/min}$$

∴ Now the theoretical piston displacement of compressor.

$$V_s = m_R \times v_1$$

$$= 10.254 \times 0.04185$$

$$\boxed{V_s = 0.429\ m^3/min}$$

(iv) Now the workdone by the comp.

$$W_C = m^\circ_R \times (h_2 - h_1)$$
$$= 10.254 \times (434.5 - 413.6)$$
$$= 214.3 \text{ KJ/min}$$
$$= \frac{214.3}{60} \text{ KJ/s}$$

$$\boxed{P = 3.57 \text{ KJ/s}}$$

(v) ∴ We know that

$$\therefore COP = \frac{RE}{W_{net}}$$
$$= \frac{h_1 - h_4}{h_2 - h_1}$$
$$= \frac{h_1 - h_{f3}}{h_2 - h_1}$$
$$= \frac{h_{g_1} - h_{f3}}{h_2 - h_{g_1}}$$

$$= \frac{413.6 - 271.97}{434.5 - 413.6}$$

$$\boxed{COP = 6.77} \quad \text{(Ans)}$$

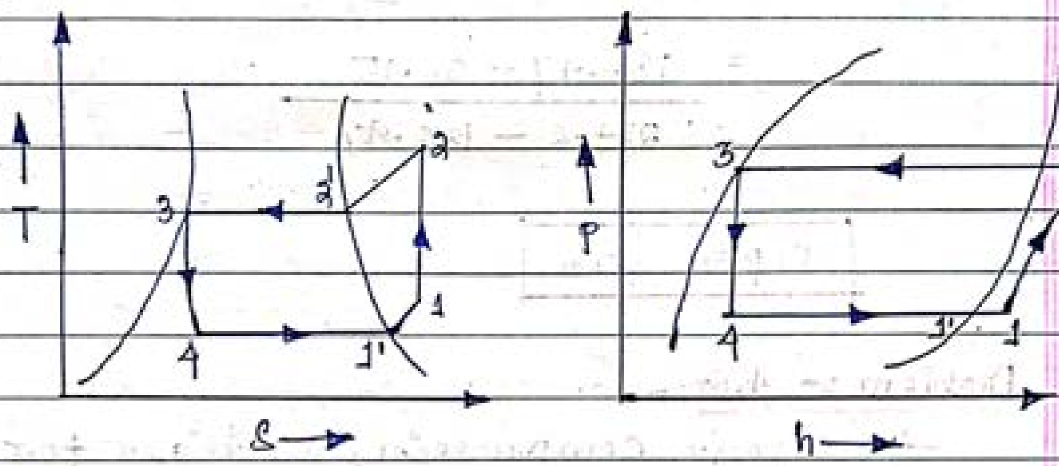
Problem - 4.12

A vapour compression refrigeration plant works between pressure limits of 5.3 bar (P_2) and 2.1 bar (P_1). The vapour is superheated at the end of compression. its temperature being 31°C. The vapour is superheated by 5°c before entering the compressor.

If the specific heat of superheated vapour is (C_P) 0.63 KJ/kg.K, Find the co-efficient of performance of the plant use the data given below:

Pressure bar	Saturation temp^{r}.	liquid heat KJ/kg (h_F)	latent heat KJ/kg (h_{fg})
5.3	15.5 T_2'	56.15	144.9
2.1	-14.0 T_1'	25.12	158.7

Ans :- Given Data :-



$P_2 = 5.3$ bar

$P_1 = 2.1$ bar

$T_2 = 37 + 273 = 310\,K$

$T_1 - T_1' = 5^\circ C - 5 + 273 = 268\,K$

$c_p = 0.63$ KJ/kg

$T_2' = 15.5 + 273 = 288.5\,K$

$T_1' = -14 + 273 = 259\,K$

$h_{F_3} = h_{F_2}' = 56.15$ KJ/kg

$h_{F_1}' = 25.12$ KJ/kg

$h_{Fg_2}' = 144.9$ KJ/kg

$h_{Fg_1}' = 158.7$ KJ/kg

$\therefore h_1 = h_1' + c_p(T_1 - T_1')$

$= (h_{F_1} + h_{Fg_2}') + c_p \times 5$

$= (25.12 + 144.9) + 0.63 \times 5$

$\boxed{h_1 = 186.97 \text{ KJ/kg}}$

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

$$= (h_{f_2}' + h_{fg_2}') + cp \times (T_2 - T_2')$$

$$= (56.15 + 144.9) + 0.63 \times (310 - 288.5)$$

$$\boxed{h_2 = 214.595 \text{ KJ/Kg}}$$

$$COP = \frac{h_1 - h_{f_3}}{h_2 - h_1}$$

$$= \frac{186.97 - 56.15}{214.6 - 186.97}$$

$$\boxed{COP = 4.73}$$

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Vapour absorption refrigeration System

CHAPTER-3

(i) In vapour absorption system, the compressor is replaced by an absorber, pump, generator, and a pressure reducing valve.

(ii) These components in VAS perform the same function as that of a compressor in vapour compression system.

(iii) In this system, the vapour refrigerant from the evaporator is drawn into an absorber where it is absorbed by the weak solution of the refrigerant forming a strong solution.

(iv) This strong solution pumped to the generator where it is heated by some external source. during heating the vapour refrigerant is driven off by the solution and enters into the condenser where it is liquidifire.

(v) The liquid refrigerant then flows into the evaporator to the receiver and expansion valve and ... the cycle is completed.

(vi) VAS uses heat energy instead of mechanical energy as in VCS. and a refrigerant commonly used in vapour absorption system is ammonia (NH_3).

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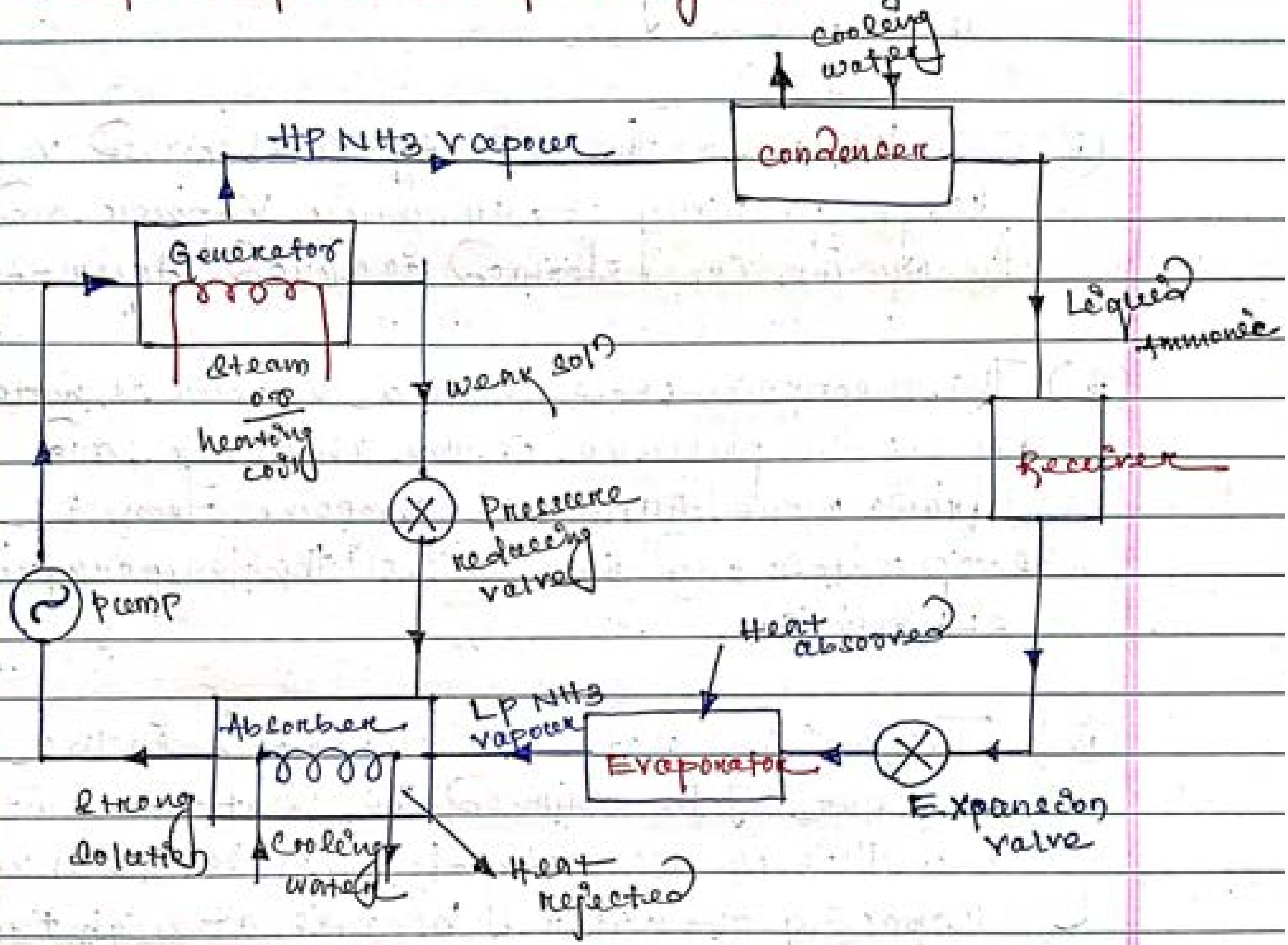
(vii) The VAS may be used in both domestic and large industrial refrigeration plant.

Simple vapour absorption system:-



Simple Ammonia Refrigerating system
or Simple VAS

(i) The simple ammonia VAS consists of an absorber, a pump, a generator and a pressure reducing valve to replaced the compressor of vapour compression system and the other components are condenser, Receiver, expansion valve and evaporator.

Working principle :-

(i) The low pressure ammonia vapour leaving a evaporator enters the absorver where it is absorved by the cold water in the absorver.

(ii) The Water has the ability to absorved very large quantity OF ammonia Vapour and the solution is formed is called Aqua-Ammonia.

(iii) The absorption OF Ammonia Vapour in water lowers the pressure in the absorver, and draws more Ammonia vapour from the evaporator and thus raises the temperature OF solution.

(iv) The cooling water is employed in the absorver to removed the Heat OF solution and this is necessary to increase the absorption Capacity OF water because at high tempr. water absorps less Ammonia Vapour.

(v) The strong solution thus formed in the absorver is pumped to the generator by liquid pump and its increases the pressure upto 10 bar.

(vi) The strong solution OF Ammonia in the generator is heated by some external source (Steam such as steam, gas or heating coil etc.

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(vii) During heating process the ammonia vapour is driven off the solution at high pressure leaving behind the hot weak ammonia solution in the generator.

(viii) This weak Ammonia solution flows back to the absorber at low pressure after passing through the pressure reducing valve.

(ix) The high pressure Ammonia Vapour from the generator is condensed in the condenser to a high pressure liquid Ammonia.

(x) This liquid Ammonia is passed to the expansion valve through the receiver and then to evaporator. This completes the cycle.

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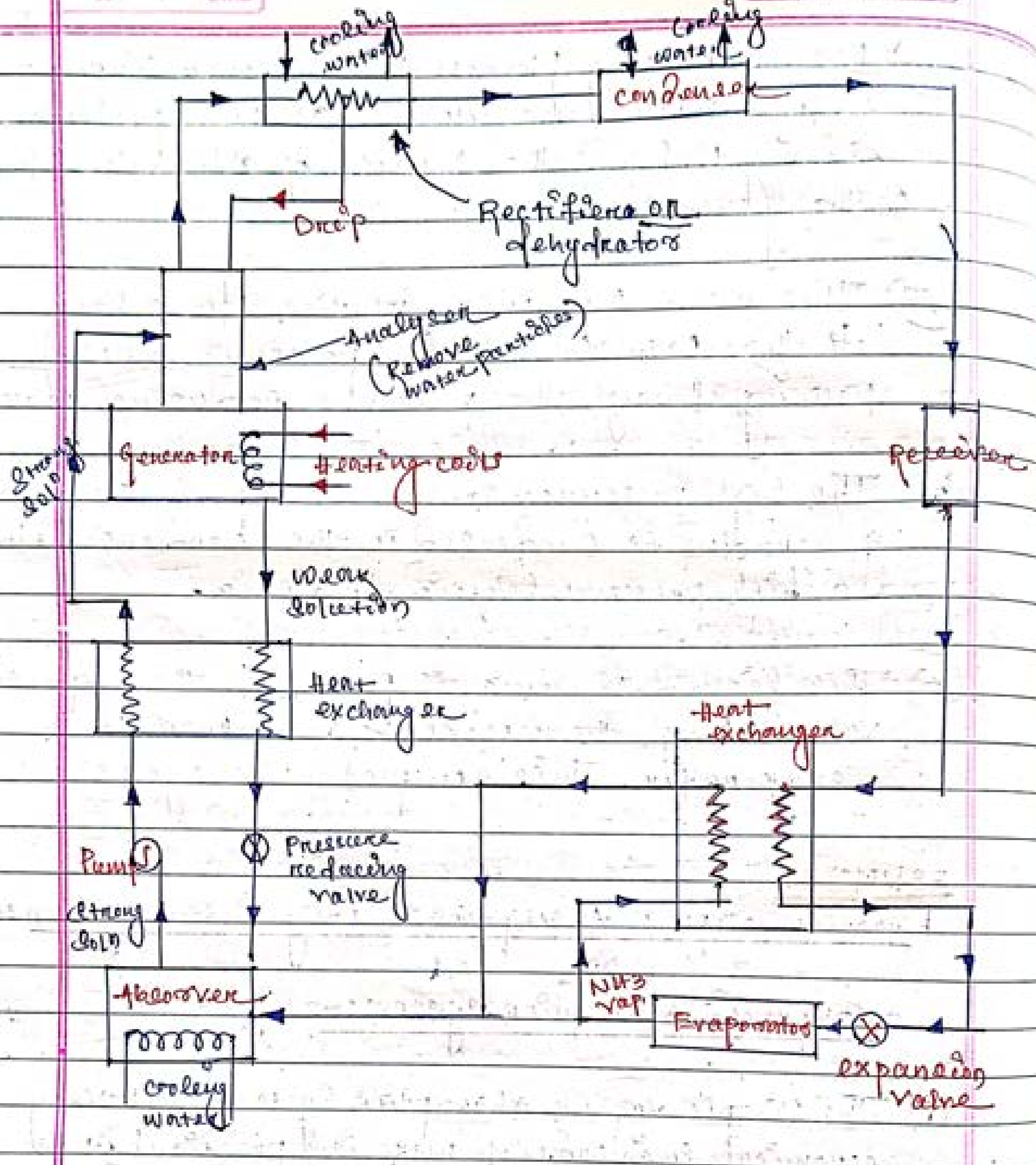
Practical vapour Absorption Refrigeration System:-

or

Improved Absorption System:-

(i) The simple vapour absorption system is not very economical so in order to make it practical it is fitted with an analyser, Rectifier and two heat exchangers in order to improved the performance of the plant.

(ii) Here also in place of compressor, absorber, Pump, Generator, pressure reducing valve, ~~absor~~ Condenser, Receiver, expansion valve and evaporator are used.



Analyser :-

(i) When Ammonia is vapourised in the generator, some water is also vapourised and will flow into the condenser along with Ammonia vapour.

(ii) If these unwanted water particles are not removed before entering into the condenser, they will enter into the expansion valve where they freeze checked the pipe line.

(iii) So in order to remove these unwanted water particles flowing into the condenser, an analyser is used.

(iv) An analyser may be built as an integrated part of the generator or made a separate piece of equipment.

(v) It consists of a series of trays mounted above the generator.

(vi) The strong solution from the absorber and the Aqua from the rectifier are introduced at the top of the analyser.

Rectifier:-

(i) In case the water vapours are not completely removed in the analyser, a closed type vapour cooler is used known as rectifier or dehydrator.

(ii) It is a water cooled, may be double pipe, shell and coils or shell and tube type.

(iii) Its function is to cool further ammonia vapour leaving the analyser, so that the remaining water vapour are condensed.

(iv) Thus only dry and an-hydrous Ammonia Vapour flow to the condenser and the condensate from the rectifier is returned to the top of the analyser by a drip returned pipe.

Heat exchanger :-

(A) i) The heat exchanger is provided between the pump and generator and is used to cooled weak hot soln returning from the generator to the absorber.

(ii) The heat remove from the weak soln raise the temperature of strong solution leaving the pump and going to the analyser and generator.

(iii) So this reduces the heat supplied to the generator and the amount of cooling required for the absorber.

(B) i) The second heat exchanger is provided between the condenser and evaporator and may be called liquid sub-cooler.

(ii) In this heat exchanger, the liquid refrigerant leaving the condenser is subcooled by low temperature Ammonia vapour from the evaporator and this subcooled liquid is now passed to the expansion valve and then to evaporator.

So, the C.O.P of the Refrigeration system

$$\text{COP} = \frac{\text{Heat absorbed in evaporator}}{\text{Workdone pump + Heat supplied to the generator}}$$

Difference between Vapour Absorption Refrigeration system and Vapour Compression Refrigeration system:-

Vapour Absorption Refrigeration system	Vapour Compression Refrigeration
(i) In VAS, the only moving part of the entire system is a pump, which has a small motor so, these system is Quiet and having little wear.	(i) In VCS, the moving part is compressor and of the same capacity has more wear, tear and noise.
(ii) It uses heat energy to change the condition of the refrigerant from the evaporator.	(ii) It uses mechanical energy to chang the condition of the refrigerant from evaporator
(iii) It can operate at reduced evaporator pressure and temperature by increasing the steam pressure to generator with little decrease in capaciting.	(iii) The capacity of vapour comp. system (VCS) drops rapidly with lowered evaporator pressure.

Superheating desired

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VAS	VCS
(iv) The load variation doesn't effect the performance of VAS.	(iv) The performance of VCS at partial loads is poor.
(v) In VAS the liquid refrigerant leaving the evaporator has no bad effect on the system accept reducing the refrigerating effect.	(v) In VCS, it is essential to superheat the vapour refrigerant leaving the evaporator so that no liquid may enter the compressor.

V.Imp

Analysis of vapour absorption system or COP of an ideal VAS :-

In an ideal VAS

(i) The heat (Q_G) is given to the refrigerant in the generator.

(ii) The heat (Q_C) is discharged to the atmosphere or cooling water from the condenser or absorber.

(iii) The heat (Q_E) is absorbed by the refrigerant in the evaporator.

(iv) The heat (Q_P) is added to the refrigerant due to pump.

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Neglecting heat due to pump work

$$\therefore \boxed{Q_C = Q_G + Q_E} \quad \text{——— (1)}$$

let,

$T_G \rightarrow$ The temp^r at which 'Q_G' is given to the generator.

$T_C \rightarrow$ The ~~con~~ temp^r. at which 'Q_C' is discharge to the atm. or cooling water from the condenser or absorber.

$T_E \rightarrow$ The temp^r. at which heat 'Q_E' is absorbed in evaporator.

$Q = f(T)$
$\dfrac{Q_1}{T_1} = \dfrac{Q_2}{T_2}$

Now consider to be rev. system from eq^n (1)

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

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

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

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

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

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

Imp

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

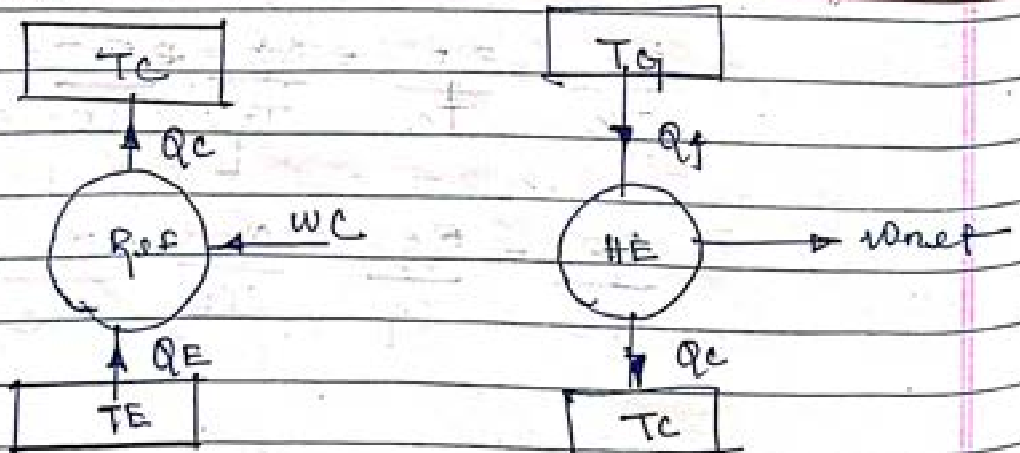
$$\therefore \text{ Maximum COP} = \frac{Q_E}{Q_G}$$

$$\Rightarrow (COP)_{max} = \frac{Q_E}{Q_E \times \left(\frac{T_C - T_E}{T_E}\right) \times \left(\frac{T_G}{T_G - T_C}\right)}$$

Imp

$$\Rightarrow \boxed{(COP)_{max} = \left(\frac{T_E}{T_C - T_E}\right) \times \left(\frac{T_G - T_C}{T_G}\right)}$$

$$\Rightarrow \boxed{(COP)_{max} = (COP)_{\text{Carnot Refrigerator}} \times \eta_{\text{Carnot Heat engine}}}$$



$\frac{T_E}{T_C - T_E}$ → The cop of Carnot refrigerator working between temperature 'T_E' and 'T_C'.

$\frac{T_G - T_C}{T_G}$ → The efficiency of Carnot Heat engine working between 'T_G' and 'T_C'.

imp

$$\therefore (COP)_{max} = \left(\frac{T_E}{T_A - T_E}\right) \times \left(\frac{T_G - T_A}{T_G}\right)$$

when absorver is given

Where,
T_A → The temp^r at heat is discharge in absorber

Homework
Problem - 7.1
In a vapour absorption refrigeration system, heating, cooling and refrigeration take place at the temperature of 100°C, 20°C and −5°C respectively. Find the max. C.O.P of the system.

Given Data

$T_G = 100 + 273 = 373\ K$
$T_C = 20 + 273 = 293\ K$
$T_E = -5 + 273 = 268\ K$

∴ Now the $(C.O.P)_{max}$.

$$(COP)_{max.} = \left(\frac{T_E}{T_C - T_E}\right) \times \left(\frac{T_g - T_C}{T_g}\right)$$

$$= \left(\frac{268}{293 - 268}\right) \times \left(\frac{373 - 293}{373}\right)$$

$$(COP)_{max} = 2.27$$ (Ans)

Homework

Imp Problem - 7.2

In an absorption type refrigerator, the heat is supplied to NH_3 generator by condensing steam at 2 bar and 90% dry. The temperature in the refrigerator is to be maintained at −5°c. Find the maximum C.O.P possible.

If the refrigeration load is 20 tonnes and actual C.O.P. is 70% of the maximum C.O.P. Find the mass of steam required per hour. Take temperature of the atmosphere as 30°c.

Soln :- Given Data

$P = 2$ bar

$x = 90\% = 0.9$

$T_E = -5°C = -5 + 273 = 268K$

$Q = 20\ TR$

Actual C.O.P = 70% OF max. C.O.P

$T_C = 30°C = 30 + 273 = 303\ K$

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From the steam table - 2 , P = 2 bar

$T_G = 120.23°C$
$= 120.23 + 273$
$= 393.23\ K$

We know that max. C.O.P.

$$\left[\frac{T_E}{T_C - T_E}\right] \times \left[\frac{T_G - T_C}{T_G}\right]$$

$$= \left[\frac{268}{303 - 268}\right] \times \left[\frac{393.23 - 303}{393.23}\right]$$

$(C.O.P)_{max.} = 1.756$ (Ans)

Mass of steam required per hour.

We know that actual C.O.P.

$= 70\%$ of max. C.O.P
$= 0.7 \times 1.756$

$(C.O.P)_{act} = 1.229$ (Ans)

∴ Actual heat supplied $= \frac{\text{Refrigeration load}}{\text{Actual C.O.P}}$

$= \frac{20 \times 210}{1.229}$

$= 3417.41\ KJ/min$

Assuming that only latent heat of steam is used for heating purposes, therefore from steam table-2 the latent heat of steam at 2 bar is $h_{fg} = 2201.9\ KJ/kg$

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∴ Mass of steam required per hour

$$= \frac{\text{Actual heat supplied}}{h_{fg}}$$

$$= \frac{3417.41}{2201.9}$$

$= 1.552$ kg/min

$= 1.552 \times 60$

$= 93.12$ kg/h (Ans)

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CHAPTER-4

Refrigeration Equipments

(A) Refrigerant compressors :-

(i) A refrigerant compressor is a machine used to compressed the vapour refrigerant from the evaporator, and raise its pressure show that the corresponding saturation temperature is higher than that of the cooling medium.

(ii) It also circulates the refrigerant through the refrigerating system.

(iii) Since the compression of refrigerant requires some work to be done on it so a compressor must be driven by some prime-mover.

imp Principle of working and constructional details of reciprocating compressors :-

(i) The compressors in which the vapour refrigerant is compressed by the compressors that is back and forth motion of the piston are called reciprocating compressors.

(ii) These compressors are used for refrigerant which has comparatively low volume per kg of refrigerant and large differential pressure. Such as Ammonia (R-717), methyle chloride (R-40), R-12, R-22 etc.

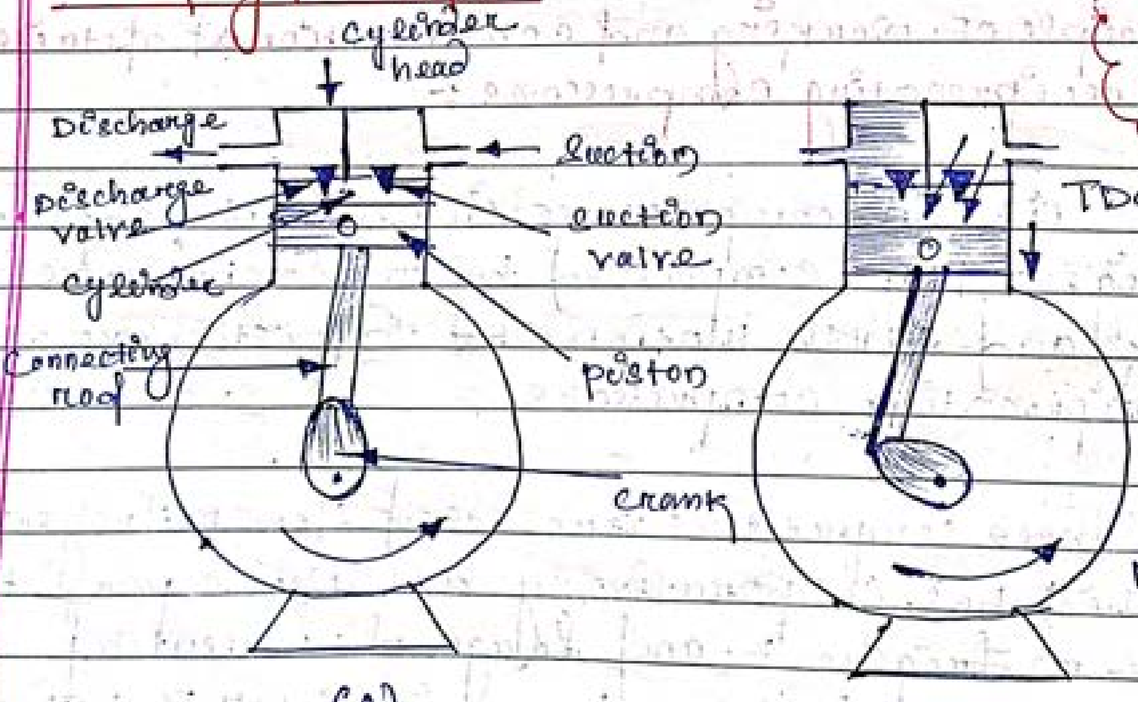
(iii) The reciprocating compressors are available in sizes as small as $\frac{1}{12}$ kW which are used in small domestic refrigerators and upto about 150 kW for large capacity.

(iv) Two types of reciprocating compressors are used and are -
(1) Single acting vertical compressor.
(2) Double acting horizontal compressor.

(v) The single acting compressors have their cylinder arranged vertically, Radially or V or W form. Where as the double acting compressor have their cylinder arranged horizontally.

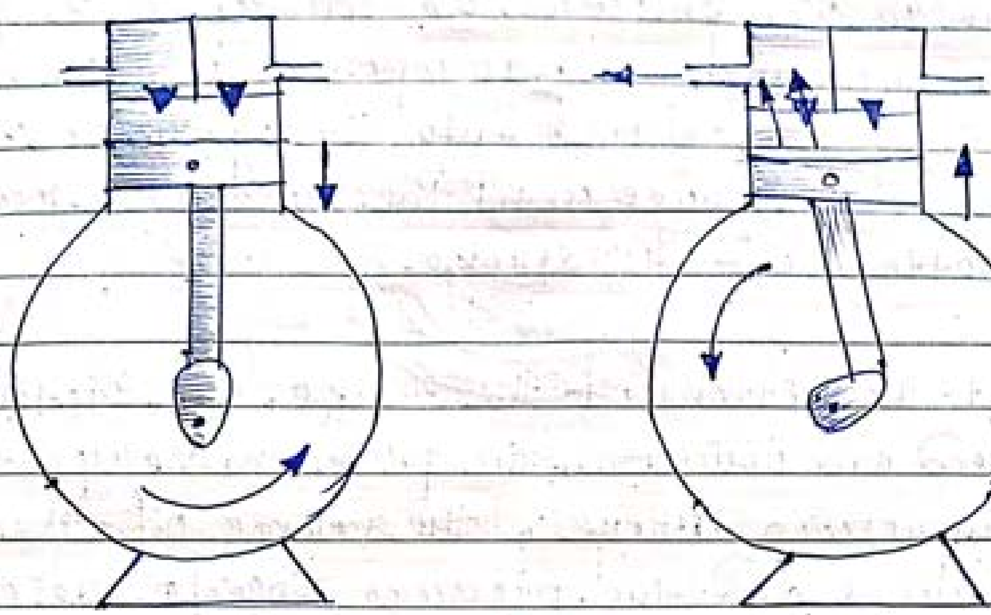
Working principle:-

Suction
compression
Discharge



(A)
Suction valve = closed.
Delivery valve = closed

(b)
Suction valve = opened



(c) Suction valve = closed

(d) Delivery valve = opened

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(i) Let us consider that the piston is at the top of it stroke and is known as TDC position of the piston and in this position the suction valve is closed as the pressure in the clearance space between the top of the piston and the cylinder head as shown in Figure-(a).

(ii) The discharge valve is also held closed as the cylinder head pressure acting on the top of the piston. When the piston moves downward during suction stroke, the refrigerant left in the clearance space expands thus the volume of the cylinder above the piston increases and the pressure inside the cylinder decreases as shown in Figure-(b).

(iii) When the pressure becomes slightly less than the suction pressure or atmospheric pressure, the suction valve gets opened and the vapour refrigerant flows into the cylinder ∴ this flow continues until the pressure reaches the bottom of its stroke.

(iv) At the bottom of the stroke, the suction valve closed and now ... the piston move upward during compression stroke, the volume of the cylinder decreases and the pressure inside the cylinder increases as shown in Figure-c.

(v) When the pressure inside the cylinder becomes greater than that on the top of the discharged valve and the discharge valve gets opened as shown in figure-d. so the vapour refrigerant is discharged into the condenser and the cycle is repeated.

→ In single acting reciprocating compressor, the suction, compression and discharge of refrigerant takes place in two stroke of the piston and one revolution of the crank shaft.

→ In double acting reciprocating compressor, the suction and compression takes place on both side of the piston.

Rotary compressor :-

(i) In rotary compressors, the vapour refrigerant from the evaporator is compressed due to movement of blade.

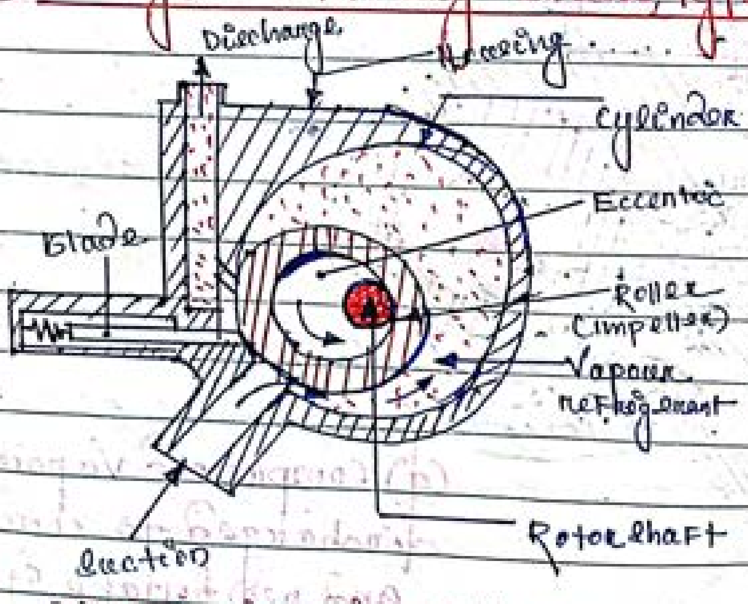
(ii) The rotary compressors are positive displacement type compressors.

(iii) The clearance in rotary compressors is negligible so, they have high volumetric efficiency.

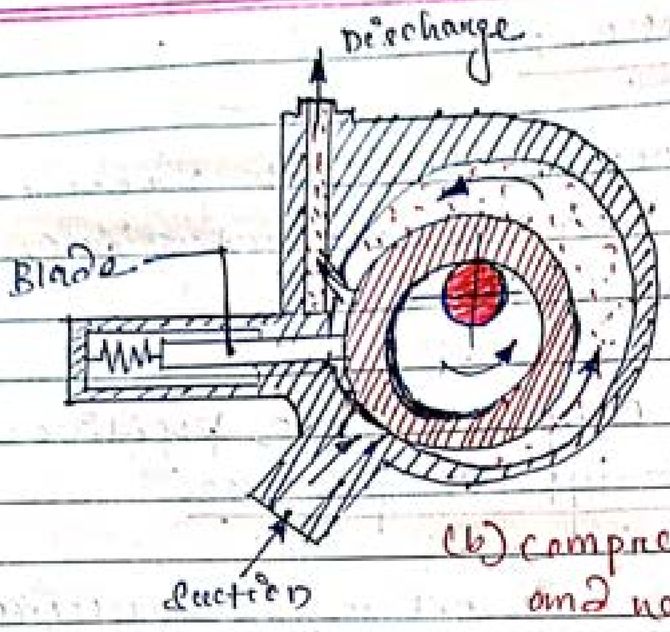
(iv) These compressors may be used with refrigerants R-12, R-22, R-114 and Ammonia etc.

(v) There are two types of rotary compressors
 (a) Single stationary blade type rotary compressors.
 (b) Rotating blade type rotary compressors.

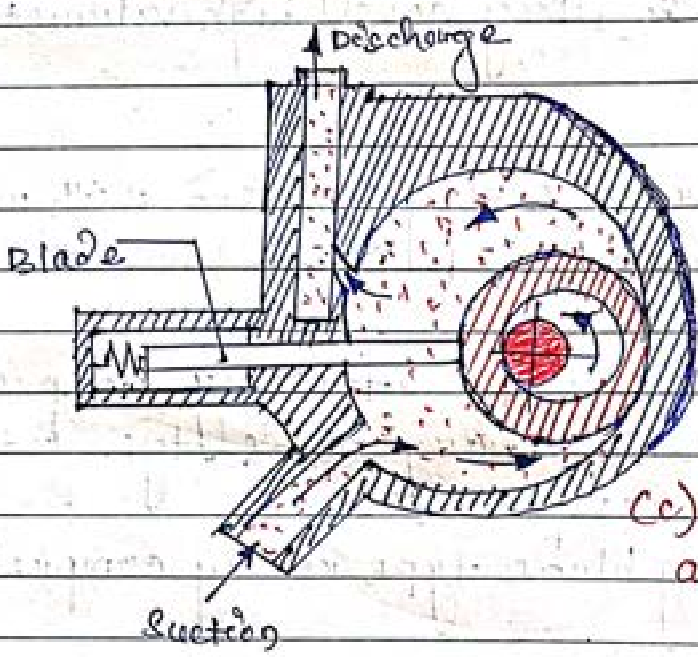
(a) Single stationary blade type rotary compressor :-



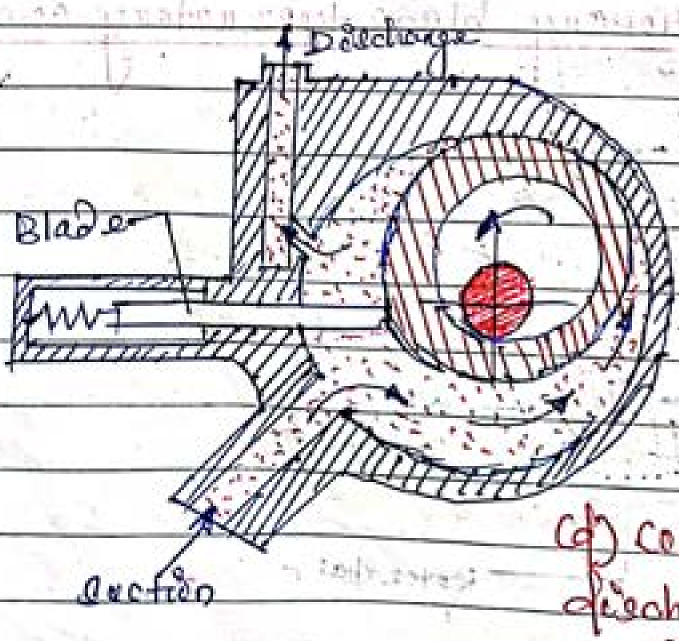
(a) completion of intake stroke and beginning of compression.



(b) compression stroke continued and new intake stroke started



(c) compression continued and new intake stroke continued.



(d) compressed vapour discharged to condenser and new intake stroke continues.

(i) A single stationary blade-type rotary compressor consist of a single stationary cylinder, a roller and a shaft.

(ii) The shaft has and eccentric on which the roller is mounted. A blade is set into the sloped of a cylinder so as to maintained contacts with the roller by a spring.

(iii) The blade move in or out of the slot to follow the rotor when its rotates so, the blade separates the suction and discharge ports. hence it is also known as sealing blade.

(iv) When the shaft rotates, the roller also rotates so that it touches the cylinder wall.

(v) Various positions of roller is shown in figure 'a' to 'd' as the vapour refrigerant is compressed. figure 'a' shows the completion of intake stroke and the begging of compression stroke.

(vi) When the rollers rotates the vapour refrigerant ahead of the roller is being compressed and the new intake from the evaporator is drawn into the cylinder, as shown in figure 'b'.

(vii) As the rollers turns towards mid position, more vapour refrigerant is drawn into the cylinder while the compressed refrigerant is discharged to the condenser as shown in Fig. 'c'.

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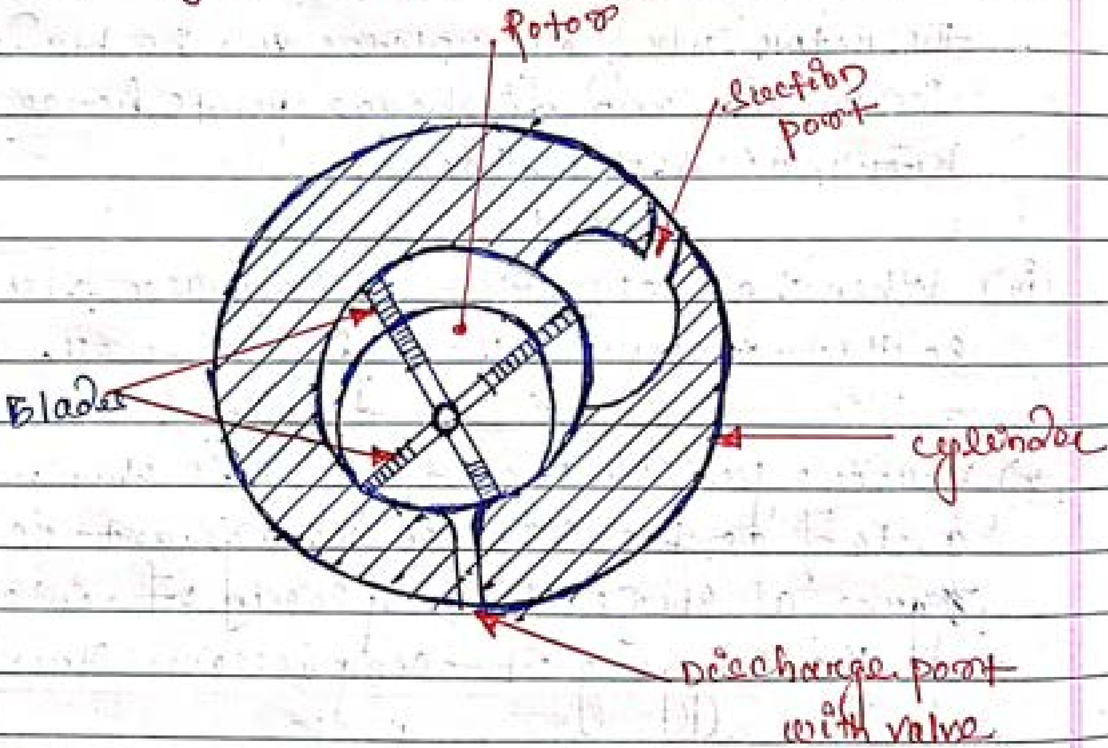
(viii) At the end of the compression stroke most of the compressed vapour refrigerant is passed through the discharged port to the condenser as shown in Figure 'd'.

(ix) A new charge of refrigerant is drawn into the cylinder and the cycle repeats.

(b) Rotating blade-type rotary compressor:-



(i) It consists of cylinder, rotor containing number of blade, suction port and discharge port.

(ii) The centre of the rotor is eccentric with the cylinder. The blades are forced against the cylinder walls by the centrifugal action during the rotation of the motor.

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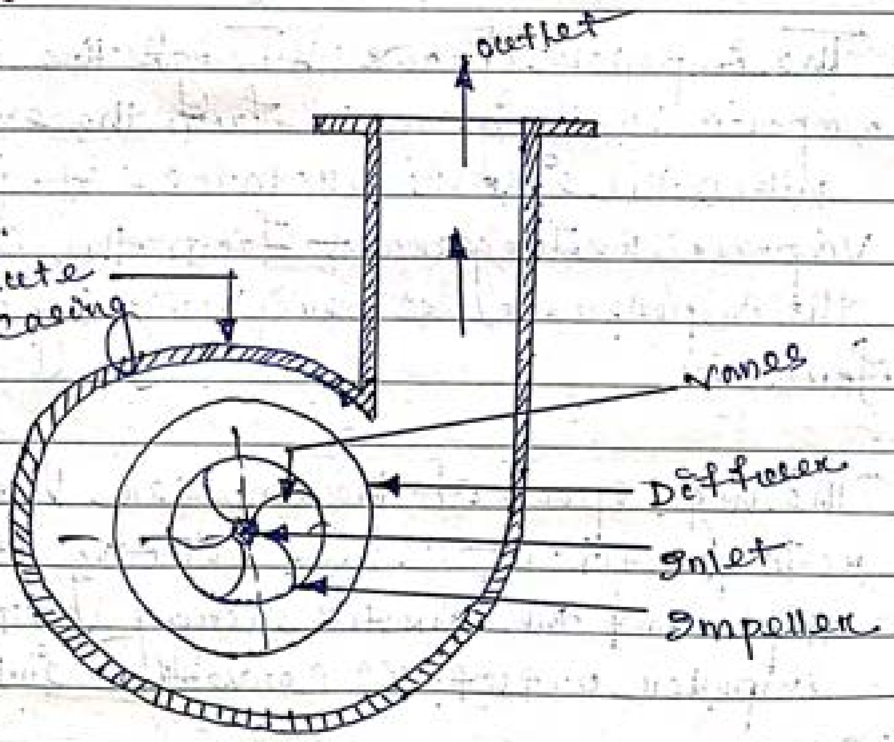
(iii) The low pressure and temperature vapour refrigerant from the evaporator is drawn through the suction port.

(iv) As the rotor turns, the suction vapour refrigerant entrapped between the two adjacent blades and is compressed.

(v) The compressed refrigerant at high pressure and tempr. is discharged through the discharge port to the condenser.

Centrifugal compressor :-



This compressor increases the pressure of low pressure vapour refrigerant to a high pressure by centrifugal force.

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Application :-

(ii) The centrefugal compressor is generally used for refrigerant that requires large displacement and low condensing pressure using refrigerant R-11, R-113 etc.

Working principle :-

(i) A single stage centrefugal compressor consists of an impeller with no. of curved vanes fitted symmetrically.

(ii) The impeller rotates in an air tight volute casing with inlet and outlet points.

(iii) The impeller draws ... in low pressure vapour refrigerant from the evaporator and when the impeller rotates, it pushes the vapour refrigerant from the centre of the impeller to its periphery by centrefugal force.

(iv) The high speed of the impeller leaves the vapour refrigerant at a high velocity at the vane tips and the kinetic energy attained at the impeller outlet is converted into pressure energy.

(v) The high velocity vapour refrigerant passes over the diffuser ... and the volute casing collects the refrigerant from the diffuser and convert the kinetic energy into pressure energy, before its leaves the refrigerant to the evaporators.

Important terms :-

(1) Suction pressure :-

It is the absolute pressure of refrigerant at the inlet of a compressor.

(2) Discharge pressure :-

It is the absolute pressure (unknown pressure) of refrigerant at the outlet of a compressor.

(3) Compression ratio or Pressure ratio :-

(i) It is the ratio of absolute discharge pressure to the absolute suction pressure. ($\because r_p = \frac{P_2}{P_1}$)

(ii) The value of compression ratio is more than one.

(iii) It also defined as the ratio of total cylinder volume to the clearance volume.

i.e. $$r_p = \frac{P_2}{P_1}$$

or $$r_p = \frac{V_{total}}{V_c}$$

(4) Suction Volume:-

It is the volume of refrigerant sucked by the compressor during its suction stroke.

(5) Clearance Factor:-

It is the ratio of clearance volume to piston displacement volume.

(ii) It is denoted as 'C' or 'K'.

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

Imp
(6) Swept volume:-

(i) It is the volume swept by the piston when it moves from its TDC to BDC or inner dead centre to outer dead centre.

(ii) It is also known as stroke volume or piston displacement volume.

(iii) It is denoted as 'V_s' or 'V_p'.

$$\therefore V_s = \frac{\pi}{4} D^2 L$$

Where, D → Diameter of the cylinder.
L → The length of stroke

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(7) Compressor Capacity :-

(i) It is the volume of actual amount of refrigerant passing through the compressor in a unit time.

(ii) It is equal to the suction Volume and expressed in m^3/s.

Imp (8) Volumetric efficiency :-

(i) It is the ratio of compressor capacity or the suction volume or actual Volume to the piston displacement volume.

(ii) It is denoted as η_v.

$$\therefore \eta_v = \frac{V_a}{V_s}$$

(iii) A good compressor has volumetric efficiency of 70% to 80%.

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Harmetically sealed compressor :-

(i) When the compressor and motor operate on the same shaft and are enclosed in a common casing are known as harmetic sealed compressor.

(ii) These types of compressors eliminate the use of crank shaft seal in order to prevent leakage of refrigerant which is necessary in ordinary compressor.

(iii) These compressors may operate on either reciprocating or rotary principle.

(iv) These are mountained with the shaft in either vertical or horizontal position.

(v) So, harmetic mean - tightly sealed, so its refers to air - tight seals used to maintained a closed system of operation.

(vi) The harmetic sealed compressor are widely used for small capacity refrigerating system such as in domestic refrigerator, window air conditioner, home freezer etc.

Advantages :-

(i) The leakage of refrigerant is completely prevented.

(ii) It is less noisy.

(iii) It requires small space because of compactness.

(iv) The lubrication is simple as motor and compressor operate in a sealed space with lubricating oil.

Disadvantages :-

(i) The maintanance is not easy because the moving parts are inaccessible.

(ii) A separate pump is required for evaquation and charging of refrigerant.

Semi-harmetically sealed compressors :-

(i) In semi-harmetically compressor the motor and compressor are often housed together but they can be accessed as needed.

(ii) A semi-harmatic compressor is a unit that the body of compressor along with the engine sealed inside the casing during operation and the casing is of cast-Iron.

Application :-

(i) These are used in refrigeration and air conditioning unit.

(ii) Air conditioning system used for the environmental control of buildings.

Advantages :-

(i) These enables maintanance check and repairs or replacement of parts as they degrade rather than a total Failure of the system.

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Condensers

(i) Condensers function is to remove heat of the hot vapour refrigerant discharged from the compressor.

(ii) It is used in high pressure side of a refrigerating system.

(iii) The hot vapour refrigerant consist of heat absorbed by the evaporator and the heat of compressor added by the mechanical energy of compressor motor.

(iv) The heat from the hot vapour refrigerant in a condenser is removed first by transferring it to the walls of the condenser tube and then tube to the condensing or cooling medium which may be air or water.

(v) According to condensing medium condensers are classified as :
(a) Air cooled condenser.
(b) Water cooled condenser.
(c) Evaporative condensers.

Principle of working and constructional details of air cooled condensers :-

Construction :-

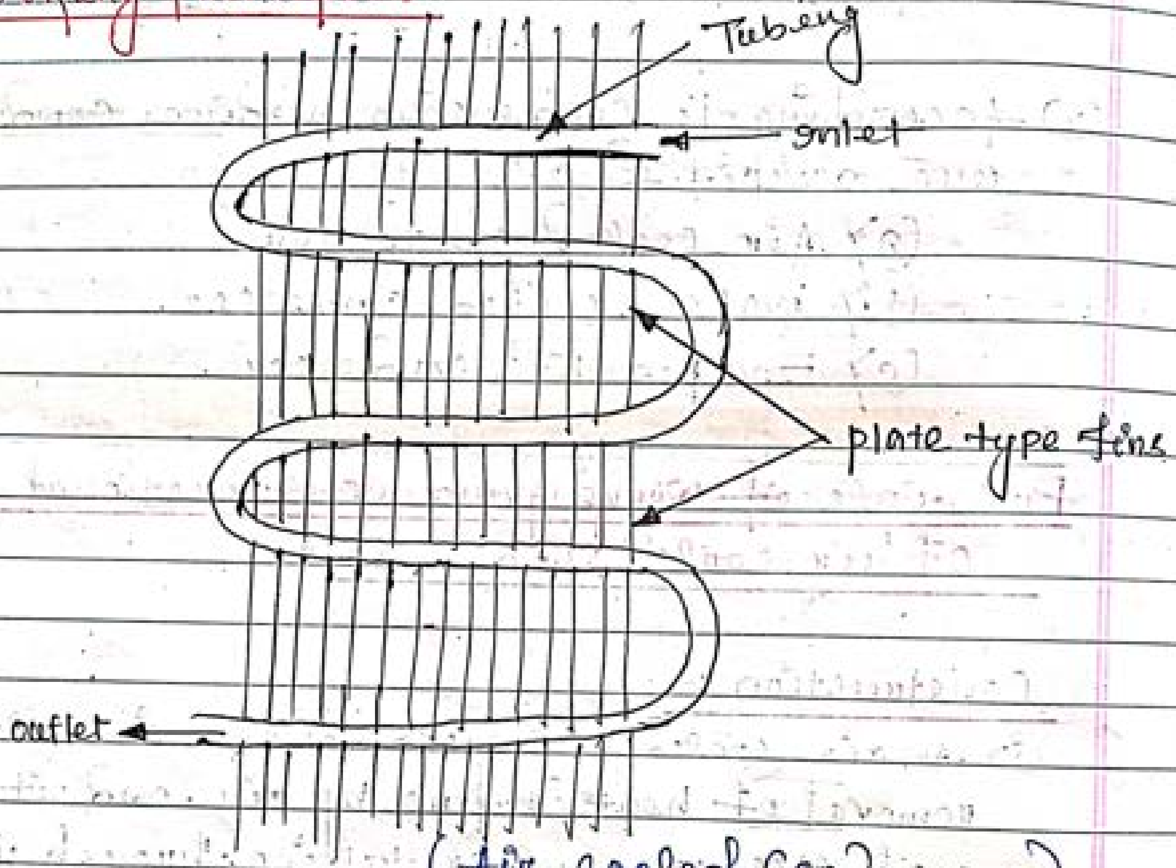
(i) An air cooled condenser is one in which the removal of heat is done by air and it consist of steel or copper tubing through which the refrigerant flows.

(ii) The size of the tube ranges from 6mm to 18mm outside diameter depending upon the size of condenser. generally the copper tubes are used because of its excellent heat transfer ability.

(iii) The condenser with steel tubes are used in Ammonia refrigerating system.

(iv) The tubes are provided with plate type fins (heat transfer) to increase the surface area for the heat transfer and fins are made from Aluminium due to its light weight.

Working principle:-



(Air cooled condensers)

(i) In air cooled condenser, the air tempr. rises as it passes through each row of tubing. So, the condensers with single row of tubing provides most efficient heat transfer.

(ii) The single row condensers require more space than multi row condensers and are used in domestic refrigerators, freezers, water coolers and room air conditioners.

Convection (It is a mode of Heat transfer)

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(iii) Air cooled condensers may have two or more rows of tubing but the condensers with upto six rows of tubing are common.

(iv) Air cooled condensers are two types
(a) Natural convection air cooled condenser
(b) Forced convection air cooled condenser.

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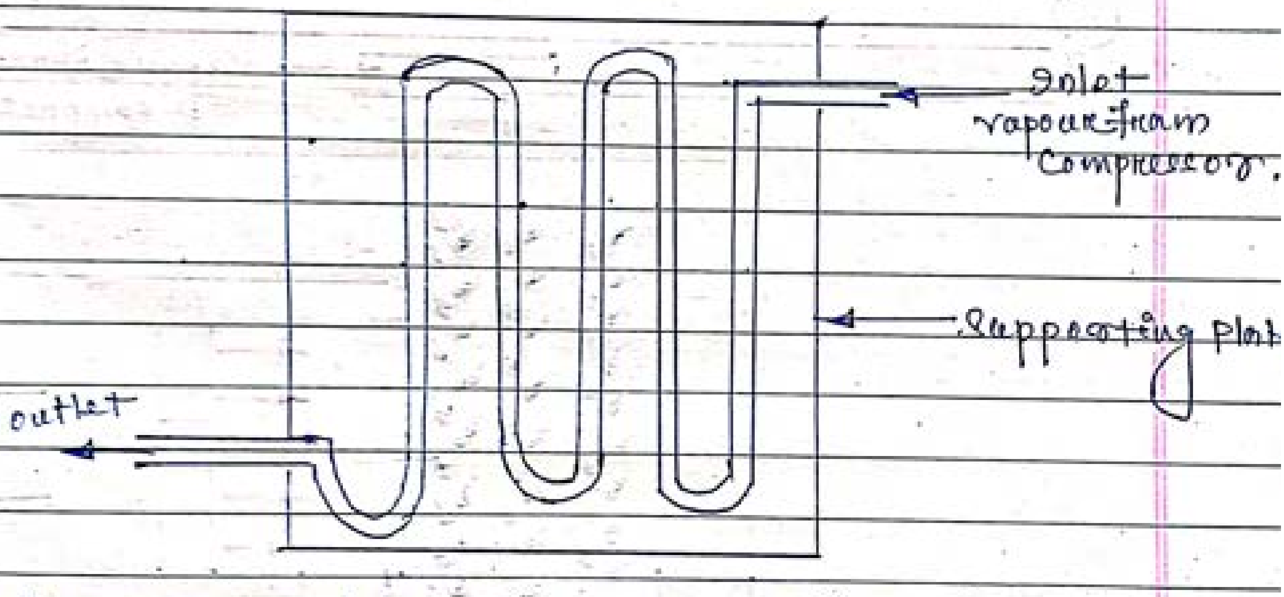
(a) Natural convection air cooled condenser :-



(i) In natural convection air cooled condenser, the heat transfer from the condenser coils to the air is done by natural convection.

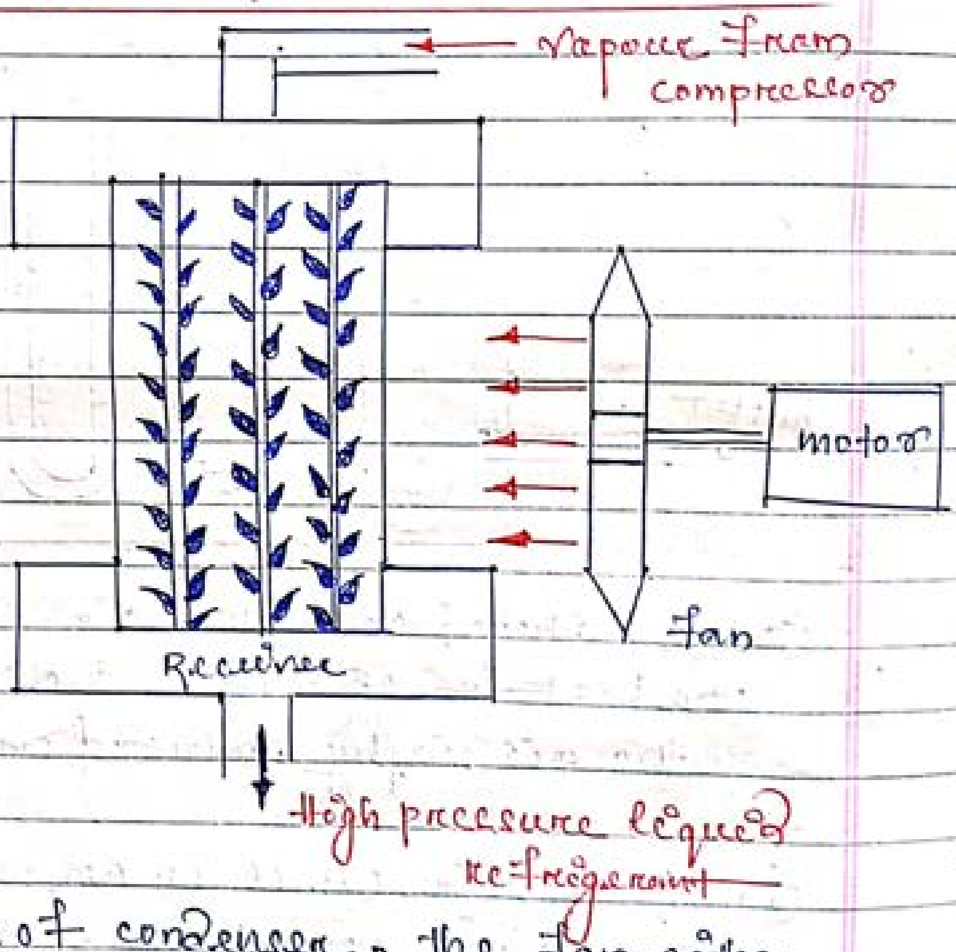
(ii) As the air comes in contact with the warm condenser tubes, it absorbs heat from the refrigerant and thus the temperature of air increases.

(iii) The warm air being lighter, rises up and the cold air from below rises to take away the heat from the condenser. This cycle continues in natural convection air cooled condensers.

Applications:-

The natural convection air cooled condenser are used in domestic refrigerator, freezers, water coolers, room air conditioner etc.

(b) Forced convection Air cooled condenser:-



(i) In this type of condenser, the fan either propeller or centrifugal is used to forced the air over the condenser coil to increase its heat transfer capacity.

(ii) The forced convection air cooled condenser are of 2 types i.e.:
(a) Base mounted air cooled condensers
(b) Remote air cooled condensers.

(iii) The base mounted air cooled condenser using propeller fans are mounted on the same base of compressor, motor, receiver and other controls, and the total arrangement is called condensing unit.

(iv) This type of condensing unit is used for refrigeration system of 10 Tonnes or less.

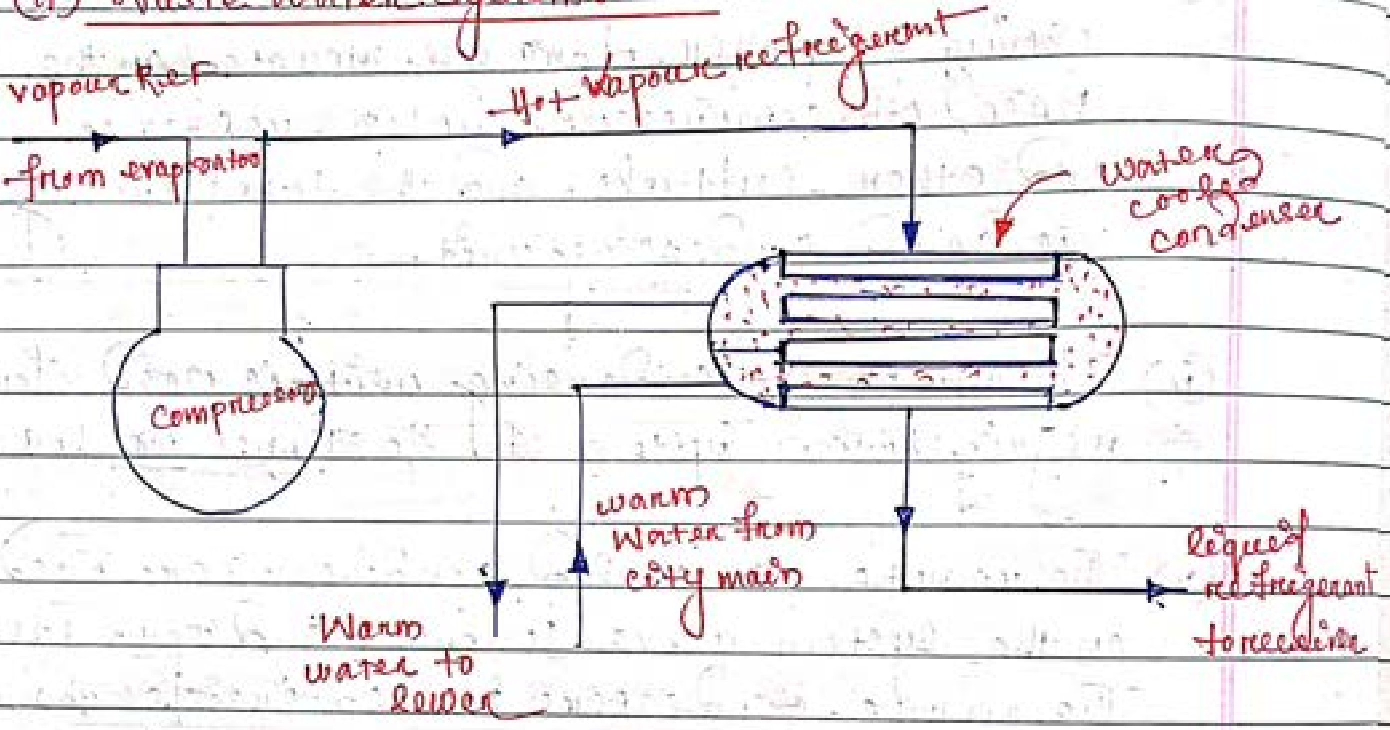
(v) The remote air cooled condensers are used on the system above 10 tonnes and upto 125 tonnes. The remote condensers located inside the building which requires duct work to carry air to and from the unit.

(b) Water cooled condensers:-
(i) A water cooled condenser is one in which water is used as the condensing medium. they are always preferred when an adequate amount of clean inexpensive water is supplied and means of water disposal are available.

(ii) These are used in commercial and industrial refrigerating units

(iii) The water cooled condensers :- used two water systems and are -
(a) Waste water system.
(b) Recirculated water system.

(a) Waste water system :-



(i) In waste water system the water after circulating in the condenser is discharge to a sewer and this system is used in small units and in locations where large quantities of fresh in expensive water and a sewer system large enough to handle the waste water available.

(ii) This mostly a source of fresh water supply is from the city main.

Simple Vapour Compression Refrigeration System

Problem - 2.1

A refrigeration system of 15 tone capacity operates on standard vapour compression cycle using refrigerant F22 at an evaporating temp. of 5°c and condensing temperature of 50°c. Refrigerant is dry and saturated at the inlet of the compressor calculate:

- Refrigerating effect
- Mass flow rate in Kg/s

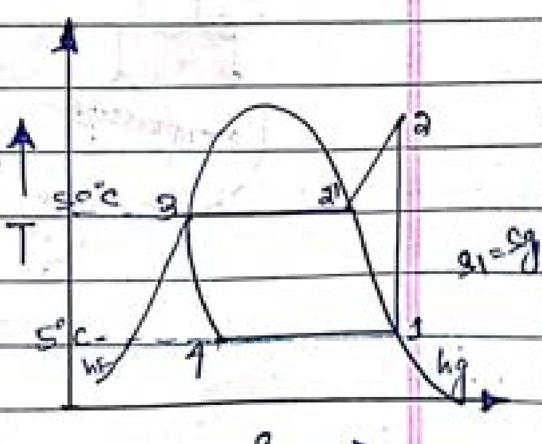
Use the following table -

Temp. °C	press (bar)	Enthalpy (KJ/kg)		Volume (m³/kg)	
		liquid (h_f)	Vapour (h_g)	liquid (v_f)	Vapour (v_g)
5	5.836	206.9	407.1	0.791	0.0404
50	19.423	263.3	417.7	0.922	0.0117

Soln :- Given Data

Capacity = 15 tone

$Q = 15 \times 210 = 3150$ KJ/min.



$T_2 = 50°C = 50 + 273 = 323$ K

$T_1 = 5°C = 5 + 273 = 278$ K

~~P = 19.423~~

~~P_2 = 5.836 bar~~

From the table,

$h_1 = h_g = 407.1$ KJ/Kg

$h_F = h_4 = h_{F3} = 263.3$ KJ/Kg

We Know that the
Refrigerating effect (RE) $= h_1 - h_4$
$= h_1 - h_{F3}$
$= 407.1 - 263.3$
$= 143.8$ KJ/Kg

Now $Q = \dot{m} \times (h_1 - h_{F3})$

$\Rightarrow \dot{m} = \dfrac{Q}{(h_1 - h_{F3})}$

$\Rightarrow \dot{m} = \dfrac{3150}{143.8}$

$\Rightarrow \boxed{\dot{m} = 21.90 \text{ Kg/s}}$ (Ans)

R.E
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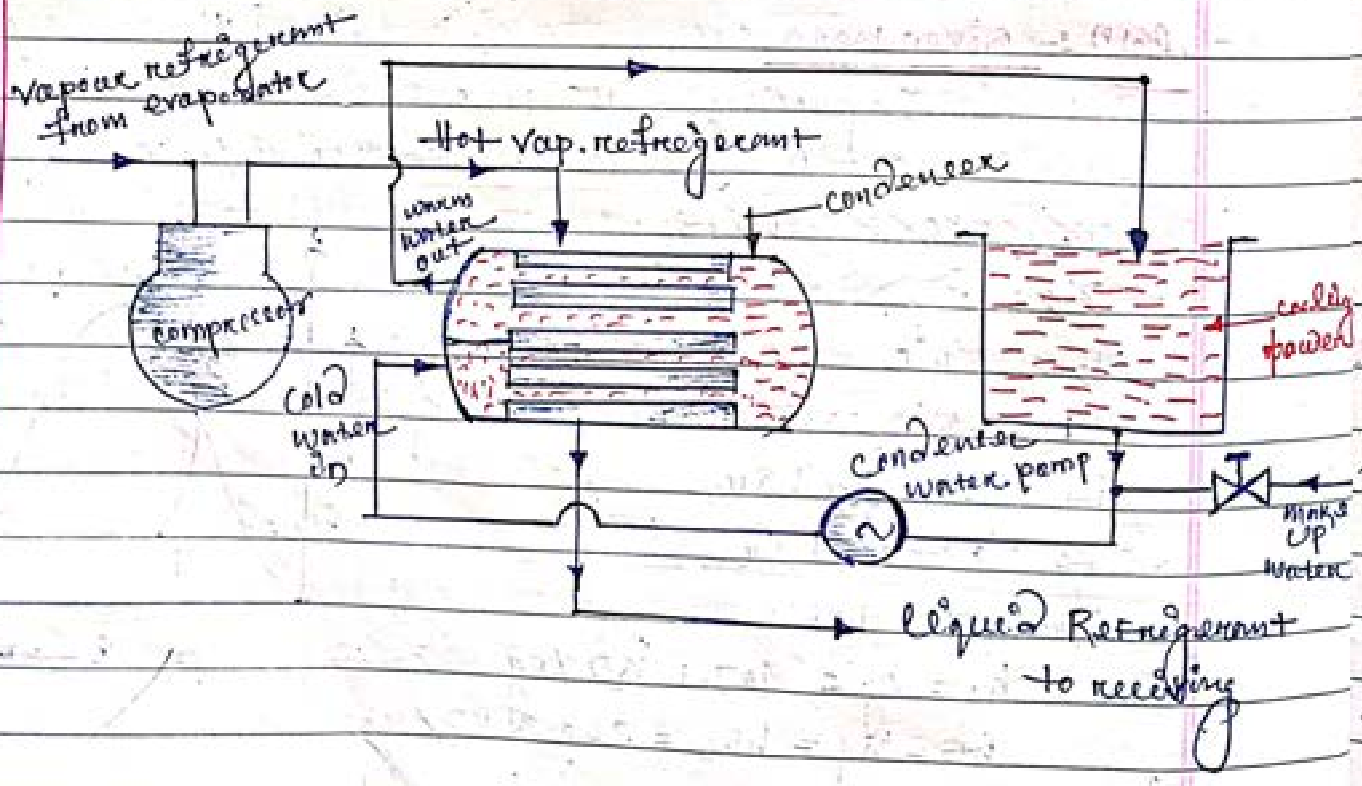
(b) Recirculated water system:-



(i) In recirculated water system, the same water circulating in the condenser is cooled and used again and again.

(ii) The cooling water towers and spray ponds at the most common cooling devices used in recirculated water system.

(iii) The warm water from the condenser is led to cooling tower where it is cooled by self evaporation into a stream of air.

(iv) Water pumps are used to circulate the water through the system and then to the cooling tower.

(v) Again the recirculated water system is filled with water which is due to the make up water.

(vi) The water cooled condenser operate at a lower condensing temp^n. than an air cooled condenser.

Imp

- Difference between Air cooled and Water cooled condenser :-

Air cooled condenser	Water cooled condenser
(i) Since the construction of air cooled condenser is very simple, so initial cost is less and maintenance cost is also low.	(i) Since the construction of water cooled condenser is complicated so, initial cost is high and maintenance cost is also high.

(ii) There is no handling problem with air cooled condenser.	(ii) The water cooled condenser are difficult to handle.
(iii) It doesn't requires piping arrangement for carrying air.	(iii) The pipes are requires to take water to and from the condenser.
(iv) There is no problem in disposing of used air.	(iv) There is a problem of disposing the used water unless recirculating cycle is provided.
(v) Since there is no corrosion, so fouling factor is low.	(v) Since, corrosion occurs inside the tubes carrying water so, fouling effect are high.
(vi) They have low heat transfer capacity due to low thermal conductivity of air.	(vi) The water cooled condenser have high heat transfer capacity due to high thermal conductivity of water.
(vii) These condenser are used for low capacity plants: less than 5 TR.	(vii) These condenser are used for large capacity plants.
(viii) The fan noise becomes objectionable.	(viii) There is no fan noise.

(ix) The distribution of air on condenser surface is not uniform.	(ix) The distribution of air on condenser surface is uniform.
(x) These condenser have high flexibility.	(x) These condenser have low flexibility.

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Heat rejection factor / Ratio (HRF) :-

(i) In a vapour compression refrigeration system, the heat is rejected in a condenser. The load on the condenser per unit of refrigeration capacity is known as heat rejection factor / Ratio.

(ii) The load on the condenser = Refrigerating capacity + Work done by the compressor

$$\Rightarrow Q_c = RE + W$$

$$\therefore \text{Heat rejection factor (HRF)} = \frac{Q_c}{RE}$$

$$= \frac{RE + W}{RE}$$

$$= 1 + \frac{W}{RE}$$

$$\boxed{HRF = 1 + \frac{1}{COP}}$$

$$\left(\because COP = \frac{RE}{W_{net}}\right)$$

(iii) In air conditioning application for R-12, R-22, The operating at the condenser temp. of 40°c and evaporator temp. of 5°C, the HRF is about 1.25.

Cooling tower and spray ponds :-

(i) A cooling tower is an enclosed tower like structure through which atm. air circulate to cool large quantities of warm water by direct contact.

~~Working~~ :

(ii) A spray ponds consists of a piping and spray nozzle arrangement suspended over an outdoor open reservoir or ~~[illegible]~~ pond.

(iii) The cooling tower and spray ponds are used for refrigeration and air conditioning system, cool the warm motor pumped from the water cooled condensers and then the same water can be used again and again to cool the condensers.

Working principle

(i) The principle of cooling the water in cooling towers and spray ponds is done by means of evaporation. The air surrounding the falling water drop lets from the spray nozzles causes some of water drop lets

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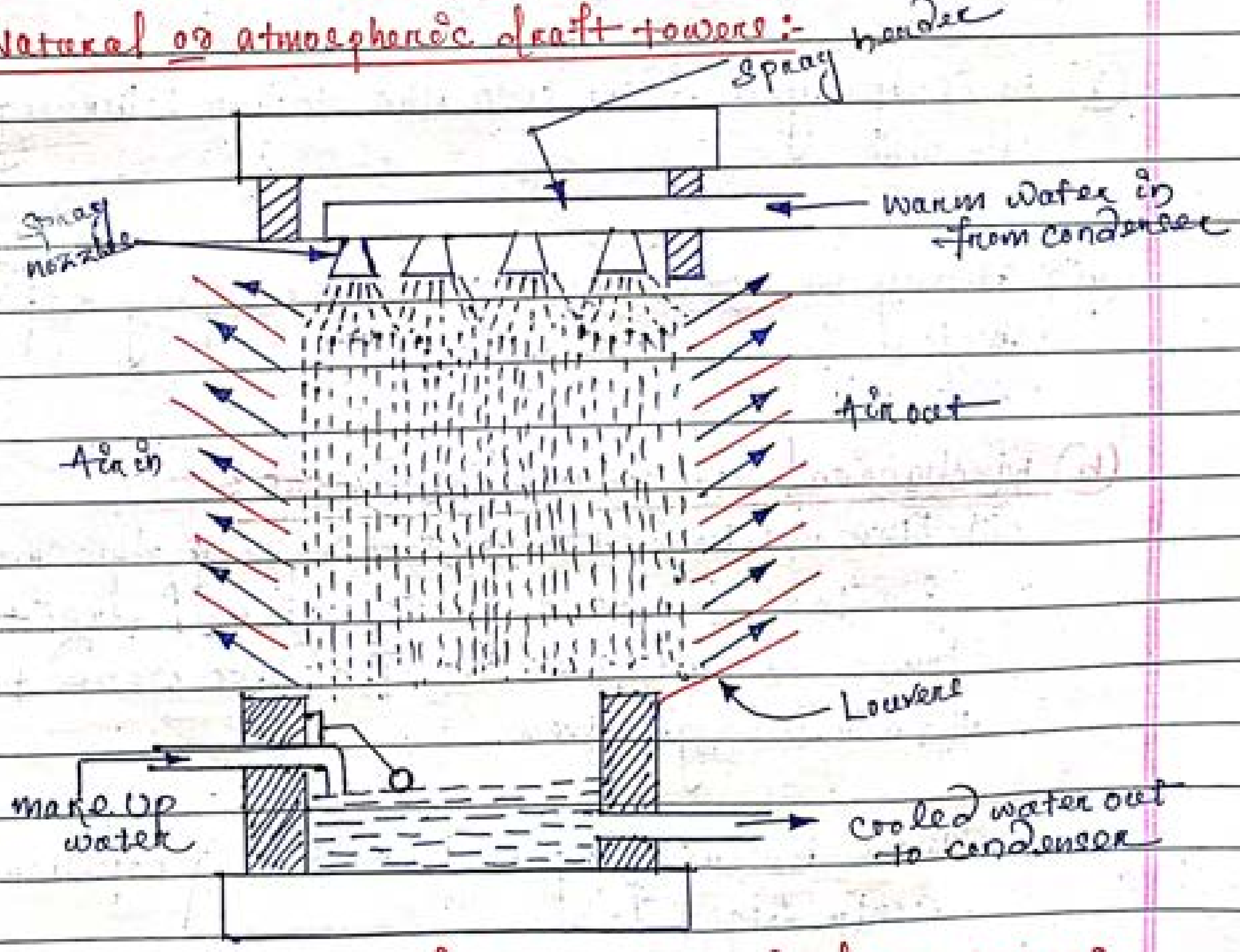
To evaporates and the evaporating water absorbs latent heat of evaporation from the remaining water and thus cool it.

(i) The air also absorbed a small amount of sensible heat from the remaining water and the cooled water collects in the pond or in a sump at the cooling tower which is again recirculated through the condenser.

cooling towers are of two types
(a) Natural draft cooling tower
(b) Mechanical draft cooling tower

(a) Natural or atmospheric draft towers :-



Natural or atmospheric draft towers

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(i) The atmospheric natural cooling tower, as shown in figure, consists of a box-shaped structure with louvers.

(ii) The louvers allow the atmospheric air to pass through the tower, but slant down towards the inside of the tower to retain water in it.

(iii) The framework and louvers are usually made of steel.

(iv) The warm water from the condenser is pumped to a spray header provided at the top of a tower.

(v) It is sprayed down into the tower through the nozzles.

(vi) It may be noted that the finer spray exposes more water surface to air.

(b) Mechanical draft cooling towers :-

(i) The mechanical draft cooling towers are similar to atmospheric natural draft cooling towers except that the fans are used to force the air through them.

(ii) These towers may use either propeller or centrifugal fans.

(iii) The mechanical draft cooling towers have the following main advantages and disadvantages over the atmospheric natural draft cooling towers.

Advantages :-

(i) As the large volume of forced air increases the cooling capacity, the mechanical draft cooling towers are smaller in size than natural draft cooling towers of the same capacity.

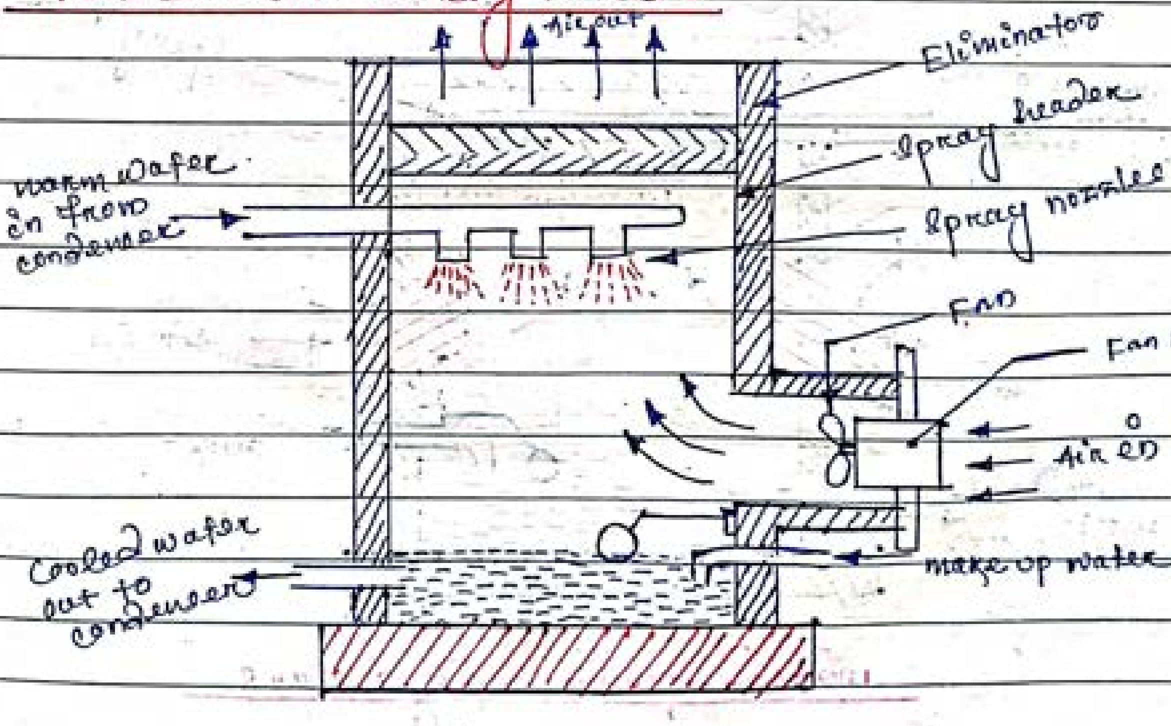
(ii) The mechanical draft cooling towers can be located inside the building because they do not depend upon atmospheric air.

Disadvantages :-

(i) The mechanical draft cooling tower require additional power to operate the fans.

(ii) The maintanance of fans, motors and controls increases the operating cost.

Forced draft cooling towers :-



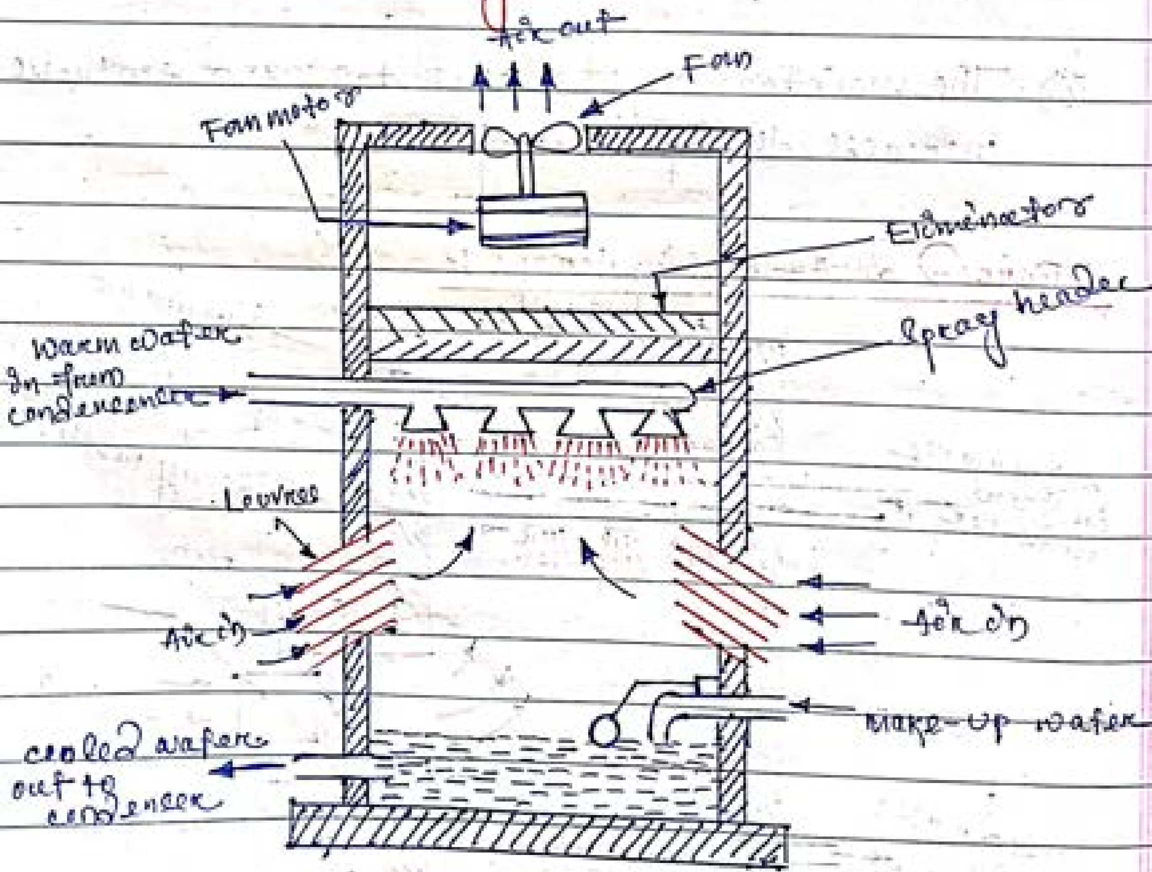
(i) In the forced draft cooling tower, as shown in figure, a fan forces the air through the tower.

(ii) In its operation, the warm water from the condenser is sprayed at the top of the tower through the spray nozzles.

(iii) The air is forced upward through the tower by the propeller fan provided on the side near the bottom of the tower.

(iv) The condenser warm water is cooled by means of evaporation.

Induced draft cooling towers:

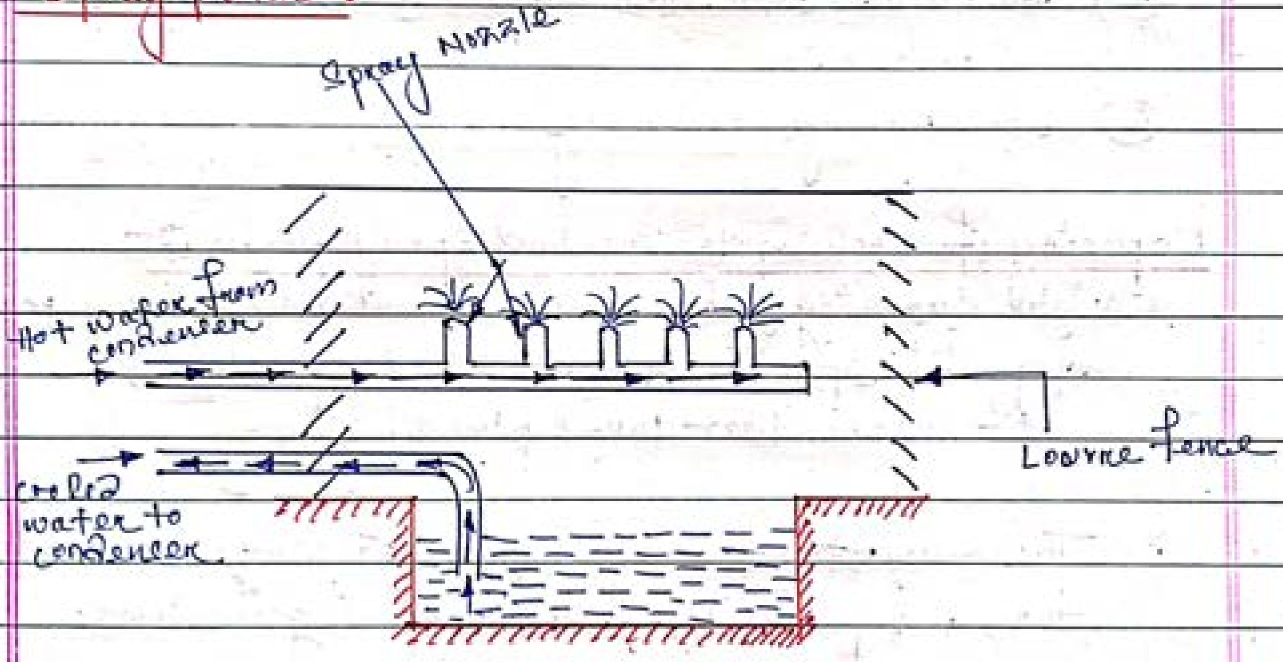


Induced draft cooling towers

(i) In the induced draft cooling tower, as shown in figure, the fan sucks the air through the tower.

(ii) The induced draft cooling towers are similar to forced draft cooling towers except that the fans are located at the top and draw the air upward through the tower.

Spray ponds :-



Spray ponds

(i) In this system warm water received from the condenser is sprayed through the nozzles over a pond of large area and cooling effect is mainly due to evaporation from the surface of water.

(ii) In this system sufficient amount of water is lost by evaporation and windage.

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(iii) The spacing of the nozzle in spray pond depends upon the design and size of the nozzles.

(iv) Nozzle may be mounted in groups of four or five.

Disadvantages :-

(i) A considerably large area required for cooling.
(ii) High spray losses.
(iii) No control over the temperature of cooled water.
(iv) Low cooling efficiency.

Capacity of cooling towers and spray ponds :-

(i) The capacity of cooling towers and spray ponds depends upon the amount of evaporation of water that takes place.

(ii) The amount of evaporation of water, in turn, depends upon the following factors:

(a) The amount of water surface exposed to the air.
(b) The length of the exposure time.
(c) The velocity of air passing over the water droplets formed in cooling towers.
(d) The wet bulb temperature of the atmospheric air.

Drier :-

(i) Moisture is harmful in refrigerating system.

(ii) Moisture in a refrigerating system freezes the automatic regulating valve or capillary tube and reduces the viscosity of oil due to formation of sludge.

(iii) Driers are invariably fitted in the liquid line between condenser and expansion valve.

(iv) Driers is a cylindrical shell containing desiccant material.

(v) Desiccant absorbs moisture, and filter is incorporated to entrap the fine particles.

Desiccants :-

(i) These are the chemical compound commonly used to remove moisture from the refrigerating system.

(ii) The common desiccant compounds are aluminium sulphate, silica gel, zeolite etc.

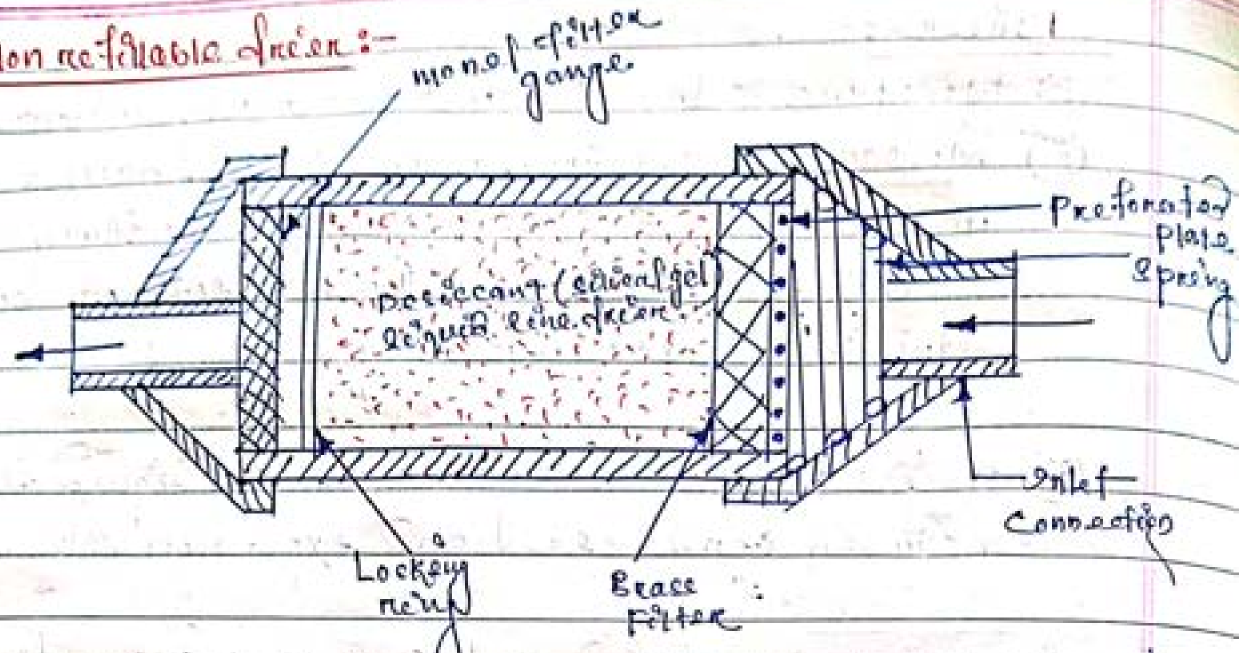
(iii) Silica gel is the most efficient and commonly used in the system.

Types of driers :-

(i) Throw away type driers or non refillable type driers.

(ii) Refillable type driers.

Non refillable drier :-



Non refillable drier

(i) The shell is charged with moisture absorbing chemicals.
(ii) The shell is equipped with inlet and outlet opening.
(iii) A strainer is provided at the outlet of shell.
(iv) It is permanently sealed with moisture absorbing chemical agents inside.

(v) The chemicals cannot be replaced when they loose their effectiveness.

Features :-

(i) The drier is usually placed in liquid line between condenser and expansion valve.

(ii) The drying agents silica gel & activated alumina removes moisture slowly than chemical driers.

(iii) They are left in the system for long periods or permanently.

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(iv) But calcium sulphate, calcium oxide and calcium chloride removes moisture very quickly.

(v) They should not be kept in the system after installation for more than 24 hours.

Refillable type drier:-

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Evaporators:

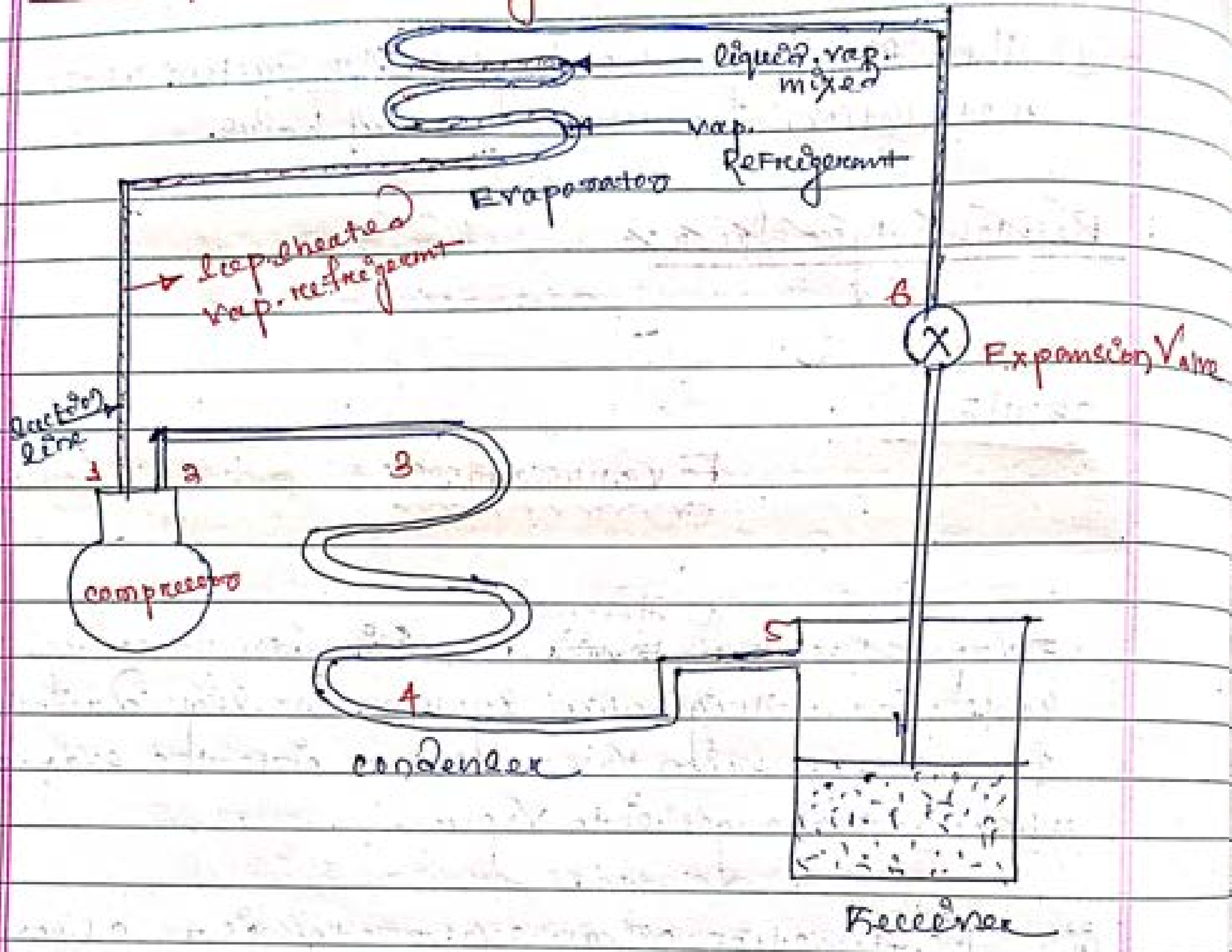
Evaporator is a device used in low pressure side of a refrigeration system. the liquid refrigerant from the expansion valves enters into the evaporator where its changes into vapour.

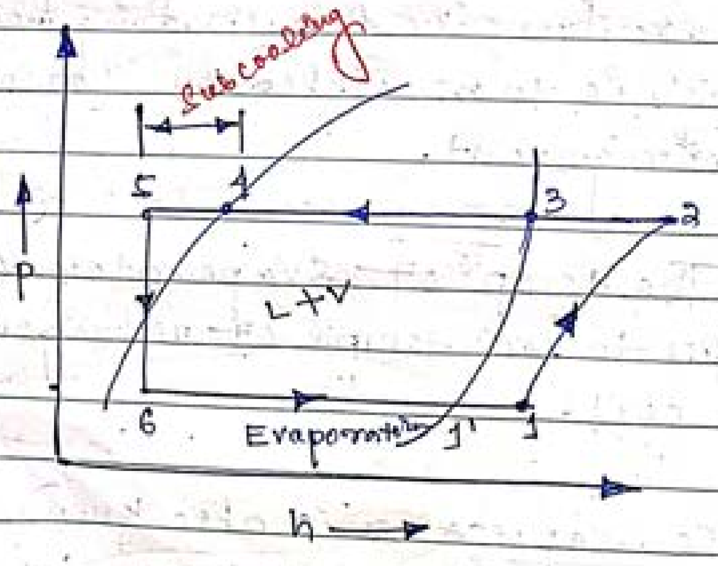
(ii) The function of an evaporator is to absorbed heat from the surrounding location or medium which is to be cooled by means of a refrigerant.

(iii) The tempr of evaporator coil is low due to low tempr of refrigerant inside the coil.

(iv) The evaporator is also known as cooling coil or chilling coil or freezing coil.

Principle of working of an evaporator :-





(i) Consider a simple refrigerating system in which the liquid refrigerant entering into the expansion valve at point '5' and the liquid refrigerant after subcooling enters the evaporator at point '6' and the liquid refrigerant passes through the evaporator coils and continuously absorbs heat through the coil walls from the medium being cooled.

(ii) During this process the refrigerant continues to boil and evaporate and at the point 1'. all the liquid refrigerant has evaporated and only vapour refrigerants remains on the evaporator coils.

(iii) The vapour temp^r. continues to rise until the vapour leave the evaporator at point '1'. and at this point the temp^r. of vapour is above the saturation temp^r. and the vapour refrigerant is superheated.

(iv) The line 1' to '1' shows the increase in the sensible heat of the vapour refrigerant.

Types of evaporators :-

(1) According to the type of construction

(i) Bare tube coil evaporator.
(ii) Finned tube evaporator.
(iii) plate tube evaporator
(iv) Shell and tube evaporator

(v) Shell & coil evaporator.
(vi) Tube-in-tube evaporator.

(2) According to the manner and which, liquid refrigerant is faced.

(i) Flooded evaporator.
(ii) Dry expansion evaporator.

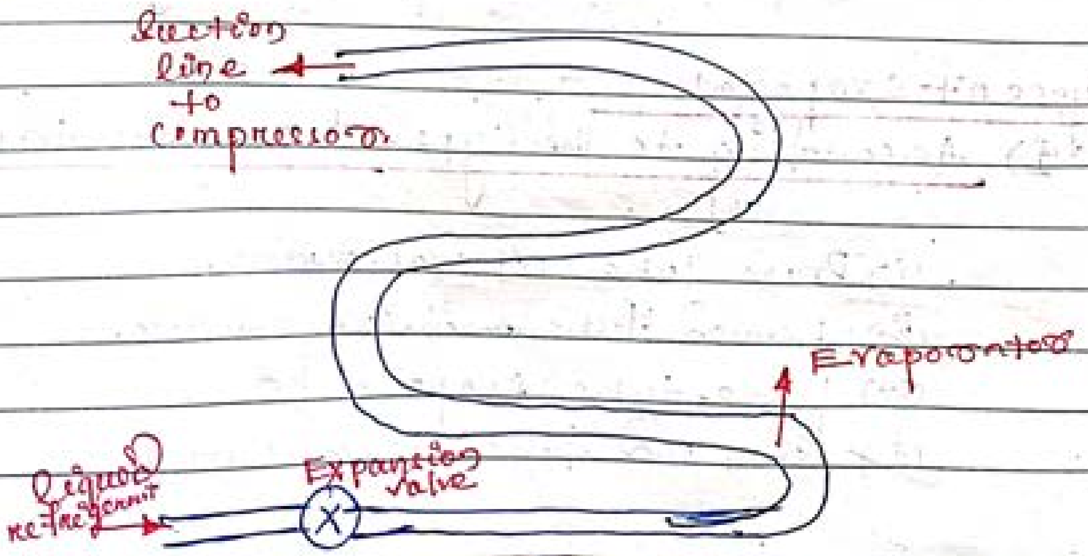
(3) According to the mode of heat transfer

(i) Natural convection evaporator.
(ii) Forced convection evaporator.

(4) According to operating conditions.

(i) Frosting evaporator.
(ii) Non-Frosting evaporator.
(iii) De-frosting evaporator.

(a) Bare tube coil evaporator:-



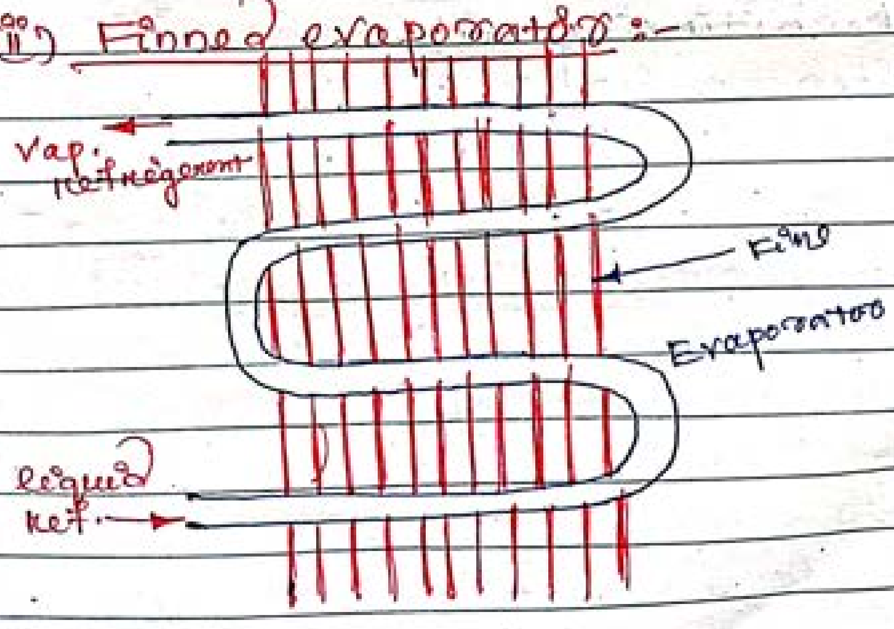
(i) This a simplest type of evaporator and is also known as prime surface evaporator.

(ii) Due to it simple construction, the bare tube coil evaporator is easy to clean and de-frost and it takes relatively little surface contact area as compare to other types of coils.

(iii) Its used is limited to application where the box tempr. are under 0°c. and in liquid cooling because the accumulation of ice and frost on these evaporator as less effect on the heat transfer then those of the [illegible] equipped fins.

(iv) This type of evaporator is used in any type of refrigeration equipement and these are extensively used in house hold refrigerator because they are easier to keep clean.

(ii) Finned evaporator :-



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(i) The finned evaporator consist of bare tube or coil over which the metal plates or fins are fastened.

(ii) The metal fins are constructed of thin sheets of metal having good thermal conductivity.

(iii) The safe, size or spacing of fins can be adopted to provide best heat transfer and these fins evaporator called extended surface evaporator.

(iv) The fins evaporator are generally designed for air conditioning application where the refrigerator temp is about 0°c.

(v) The finned coil which frost on the cycle and de-frost on the off-cycle have wider fins spacing. and generally the fins spacing is as small as 3mm for the air conditioning coils.

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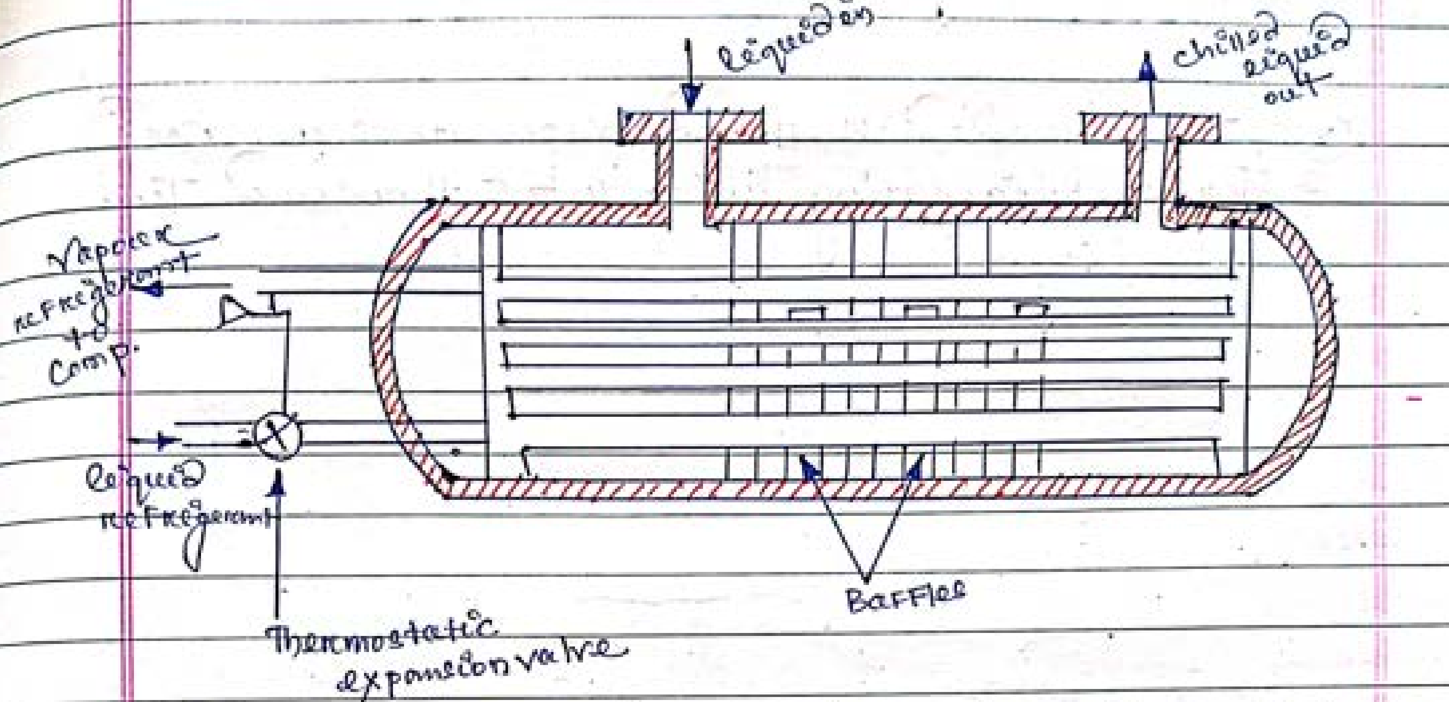
(iii) Shell and tube evaporator :-



(i) It consists of a number of horizontal tubes enclosed in a cylindrical shell. The inlet and outlet headers with perforated metal tubes sheets are connected at each end of that tubes.

(ii) These evaporator are generally used to chill water of brine solution. When it is operated as dry expansion evaporator, the refrigerant circulate through the tube and the liquid to be cooled fills the space around the tubes within the shell.

(iii) The dry expansion shell and tube evaporators are used for refrigerating unit of 2 to 250 tons capacity.

(iv) When it is operated as a flooded evaporator, the water ~~of~~ or brine flows through the tubes

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and the refrigerant circulate around the tubes.

(v) The flooded shell and evaporators are used for the refrigerating unit 10 - 5 thousand Tons capacity.

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CHAPTER - 5

Refrigerant flow controls, Refrigerants and Application of refrigerants

5.1) Expansion valves :-

(i) The expansion device is also known as throttling device or metering device which devides the high pressure side and low pressure side of a refrigerating system.

(ii) It is connected between receiver and evaporator.

(iii) The functions of expansion valves are

(a) It reduces the high pressure liquid refrigerant to low pressure liquid refrigerant before being fed to the evaporator.

(b) It maintanes the desired pressure difference between high and low pressure side of a system.

(c) It controls the flow of refrigerant according to the load on the evaporator.

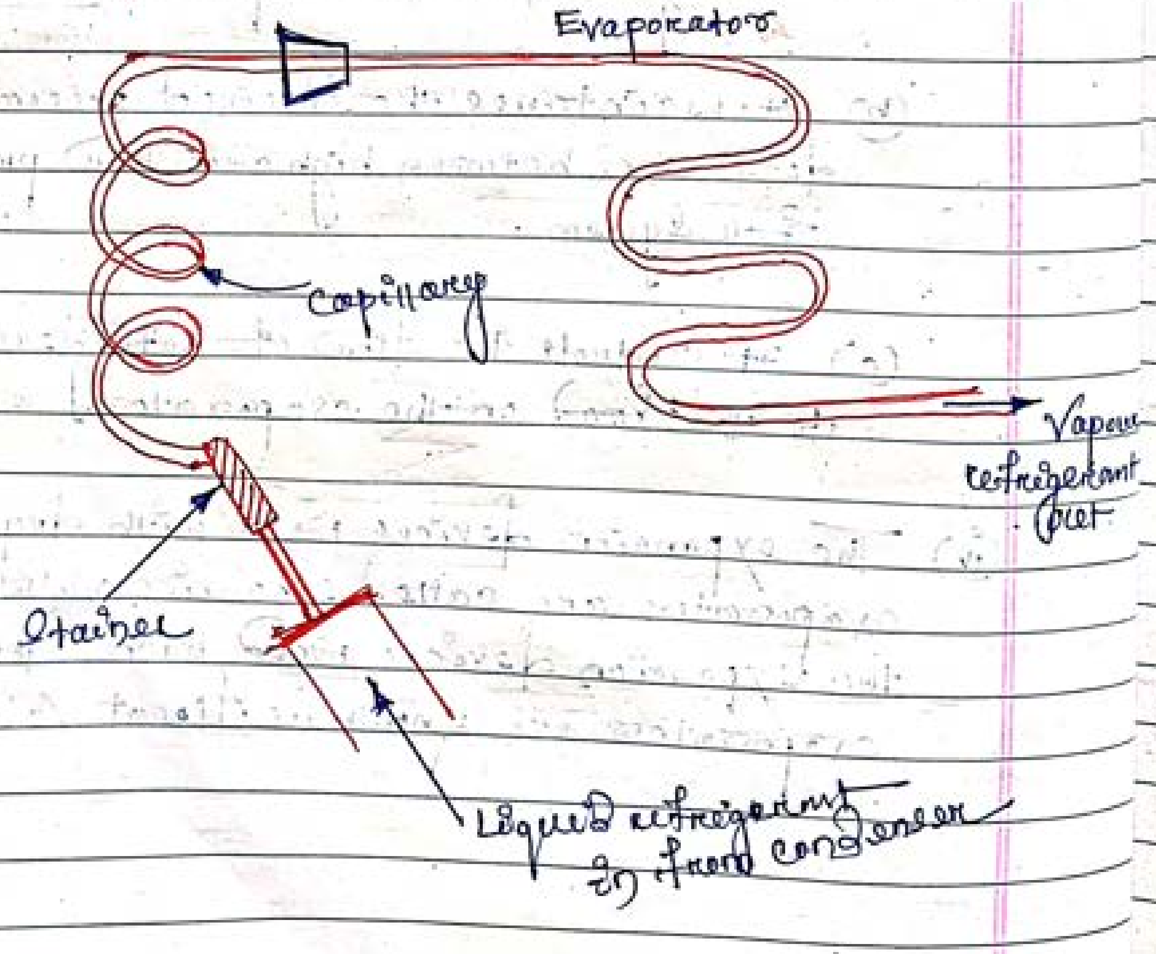
(iv) The expansion devices used with dry expansion evaporator are called expansion valves where as the expansion devices used with flooded evaporator are known as float valves.

(v) The expansion devices are used in industrial and commercial refrigeration and air conditioning system.

Types of expansion Devices :-

1) Capillary tube
2) Hand operated expansion valve.
3) Automatic or constant pressure expansion valve.
4) Thermostatic expansion valve.
5) Low side float valve.
6) High side float valve.

1) Capillary Tube :-



(i) The capillary tube is used as an expansion device in small capacity hermatic sealed refrigeration unit such as- domestic refrigerator, water coolers, room air conditioner and Freezer

(ii) It is a copper tube of small internal diameter and of varying length depending upon the applications.

(iii) It is installed in the liquid line between condenser and evaporator.

(iv) A fine mesh screen is provided at the inlet of the tube in order to protect it from contaminants

(v) A small Filter drier is used in some system to provide additional freeze applications.

(vi) In its operation, the liquid refrigerant from the condenser enters the capillary tubes.

(vii) Since the frictional resistance is directly proportional to the length and inversely proportional to the diameter. So longer the capillary tube and smaller the inside diameter, greater is the pressure drop created in the refrigerant flow.

(viii) So greater the pressure difference between the condenser and evaporator is needed for a given flow of refrigerant.

(ix) The refrigerating system using capillary tube have the following advantages.

(a) The cost of capillary tube is less than all other forms of expansion devices

(b) The low starting torque motors (low cost motor can be used to drive the compressor which is a great advantage).

(c) Since the refrigerant charge in a capillary tubed system is critical so no receiver necessary.

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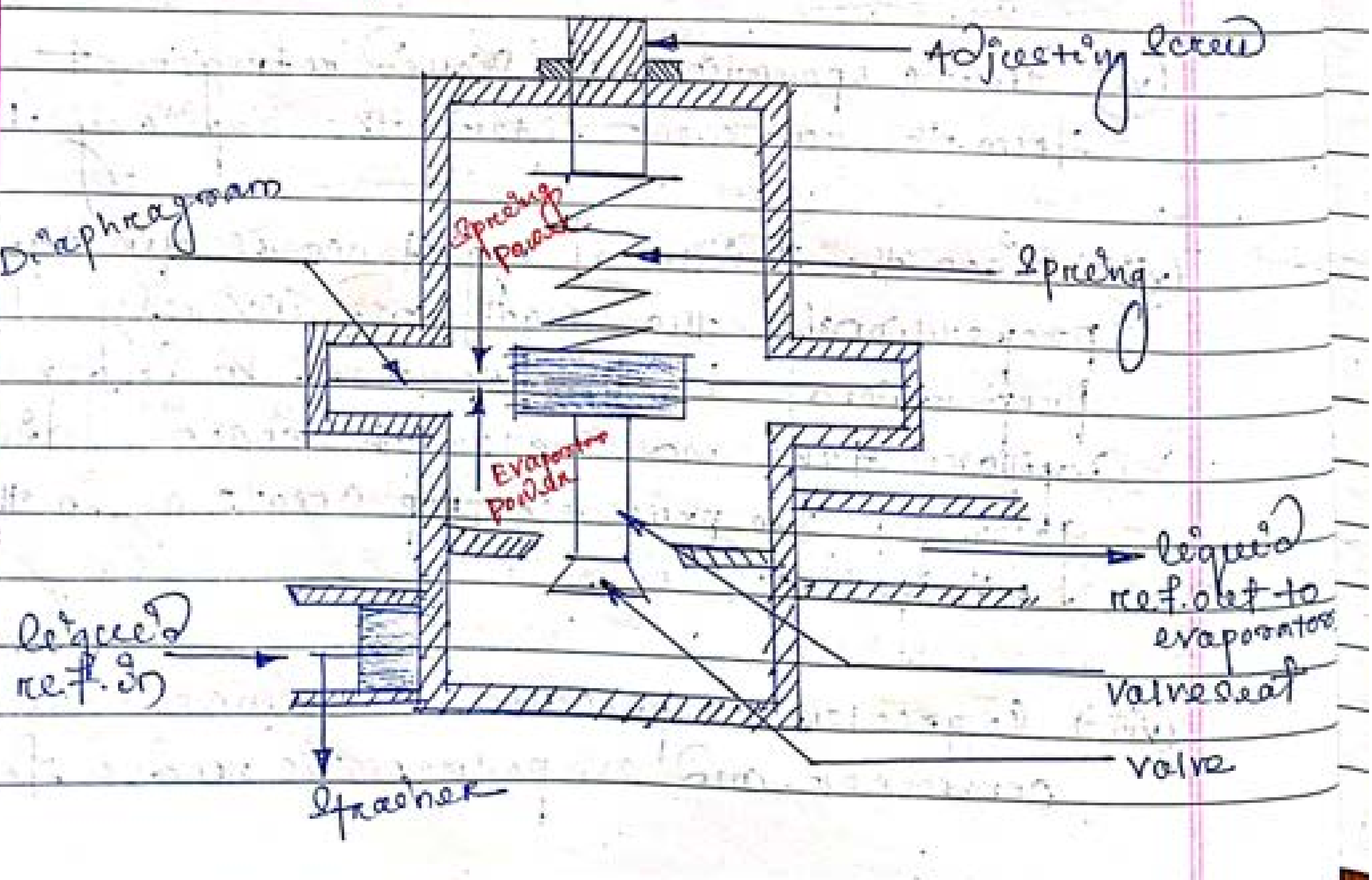
Automatic expansion valve :-



(i) The automatic expansion valve is known as constant pressure expansion valve as it maintains constant evaporator pressure regardless of the load on the evaporator.

(ii) Its main moving force is the evaporator pressure and it is used with dry expansion evaporator, where the load is relatively constant.

(iii) The automatic expansion valve consist of needle valve, and a seat which forms an orifice, a metallic Diaphragm, a spring and an adjusting screw.

(iv) The opening and closing of the valve with respect to seat depending upon two opposing forces acting on the diaphragm.

(a) The spring pressure and atmospheric pressure acting on the top of the diaphragm.

(b) Evaporator pressure acting below the diaphragm.

(v) When compressor is running the valve maintains and evaporator pressure in equilibrium with the spring pressure and atmospheric pressure.

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(vi) Once the spring is adjusted for a desired evaporator pressure then the valve operates automatically to maintain constant evaporator pressure by controlling the flow of refrigerant to the evaporator.

(vii) When the evaporator pressure falls down the diaphragm moves downward to open the valve.

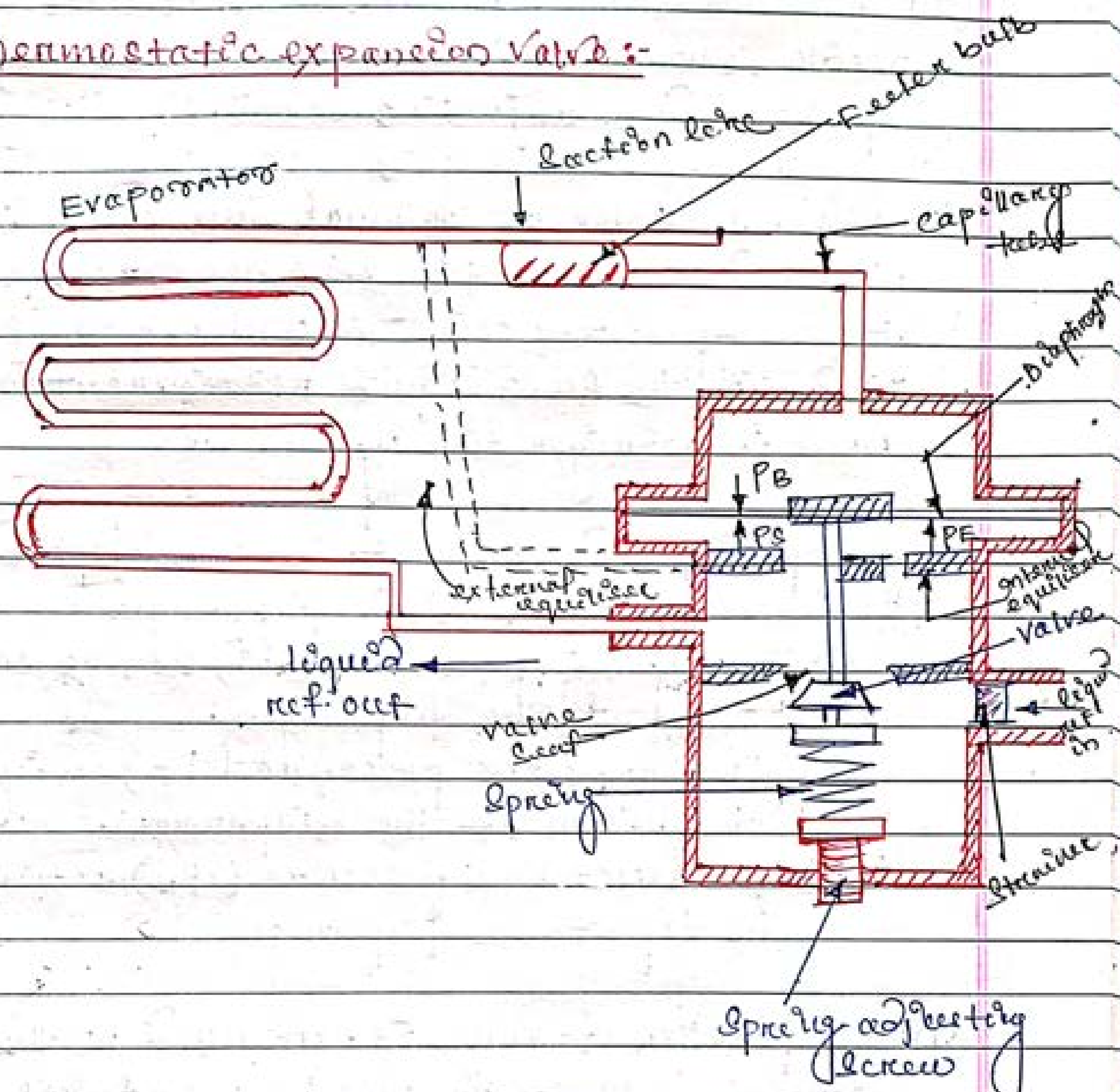
(viii) This allows more liquid refrigerant to enter into the evaporator and thus, increasing the evaporator pressure till the desired evaporator pressure is reached.

(ix) When the evaporator pressure rises, the diaphragm moves upward to reduce the opening of the valve and this decreases the flow of liquid refrigerant to the evaporator.

(x) When the compressor stop, the liquid refrigerant continues to flow into the evaporator and increases the pressure in the evaporator.

(xi) This increase in evaporator pressure causes the diaphragm to move upward and the valve is closed and its remains closed until the compressor start again and reduces the pressure in the evaporator.

Thermostatic expansion valve :-



(i) These expansion devices are used in commercial and industrial refrigeration system.

(ii) This is also called a constant superheat valve because it maintains a constant superheat of the vapour refrigerant at the end of the evaporator coil by controlling the flow of liquid refrigerant through the evaporator.

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(iii) The thermostatic expansion valve consists of a needle valve and a seat, a metallic diaphragm, spring and an adjusting screw.

(iv) It has a feeler or thermal bulb which is mounted on the suction line near the outlet of the evaporator coil. The feeler bulb is partly filled with the same liquid refrigerant as used in refrigeration system.

(v) The opening and closing of the valve depends upon the forces acting on the diaphragm are—
(i) The spring pressure (Ps) acting on the bottom of the diaphragm.
(ii) The evaporator pressure (PE) acting on the bottom of the diaphragm.
(iii) The feeler bulb pressure (PB) acting on the top of the diaphragm.

(vi) The operation of valve is controlled by the difference between the two temperatures i.e saturation temperature and feeler bulb temperature which is superheat.

(vii) When a valve is set for a certain superheat, then it maintains that setting under all load conditions on the evaporator.

(viii) If the load on the evaporator increases, it causes the liquid refrigerant to boil faster in the evaporator coil. The temperature of the feeler bulb increases due to early.

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Vaporisation of the liquid refrigerant.

(ix) Thus feeler bulb pressure increases, and this pressure is transmitted through the capillary tube to the diaphragm. The diaphragm moves downward and open the valve to admit more quantity of liquid refrigerant to the evaporator coil.

(x) The evaporator pressure decrease due to reduced quantity of liquid refrigerant flowing to the evaporator.

(xi) This continues till the evaporator pressure and the spring pressure maintains equilibrium with the feeler bulb pressure.

(xii) The thermostatic expansion valves are usually in tonnes of refrigeration.

(xiii) Most thermostatic expansion valves are set for 5°c of superheat.

(5.2) Refrigerants

(i) The refrigerant is a heat carrying medium which during the cycle that is compression, condensation, Expansion and evaporation processes in the refrigeration system absorbes heat from a low temperature system and discard the heat so absorbed to a higher temperature system.

(ii) Example – Natural ice, Amonia, Sulphur dioxide, methyle chloride, CO_2, R-11, R-22, R-134a, etc.

Ideal refrigerant :-

A refrigerant is said to be ideal, if it has the following properties.

(specific heat Cp, Cv)

(i) Low boiling point.
(ii) High critical temperature.
(iii) High latent heat of vapourization.
(iv) Low specific heat of liquid.
(v) Low specific volume of vapour.
(vi) Non-corrosive to metal
(vii) Non-Flamable and non-explosive.
(viii) Non-toxic.
(ix) Low cost
(x) easy to liquidified at moderate pressure and temperature.
(xi) easy of locating leaks by odour or indicator

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Classification of refrigerants :-

It is of two types:-

(1) primary refrigerant.
(2) secondary refrigerant.

Primary refrigerant	Secondary refrigerant
(i) The refrigerant which directly take part in the refrigeration system are called Primary refrigerant.	(i) The refrigerant which are first cooled by primary refrigerant and then used for cooling purposes are known as secondary refrigerant.
(ii) Primary refrigerant are four groups. → Halo-carbon refrigerant → Azeotrope refrigerant → Inorganic refrigerant → Hydrocarbon refrigerant	(ii) Brines are the secondary refrigerant.

Primary refrigerant :-

(1) Halo-carbon refrigerant :-

(i) These refrigerants are synthetically produced and were Freon family of refrigerants.

(ii) The first Halo-carbon refrigerant is R-12 and the others commonly used Halo-carbon refrigerants are R-11, R-12, R-13, R-21,

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R-22, R-40, R-100, R-114

R-11 :-

(i) It is a synthetic chemical product used as refrigerant.

(ii) It is stable, non-flammable, non-toxic.

(iii) Due to low operating pressure, this refrigerant is used in large centrifugal compression system of 200 tonne.

(iv) The cylinder colour code for R-11 is orange.

(v) R-11 (Trichloromonofluoro methane) (CCl_3F)

R-12

(i) It is a very popular refrigerant, colourless and almost odourless liquid with boiling point of $-29°c$ at Patm.

(ii) It is non-toxic, non-corrosive, non-irritating and non-inflammable.

(iii) It is generally used in refrigerators, freezers, water coolers, window A.C unit. etc.

(iv) The cylinder colour code is White.

(v) R-12 (Dichlorodifluoro methane) (CCl_2F_2).

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R-22 :-

(i) It is a man made refrigerant used for refrigeration and at a low evaporating temperature i.e., −29°C to −70°C.

(ii) It is used in A.C units and in household refrigerators, reciprocating and centrifugal compressors.

(iii) It is stable, non-toxic, non-corrosive, non-flammable.

(iv) The cylinder colour code is green.

(v) R-22 (Monochloro di-fluoro methane) ($CHClF_2$)

(2) Azeotrope refrigerant :-

(i) Azeotropes refers to a stable mixture of refrigerants whose vapour and liquid phases retain identical composition over a wide range of temperature.

(ii) Some Azeotropes refrigerants are :-

(a) R-500 → 73.8% R-12 & 26.2% R-152
cylinder colour - Yellow.

(b) R-502 → 48.8% R-22 & 51.2% R-115
cylinder colour - Orchid

(c) R-503 → 40.1% R-23 & 59.9% R-13
cylinder colour - aqua marine

(iii) Azeotrope R-500 is used in both industrial and commercial application and non-flammable, less in toxicity and non-corrosive.

(iv) Azeotrope area R-502 is used in frozen food lockers, frozen food processing plants, in storage units of ice-cream and only used with reciprocating compressors.

(3) Inorganic refrigerants :-

(i) Inorganic refrigerant are used before the introduction of halo-carbon refrigerant.

(ii) The various inorganic refrigerants are :-

Ref. Name	chemical name	chemical formula
1) R-717 →	Ammonia →	NH_3
2) R-729 →	Air →	—
3) R-744 →	Carbon-dioxide →	CO_2
4) R-764 →	Sulphur dioxide →	SO_2
5) R-118 →	water →	H_2O

(iii) R-717 is widely used in VAS and it is colourless gas but poisonous gas if inhaled large quantity.

(iv) The condenser for R-717 are usually water cooled type.

(v) It is generally used in cold storage, ice-cream manufacturing plants, food freezing plants etc.

(vi) The dry air is used as gaseous refrigerant in some compression system i.e in air craft air conditioning system.

(vii) R-118 is used ... as the refrigerant vapour in some vapour absorption system and with steam jet compressors.

(4) Hydro-carbon refrigerant :-

(i) These refrigerant are generally used in industrial and commercial purposes.

(ii) These are highly flammable and explosive but they posses satisfactory thermodynamic property.

(iii) Some hydro-carbon refrigerants are :-

Ref. Name		Chemical Name		Chemical Formula
1) R-170	→	Ethane	→	C_2H_6
2) R-290	→	Propane	→	C_3H_8
3) R-600	→	Butane	→	C_4H_{10}
4) R-600a	→	isobutane	→	C_4H_{10}
5) R-1150	→	Ethylene	→	C_2H_4
6) R-1270	→	Propylene	→	C_3H_6

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Secondary refrigerants :-

Brines :-

(i) Brines are secondary refrigerant used where temperature are required to be maintained below the freezing point of water.

(ii) If the temperature is above freezing point of water then water is commonly used as a secondary refrigerant.

(iii) Brines is a solution of salt in water and when the salt is mixed in water, the freezing temperature of solⁿ. becomes lower than that of water.

(iv) This is due to the fact that the salt while dissolving in water takes off its latent heat from the solution and cools it below the freezing points of water.

(v) The mass of salt in the solution expressed as percentage of mass of the solution and is known as concentration of the solution.

(vi) The brine used should have concentration for which freezing point of brine is atleast 5°c to 8°c lower than brine temperature required.

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(vii) examples of brines :-
The brines commonly used are calcium chloride ($CaCl_2$), NaCl, glycols such as Ethylene glycol, propylene glycol etc.

(viii) $CaCl_2$ has eutectic temperature of −55°C at salt concentration where has NaCl brine has eutectic tempr of −21.1°C at salt concentration of 23% by mass.

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Anti-freeze :-
(i) The water soluble compound which are used for decreasing the freezing point of water for certain refrigeration are called anti-freeze.

(ii) Ethylene and propylene glycol have number of good properties and since they are non-corrosive and non-electrolytic, Even in presence of water these brines are used as anti-freeze elements.

Designation / Nomenclature for Refrigerant :-
(i) Refrigerant followed by a two digit number that indicates that a refrigerant is derived from methane base, where 3 digit number represent ethane base.

(ii) The numbers are assigned to hydro-carbon and hollow-carbon refrigerants.

(iii) The general chemical formula for the refrigerant either methane base or ethane base is

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chemical formula = $C_mH_nCl_pF_q$, where,
$n+p+q = 2m+2$

number of refrigerants = $R(m-1)(n+1)q$

Where, m → no. of carbon atoms
n → The no. of hydrogen atoms.
p → The no. of chlorine atoms.
q → The no. of fluorine atoms.

Problem-1

Find the chemical formula and refrigerant no. of di-chloro-tetrafluoro ethane.

Ans :- Di-chlorotetrafluoro ethane:-

no. of chlorine atoms, p = 2
no. of fluorine atoms, q = 4
no. of Hydrogen atoms, n = 0

We know,

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

$$\Rightarrow 0+2+4 = 2\times m+2$$

$$\Rightarrow m = \frac{4}{2} = 2$$

$$\Rightarrow \boxed{m = 2}$$

∴ no. of carbon atoms, m = 2

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(i) the chemical formula

$C_mH_nCl_pF_q$

$\Rightarrow C_2H_0Cl_2F_4$

$\Rightarrow$ $\boxed{C_2Cl_2F_4}$

(ii) no. of refrigerant

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

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

$\Rightarrow$ $\boxed{R-114}$

Problem-2

Find the chemical formula and refrigerant no. of di-chloro di-fluoro methane.

Ans: Di-chloro di-fluoro methane

no. of chlorine atoms, $p=2$

no. of fluorine atoms, $q=2$

no. of Hydrogen atoms, $n=0$

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

$\Rightarrow 0+2+2=2\times m+2$

$\Rightarrow m=\frac{2}{2}$

$\Rightarrow$ $\boxed{m=1}$

no. of carbon atoms, $m=1$

(i) chemical formula

$C_mH_nCl_pF_q$

$\Rightarrow C_1H_0Cl_2F_2$

$\Rightarrow$ $\boxed{CCl_2F_2}$

(ii) no. of refrigerant

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

$\Rightarrow R(1-1)(0+1)2$

$\Rightarrow$ **R-12**

Problem-3

CH_3Cl and $C_2H_4Cl_4$ find the refrigerant number.

Ans- (i) CH_3Cl, (methyle chloride)

So, $m = 1$

$n = 3$

$p = 1$

We know, $n+p+q = 2m+2$

$\Rightarrow 3+1+q = 2\times1+2$

$\Rightarrow \cancel{4}+q = \cancel{4}$

$\Rightarrow q = 0$

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

$\Rightarrow R(1-1)(3+1)0$

$\Rightarrow R\,040$

$\Rightarrow$ **R-40**

(ii) $C_2H_4Cl_4$

$m = 2$

$n = 4$

$p = 1$

$n+p+q = 2m+3$

$\Rightarrow 4+1+q = 2\times2+3$

$\Rightarrow 5+q = 7$

$\Rightarrow 5+q = 5-7$

$\Rightarrow$ **$q = -2$**

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

$\Rightarrow R\,15-2$

$\Rightarrow R-(-152)$

$\Rightarrow$ **R--152**

[N.B]

R-134a (tetrafluoro ethane)

[CF_3CH_2F] chemical formula

Homework
write thermodynamic properties and physical properties and chemical properties of refrigerant.

Thermodynamic properties of refrigerants :-

Boiling temp^r :-

(i) The boiling temperature of the refrigerant at atmospheric pressure should be low.

(ii) If the boiling temperature of refrigerant is high at atmospheric pressure, the compressor should be operated at high vacuum.

(iii) The high boiling temperature reduces the capacity and operating cost of the system.

Freezing temp^r :-

(i) The freezing temperature of a refrigerant should be well below the operating evaporator temperature.

(ii) Since the freezing temperature of most of the refrigerants are below −35°C, therefore this property is taken into consideration only in low temp^r operation.

Evaporator and condenser pressure :-

(i) Both the evaporating (low side) and condensing (high side) pressures should be positive (i.e. above atmospheric) and it should be as near to the atmospheric pressure as possible.

(ii) The positive pressures are necessary in order to prevent leakage of air and moisture into the refrigerating system.

(iii) It also permits easier detection of leaks.

Critical tempr. and pressure :-

(i) The critical temperature of a refrigerant is the highest temperature at which it can be condensed to a liquid • regardless of a higher pressure.

(ii) It should be above the highest condensing tempr. that might be encountered.

(iii) If the critical tempr. of a refrigerant is too near the desired condensing temperature, the excessive power consumption results.

COP and power requirements :-

For an ideal refrigerant operating between -15°C evaporator tempr. and 30°C condenser temperature the theoretical COP for the reversed Carnot cycle is 5.74.

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Latent heat of vaporization :-

(i) A refrigerant should have a high latent heat of vaporization at the evaporator temp^r.

(ii) The high latent heat results in high refrigerating effect per Kg of refrigerant circulated which reduces the mass of refrigerant to be circulated per tonne of refrigeration.

Specific Volume :-

(i) A [illegible] specific volume of the refrigerant vapour at evaporate temperature indicates the theoretical displacement of the compressor.

(ii) The reciprocating compressors are used with refrigerants having high pressure and low volumes of the suction vapour.

Physical properties of refrigerants :-

Stability and inertness :-

(i) An ideal refrigerant should not decompose at any temperature normally encountered in the refrigerating system.

(ii) It should not form higher boiling point liquids or solid substances through polymerization.

(iii) Some refrigerants disintegrate forming non-condensable gases which causes high condensing pressure and vapour lock.

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(iv) The disintegration of refrigerant may be due to reaction with metals.

(v) The freon group of refrigerants are stable up to a tempr. of 535°c.

Corrosive Property :-

(i) The corrosive property of a refrigerant must be taken into consideration while selecting the refrigerant.

(ii) The freon group of refrigerants are non-corrosive with practically all metals.

(iii) Ammonia is used only with iron ~~or~~ steel.

Viscosity :-

(i) The refrigerant in the liquid and vapour states should have low viscosity.

(ii) The low viscosity of the refrigerant is desirable because the pressure drops in passing through liquid and suction lines are small.

Thermal conductivity :-

(i) The refrigerant in the liquid and vapour states should have high thermal conductivity.

(ii) This property is required in finding the heat transfer coefficients in evaporators and condensers.

Dielectric Strength :-

(i) The dielectric strength of a refrigerant is important in hermetically sealed units in which the electric motor is exposed to the refrigerant.

(ii) The relative dielectric strength of the refrigerant is the ratio of the dielectric strength of nitrogen at atmospheric pressure and room temperature.

Leakage tendency :-

(i) The leakage tendency of a refrigerant should be low.

(ii) If there is a leakage of refrigerant, it should be easily detectable.

(iii) The leakage occurs due to openning in the joints or flaws in material used for construction.

(iv) The ammonia leakage is easily detected due to its pungent odour.

(v) The leakage of fluorocarbon refrigerants may be detected by soap solution, a halide torch or an electronic leak detector.

(vi) The latter is generally used in big refrigerating plants.

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Cost :-

(i) The cost of refrigerant is not so important in small refrigerating units but it is very important in high capacity refrigerating systems like industrial and commercial.

(ii) The ammonia, being the cheapest, is widely used in large industrial plants such as cold storages and ice plants.

Chemical properties of refrigerants :-

Flammability :-

(i) We have already discussed that hydro-carbon refrigerants such as ethane, propane etc. are highly flammable.

(ii) Ammonia is also somewhat flammable and becomes explosive when mixed with air in the ratio of 16 to 25 percent of gas by volume.

(iii) The halo-carbon refrigerant are neither flammable nor explosive.

Toxicity :-

(i) The toxicity of refrigerant may be of prime or secondary importance, depending upon the application.

(ii) Some non-toxic refrigerants when mixed with certain percentage of air become toxic.

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Solubility of water :-

(i) Water is only slightly soluble in R-12. At -18°C, it will hold six parts per million by weight.

(ii) The solution formed is very slightly corrosive to any of the common toxic.

(iii) The solubility of water with R-22 is more than R-12 by a ratio of 3 to 1.

Miscibility :-

(i) The ability of a refrigerant to mix with oil is called miscibility. The property of refrigerant is considered to be a secondary factor in the selection of a refrigerant.

(ii) The degree of miscibility depends upon the temperature of the oil and pressure of the refrigerating vapour.

(iii) The freon group of refrigerants are highly miscible refrigerants while ammonia, carbon-dioxide, sulphur dioxide and methyl chloride are relatively non-miscible.

(iv) The non-miscible refrigerants require larger heat transfer surface due to poor heat conduction properties of oil.

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Effect on perishable materials :-

(i) The refrigerants used in cold storage plant and in domestic refrigerators should be such that in case of leakage, it should have no effect on the perishable materials.

(ii) The freon group of refrigerants have no effect upon dairy products, meats, vegetables, flowers and furs.

(iii) There will be no change in colour, taste or texture of the material when exposed to freon.

(iv) Sulphur dioxide destroys flowers, plants and furs, but it doesn't effect foods.

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R-134(a) (Tetrafluoroethane - CF_3CH_2F)

(i) R134a is also known as tetrafluoroethane (CF_3CH_2F) from the family of HFC refrigerant.

(ii) With the discovery of damaging effect of CFCs and HCFCs refrigerants to the ozone layer, the HFC family of refrigerant has been widely used as their replacement.

(iii) It is now being used as a replacement for R-12 CFC (CCl_2F_2) refrigerant in the area of centrifugal, rotary screw, scroll and reciprocating compressor.

(iv) It is safe for normal handling as it is non-toxic, non-flammable and non-corrosive.

Imp

	Chemical Name	Chemical formula
R-12	Dichloro difluoro methane	CCl_2F_2
R-22	Mono chloro difluoro methane	$CHClF_2$
R-134a	Tetrafluoroethane	CF_3CH_2F
R-11	Trichloro monochloro methane	CCl_3F

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Substitute for CFC refrigerant :-

(i) The commonly used Halocarbon or organic refrigerants are chlorofluoro derivatives of methane and ethane.

(ii) The fully halogenated refrigerants with chlorine atom in their molecules are known as

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Chloro-fluoro-carbon (CFC refrigerants).

(iii) Examples- refrigerant such as R-11, R-12, R-13, R-114, R-115 etc. are CFC refrigerants.

(iv) HCFC :- The refrigerant which contains hydrogen atom in their molecule along with chlorine (Cl) and fluorine (F) atoms are known as Hydro-chloro-fluoro-carbon. (HCFC) refrigerant.

Ex- R-22, R-123

(v) HFC refrigerant :-

The refrigerants which contains no chlorine atom in their molecules are known as hydro-fluoro carbon (HFC) refrigerant.

Ex- R-134a, R-152a.

(vi) HC refrigerant :-

The refrigerant which contains no chlorine and fluorine atom in their molecules are known as hydro-carbon (HC) refrigerants.

Ex- R-290, R-600a etc.

→ As the chlorine atoms in the molecules of refrigerant is consider to be responsible for the depletion of ozone layer in the upper atmosphere which allows harmful ultra violet rays from the sun to penetrates through the atmosphere and reach the earth surface causing skin cancer.

→ So, the chloro-fluoro carbon (CFC) refrigerants have been linked to the depletion of ozone layer and also create global warming effect which may cause serious changes in the environment.

→ The some of the substitutes of CFC refrigerant are-

(i) HCFC refrigerant (R-123) (CF_3CHCl_2) in place of R-11.

(ii) HFC refrigerant (R-134a) and (R-152a) in place of R-12.

(iii) The HFC refrigerant (R-143a) and (R-125) in place of R-502 (Azeotrope).

(5.3) Application of Refrigeration :-

Cold Storage :-

(i) Cold Storage plant works on the vapour compression refrigeration cycle. The second law of thermodynamics is the basic of cooling. As per second law, in order to transfer heat from a low temperature body to high temperature body one needs to put extra energy according to Clausius; so compressor work is the work of energy needed for cooling process continuation.

(ii) The cold storage is a building designed to store certain goods like food, stable, fruits, vegetables, dairy products within well defined temperature range and relative humidity (RH).

(iii) The cold storage is an application of air conditioning.

(iv) The temperature and humidity conditions maintained inside a cold storage depend upon the type of product stored i.e :-

(a) for vegetables, tempr around 0°C to 5°C (278 K to 278 K) with high RH of 80-90%.

(b) for milk, tempr ... -4°C to 5°C (277 K to 278 K).

(c) For quick freezing of fish, temp -25°C to -30°C.

(d) For chlorine liquidise temp. is -20°C to -45°C.

(v) Hence, the conditions required for storage can be divided into two categories -

(a) cold storage for products which are to be maintained at temperature of 0°C and above

(b) Cold Storage for products which are to be maintain at temperature below 0°C.

During storage, the fresh vegetables and fruits product heat of respiration. Thus refrigeration plant must be designed to take care of this load in addition to usual heat loads, i.e. load due to heat rele.

Dairy refrigeration :-

(i) Refrigeration is a basic requirement for the processing and storage of milk and milk products as majority of dairy products are perishable in nature.

(ii) If its not maintained at sufficient low temperature, it gets spoiled due to growth of bacteria and other organisms.

(iii) The bacterial content can be eliminated to a great extent by heating the milk to 62°C (335 K) and holding it at that temperature for about 30 minutes. There after to minimize the bacterial growth and preoxation, the milk is cooled to 4°C to 5°C (277K to 278 K).

(iv) This process of heating and immediately cooling the milk for controlling the bacterial growth is known as pasteurization.

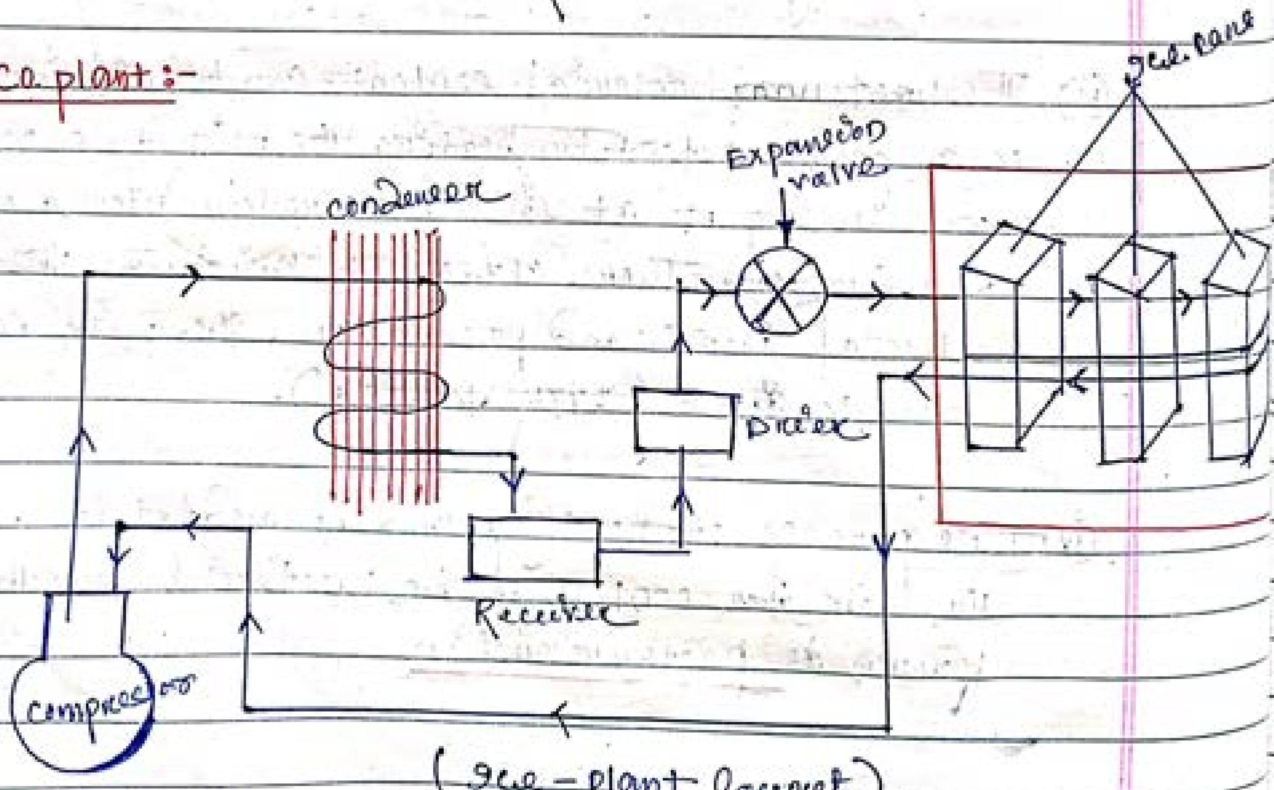
(v) The raw milk is heated by hot water or steam to 62°c and heating is done by hotwater which is sprayed around the outside lining of the vat by a distributor, which gets collected in a sump at the bottom of the vat, reheated and once again sprayed.

(vi) The heated milk is then cooled first by cooling power water and then by the chilled water or breadne to 4°c to 5°c.

(vii) In order to control the fat content of milk, it is defined to churn the milk which is called toned milk.

(viii) The fat thus removed is processed as butter and stored at 4°c to 5°c and cheese is another product from milk stored at 4°c.

Ice plant :-



(Ice-plant layout)

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(i) In ice plant, commercial ice is produced by freezing portable water in standard cans placed in rectangular tan. which are filled with chilled brine.

(ii) For increasing the heat transfer from water, the brine solution is kept in constant motion by agitators and the brine temp is maintained by refrigeration plant at -10°C to -11°C.

(iii) The ammonia gas is used as refrigerant because of its excellent thermal properties and it produces very high refrigerating effect per kg of refrigerant.

(iv) The high temperature, high pressure ammonia vapours are condensed in a condenser which may be shell and tube type or evaporative type.

(v) The condensed liquid ammonia is collected in the receiver and expanded through the expansion valve.

(vi) Due to expansion, the pressure of the liquid ammonia is reduced and it then passes through the evaporator coils surrounding a brine tank in which brine solution is filled.

(vii) The low pressure liquid ammonia absorbs heat from the brine solution, gets converts to vapour state and is again fed to compressor to complete the cycle.

(viii) The ice cans are fabricated from galvanised steel sheets and are given chromium treatment to prevent corrosion due to chemical reaction.

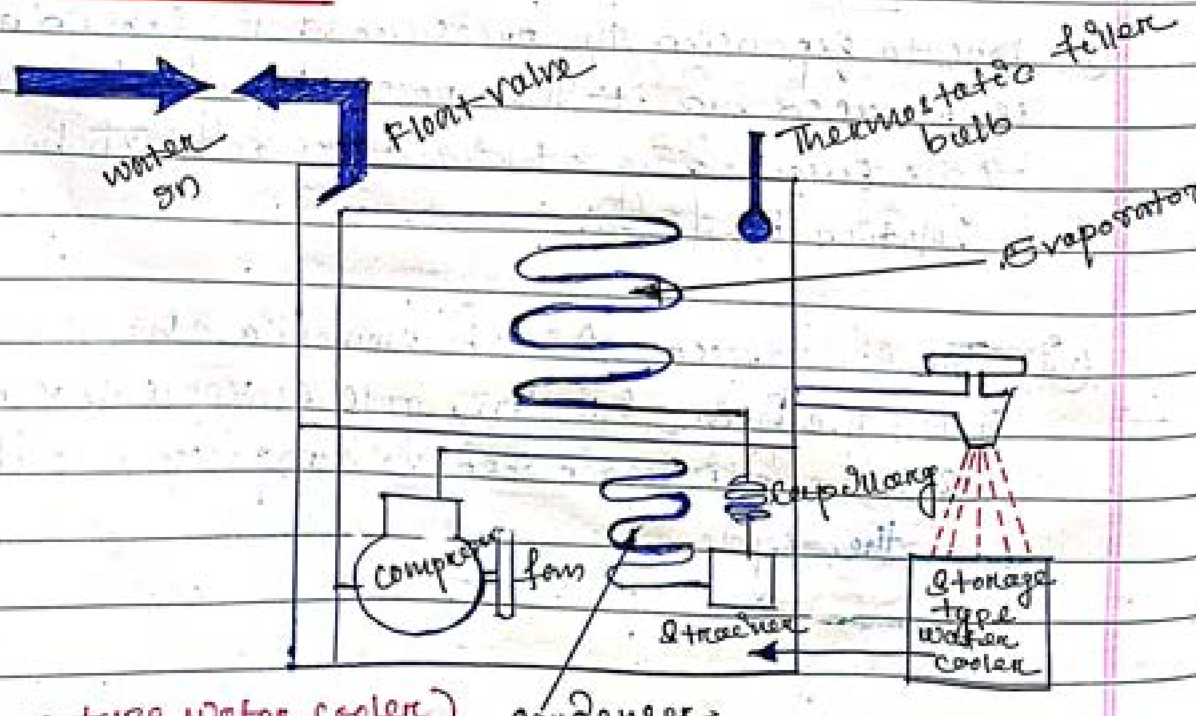
(ix) Ice of potable water frozen at a temperature lower than $-12°C$ can crack, hence brine temperature is kept at $-11°C$ to $-10°C$.

(x) Water in ice cans placed in brine cools rapidly upto temp^{r}. of $2°C$ to $4°C$. so it takes more time for water to touch $0°C$.

Generally sodium chloride ($NaCl$), calcium chloride ($CaCl_2$) is used as brine. Due to low cost and being less injurious $NaCl$ is used.

(xi) The freezing time is depending upon the brine temperature and brine water agitation.

Water Cooler:-



(Storage type water cooler)

Working :-

(i) Temperature is controlled by thermostatic switch as per our desired temperature.

(ii) The low pressure low temperature refrigerant then extracts heat of water from the evaporator tank.

(iii) By taking heat from water, refrigerant evaporates and this vapour refrigerant sucked by compressor and process continues.

Purpose / Application :-

(i) The purpose of a water cooler is to make water available at a constant temperature irrespective of ambient temp^{r}.

(ii) The temperature of cold water is controlled with the help of a thermostatic switch set within 7°C to 13°C range, and is used for thirst especially in hot summer.

Types of water cooler :-

There are two type of unitary water coolers.

(a) Storage type water cooler.
(b) Instaneous type water cooler.

(a) Storage type water cooler :-

(i) In storage type water coolers, the evaporator coils is soldered on to walls of the storage tank de the ... . coolers, i.e on the of outside surface of the walls.

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i) The tank may be galvanised steel or stainless steel sheets. and the water level in the tank is maintained by a float valve.

ii) In this type of water cooler, the machine will have to run for a long time to bring down the temperature of mass of water in the storage tank.

iii) once the temperature touches the set point of thermostat, the machine cycle is stopped.

iv) When the water is drawn from the cooler and an equal amount of fresh water is allowed in the tank, the temperature will rise up slowly and the machine starts again.

(b) Instantaneous type water coolers :-

(i) In this type of water cooler, the evaporator consists of two separate cylindrically wound coils made of copper or stainless steel tube.

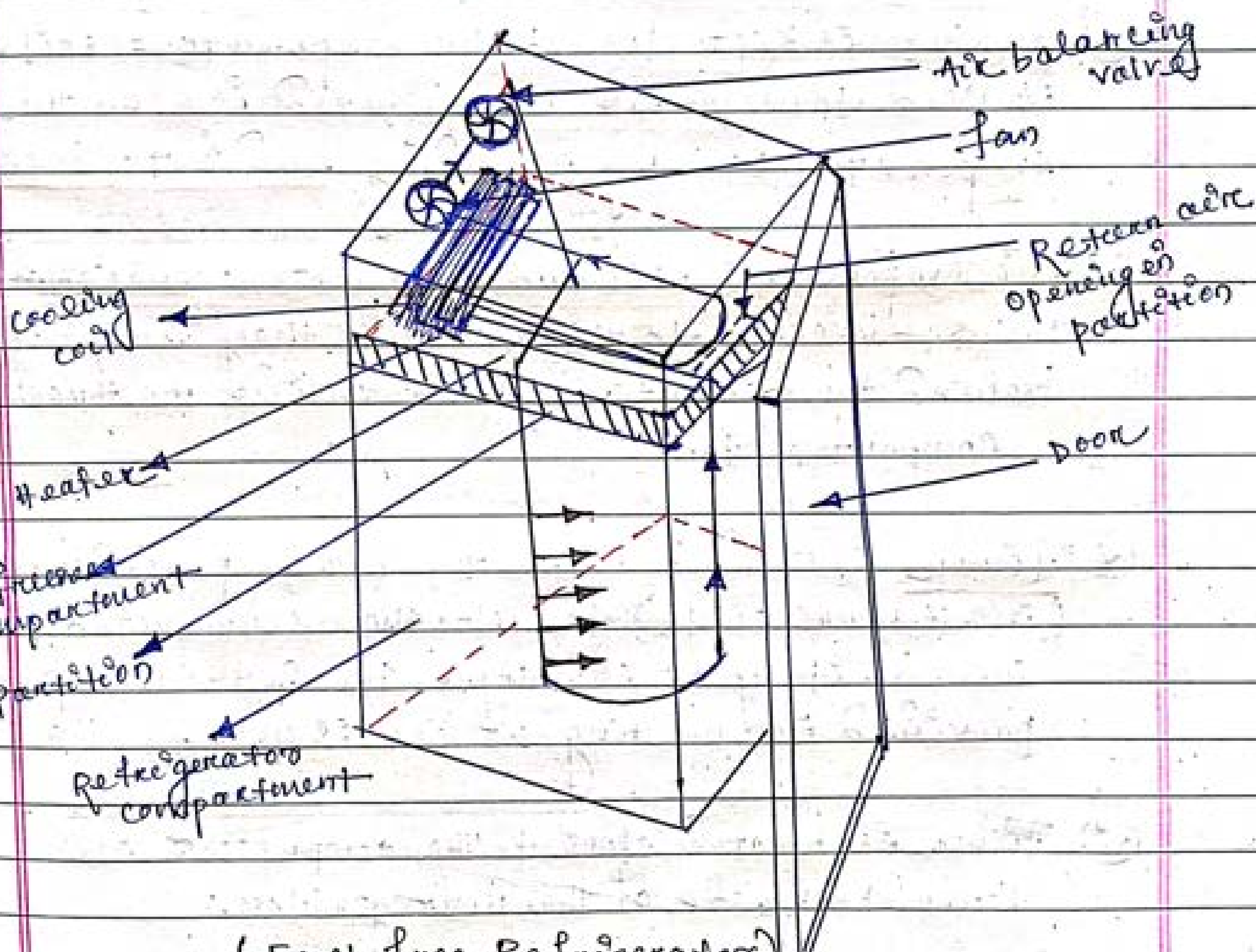
(ii) The evaporat refrigerant is in one of the coils and the water to be cooled is in the other coil.

(iii) : The water is cooled by the refrigerant in evaporator by conduction.

(iv) Here the factor bulb of the thermostat is clamped on to the water pipe at its outlet.

(v) In this case, it is very important that the flow rate of water is adjusted to match its capacity and if the rate of flow is higher, the cooler will not be able to bring down the temperature of water to the sea level.

Frost free Refrigerator :-



(Frost free Refrigerator)

(i) In frost free refrigerator, refrigerant coil is not provided in the evaporator (freezer) box, instead it is provided behind the back panel of the freezer compartment.

(i) In frost free refrigerator design, three additional components i.e., heater, fan and timer are provided.

(ii) Heater is kept closed to the evaporator coil, and the heater are not visible to the users as they are hidden behind.

(iii) Heater is kept close to the evaporator coil, and is used to melt the accumulated ice on the evaporator coil by providing radiant heating.

(iv) The evaporator coil and the heater are not visible to the users as they are hidden behind the decorative panels inside the freezer compartments.

(v) Timer is used to make the heater periodically (i.e. 16 hours cycle) to melt the accumulated ice and it gets off after the set time period provided for melting of ice is over.

(vi) Timer is located close to the compressor on lower back side of the refrigerator.

(vii) A fan is provided to maintain the circulation of air in refrigerator and freezer.

(viii) An air balancing valve with three settings i.e. freezer max / refrigerator max / normal, is provided in the air circuit to control the quantity of air to be sent to freezer and refrigerator.

Working :-

(i) When the valve is kept in "freezer max" position to make ice, ice trays fast, the opening of balancing valve gets almost closed allowing max air to go into the freezer with minimum air going into the refrigeration compartment.

(ii) The air after absorbing the heat from refrigerant gets warmed up and rises upward and enters through a return air opening provided on the front side of the lower face of the partition between freezer and refrigerator compartment.

(iii) The fan then draws return air from the refrigerator and freezer compartment over the heater/cooling coil.

(iv) By periodic automatic defrosting of the coil. higher the heat transfer rates are maintained for the evaporator coil reducing the running cost of the refrigerator.

An additional modification is is provided in the new frost free refrigerators is the flat back design.

(v) In flat back design of the refrigerator, the normally visible condenser on the back side of refrigerator is brazed on the inner side of the back & side panel sheets of the refrigerator body.

(vi) The entire surface of back & side panels acts as a heat transfer surface.

(vii) This design improves aesthetic look of refrigerator and provides safety of the refrigerator during transportation.

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04/01/2023

CHAPTER-6

Psychometrics and comfort air conditioning systems

Psychometrics :-

(i) It is a branch of science which deals with the study of moist air that is dry air mixed with water vapour or humidity.

(ii) It also includes the study of behaviour of dry air and water vapour mixture under various sets of conditions.

(iii) The psychometrics terms are-
(a) Dry air
(b) Moist air
(c) Saturated air
(d) Degree of saturation
(e) Humidity
(f) Absolute Humidity

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(g) Relative humidity.
(h) Dry bulb temperature.
(i) wet-bulb temperature.
(j) wet bulb depression
(k) Dew point temperature.
(l) Dew point depression
(m) Psychrometer.

(1) Dry air :-

(i) The pure dry air is a mixture of a number of gases such as nitrogen, oxygen, Hydrogen, Helium, Argon.

(ii) The molecular mass of dry air is 28.966 and the gas constant of air $(R_a) = 0.287\ KJ/Kg \cdot K$.

(iii) Pure dry air doesn't exist in nature because it always contains some water vapour.

(iv) Both water vapour and dry air can be consider as perfect gas because both exist in atmosphere at low pressure.

(v) The molecular mass of water vapour $M = 18.016$ and gas constant for water vapour $R_v = 0.461\ KJ/kgK$

(vi) Density of dry air $(\rho_a) = 1.293\ Kg/m^3$ at 1.0135 bar and at $0°C$.

(2) Moist air :-

(i) It is a mixture of dry air and water Vapour.

(ii) The amount of water vapour present in air depends upon absolute pressure and temperature of mixture.

(3) Saturated air :-

(i) It is a mixture of dry air and water Vapour when the air is reached the maximum amount water vapour into it.

(ii) The water vapour occurs in the form of superheated steam as an invisible gas.

(4) Degree of saturation :-

(i) It is a 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 the same temp^{r}.

(ii) It is denoted as 'μ'.

(iii) It is also known as percentage humidity.

$$\therefore \boxed{\mu = \frac{w}{w_s}}$$

(5) Humidity :-

(i) It is a mass of water vapour present in 1 kg of dry air, unit gram per kg of dry air.

(ii) It is also called specific humidity or humidity ratio or moisture content.

(iii) It is denoted as 'w'.

(6) Absolute humidity :- (ρ_v)

(i) It is the mass of water vapour present in $1 m^3$ of dry air.

(ii) It is expressed in gram $/m^3$ of dry air or it is expressed in grains$/m^3$ of dry air.

(iii) It is also known as vapour density. $\therefore \rho_v = w \cdot \rho_a$

(7) Relative humidity :-

(i) It is the ratio actual mass of water vapour in a given volume of moist air to the mass of water vapour in the same volume of saturated air at the same temperature and pressure.

(ii) It is denoted as 'ϕ' or RH.

$$\therefore \phi = \frac{m_v}{m_s}$$

(8) Dry bulb temperature :-

(i) It is a temperature of air recorded by a thermometer when it is not effected by moisture present in the air.

(ii) It is denoted as 'td' or 'tdb'

(9) Wet bulb temperature :-

(i) It is a temperature of air recorded by a thermometer when its bulb is surrounded by a wet cloth exposed to the air.

(ii) It is denoted as 'tw' or 'twb'.

(iii) Such thermometer is called wet bulb thermometer.

(10) Wet bulb depression :-

(i) It is a difference between dry bulb temperature and wet bulb temperature at any point.

(ii) The wet bulb depression indicate relative humidity of air.

05/01/23

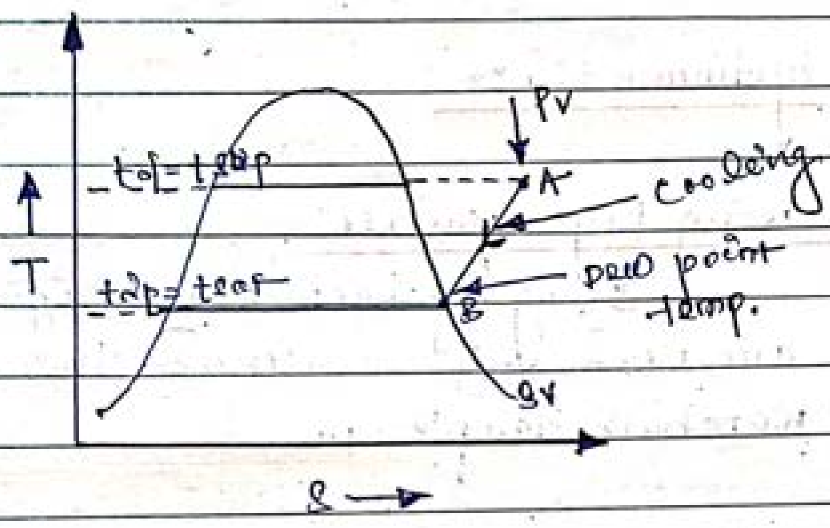
(11) ~~Wet bulb~~.

Dew point temperature :-

(i) It is a tempr of air recorded by a thermometer when the moisture present in it begins to condense.

(ii) It is the temp^{r}. or saturation temp^{r}. corresponding to the partial pressure of water vapour (P_v)

(iii) Dew point temperature is denoted as 't_{dp}'.



(iv) The water vapour in air exist in the superheated states moist air containing in superheated states is said to be unsaturated air.

(v) When the partial pressure of water vapour 'P_v' is equal to the saturation pressure 'P_s', the water vapour is in dry conditions and the air is called saturated air.

(vi) The point A → The unsaturated air.
B → Saturated states and the temp^{r}. at B is called Dew point temp^{r}.

N.B

For sat. air the dry bulb temp^{r}, the wet bulb temp^{r}. and Dew point temp^{r}. is same.

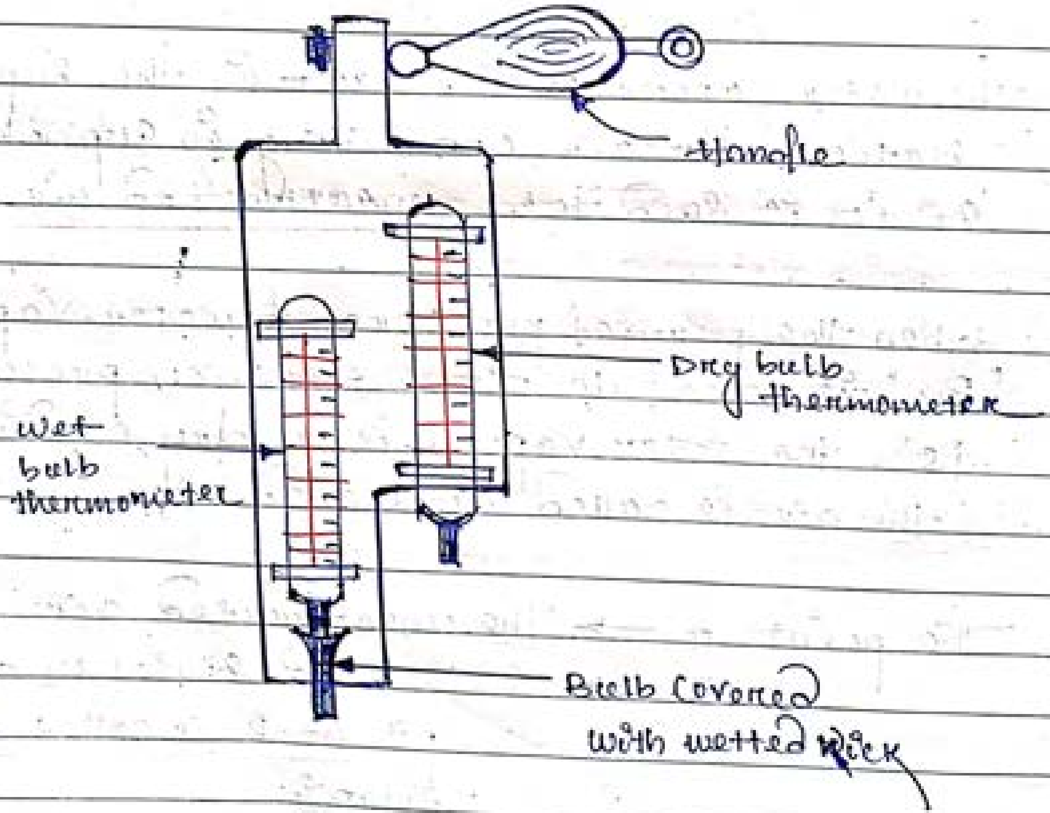
(12) Dew point Depression :-

(i) It is the difference between Dry bulb tempr. and Dew point tempr.

(13) Psychrometer :-

Sling Psychrometer

Sling Psychrometer, Digital Psychrometer are used to measured the dry bulb tempr. wet bulb tempr. etc.



(ii) There are different types of psychrometer but sling psychrometer is widely used.

(iii) It consist of a dry bulb thermometer and a wet bulb thermometer mounted side by side in a protective case.

(iv) The case is attached to a handle by a swivel connection, so that the case can be easily rotated.

(v) The dry bulb thermometer is directly exposed to the air and measured the actual temp^r of air.

(vi) The bulb of wet bulb thermometer is covered by a wick .... thoroughly wetted by distilled water.

(vii) The temperature measured by the wick covered bulb of a thermometer is the temp^r. of liquid water in the wick and is called wet bulb temperature.

(viii) The sling psychometer is rotated in the air for 1 minute after which the readings from both the thermometer are taken. The process is repeated several ~~typ~~ times to assure that lowest possible wet bulb temp^r. is recorded.

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Daltons law of partial pressure :-

(i) It states that the total pressure exerted by the mixture of air and water vapour is equal to the sum of pressures which its constituent would exert if it occupied the same space by itself.

or

(ii) The total pressure exerted by air and water vapour mixture is equal to the barometric pressure.

∴ Barometric pressure of the mixture -

$$P_b = P_a + P_v$$

Where, P_a → The partial pressure of dry air.

P_v → The partial pressure of water vapour.

Psychrometric Relations :-

Term	Defination	Formula
1. Specific humidity or humidity ratio moisture content (W)	(i) Mass of water vapour present in 1kg of dry air. (ii) Ratio of mass of water vapour to mass of dry air in a given vol. of air-vapour mixture (iii) It is denoted as 'W'.	$W = \frac{m_v}{m_a}$ $W = \frac{R_a P_v}{R_v P_a}$ but $R_a = 0.287$ KJ/kgK, $R_v = 0.461$ KJ/kgK $W = 0.622 \frac{P_v}{P_a}$ $= 0.622 \cdot \frac{P_v}{P_b - P_v}$ $\because P_b = P_a + P_v$ $P_a V_a = m_a R_a T_a$ $P_v V = m_v R_v T_v$
* Where m_a, P_a, V_a, m_v, P_v, V_v, R_v,	R_a, T_a → P, V, gas constant mass, temp for dry air. T_v → mass, P, V gas constant, temp for water vapour.	* For saturated air, maximum specific humidity or humidity ratio. $W_s = W_{max} = \frac{0.622 P_s}{P_b - P_s}$
P_s → Partial pressure of air to saturation temp.		
P_b → Barometric pressure.		

(2) Degree of saturation or Percentage humidity (μ)	It is ratio of actual specific humidity to the specific humidity of saturated air at the same dry bulb temperature denoted as 'μ'.	$\therefore \mu = \frac{w}{w_s}$ $= \frac{\left(\frac{0.622 P_v}{P_b - P_v}\right)}{\left(\frac{0.622 P_s}{P_b - P_s}\right)}$ $= \frac{P_v}{P_s}\left[\frac{1-\left(\frac{P_s}{P_b}\right)}{1-\left(\frac{P_v}{P_b}\right)}\right]$
(3) Relative humidity (ϕ)	(i) It is ratio of actual mass of water vapour (m_v) in a given volume of moist air to the mass of water vapour (m_s) in same volume of saturated air at the same temp & pressure.	$\therefore \phi = \frac{m_v}{m_s}$ $\phi = \frac{P_v}{P_s} = \frac{m_v}{m_s}$ $\left[\begin{array}{l} \because P_v V_v = m_v R_v T_v \\ P_s V_s = m_s R_s T_s \end{array}\right]$ $V_s = V_v$ $T_s = T_v$ $\because R_v = R_s = 0.461 \text{ kJ/kg}$
	for saturated air, relative humidity 100%.	$* \ \mu = \frac{P_v}{P_s}\left[\frac{1-\frac{P_s}{P_b}}{1-\frac{P_v}{P_b}}\right]$ $= \phi \cdot \left[\frac{1-\frac{P_s}{P_b}}{1-\phi \cdot \frac{P_s}{P_b}}\right]$ $\Rightarrow \phi = \frac{\mu}{\left[1-(1-\mu)\frac{P_s}{P_b}\right]}$

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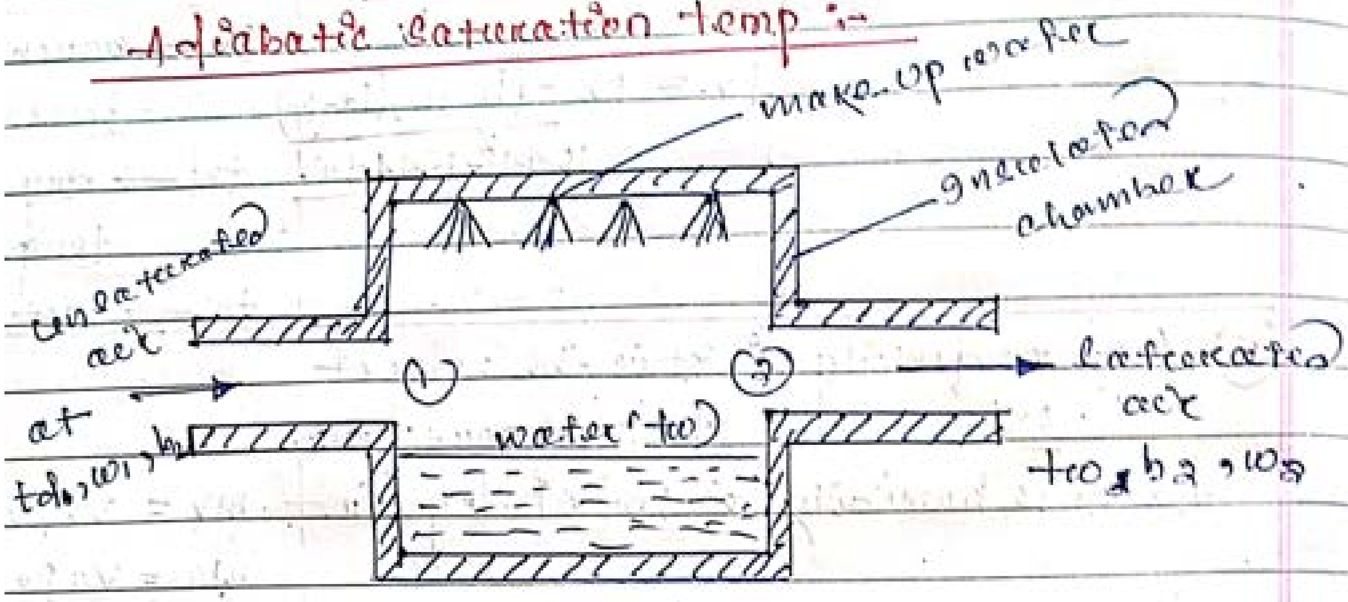
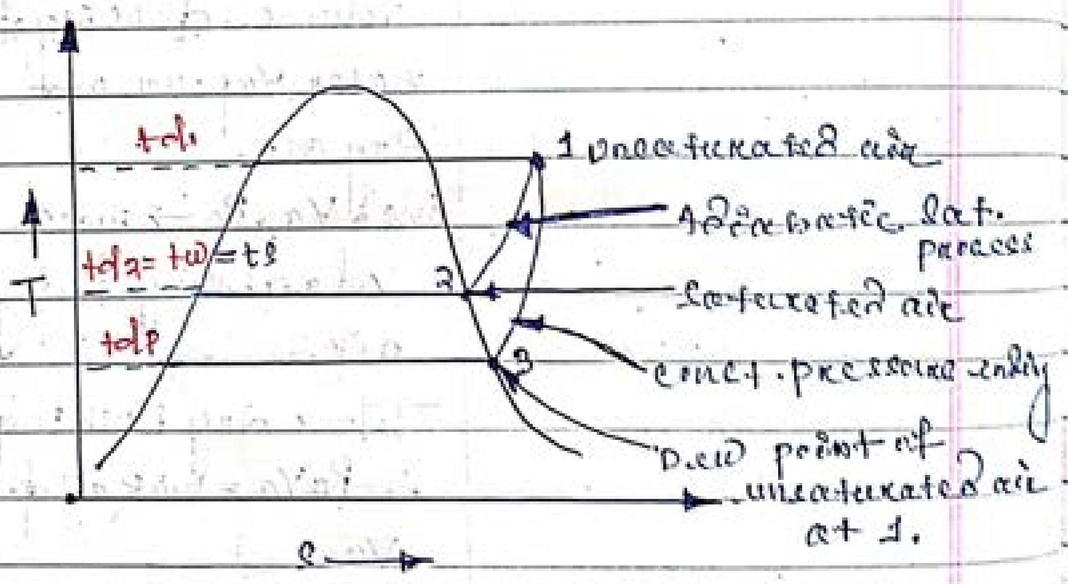
(4) Pressure of water vapour (P_v)	According to Carrier's equation, the partial pressure of water vapour. $$P_v = P_w - \frac{(P_b - P_w)(t_d - t_w)}{1544 - 1.44 t_w}$$	Where, $P_w \rightarrow$ sat. pressure to wet bulb temp. $P_b \rightarrow$ barometric pressure. $t_d \rightarrow$ dry bulb temp. $t_w \rightarrow$ wet bulb temp.
(5) Vapour density or Absolute humidity	(i) It is the mass of water vapour present in 1 m^3 of dry air. $m_v, V_v, \rho_v \rightarrow$ mass, volume, density of water vapour of dry air. $m_a, V_a, \rho_a \rightarrow$ mass, vol, density of dry air. $T_d \rightarrow$ dry bulb temp. $\therefore P_a V_a = m_a R_a T_d$. $V_a = \frac{1}{\rho_a}$ $P_a \times \frac{1}{\rho_a} = R_a T_d$. $\Rightarrow \rho_a = \frac{P_a}{R_a \cdot T_d}$	$m_v = V_v \rho_v$ $m_a = V_a \rho_a$ $\therefore \frac{m_v}{m_a} = \frac{V_v \rho_v}{V_a \cdot \rho_a}$ humidity ratio $W = \frac{m_v}{m_a} = \frac{\rho_v}{\rho_a}$ $(\because V_a = V_v)$ $\Rightarrow \rho_v = W \rho_a$ $\therefore \rho_v = W \cdot \frac{P_a}{R_a \cdot T_d}$ $= \frac{W(P_b - P_v)}{R_a \cdot T_d}$

06|01|2022

Thermodynamic Wet bulb temp :-
or
Adiabatic saturation temp :-





(i) It is the temp^r. at which the air can be brought to saturation state adiabatically by the evaporation of water into the flowing air.

(ii) The equipment used for adiabatic saturation of air consist of an insulated chamber containing adequate quantity of water and extra water known as make up water to

Flow into the chamber from its top.

(iii) The unsaturated air enters at section (1), as the air passes through the chamber over a long sheet of water, the water evaporates carrying with flowing stream of air and the specific humidity of air increases.

(iv) Both air and water are cooled as the evaporation takes place and this process continuous until the energy transfered from air to water.

(v) When the steady condition are reached, the air flowing at section (2) is saturated with water vapour.

(vi) The temperature of the saturated air at section (2) is known as thermodynamic wet bulb tempr or adiabatic saturation tempr.

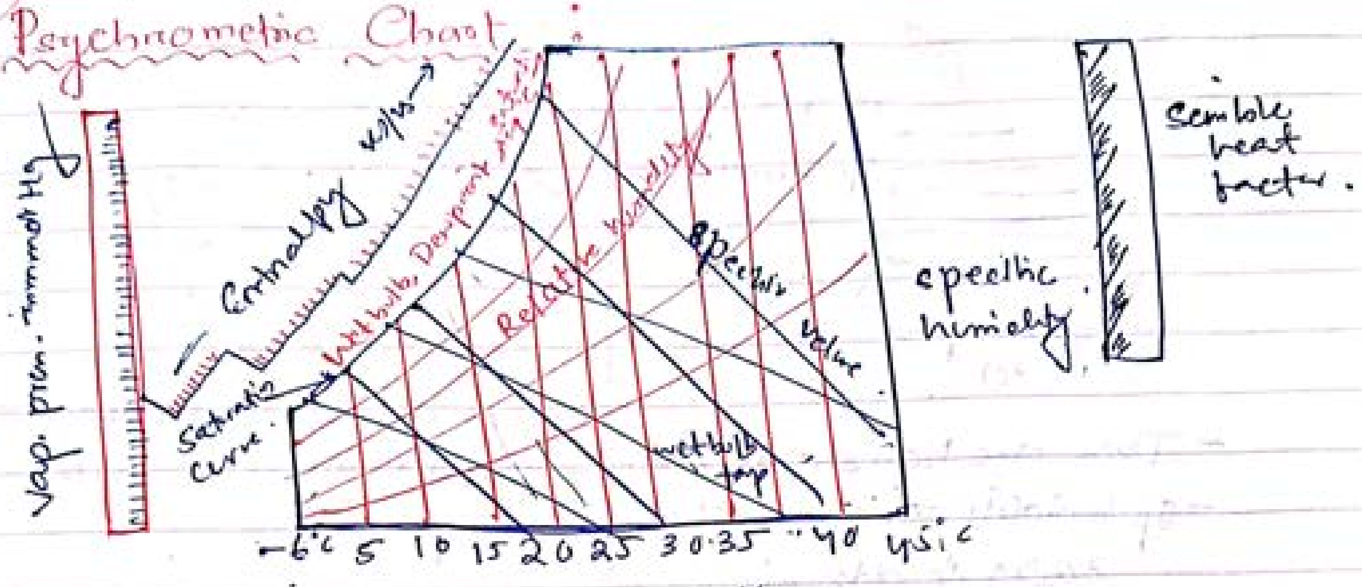
The process 1-2 → The adiabatic saturation process

(vii) The adiabatic saturation tempr is taken to be equal to the wet bulb tempr.

$$\boxed{T_d = T_w}$$

6.3

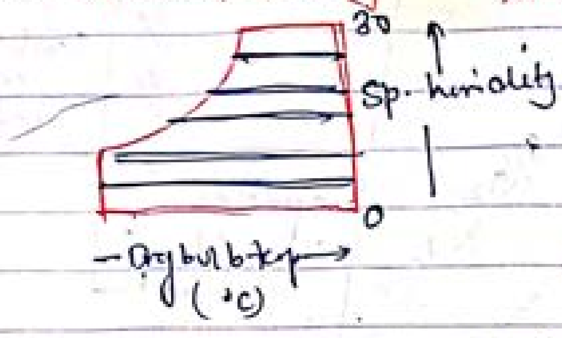
Psychrometric Chart :



- It is a graphical representation of various thermodynamic properties of moist air & useful for finding various properties of air.
- The saturation curve represents 100% relative humidity at various dry bulb temp.
- Different lines in psychrometric chart
  - (a) Dry bulb temp. lines.
  - (b) specific humidity or moisture content lines.
  - (c) Dew point temp lines –
  - (d) wet bulb temp lines
  - (e) Enthalpy lines
  - (f) specific volume lines
  - (g) vapour pressure lines
  - (h) Relative humidity lines

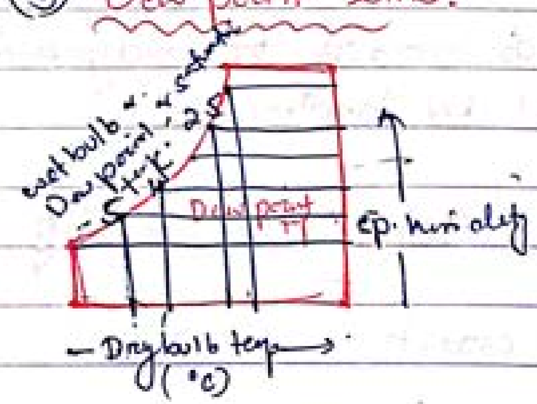
(a) Dry bulb temp : (i) These are vertical lines
(ii) Temp range from -6°C to 45°C
(iii) Dry bulb temp also shown on the saturation curve.

(2) Specific humidity: (Moisture content lines)



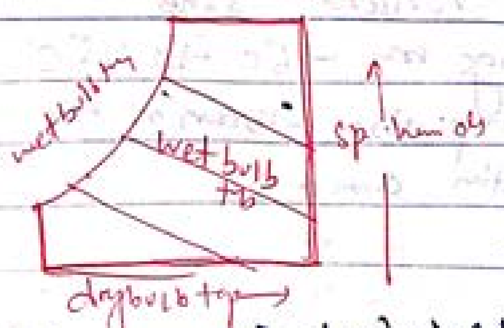
- These are horizontal lines
- sp. humidity ranges 0 to 30 g/kg of dry air

(3) Dew point temp lines:



- Dew point temp lines are horizontal.
- At any point on saturation curve drybulb and dew point temp are equal.

(4) Wet bulb temp

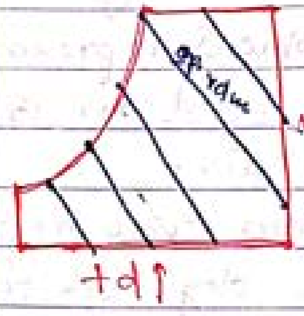


- lines are inclined straight.

(5) Enthalpy lines

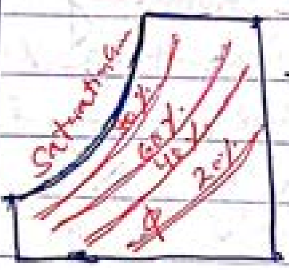
- lines are inclined straight lines.
- parallel to wet bulb temp lines.

(6) Specific volume lines.



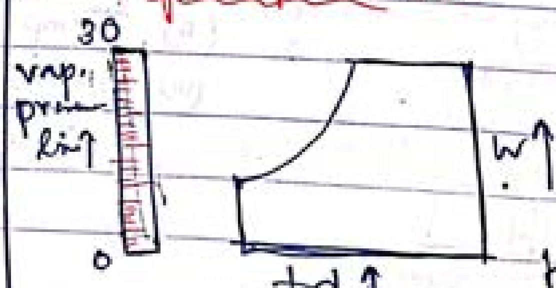
- The lines are obliquely inclined straight lines.

(7) ~~Vapour pressure lines~~ Relative humidity lines



- These are curved lines follows the saturation curve.
- saturation curve represents 100% relative humidity

(8) Vapour pressure lines



- lines are horizontal

Problem 441-P3

(6.4)

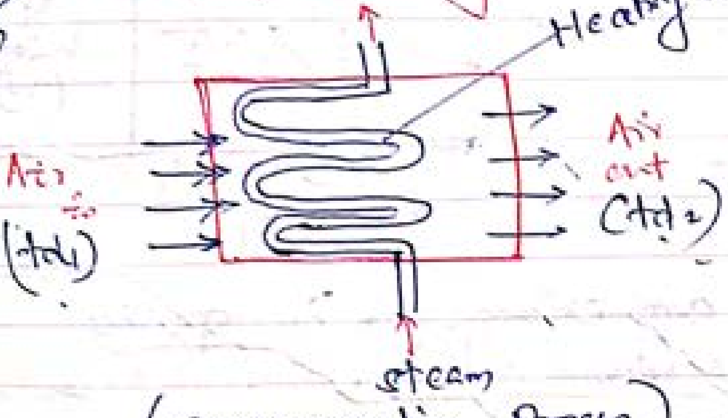
Psychrometric Processes :→ The psychrometric process involved in air conditioning are :

1). Sensible heating.
2). Sensible cooling
3). Humidification & dehumidification.
4). Cooling and adiabatic humidification
5) Cooling & humidification by water injection.
6) Heating & humidification.
7) Humidification by steam injection.
8) Adiabatic chemical dehumidification.
9) Adiabatic mixing of air streams.

(6.4.1)

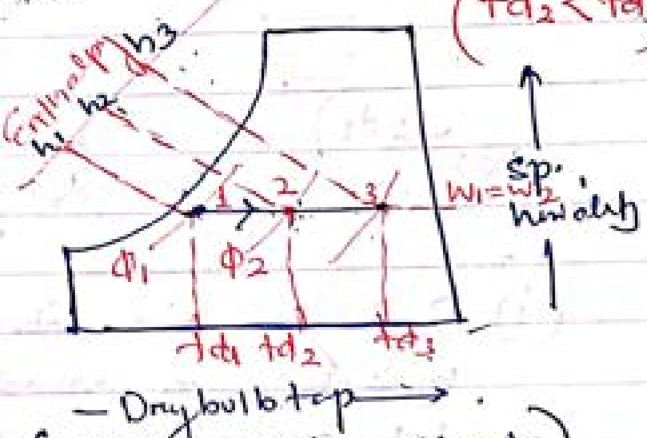
(1) Sensible heating :—

P-442 / B3



(psychrometric Process)

$(td_2 < td_3)$



(psychrometric Chart)

(i) The heating of air without any change in its specific humidity is called sensible heating. (W = const)

(ii) let
td_1 → temp of air at inlet
td_2 → " " " at outlet
td_3 → " " heating coil.

$(td_2 < td_3)$ (less)

1-2 → represents sensible heating process.
point 3 → represents surface temp of heating coil.
∴ heat absorbed during sensible heating,

$$q = h_2 - h_1$$

$\Rightarrow q = h_2 - h_1$

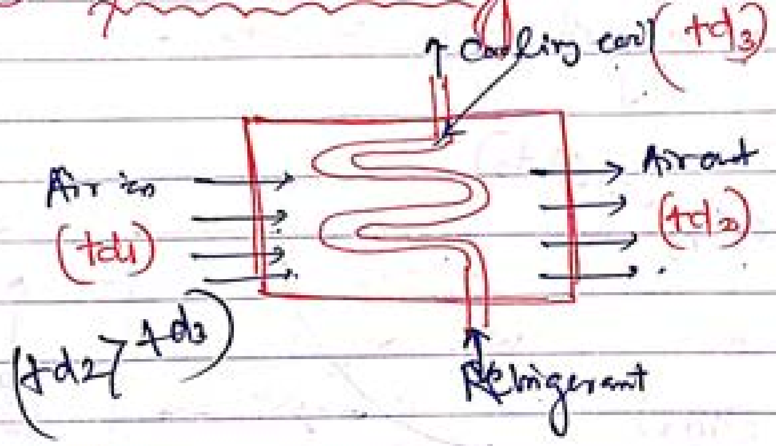
$= C_{pa}(t_{d2} - t_{d1}) + W C_{ps}(t_{d2} - t_{d1})$

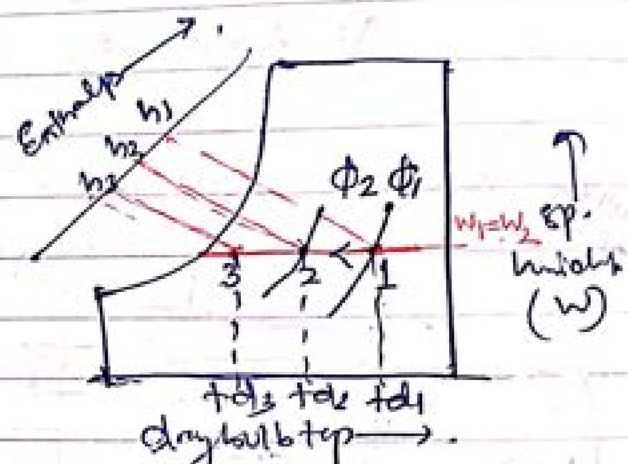
$= (C_{pa} + W C_{ps})(t_{d2} - t_{d1})$

$$q = C_{pm}(t_{d2} - t_{d1})$$

term $(C_{pa} + W C_{ps})$ is called humid specific heat (C_{pm}) & its value is 1.022 kJ/kgK.

(2) Sensible Cooling :





(i) Cooling of air without any change in its specific humidity is called sensible cooling. (W = const)

(ii) let air at temp t_{d1} pass over a cooling coil of temp t_{d3} & temp of air leaving the cooling coil (t_{d2}) $(t_{d2} > t_{d3})$. $(W_1 = W_2)$

(iii) line 1-2 → represents sensible cooling process. point 3 → surface temp of cooling coil.

Heat rejected by air during sensible cooling

$\therefore q = h_1 - h_2$

$= C_{pa}(t_{d1} - t_{d2}) + W C_{ps}(t_{d1} - t_{d2})$

$= (C_{pa} + W C_{ps})(t_{d1} - t_{d2})$

$$q = C_{pm}(t_{d1} - t_{d2})$$

where $(C_{pa} + W C_{ps})$ is called humid specific heat (C_{pm}) & its value is 1.022 KJ/kgK.

∴ Heat rejected, $q = 1.022\,(t_{d1} - t_{d2})$ KJ/kg.

For air conditioning process sensible heat / minute is

$$SH = m_a C_{pm} \Delta t = V \rho C_{pm} \Delta t \quad \text{KJ/min} \quad (m = V\rho)$$

where $V \rightarrow$ rate of dry air blowing in m³/min

$\rho \rightarrow$ density of moist air at 20°C & 50% relative humidity = 1.2 kg/m³ of dry air

$C_{pm} \rightarrow$ humid sp. heat = 1.022 KJ/kgK.

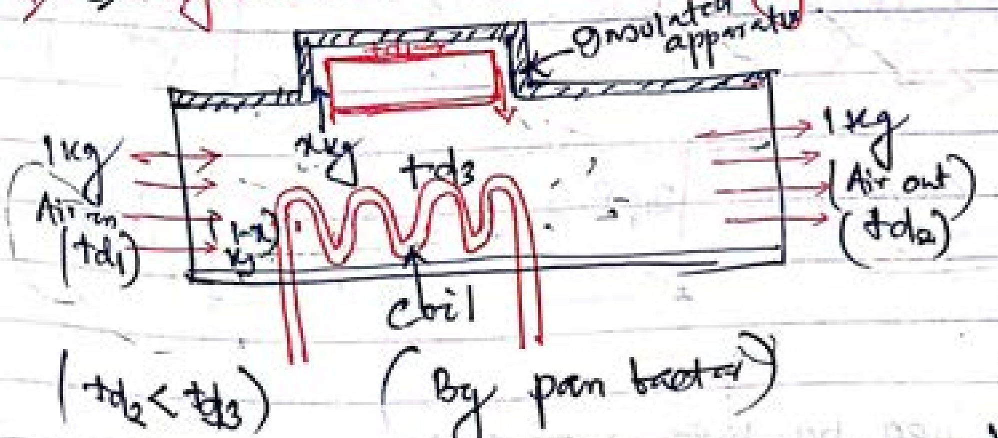
$\Delta t = t_{d1} - t_{d2}$

= difference of dry bulb temp betⁿ the entering & leaving cond's of air °C.

$$\therefore SH = V \times 1.2 \times 1.022 \times \Delta t$$
$$= 1.2264\,(V\,\Delta t) \text{ KJ/min} = \frac{1.2264}{60}(V \times \Delta t)$$
$$= 0.02044\,(V \times \Delta t) \text{ kW}.$$

6.4.6 (p-444)

By pass factor of Heating and Cooling coil :→



- let 1kg of air at temp t_{d1} is passed over the coil its temp is t_{d3}.
- when air pass over a coil, let x kg by pass unaffected air while the remaining (1-x) kg comes in direct contact with the coil.

→ This bypass process of air is measured in terms of a by-pass factor. The bypass factor depends on factors :-

(i) The number of fins provided in a unit length.
(ii) The no. of rows in a coil in the dirⁿ of flow.
(iii) The velocity of flow of air.

→ Under ideal condⁿs, the dry bulb temp. of air leaving the apparatus (td_2) should be equal to that of coil (td_3). But it is not so becoz of inefficiency of coil. This phenomenon is known as by-pass factor.

NB :- The by pass factor of a cooling coil decreases with decrease in fin spacing & increase in number of rows.

- Balancing enthalpies,

$$\therefore x\, C_{pm}\, td_1 + (1-x)\, C_{pm}\, td_3 = 1 \times C_{pm}\, td_2 \qquad (h = mC_pT)$$

$$\Rightarrow \boxed{x = \frac{td_3 - td_2}{td_3 - td_1}}$$

where x is called by-pass factor of the coil or BPF.

C_{pm} → specific humid heat.

(i) Bypass factor for heating coil, $\boxed{BPF = \frac{td_3 - td_2}{td_3 - td_1}}$ $\left(\frac{32}{31}\right)$

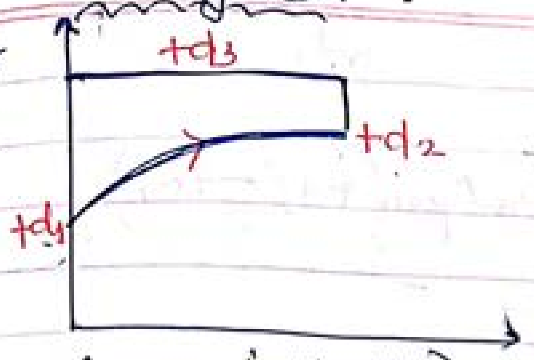
1 ← 2 ← 3
td_1 ← td_2 ← td_3

(ii) By pass factor for cooling coil, $\boxed{BPF = \frac{td_2 - td_3}{td_1 - td_3}}$ $\left(\frac{23}{13}\right)$

1 → 2 → 3
td_1 → td_2 → td_3

NB ✱ A coil with low BPF has better performance.

Heating Coil :



(temp distribution)

Consider air pass over a heating coil & therefore sensible heat given out by the coil

$$\therefore Q_s = U A_c \cdot t_m \quad \text{—— (i)}$$

where,

$U \rightarrow$ Overall heat transfer Coefficient

$A_c \rightarrow$ surface area of coil

$t_m \rightarrow$ Logarithmic mean temp. difference

$$\therefore t_m = \frac{\theta_o - \theta_i}{\ln(\theta_o/\theta_i)}$$

$$= \frac{t_{d3} - t_{d1} - t_{d3} + t_{d2}}{\ln\left(\frac{t_{d3} - t_{d1}}{t_{d3} - t_{d2}}\right)} \quad \left(\begin{array}{l}\theta_o = t_{d3} - t_{d1} \\ \theta_i = t_{d3} - t_{d2}\end{array}\right)$$

$$t_m = \frac{t_{d2} - t_{d1}}{\ln\left(\frac{t_{d3} - t_{d1}}{t_{d3} - t_{d2}}\right)} \quad \text{—— (ii)}$$

& we know BPF for heating coil $= \frac{t_{d3} - t_{d2}}{t_{d3} - t_{d1}}$

from eqn (ii)

$$\therefore t_m = \frac{t_{d2} - t_{d1}}{\ln\left(\frac{1}{BPF}\right)}$$

Now from eqn (i),

$$Q_s = U \cdot A_c \cdot \frac{t_{d2} - t_{d1}}{\ln\left(1/BPF\right)} \quad \text{—— (iii)}$$

Again heat added during sensible heating

$$Q_s = m_a C_{pm} (t_{d2} - t_{d1}) \quad \text{—— (iv)}$$

where C_{pm} = humid specific heat = 1.022 KJ/KgK

m_a = Mass of air passing over the coil.

From eq^n (iii) & (iv) we get,

$$\therefore \frac{U A_c \cdot (t_{d2} - t_{d1})}{\ln(1/BPF)} = m_a C_{pm}(t_{d2} - t_{d1})$$

$$\Rightarrow \ln\left(\frac{1}{BPF}\right) = \frac{U \cdot A_c}{m_a \cdot C_{pm}}$$

$$\Rightarrow \ln BPF = -\frac{U A_c}{m_a \cdot C_{pm}}$$

$$\Rightarrow \boxed{BPF = e^{-\frac{U A_c}{m_a \cdot C_{pm}}}}$$

$$\Rightarrow \boxed{BPF = e^{-\left(\frac{U A_c}{1.022 m_a}\right)}}$$

* Efficiency of heating and cooling coils :→

(i) The term (1 − BPF) is known as efficiency of coil or contact factor.

(ii) The efficiency of heating coil.

$$\therefore \eta_H = 1 - BPF = 1 - \frac{t_{d3} - t_{d2}}{t_{d3} - t_{d1}}$$

$$\Rightarrow \boxed{\eta_H = \frac{t_{d2} - t_{d1}}{t_{d3} - t_{d1}}}$$

(iii) The efficiency of cooling coil;

$$\eta_C = 1 - \frac{t_{d2} - t_{d3}}{t_{d1} - t_{d3}}$$

$$\Rightarrow \boxed{\eta_C = \frac{t_{d1} - t_{d2}}{t_{d1} - t_{d3}}}$$

Problem 347 (RS)

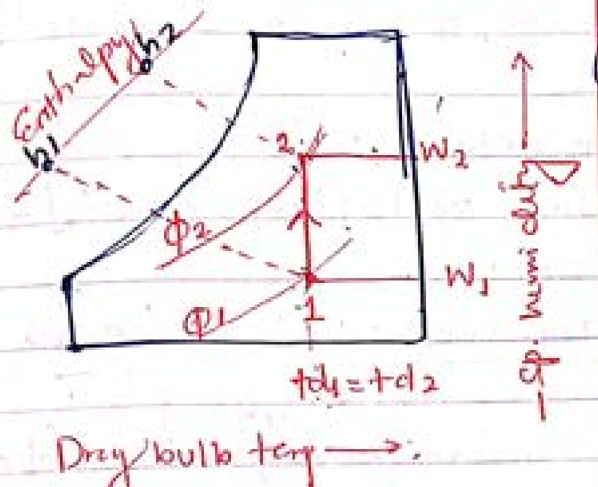
(1.4.3)

Humidification and Dehumidification

Humidification

(1) The addition of moisture to the air without change in its dry bulb temp is known as humidification.

(2)



(3) here specific humidity (W) increases from w_1 to w_2 & Relative humidity (ϕ) increases from ϕ_1 to ϕ_2.

(4) Here change in enthalpy $= (h_2 - h_1)$ & since dry bulb temp constant, so sensible heat also remain constant.

∴ Latent heat

$$LH = h_2 - h_1 = h_{fg}(W_2 - W_1)$$

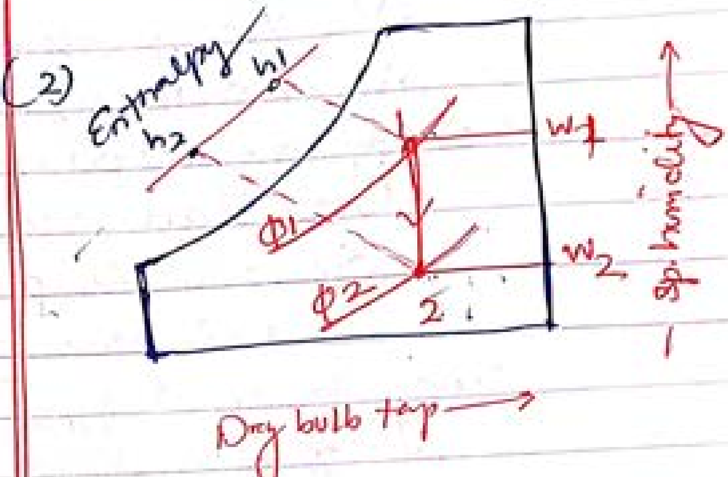
where h_{fg} → Latent heat of vaporisation at dry bulb temp (t_{d1}).

(5) eg: Ultrasonic humidification system.

Dehumidification

(1) The removal of moisture from the air without change in its dry bulb temp is known as dehumidification.

(2)



(3) Here specific humidity decreases from w_1 to w_2 and relative humidity decreases from ϕ_1 to ϕ_2.

(4) For dehumidification,

$$LH = h_1 - h_2 = h_{fg}(W_1 - W_2)$$

(5) eg: Multiple small plate dehumidification system.

→ SH refers to heat you can feel or sense. i.e. any heat which can be measured in a thermometer whether it's heat from sun or flame or candle

→ When an object is heated, the object increase in temp its SH, similarly when heat is removed from an object, its temp falls, this is also SH. because we can ~~feel~~ feel the difference

(Not)

* Methods of obtaining humidification & Dehumidification :-

(1) The humidification is achieved either by -

(a) Supplying and spraying steam or hot water or cold water into the air.

(b) by using direct method : i.e water is sprayed in a highly atomised state into room to be air conditioned.

(c) by using indirect method : i.e by using an air washer in the water & air conditioning plant.

Again the air washer humidification may be of 3 types

(i) by using recirculated spray water without prior heating of air.

(ii) by preheating the air and then washing it with recirculated water.

(iii) by using heated spray water.

(2) The dehumidification may be done -

(a) by using an air washer.

(b) by using chemicals.

(Imp) * The chemicals known as absorbents such as calcium chloride, silica gel, and activated alumina are used for dehumidification.

(PTO) SH/LH : SH relates to the change in temp. of an object or gas without a change in the phase.
LH relates to change in phase bet^n solids, liquids, gas.

(6.4.6)

* Sensible Heat Factor (SHF)

(i) The heat added during a psychrometric process may be sensible heat and Latent heat.

(ii) The ratio of sensible heat to the total heat is known as sensible heat factor (SHF) or sensible heat ratio (SHR).

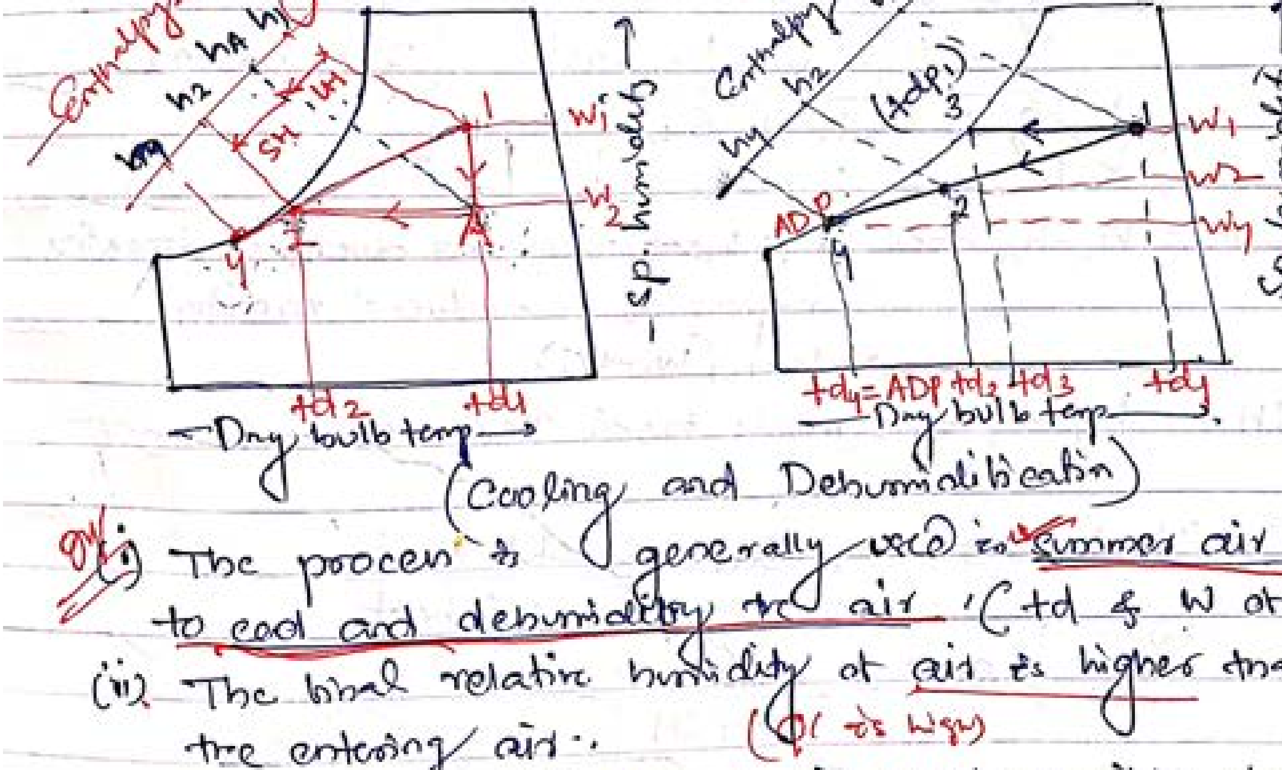
$$\therefore SHF = \frac{\text{Sensible heat}}{\text{Total heat}} = \frac{SH}{SH + LH}$$

IMP

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

(6.4.2)

* Cooling and Dehumidification :-



(Cooling and Dehumidification)

IMP (i) The process is generally used in summer air conditioning to cool and dehumidify the air. (td & W of air decrease)

(ii) The final relative humidity of air is higher than that of the entering air. (ϕ is high)

(iii) The dehumidification of air is only possible when the effective surface temp of the cooling coil (tdy) is less the dew point temp of the air entering the coil. (tdp1)
($t_{dy} < t_{dp1}$, ADP)

IMP (iv) The effective surface temp of the coil is known as apparatus dew point (ADP).

let ptd1 → Dry bulb temp of air enters the coil.
tdp1 → Dew pt. temp. of entering air = td3.
tdy → Effective surface temp or ADP of coil.

((cooling) 4 ← 2 ← 1 & $t_{d4} = ADP$)

$$BPF = \frac{t_{d2} - t_{d4}}{t_{d1} - t_{d4}} = \frac{t_{d2} - ADP}{t_{d1} - ADP}$$

Also
$$BPF = \frac{W_2 - W_4}{W_1 - W_4} = \frac{h_2 - h_4}{h_1 - h_4}.$$

* Path
  - 1-2 → Cooling and dehumidification
  - 1-A → dehumidification. (LH)
  - A-2 → Cooling. (SH)
  - 1-4 → sensible heat factor line.

* The total heat removed from the air during cooling & dehumidification process,

$$\therefore q = h_1 - h_2$$
$$= (h_1 - h_A) + (h_A - h_2)$$
$$\Rightarrow q = LH + SH$$

$LH = h_1 - h_A$
$SH = h_A - h_2$

LH → $h_1 - h_A$ → Latent heat removed due to condensation of vapour of the reduced moisture content $(W_1 - W_2)$.

SH → $h_A - h_2$ = Sensible heat removed.

∴ Sensible heat factor, $SHF = \frac{\text{Sensible heat}}{\text{total heat}}$

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

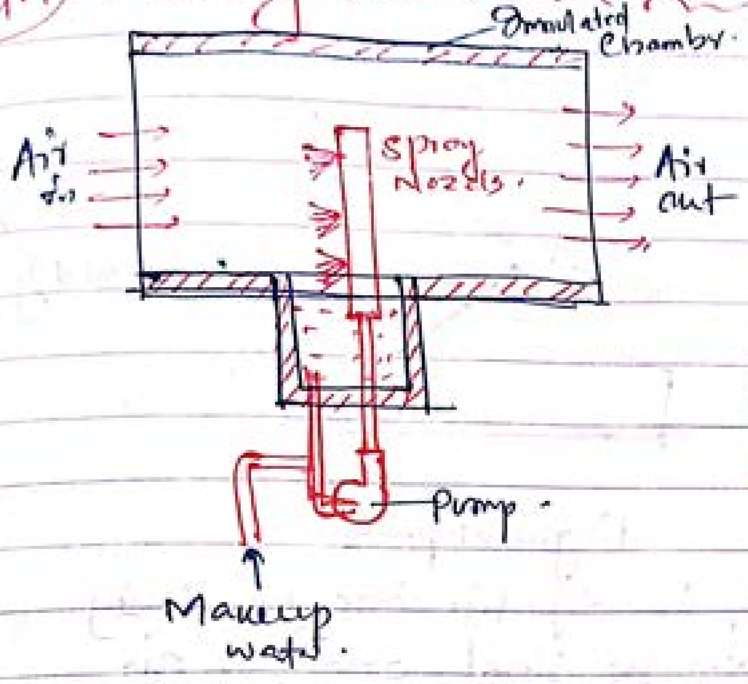
$$\Rightarrow SHF = \frac{h_A - h_2}{h_1 - h_2}$$

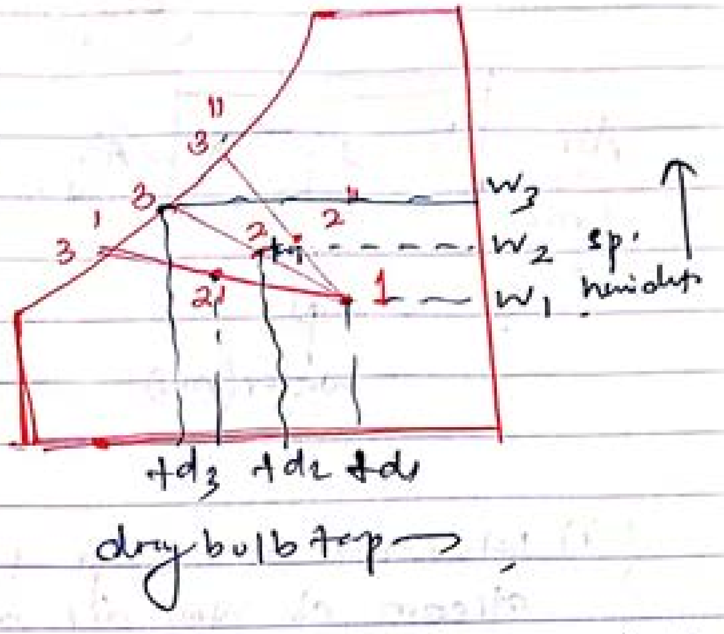
* The line 1-4 → line joining the point of entering air and apparatus dew point called **sensible heat factor line**.

Problem: 455 (RS)

(NOT) P – 459

* (6.4.4) Cooling with Adiabatic humidification :–





* The line 1-3 → constant wet bulb temp line or constant enthalpy line.

* The point 2 may be obtained by dividing the line 1-3

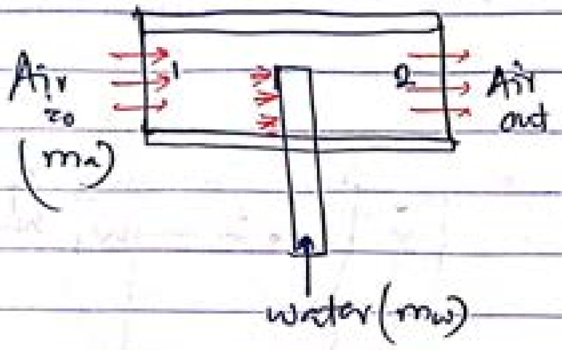
$$\frac{\text{length } 2-3}{\text{length } 1-3} = BPF = 0.1$$

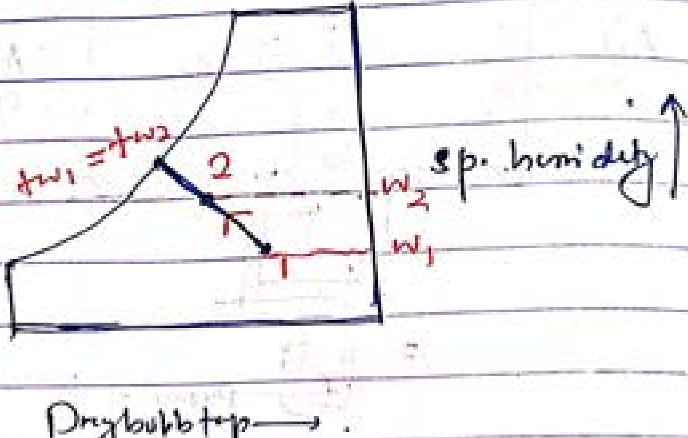
* The effectiveness or humidifying efficiency of spray chamber is.

$$\therefore \eta_H = \frac{\text{Actual drop in DBT}}{\text{Ideal drop in DBT}}$$

$$\Rightarrow \eta_H = \frac{td_1 - td_2}{td_1 - td_3} = \frac{W_2 - W_1}{W_3 - W_1}$$

Cooling and humidification by water Injection :— (Evaporative Cooling)





(i) let water at a temp t_1 is injected into the flowing stream of dry air and the final cond^n of air depends upon the amount of water evaporation.

(ii) when the water is injected at a temp equal to wet bulb temp of entering air (t_{w1}), then the process follows the path of constant wet bulb temp line.

let $m_w \rightarrow$ Mass of water supplied.
$m_a \rightarrow$ mass of dry air.
$w_1 \rightarrow$ sp. humidity of entering air
$w_2 \rightarrow$ sp. humidity of leaving air.
$h_w \rightarrow$ Enthalpy of water injected into air.

(iii) For mass balance, $\therefore w_2 = w_1 + \frac{m_w}{m_a}$

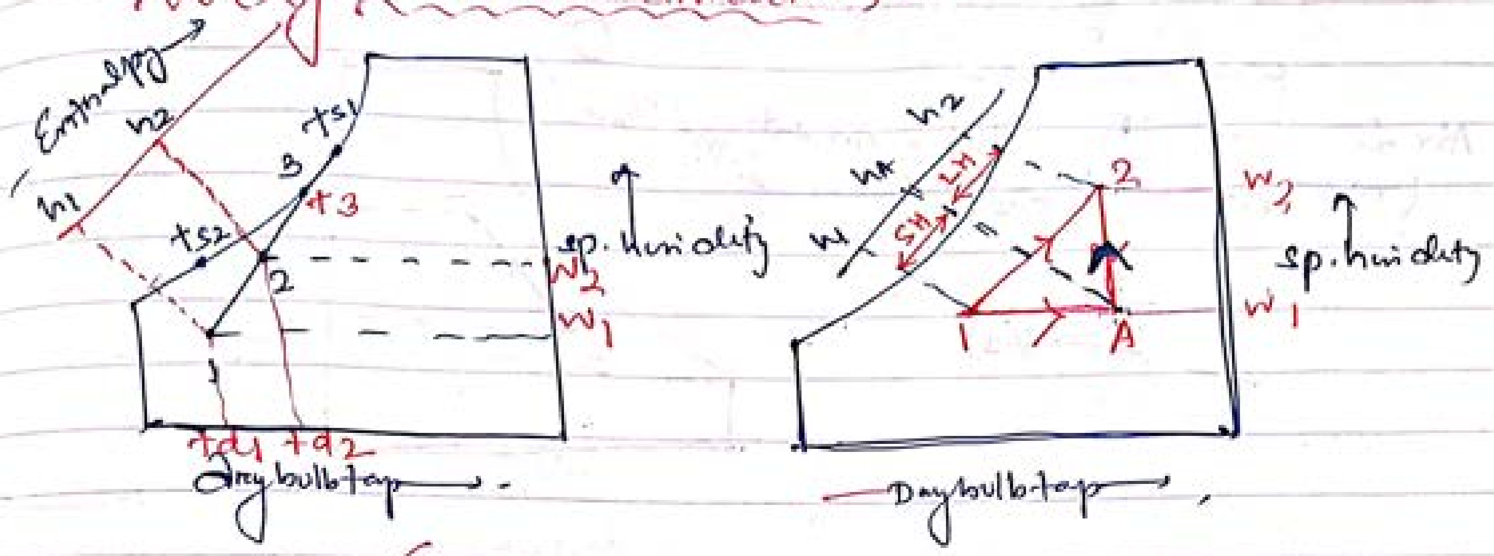
and for heat balance,

$$\therefore h_2 = h_1 + \frac{m_w}{m_a} \times h_{fw}$$
$$= h_1 + (w_2 - w_1)\, h_{fw}$$

Problem - 461
RS.

RS-460
6-4-23

Heating and humidification :-



(Heating & Humidification)

(i) This process is generally used in winter airconditioning to warm and humidify the air & this reverse of cooling and dehumidification.

(ii) When air passed through a humidifier having spray water temp., higher than the dry bulb temp of entering air, the unsaturated air will reach the end of saturation & the air becomes hot.

(iii) The air becomes heated and humidified. The process of heating and humidification is shown by line 1-2. The air enters at end 1 and leaves at 2. so drybulb temp aswell as sp. humidity of air increases.

(iv) path [1-A → heating
A-2 → humidification.

∴ total heat added to air, $q = h_2 - h_1$

$= (h_2 - h_A) + (h_A - h_1)$

$= LH + SH = q_L + q_s$.

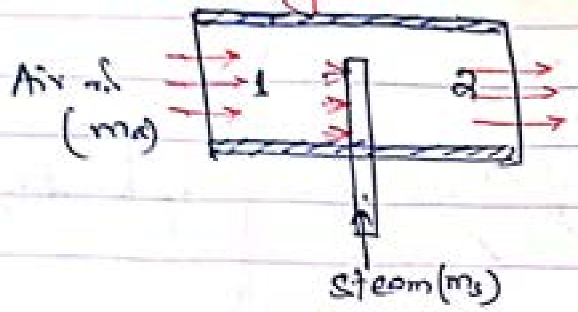
(v) Sensible heat factor

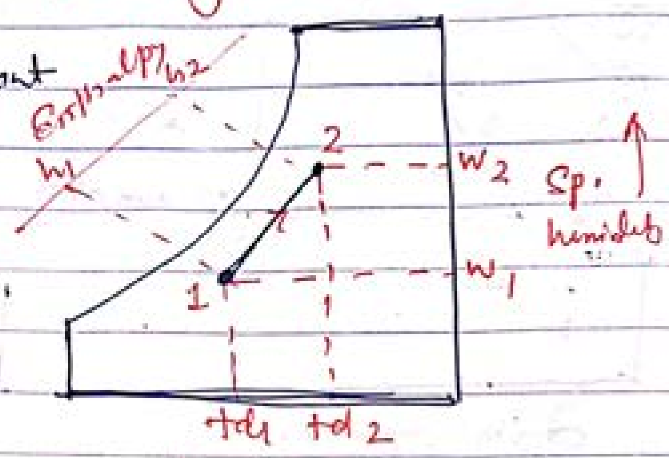
$$SHF = \frac{SH}{SH+LH} = \frac{h_A - h_1}{h_2 - h_1}.$$

path 1-2 → sensible heat factor line.

NS-P-467

* Heating and humidification by steam injection :-





(i) The steam is normally injected into the air in order to increase its specific humidity & possibly is used for the air conditioning of textile mills where higher humidity is to be maintained.

(ii) let m_s → mass of steam supplied
m_a → " " dry air entering
W_1, W_2 → sp. humidity of air entering and leaving
h_1, h_2 → enthalpy of air leaving & leaving.
h_s → " of steam injected into air.

(iii) For mass balance, $$W_2 = W_1 + \frac{m_s}{m_a}$$

For heat balance,

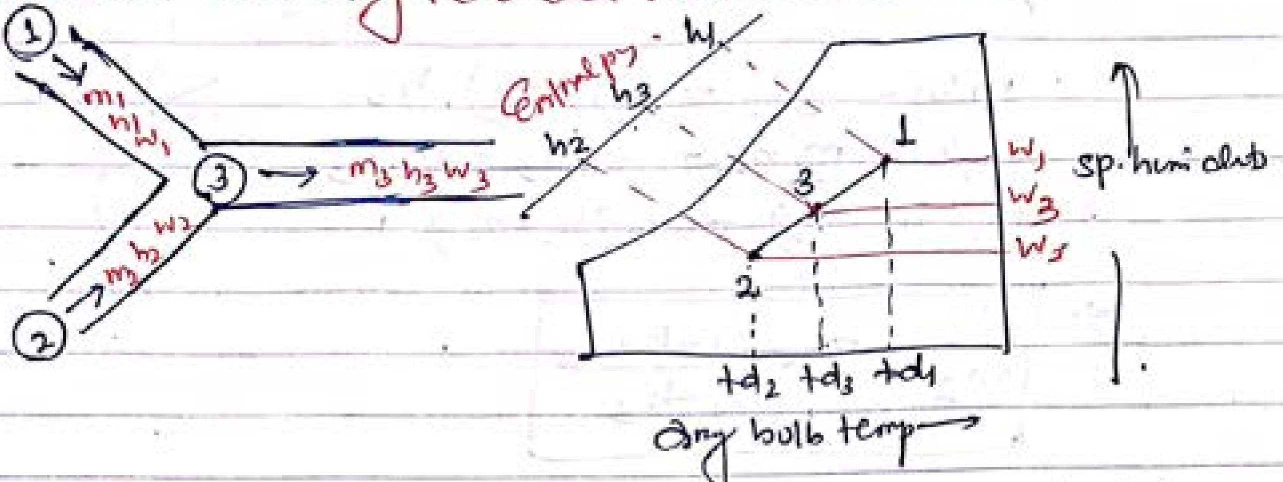
$$\therefore h_2 = h_1 + \frac{m_s}{m_a}$$

$$\Rightarrow \therefore h_2 = h_1 + (W_2 - W_1) \cdot h_s$$

Problem 467

P-474 Imp

(6.4.7) * Adiabatic Mixing of Two Air Streams :-



(I) When two quantities of air having different enthalpies and different specific humidity are mixed, the final condition of air mixture depends upon the mass involved and on the enthalpy and sp. humidity of each constituent mass which enters the mixture.

(II) Consider two air streams ① & ②, mixing adiabatically

let $m_1 \rightarrow$ mass of air entering at 1

$h_1 \rightarrow$ enthalpy of air " " 1

$w_1 \rightarrow$ sp. humidity of air " " "

$m_2, h_2, w_2 \rightarrow$ values of air entering at 2

$m_3, h_3, w_3 \rightarrow$ " " " leaving at 3.

Assuming no loss of enthalpy and sp. humidity during the air mixing process, for mass balance,

$$\therefore \boxed{m_1 + m_2 = m_3} \quad \text{--- (i)}$$

For energy balance :- $$\boxed{m_1 h_1 + m_2 h_2 = m_3 h_3} \quad \text{--- (ii)}$$

For mass balance of water vapour.

$$\therefore \boxed{m_1 w_1 + m_2 w_2 = m_3 w_3} \quad \text{--- (iii)}$$

Putting value of m_3 in eqⁿ (iii) we get

$$\therefore m_1h_1 + m_2h_2 = (m_1 + m_2).h_3$$
$$\Rightarrow m_1h_1 + m_2h_2 = m_1h_3 + m_2h_3$$
$$\Rightarrow m_1(h_1 - h_3) = m_2(h_3 - h_2)$$

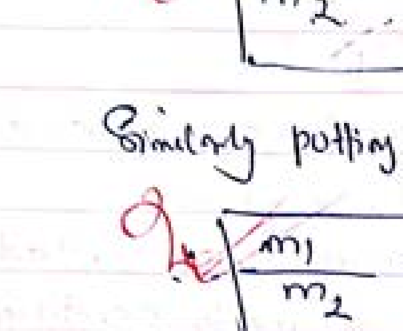
Imp →
$$\boxed{\frac{m_1}{m_2} = \frac{h_3 - h_2}{h_1 - h_3}}$$

Similarly putting eqⁿ (i) in eqⁿ (iii) we get

Imp
$$\boxed{\frac{m_1}{m_2} = \frac{W_3 - W_2}{W_1 - W_3}}$$

* The final condition of the mixture (point 3) lies on the straight line 1-2.

~Imp. **Fog** :—



(i) When warm and high humidity air is mixed with cold air, the resulting mixture will be a "fog"

(ii) The point 3 on the psychrometric chart lie to the left or above the saturation curve which represents fog region.

(iii) The temp. of the fog is that of extended wet bulb line passing through point 3.

(iv) The fog may result when steam or very fine water spray is injected to air in a greater quantity than required to saturate the air;

(v) Even lesser quantity of steam, if not mixed properly may result fog.

(vi) The fog may be cleared by (a) heating the fog.

(b) mixing fog with warmer unsaturated air.

(c) Mechanically separating water droplets from the air.

———— X ————

Problem - 4.75

Q.17 (8) (2021) (6.5)

Physiological Factors or Requirements of Comfort Air Conditioning:

Human Comfort :(i) Human Comfort is that condition of mind which expresses satisfaction with the thermal environment.

(ii) A human body feels comfortable when the heat produced by metabolism of human body is equal to sum of heat dissipated to the surroundings and heat stored in human body by raising the temp. of body tissues.

$$\therefore \; Q_M - W = Q_E \pm Q_R \pm Q_C \pm Q_S$$

where Q_M → Metabolic heat produced within the body (due to food)

W → useful rate of working.

$Q_M - W$ → Heat to be dissipated to the atm.

Q_E → Heat lost by evaporation.

Q_R → Heat lost or gained by radiation.

Q_C → Heat lost or gained by convection.

Q_S → Heat stored in body.

* **Factors affecting Human Comfort / human body** → The factors affecting human (body) comfort in designing winter or summer air-conditioning system are:—

(a) Effective temperature.
(b) Heat production and regulation in human body
(c) Heat and moisture losses from human body
(d) Moisture content of air.
(e) Quality and quantity of air.
(f) Air motion.
(g) Hot and cold surfaces
(h) Air stratification

Q.5

(a) Effective Temperature :

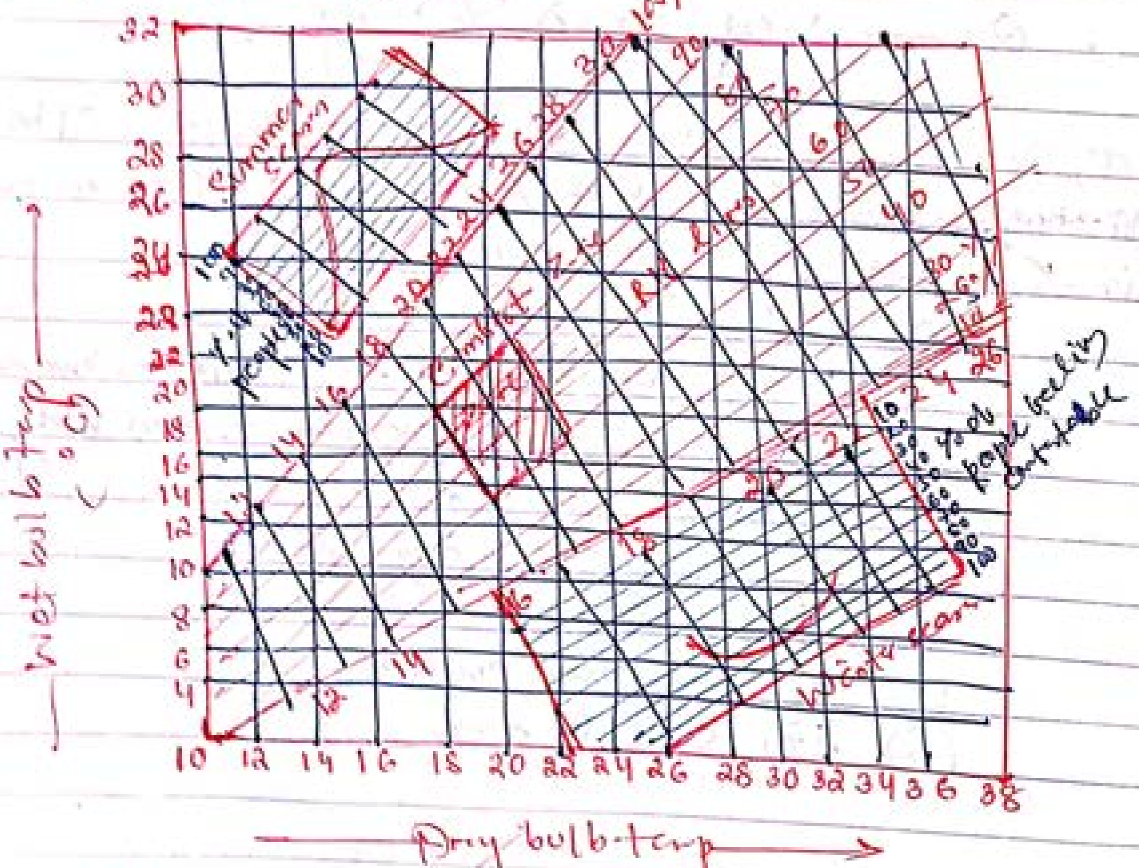
(i) "The degree of warmth or cold felt by a human body depends on factors - (1) Dry bulb temperature (2) Relative humidity (3) Air velocity.

(ii). To evaluate the combined effect of these factors a term effective temperature is used.

(iii) "It is defined as that index which corelates the combined effects of air temp, relative humidity and air velocity on the human body".

(iv) The numerical value of effective temp is equal to the temp. of still saturated air i.e 5 to 8 m/min air velocity. & the practical application of the concept of effective temp. is presented by the comfort chart.

Comfort Chart :



(Comfort Chart for still air (air velocity 5 to 8 m/min)

(i) Comfort Chart is the result of research made on different kinds of people subjected to wide range of environmental temp, relative humidity and air movement by ASHRAE (American Society of Heating, Refrigeration & Airconditioning Engineers).

(ii) In Comfort chart, the dry bulb temp is taken as abscissa and wet bulb temp as ordinates & relative humidity lines are plotted from the psychrometric Chart.

(iii) This chart corresponds to summer and winter season and have effective temp scale as abscissa and % of people feeling comfortable as ordinate.

(iv) All points located on a given effective temp line donot indicate conditions of equal comfort or discomfort. The extremely high or low relative humidities may produce cond's of discomfort regardless of the existent effective temp.

(v) The most desirable relative humidity range lies bet^n 30 & 70 % when relative humidity is much below 30% the mucous membranes and the skin surface become too dry for comfort and health.

(vi) If relative humidity is above 70%, there is a tendency for a clammy or sticky sensation to develop.

(vii) The Comfort chart shows the range for both summer and winter conditions within which a condition of comfort exists for most people.

(viii) For summer conditions, the chart indicates that a maximum of 98 % people felt comfortable for an effective temp of 21.6°C.

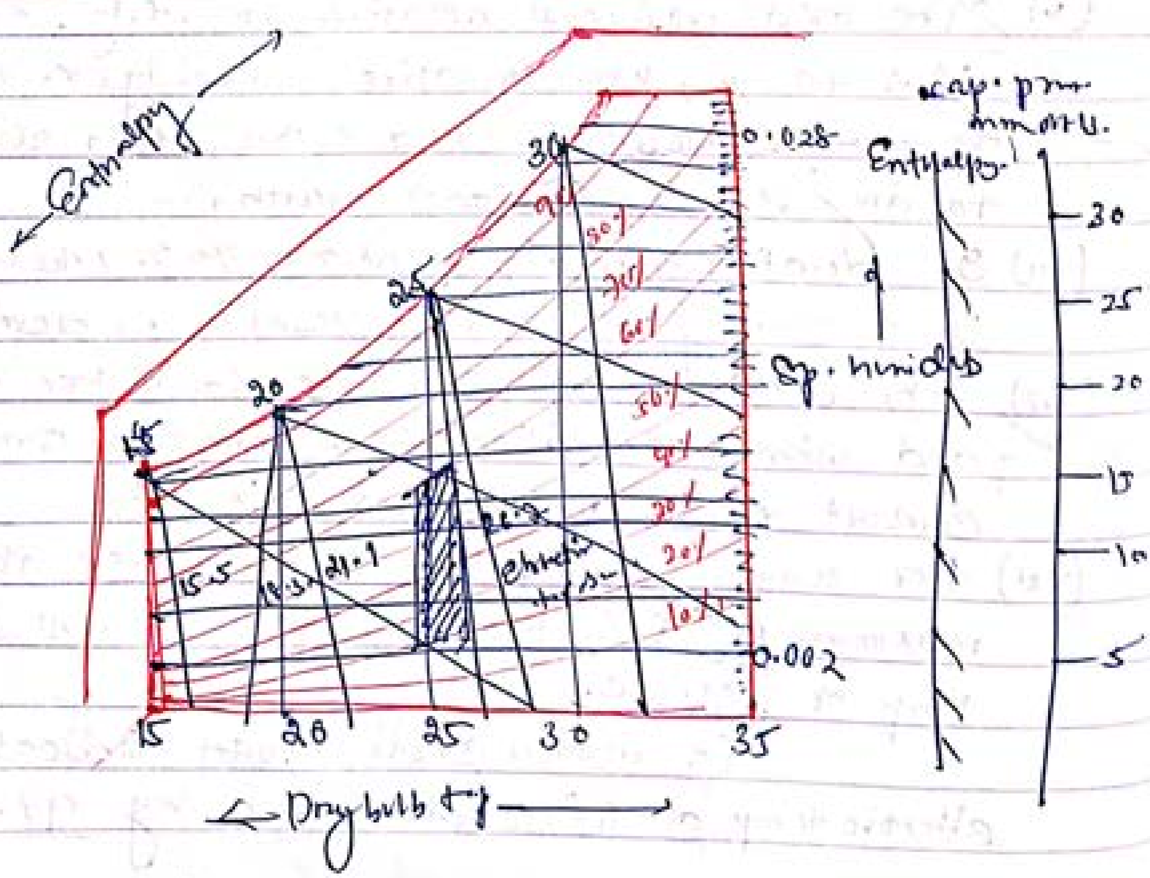
For winter cond's, chart indicates that an effective temp of 20°C was desired by 97.7 % people.

(IX) For comfort, women require 0.5°C higher effective temp than men. All men and women above 40 yrs of age prefer 0.5°C higher effective temp than the person below 40 yrs of age.

(X) Comfort conditions for persons at work vary with the rate of work and amount of clothing worn. So greater the degree of activity, lower the effective temp. necessary for comfort.

• (XI) Comfort chart doesnot take into account the variations in comfort conditions with mean radiant temp. The effect of mean radiant temp on comfort is less pronounced at high temp than at low temp. So this chart is obsolete now-a days and a modified comfort chart is generally used now a day.

p-459 Modified Comfort Chart:-



(b) Heat Production and Regulation in human body :-

Metabolism of human body

(i) The human body gets its energy from the combustion of food within the body and the process of combustion called metabolism produces heat and energy due to the oxidation of products in the body by oxygen obtained from inhaled air.

(ii) The rate of heat production depends upon the individual's health, his physical activity and his environment.

(iii) The rate at which body produces heat is called metabolic rate and a normal healthy person when asleep called basal metabolic rate, is about 60 watts & is about 10 times more than a person carrying very hard work.

(iv) The rate and manner of rejection of heat is controlled by the automatic regulation system of a human body. & the heat loss from skin, body takes place by radiation, convection and by evaporation.

(v) When the process of radiation or convection or both fails to produce necessary loss of heat, the sweat glands become more active and more moisture is deposited on skin, carrying heat away as it evaporates.

(c) Heat and moisture losses from the human body :-

(i) The heat is given off from the human body as either sensible or latent heat or both. In order to design an air conditioning system for spaces which human bodies are to occupy,

(ii) Sensible heat loss by radiation and convection for an average man and dry bulb temp. for different kind of activity. Latent heat loss by evaporation of an average man and dry bulb temp.

p-490

(d) Moisture Content of Air :→

(i) The moisture content of outside air during winter is generally low and its above the average during summer becz capacity of air to carry moisture is dependent upon its dry bulb temp.

(ii) In winter, the cold outside air having a low moisture content leaks into conditioned space, it will cause a low relative humidity unless moisture is added to air by the process of humidification.

(iii) In summer, the reverse will take place by removing moisture from inside air by dehumidification process.

(iv) For air conditioning system in summer & winter, proper dry bulb temp and relative humidity are to be chosen.

* for winter → average residence, relative humidity above 35 to 40 % cannot practical.
* In summer → relative humidity above 60%.

(e) Quality and Quantity of air

(1) The air in an occupied space, at all times be free from toxic, unhealthful & disagreeable fumes such as CO_2, dust and odour.

(2) A large amount of air is recirculated over and above the required amount of outside air to satisfy the minimum ventilation conditions in regard to odour and purity.

(3) So a minimum of 0.3 m^3/min of outside air per person mixed with 0.6 m^3/min of recirculated air is good.

(5) Air motion :

(i) The air motion which include the distribution of air is important to maintain uniform temp in a conditioned space.

ii) No air conditioning system is satisfactory unless the air handled is properly circulated and distributed.

iii) Air velocity in an occupied zone should not exceed 8 to 12 m/min. The air motion without proper air distribution produces local cooling sensation known as draft.

g) Air stratification :-

i) When air is heated, its density decreases and it rises to upper part of the confined space.

ii) This results in a considerable variation in the temp bet^n the floor and ceiling levels.

iii) The movement of air to produce the temp. gradient from floor to ceiling is called air stratification.

iv) In order to achieve comfortable conditions, so it must be designed to reduce air stratification to a minimum by air conditioning system.

* Factors affecting optimum Effective temperature :- Factors are

(1) Climatic and seasonal differences.
(2) Clothing
(3) Age & Sex
(4) Duration of stay
(5) Kind of activity
(6) Density of occupants.

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9/3/ (7) (18) (7) Air Conditioning Systems :-

"The air conditioning deals with the study of conditioning of air i.e. supplying and maintaining desirable internal atmospheric conditions for human comfort, irrespective of external conditions."

(7.1) * Factors affecting Comfort Air Conditioning :- factors are-

(1) Temperature of air
(2) Humidity of air
(3) Purity of air
(4) Motion of air.

(1) Temperature of air :→

* In air conditioning, the control of temp means the maintenance of any desired temp. within an enclosed space even though the temp. of outside air is above or below the desired room temp.
* So it can be done by addition or removal of heat from the enclosed space.
* A human being feels comfortable when the air is at 21°C with 56% relative humidity.

(2) Humidity of air :—

* The control of humidity of air means the decreasing or increasing of moisture contents of air during summer or winter in order to produce comfortable and healthy conditions.
* For summer air conditioning, the relative humidity should not less than 60% whereas for winter air conditioning, it should not be more than 40%.

(3) Purity of air :→ proper filtration, cleaning and purification of air is essential to keep free from dust and other impurities. So people don't feel comfortable when breathing contaminated air, so purity of air required.

(4) Motion of air :→
* The motion or circulation of air is an important factor which should be controlled in order to keep constant temp. throughout conditioned space.
* So there should be equi-distribution of air throughout the space to be air conditioned.

Air Conditioning System :-
* The system which effectively controls the temp. of air, humidity of air, purity of air and motion of air, to produce the desired effect upon the occupants of the space, is known as air conditioning system.

7.2 * Equipments used in air conditioning system are →

(a) Circulation fan : to move air to and from the room.

(b) Air Conditioning Unit : It is a unit, consists of cooling and dehumidifying process for summer air conditioning or heating and humidification for winter air conditioning.

(c) Supply duct : It directs the conditioned air from the circulating fan to the space to be air conditioned at proper point.

directs the flow of air.

(d) Supply outlets : These are grills, which distribute the conditioned air evenly in the room.

(e) Return outlets : These are opening in a room surface which allow the room air to enter the return duct.

(f) Filters : It's fun^n is to remove dust, dirt, and other harmful bacteria from the air.

7.3 * Classification of Air Conditioning System,

Process in Air Conditioning System :-

* Classification : The air conditioning system may be classified into 3

(1) According to purpose :-	(2) According to season of year.	(3) According to arrangement of equipment.
(a) Comfort air conditioning system	(a) Winter air. C.S	(a) Unitary A-C-S.
(b) Industrial air conditioning system	(b) Summer A.C.S.	(b) Central A-C-S.
	(c) Year-round A-C-S.	

(*) Comfort air Conditioning system :-

(i) In comfort air conditioning system, the air is brought to the required dry bulb temp and relative humidity for human health, comfort and efficiency.

(ii) At 21°c dry bulb temp, & 50% relative humidity the SHF is taken as.

For private offices & residence = 0.9
For restaurant or busy office = 0.8
For Auditorium or cinema hall = 0.7
Ball room dance hall = 0.6

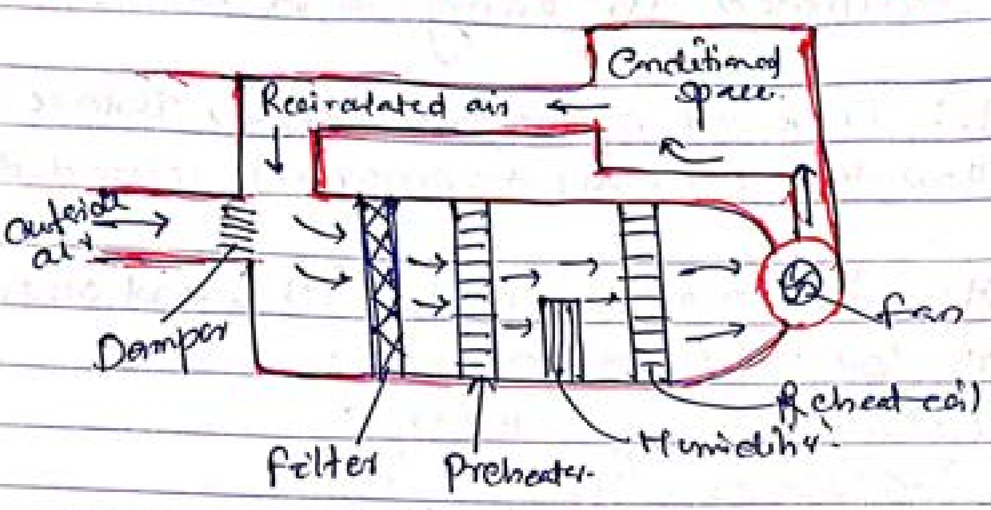
{ Cinemas, homes, offices, shops etc.

Problem 499

Q7/2.50

(7.4) Winter Air Conditioning System :→

- Fan
- Conditioned space
- Damper.
→ Filter
- Preheater
- Humidifier.
- Reheat coil.



(i) The outside air flows through a damper and mixes up with the recirculated air, which is obtained from the conditioned space.

(ii) The mixed air passes through a filter to remove dirt, dust and other impurities.

(iii) The air now passes through a preheat coil, in order to prevent the possible freezing of water & to control the evaporation of water in the humidifier.

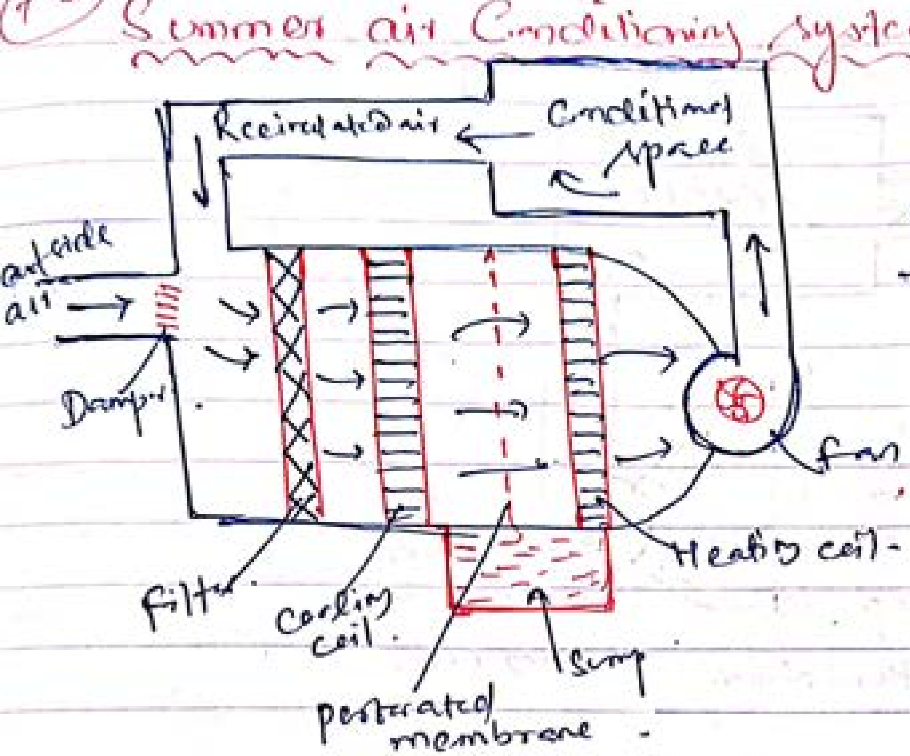
(iv) After that the air is made to pass through a reheat coil to bring the air to the ~~desired~~ ~~designed~~ desired dry bulb temperature.

(v) Now the conditioned air is supplied to the conditioned space by a fan. & from the conditioned space a part of used air is exhausted to the atmosphere by exhaust fan or ventilators.

(vi) The remaining part of used air i.e. recirculated air is again conditioned.

(vii) In The winter air conditioning the air is heated & generally accompanied by humidification.

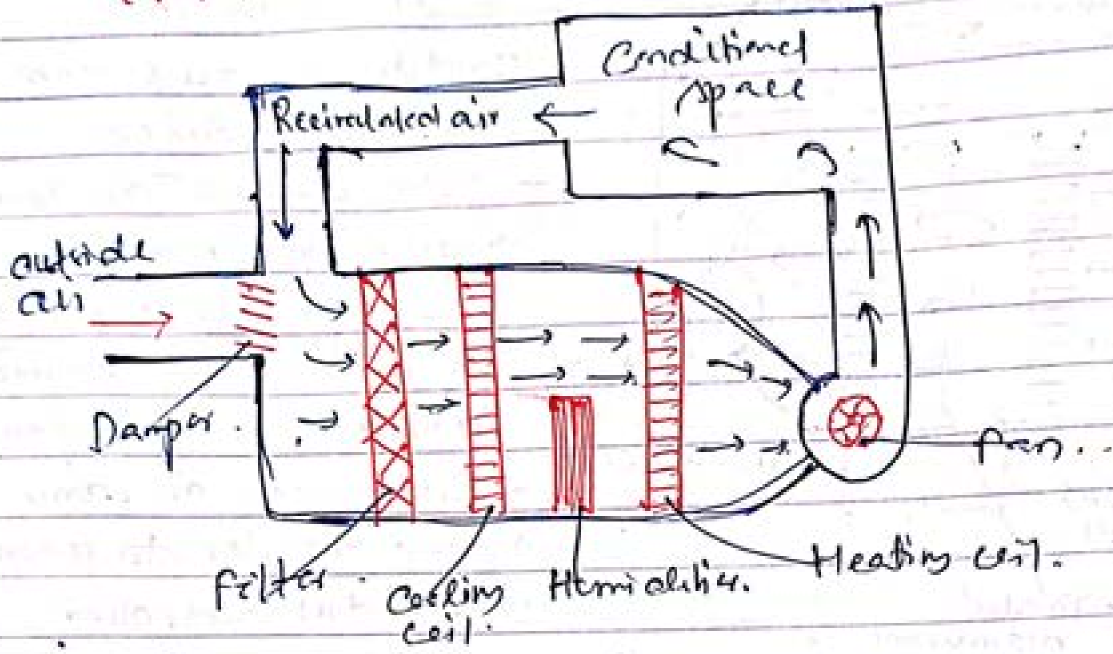
(7.5) Summer air Conditioning system :—



- In Summer air conditioning air is cooled and dehumidified.
- The outside air flows through the damper & mixes up with recirculated air (which is obtained from the conditioned space)
- The mixed air passes through a filter to remove dirt, dust and other impurities.
- The air now passes through a cooling coil & the coil has a temp. much below the required dry bulb temp. of the air in the conditioned space.
- The cooled air passes through a perforated membrane, and loses its moisture in the condensed form which is collected in a sump.
- After that the air is made to pass through a heating coil which heats up the air slightly & this is done to bring the air to designed dry bulb temp. & relative humidity.
- Now conditioned air is supplied to the conditioned space by a fan & from conditioned space, a part of used air is exhausted to the atm. by the exhaust fans or ventilators.
- The remaining part of used air, called recirculated air is again circulated & again conditioned.
- The outside air is sucked and made to mix with recirculated air to make up for the loss of conditioned air through exhaust fans from the conditioned space.

Problem 502

Year-Round Air Conditioning System:



(i) It has the equipment for both the summer and winter air conditioning.

(ii) The outside air flows through the dampers and mixes up with the recirculated air, which is obtained from conditioned space.

(iii) The mixed air passes through a filter to remove dirt, dust and other impurities.

(iv) In summer air conditioning, the cooling coil operates to cool the air to the desired value & the dehumidification is obtained by operating cooling coil at a temp. lower than the dew point temp (apparatus dew point)

v) In winter, cooling coil is made inoperative & the heating coil operates to heat the air.

vi) The spray type humidifier is use in dry season to humidify the air.

(14)

* Unitary Air Conditioning systems :

① Window Units

- These are self contained units of small capacity of 1TR to 3TR
- These are mounted in a window or through the wall :
- It is employed to condition the air of one room only. If room is bigger size then two or more units are installed.

② Vertical packed Units

(1) These are self contained units of bigger capacity of 5 to 20TR
- These are installed adjacent to the space to be conditioned.
- This is useful for conditioning the air of a resturant, bank or small office.

* The Unitary air conditioning system may be adopted for winter, summer and year round air conditioning.

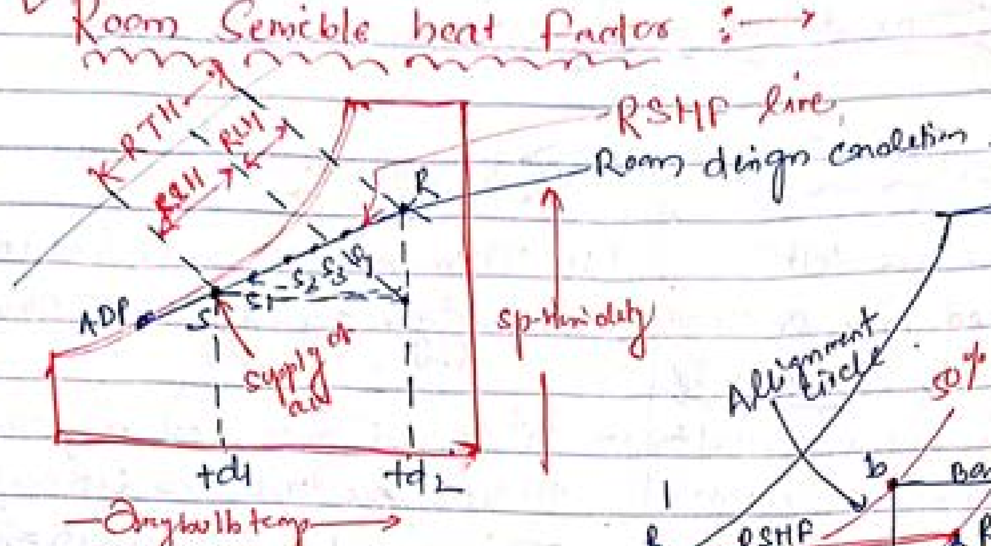
* Central Air Conditioning system :-

i) It is most important type of air conditioning system, adopted when the cooling capacity required is 25 TR or more.

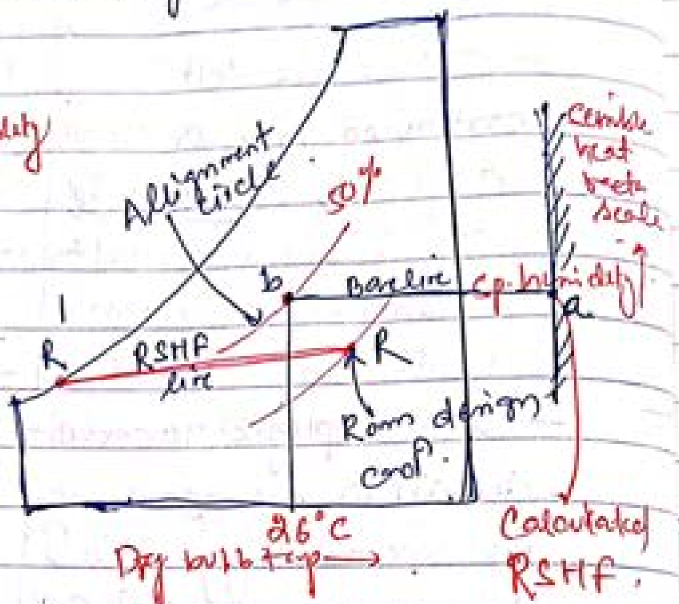
ii) The Central air conditioning system is adopted when the air flow is more than 300 m^3/ min or different zones in a building are to be conditioned.

problem
Pg - 508

Room Sensible heat factor :→



(Supply air condition & room design condition)



(Room Sensible heat factor line RSHF line)

(i) It is defined as the ratio of room sensible heat to the room total heat.

(ii) ∴ Room sensible heat factor,

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

where RSH → Room sensible heat
RLH → " latent "
RTH → " total "

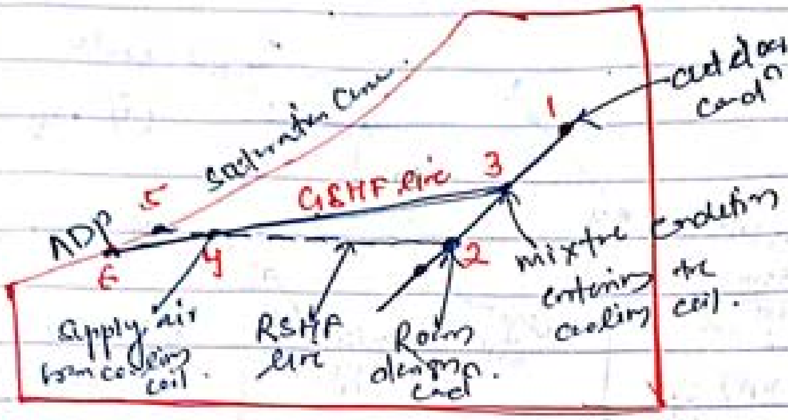
(iii) The line SR → called room sensible heat factor line

(iv) In a cooling and dehumidification process, the temp at which the room sensible heat factor line intersects the saturation curve is called room apparatus dew point (ADP).

S → supply air condition.
R → required room design cond.
ab → base line

(page - 573)

Grand sensible heat factor :-



(i) It is the ratio of total sensible heat to the grand total heat which the cooling coil or the conditioning apparatus is required.

(ii) $$GSHF = \frac{TSH}{GTH} = \frac{TSH}{TSH + TLH} = \frac{RSH + OASH}{(RSH + OASH) + (RLH + OALH)}$$

where, TSH → total sensible heat = RSH + OASH.

TLH → " Latent " = RLH + OALH.

GTH → Grand total heat = TSH + TLH.

OASH → out-side air sensible heat

$= 0.0204 4 v_1 (t_{d1} - t_{d2})$ kW.

OALH → outside air latent heat.

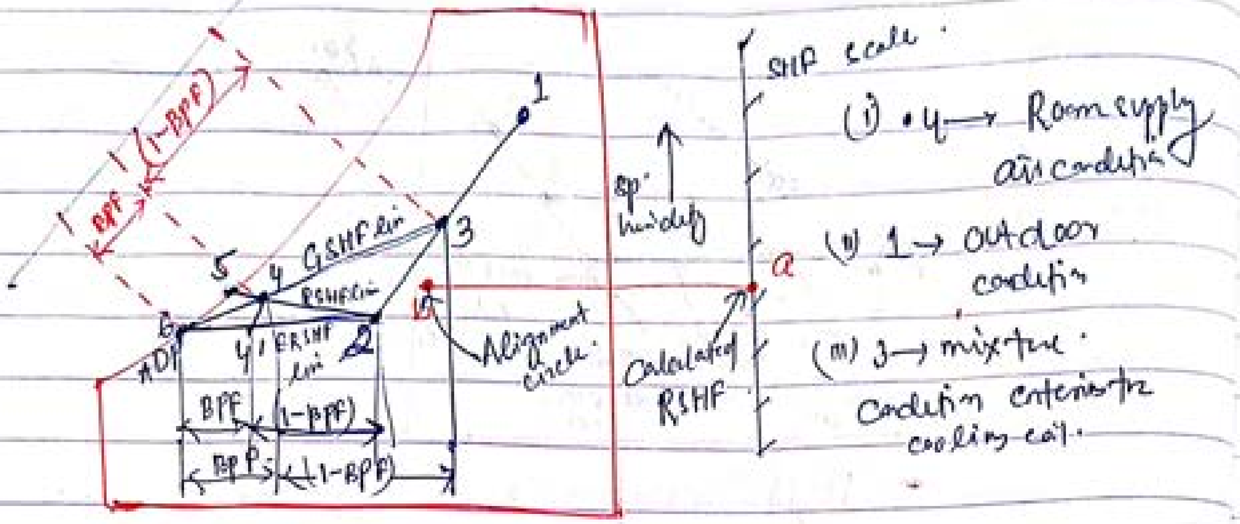
$= 50 v_1 (w_1 - w_2)$ kW.

OATH → outside air total heat

$= OASH + OALH = 0.02 v_1 (h_1 - h_2)$ kW.

3-4 → grand sensible heat factor line (GSHF line)

Effective room sensible heat factor :→



(i) It is the ratio of effective room sensible heat to effective room total heat.

(ii) $$ERSHF = \frac{ERSH}{ERTH} = \frac{ERSH}{ERSH + ERLH},$$

where ERSH = Effective room sensible heat

$= RSH + OASH \times BPF$

$= RSH + 0.02044\, v_1\, (td_1 - td_2)\, BPF$

ERLH = Effective room latent heat

$= RLH + OALH \times BPF$

$= RLH + 50\, v_1\, (W_1 - W_2) \cdot BPF$

ERTH = Effective room total heat

$= ERSH + ERLH$.

BPF = By pass factor.

Pradip Ranjan

2-6 → Effective room sensible heat factor line (ERSHF line)

$$BPF = \frac{\text{length } 4\text{-}6}{\text{length } 3\text{-}6} = \frac{\text{length } 4'\text{-}6}{\text{length } 2\text{-}6}$$

or

$$BPF = \frac{td_4 - ADP}{td_3 - ADP} = \frac{td_4' - ADP}{td_2 - ADP}$$

VGK problems (516 – 529)