LECTURE NOTE

ON

REFRIGERETION AND AIR CONDITIONING(TH-5)

5TH SEM. MECHANICAL (DIPLOMA COURSE)

PREPARED BY:

ER. GITANJALI SETHI

SENIOR LECTURER MECHANICAL

GOVERNMENT POLYTECHNIC JAJPUR

01 Air Refrigeration cycle

Refrigeration :-

It is defined as the process of removing & maintaining a temperature well bellow that of surrounding atmosphere.

* In other words refrigeration is the process of cooling substance.

Unit of refrigeration :-

Unit :- Tonne

A tonne of refrigeration is defined as amount of refrigeration effect produced by the uniform melting of one tonne (1000 kg) of ice from at 0°C in 24 hours.

$$1\ TR = 1000 \times 335\ KJ \text{ in 24 hours}$$

$$= \frac{1000 \times 35}{24 \times 60} = 232.6\ KJ/min$$

$$\boxed{1\ TR = 210\ KJ/m}$$

or 3.5 KW or 3.5 KJ/sec

Defination of C.O.P :-

The co-efficient of performance (C.O.P) is the ratio of heat extracted in the refrigerator ~~Q~~ to the work done on the refrigerant.

* It is also known as theoritical co-efficient of performance.

Theoretical $C.O.P = \frac{Q}{W}$

where, Q = Amount of heat extracted in the refrigerator.

W = Amount of work done

* Per unit mass C.O.P =
* C.O.P is the reciprocal of the efficiency $\left(\frac{1}{\eta}\right)$ of a heat engine.

Relative co-efficient of performance

The ratio of the actual C.O.P to the theoretical C.O.P is known as relative co-efficient of performance.

Mathematically,

$$\text{Relative C.O.P} = \frac{\text{Actual C.O.P}}{\text{Theoretical C.O.P}}$$

problem

Find the C.O.P of a refrigeration system if the work input is 80kJ/kg and refrigeration effect produce is 160 kJ/kg of refrigerant flowing.

sol

Given $w = 80\ kJ/kg$

$q = 160\ kJ/kg$

C.O.P of refrigeration $= \frac{q}{W} = \frac{160}{80} = 2$ (Ans)

Refrigerating effect (R.E)

Refrigerating effect is the heat absorbed in the evaporator per lb of refrigerant.

* It is determined by the difference in enthalpy of a lb or refrigerant vapour leaving the evaporator and that of a lb of liquid just upstream (ahead) of the expansion valve at the evaporator.

* Refrigeration effect means that cooling action should be done at the rate of heat absorption from any place in a cycle.

Principle of working of open and closed system of refrigeration :—

Air cycle refrigerations is one of the earliest method used for cooling the key features of this method is that, the refrigerant air remain gaseous state through out the refrigeration cycle.

Based on the operation, the air refrigeratio system can be classified into

1. open air refrigeration cycle
2. closed air refrigeration cycle
   or Dense air refrigeration cycle

open air refrigeration cycle :—

→ In an open air refrigeration system, the air is directly passed over the space is to be cooled and allowed to circulate through the cooler.

→ The pressure of open refrigeration cycle is limited to the atmospheric pressure.

Advantages & applications :-

⇒ It eleminates the need of a heat exchanger

⇒ It is used in aircraft because it helps to pressurization and air conditioning at once.

Disadvantages

⇒ One of the disadvantages of this system is that its large size.

⇒ The air supplied to the refrigeration system is large.

⇒ Thus the size of the compressor and expander also should be large. Another disadvantages of the open cycle system is that the moisture is regularly carried away by the circulating air, this leads to be the formation of frost at the end of the expansion process and clogs the line and hence a use of dryer is preferable to the open air refrigeration system.

* Closed air refrigeration system / Dense air refrigeration system :—

⇒ In closed or dense air refrigeration cycle air refrigerant is contained within pipes and components part of the system at all the time.

The circulated air does not have to direct contact with the space to be cooled, so the disadvantages instead in open air refrigeration can be eleminated.

Advantages :-

- ⇒ The suction to the compressor may be at higher pressure therefore the volume of air handled by the compressor and expander is smaller as compared to the open air system.
- ⇒ The chance of freezing of moister and choke the valve is eliminated.
- ⇒ In this system, higher co-efficient of performance can be achived by reducing operating pressure ratio.

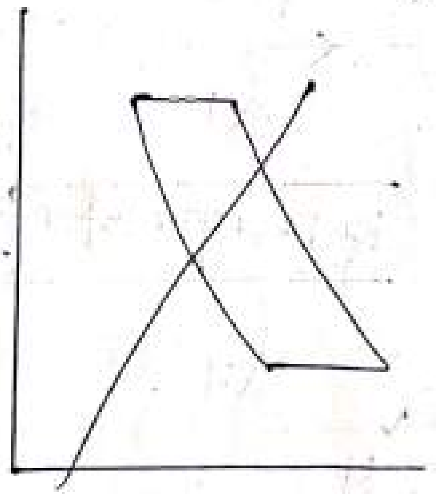
Bell coleman cycle :-

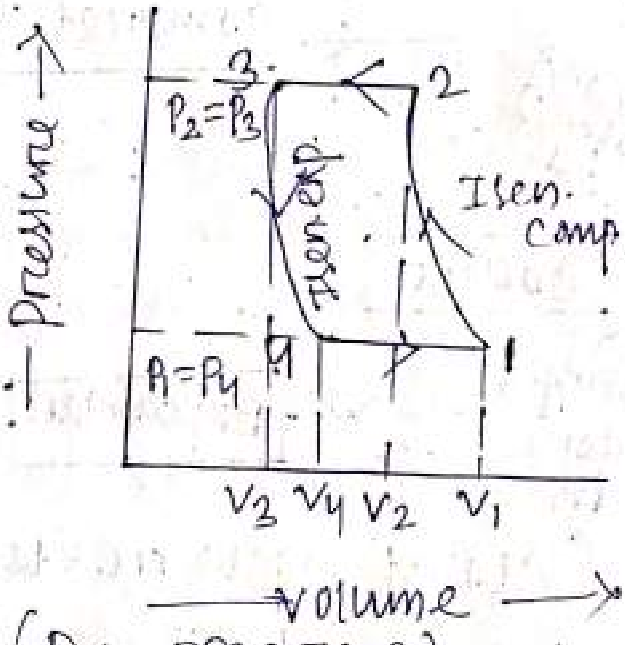
- ⇒ Bell coleman cycle also known as reversed Brayton cycle or the Joule cycle.
- ⇒ The Bell-coleman cycle is a refrigeratio cycle where the working fluid is air which is compressed and expanded by but do not change ~~stage~~ state in this cycle.

→ The process of compression and expansion of gas is isentropic and heat absorption and rejection ~~of~~ takes place at constant pressure (i.e. isobaric process)

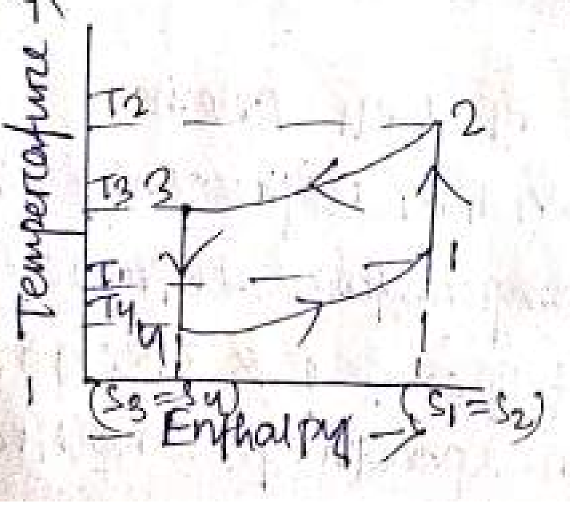
Working of Bell - Coleman cycle :-

1. Isentropic compression process.
2. Constant pressure cooling process
3. Isentropic expansion process.
4. Constant pressure expansion process.

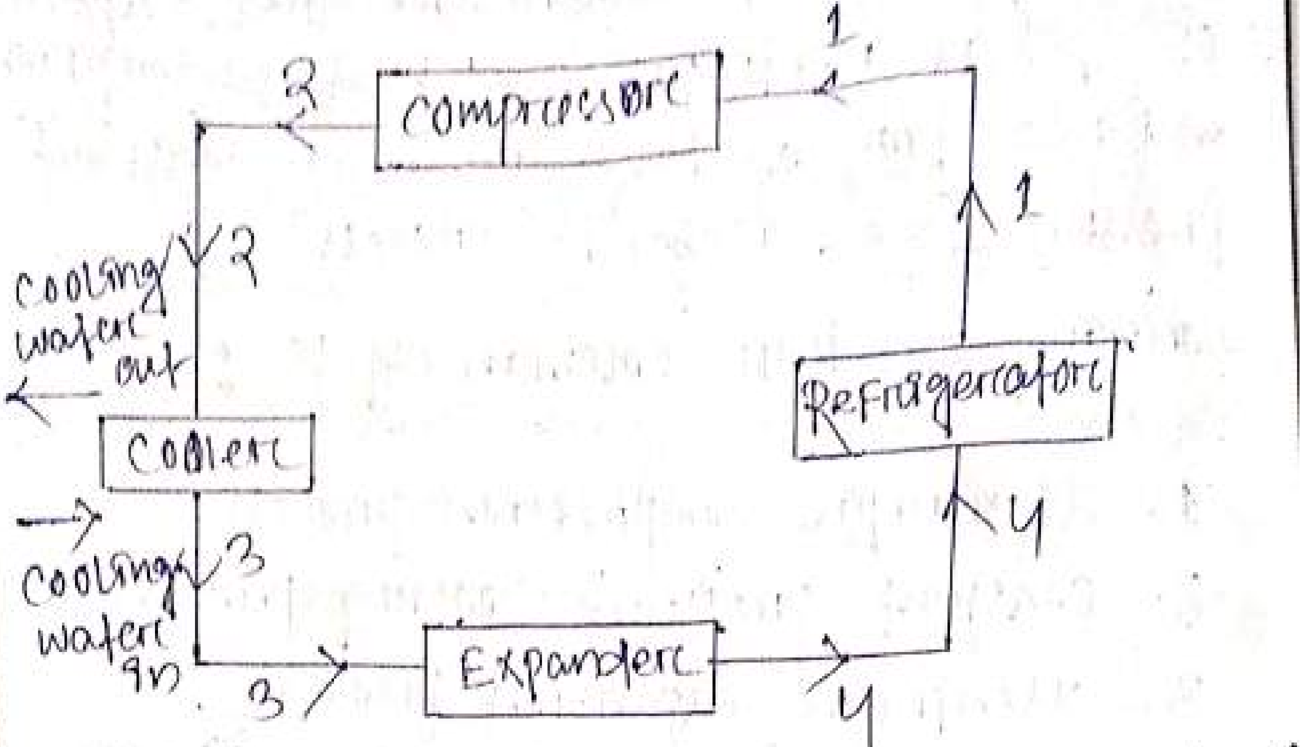




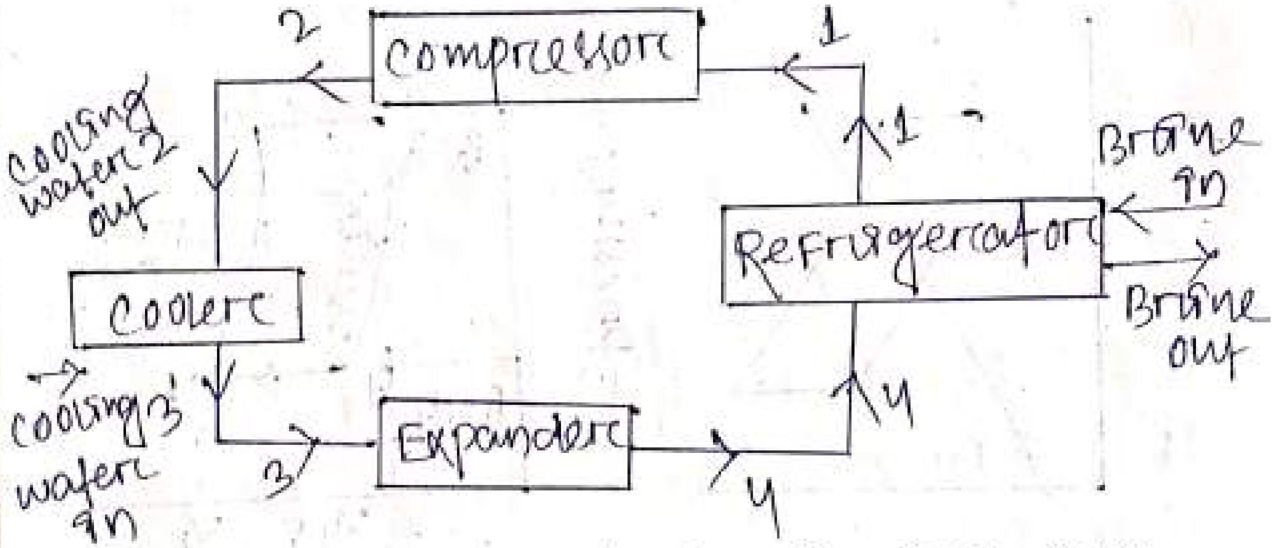
(P-V Diagram)



(T-S Diagram)



(open cycle air Bell-Coleman Refrigerato



(closed cycle or dense air Bell-Coleman Refrigerator)

P-V & T-S diagram of bell coleman refrigerator here P_1, V_1, T_1, S_1 represents the pressure, volume, temperature, entropy of air ~~rep~~ respective at point 1 & so on it represents the corresponding condition of air when it passes through the components.

process (1-2) Isentropic compression

The cold air from the refrigerator is brought into the compressor and compressed isentropically. during this process the pressure increment from P_1 to P_2: the specific volume decreases from v_1 to v_2 and the temperature increments from T_1 to T_2. during this process, Entropy stays steady ($S_1 = S_2$). No heat is absorbed or rejected by air.

Process (2-3) constant pressure cooling process :—

The warm air from the compressor is then passed into the cooler where it is cooled at constant pressure, reducing the temperature from T_3 to T_2. The specific volume reduces from v_2 to v_3.

Heat rejected by the air

$$Q_r = c_p (T_2 - T_3)$$

Process (3-4) Isentropic expansion

Air from the cooler is presently brought into the expander and is extended isentropically. The pressure of air ~~stays~~ decreases from P_3 to P_4. Specific volume increases from v_3 to v_4 and temperature decreases from T_3 to T_4.

→ No heat addition or rejection takes place in this process.

Process (4-1) constant pressure Expansion

→ During this process pressure of air is constant and temperature increases from T_4 to T_1 and specific volume increases from v_4 to v_1

→ Heat addition by air takes place in this process during constant pressure per kg of air.

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

$$\boxed{(C_p)_{air} = 1.005 \text{ KJ/Kg-K}}$$

workdone during the cycle per kg of air

= Heat rejected − Heat absorbed

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

C.O.P during the cycle per kg. of air

$$= \frac{\text{Heat absorbed}}{\text{workdone}}$$

$$\Rightarrow \boxed{C.O.P = \frac{C_p(T_1 - T_4)}{C_p(T_2 - T_3) - C_p(T_1 - T_4)}}$$

$$\Rightarrow \boxed{C.O.P. = \frac{(T_1 - T_4)}{(T_2 - T_3) - (T_1 - T_4)}}$$

$$C.O.P = \frac{T_4\left(\frac{T_1}{T_4} - 1\right)}{T_3\left(\frac{T_2}{T_3} - 1\right) - T_4\left(\frac{T_1}{T_4} - 1\right)} \longleftarrow (1)$$

For isentropic compression process (1-2)

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

For isentropic expansion process (3-4)

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

since, $P_2 = P_3$ & $P_1 = P_4$ therefore, from eqn (i) and (ii)

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

Now substituting these values in eqn ①

$$C.O.P = \frac{T_4}{T_3 - T_4} = \frac{1}{\frac{T_3}{T_4} - 1}$$

$$= \frac{1}{\left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} - 1} = \frac{1}{\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1}$$

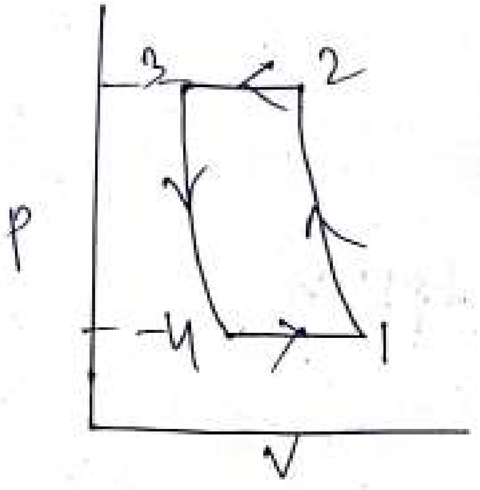
$$= \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}} - 1}$$

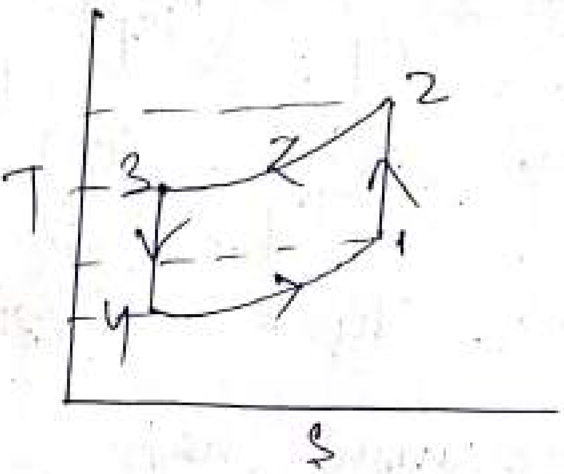
where r_p = compression or ~~E~~expansion ratio $= \frac{P_2}{P_1} = \frac{P_3}{P_4}$

Problem - 1

In a refrigeration plant working on Bell-Coleman cycle. air is compressed to 5 bar from 1 bar. Its initial temperature is 10°C. After compression, the air is cooled up to 20°C in a cooler before expanding back to a pressure of 1 bar. Determine the theoretical cop of the plant and net refrigerating effect. Take $c_p = 1.005$ kJ/kg k and $c_v = 0.718$kJ

Solution given data.





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

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

$T_1 = 10°C + 273 = 283K$

$T_3 = 20°C + 273 = 293K$

$C_p = 1.005 \text{ kJ/kgK}$

$C_v = 0.718 \text{ kJ/kgK}$

we know Isentropic index

$$\gamma = \frac{C_p}{C_v} = \frac{1.005}{0.718} = 1.4$$

For isentropic compression process (1-2)

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{5}{1}\right)^{\frac{1.4-1}{1.4}}$$

$$= (5)^{0.286} = 1.584$$

$\Rightarrow T_2 = T_1 \times 1.584 = 283 \times 1.584$

$\Rightarrow T_2 = 448.272K$

For isentropic expansion process

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

$$\Rightarrow \frac{293}{T_4} = (5)^{\frac{1.4-1}{1.4}}$$

$$\Rightarrow T_4 = \frac{293}{1.584} = 185 K.$$

we know that

$$\text{C.O.P of the plant} = \frac{T_4}{T_3 - T_4}$$

$$= \frac{185}{293 - 185} = 1.713 \text{ Ans}$$

Net refrigerant effect

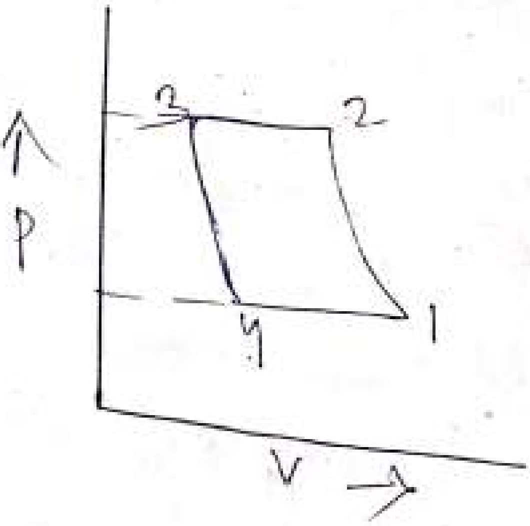
$$R.E. = C_p (T_1 - T_4)$$

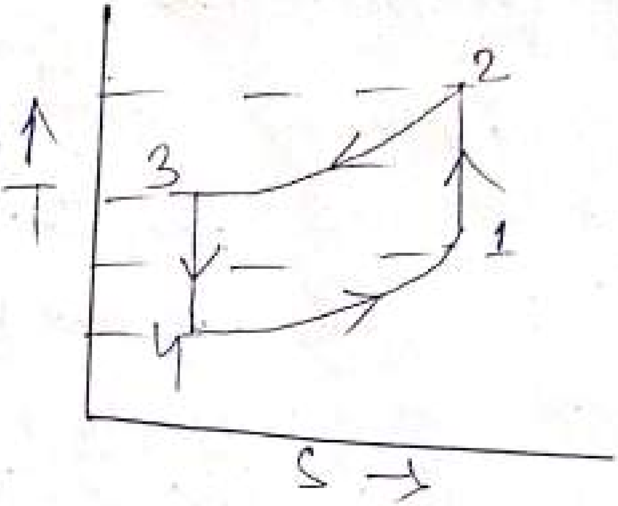
$$= 1.005 (283 - 185)$$

$$= 98.5 \text{ kJ/kg} \text{ Ans.}$$

Q) A refrigerator working on Bell-Coleman cycle operates betn 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 $pv^{1.3}$ = constant. Determine the theoretical C.O.P of the system.

Solution: given data.





$P_1 = P_4 = 1.05$ bar

$P_2 = P_3 = 8.5$ bar

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

$T_3 = 30^\circ C + 273 = 303 K$

$n = 1.3$ (polytropic index)

since the compression and expansion follows the law $pv^{1.3} = C$, therefore

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = \left(\frac{8.5}{1.05}\right)^{\frac{1.3-1}{1.3}}$$

$\Rightarrow T_2 = T_1 \times 1.62$

$\Rightarrow T_2 = 283 \times 1.62 = 458.46 K$

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

$\Rightarrow \frac{T_3}{T_4} = 1.62$

$\Rightarrow T_4 = \frac{T_3}{1.62} = \frac{303}{1.62} = 187 K$

We know that theoretical coefficient of performance :

$$C.O.P = \frac{T_1 - T_4}{\frac{n}{n-1} \times \frac{\gamma - 1}{\gamma} \left(T_2 - T_3\right) - \left(T_1 - T_4\right)}$$

$$= \frac{(283 - 187)}{\frac{1.3}{(1.3-1)} \times \left(\frac{1.4-1}{1.4}\right) \left[(452.65 - 303) - (283 - 187)\right]}$$

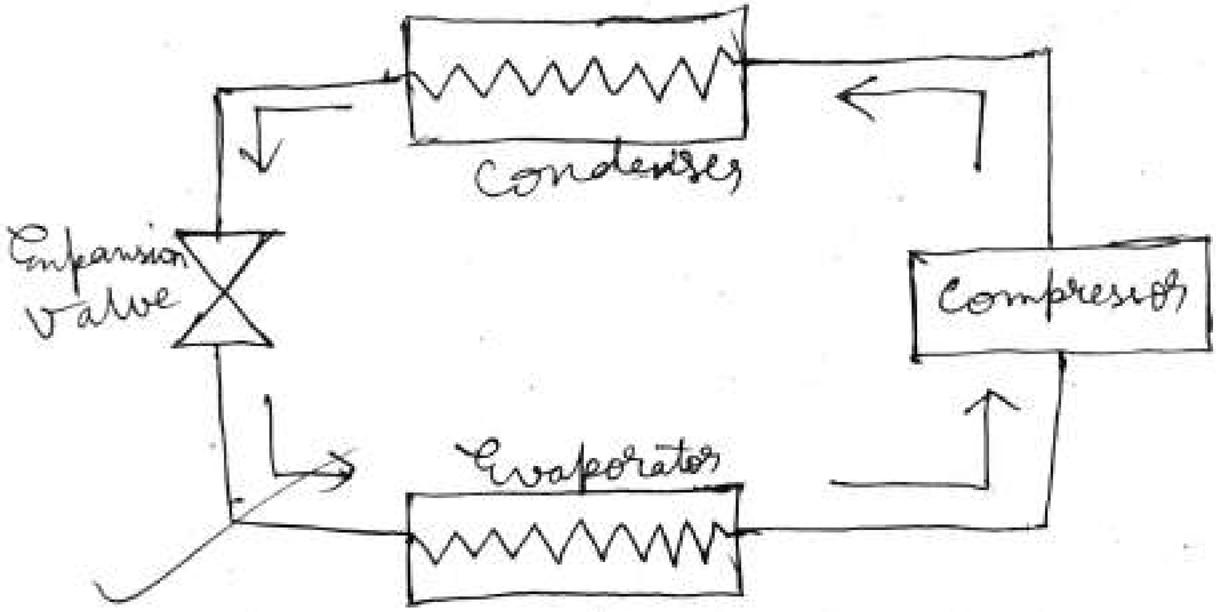
(Taking $\gamma = 1.4$)

$$= 1.28$$ Ans

Chapter-2

Simple Vapour Compression Refrigeration Cyc

Mechanism of a Simple Vapour Compression refrigeration System (VCRS)



Compressor:-

The low pressure and temperature vapour refrigerant from evaporator goes to compressor through inlet valve then in compressor, low pressure and temperature compressed to a high pressure and temperature. Then this high pressure and temperature vapour refrigerant is discharged into the condenser through delivery valve.

Condenser :-

The Condenser consists of coils of pipe in which the high pressure and temperature vapour refrigerant change into fluid medium. The refrigerant gives it's latent heat to the surrounding condensing medium which is normally air or water.

Expansion valve :-

It is also called refrigerant control valve. The function of the expansion valve is to expand the refrigerant from high pressure & temperature to low temperature.

Evaporator :-

An evaporator consists of coils of pipe in which the liquid vapour refrigerant is evaporated and changed into vapour refrigerant at low pressure and temperature. In evaporating the liquid vapour refrigerant absorbs it's latent heat of vapourisation which the medium (air, water or brine) is to be cooled.

1) Mention the advantages of Vapour Compression Refrigeration System over Air Compression Refrigeration System.

2) Describe the mechanism of a
a) Simple ~~Co~~ Vapour compression Refrigeration System.

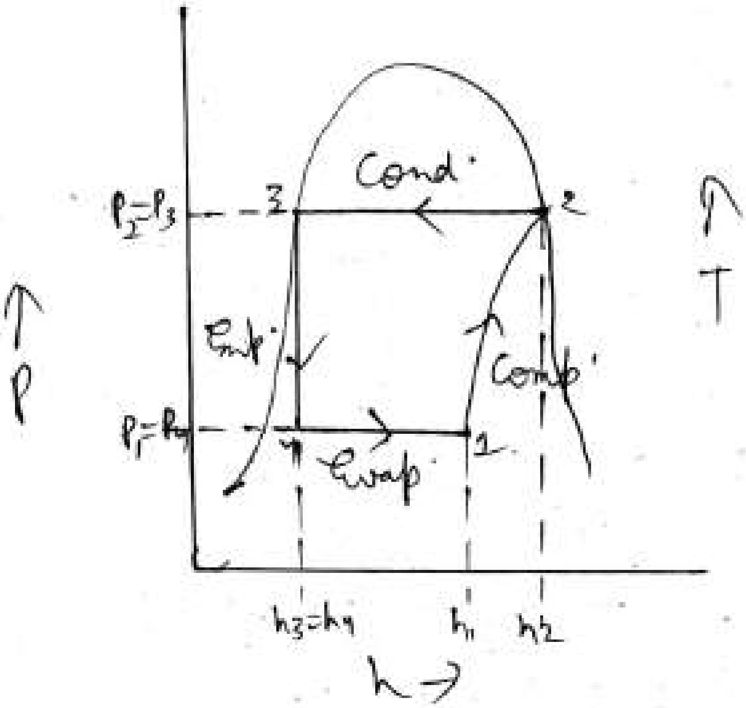
b)

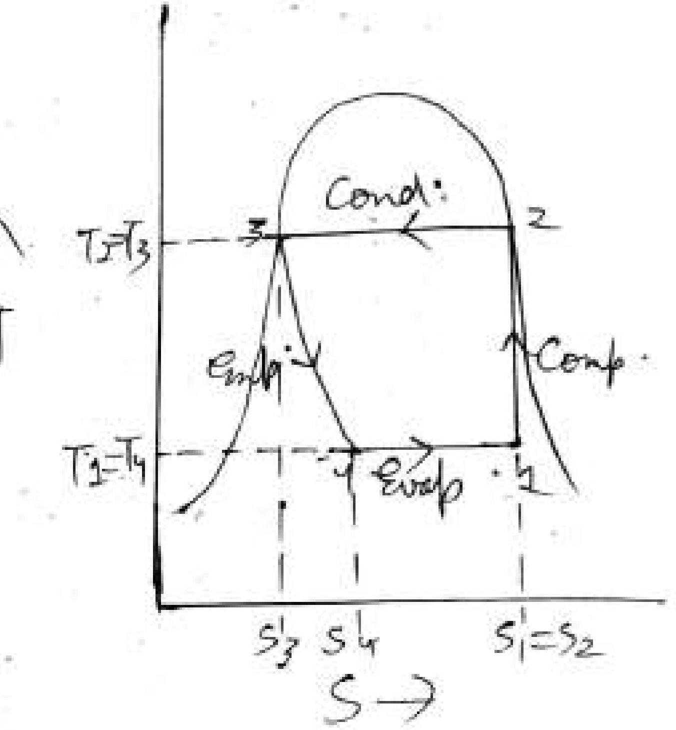
Types of Vapour Compression System

(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 sub-cooling of refrigerant.

Types of Vapour Compression Cycle (VCRs

(i) Dry Saturated Vapour after Compression





(Process 1-2) Compression Process

⇒ The vapour refrigerant at low pressure (P_1) and temperature (T_1) is compressed isentropically to dry saturated vapour.

⇒ Workdone happens during this process and is done on the system.

⇒ Workdone $= h_2 - h_1$

(Process 2-3) Condensing Process

⇒ In this process the high pressure and temperature vapour refrigerant is Condensed at Pressure P_2.

(Process 3-4) Expansion Process

⇒ In this process the liquid vapour refrigerant is expanded through expansion valve to a low pressure (P_3) and temperature (T_4).

⇒ No heat is absorbed or rejected by the refrigerant in the process.

(Process 4-1) Evaporation Process

⇒ In this process the liquid vapour mixture refrigerant is evaporated to vapour refrigerant at constant pressure and temperature.

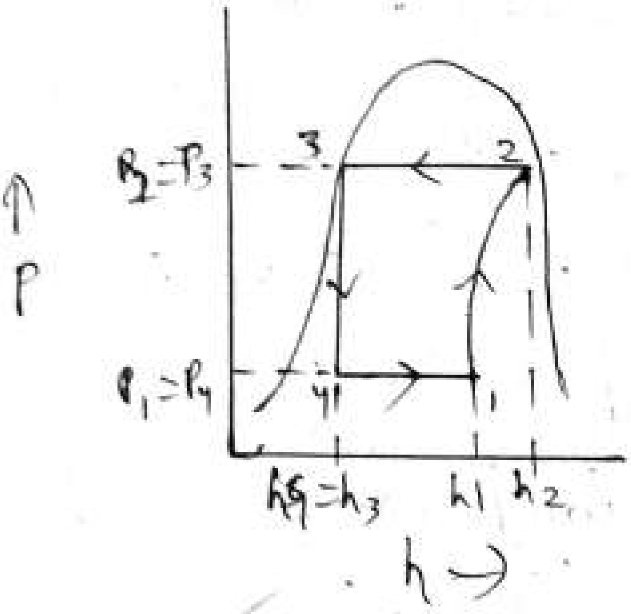
⇒ During this process the refrigerant absorbs its latent heat of vaporisation from the medium (air, water, brine) which is to be cooled.

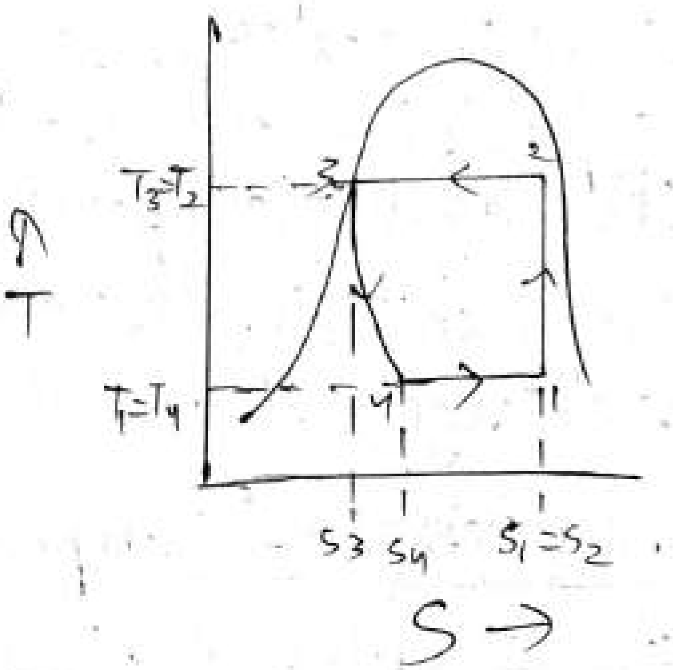
⇒ So refrigerating Effect (R.E) $= h_1 - h_4$

⇒ The cycle is thus repeated.

$$\boxed{\text{C.O.P of the cycle} = \frac{R.E}{W.D} = \frac{h_1 - h_4}{h_2 - h_1}}$$

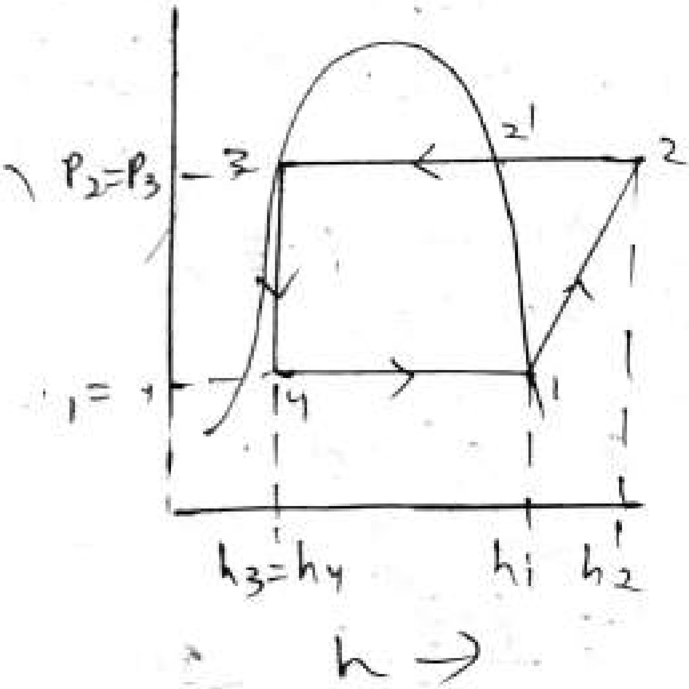
(ii) Wet vapour after Compression

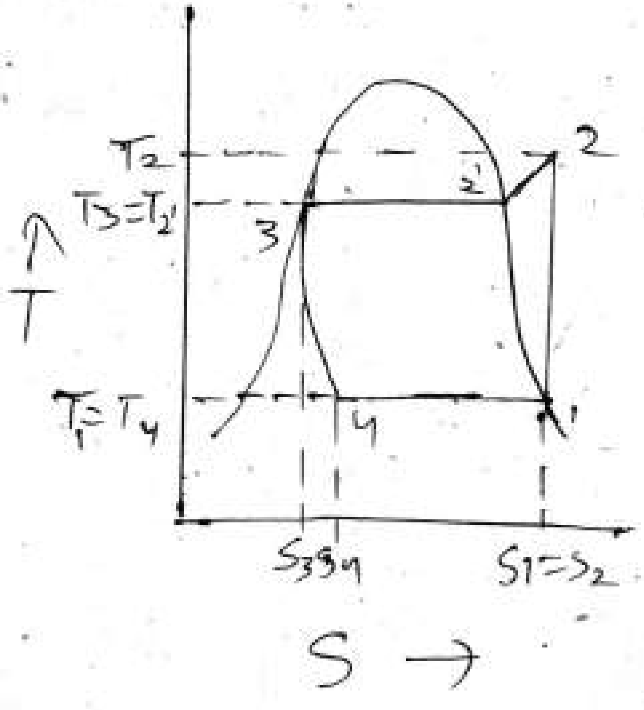




$$\boxed{C\cdot O\cdot P = \frac{R\cdot E}{W\cdot D} = \frac{h_1-h_4}{h_2-h_1}}$$

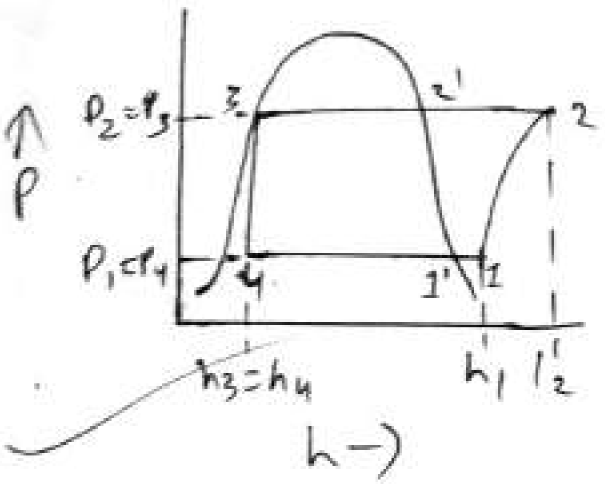
(iii) Superheated vapour after Compression

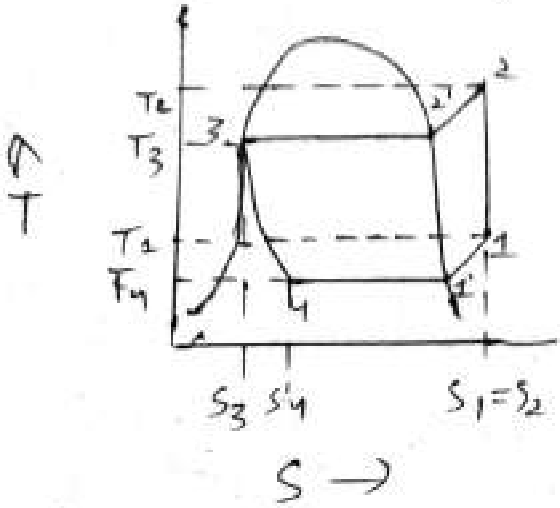




$$\boxed{C\cdot O\cdot P = \frac{R\cdot E}{W\cdot D} = \frac{h_1 - h_4}{h_2 - h_1}}$$

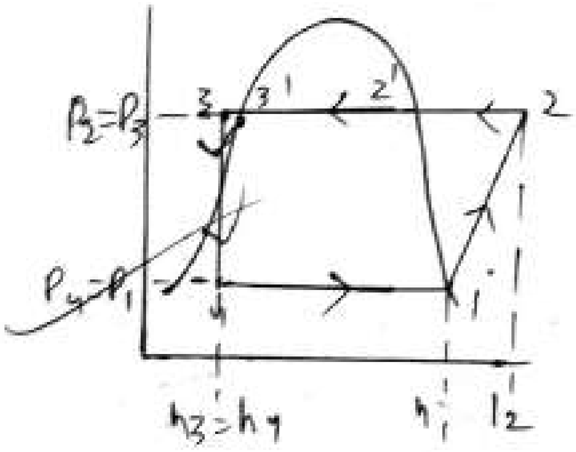
(iv) Superheated vapour before compression

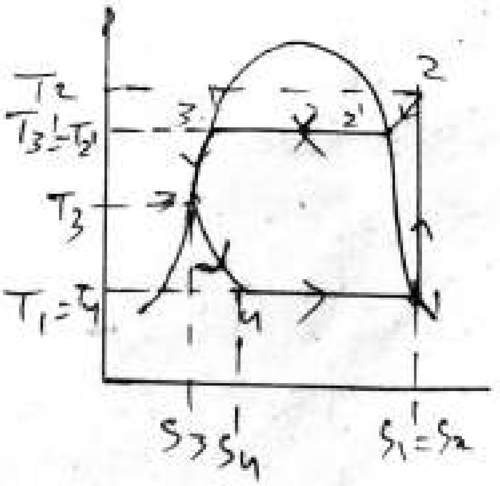




$$\boxed{C\cdot O\cdot P = \frac{R\cdot E}{W\cdot D} = \frac{h_1 - h_4}{h_2 - h_1}}$$

(v) Vapour Compression with Sub-Cooling





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

Advantages of Vapour Compression refrigeration System over Air Compression refrigeration system :-

1) It has smaller size for the given capacity of refrigeration.
2) It has less running cost.
3) It can be employed over a large range of temperatures.
4) The coefficient of performance is quite high.

Disadvantages

1) The initial cost is high
2) The prevention of leakage of the refrigerant is the major problem in vapour compression system.

In an ammonia vapour compression the pressure in the evaporator is 2 bar. Ammonia at exit is 0.85 dry and at the entry its dryness fraction is 0.19. During compression the work done per kg of ammonia is 150 KJ. Calculate the C.O.P and the volume of vapour entering the compressor per minute. If the rate of ammonia circulation 4.5 kg per min. The latent heat and specific volume at 2 bar is 1325 KJ/kg and 0.58 m^3/kg

Ans:- Given data:-

$P_1 = P_4 = 2$ bar

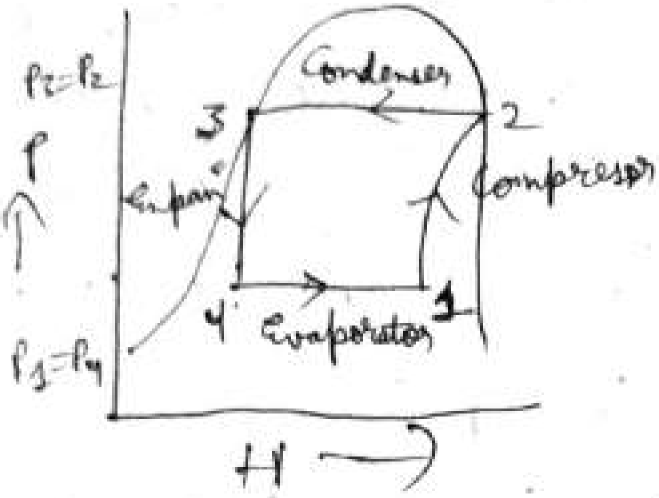
$x_1 = 0.85$

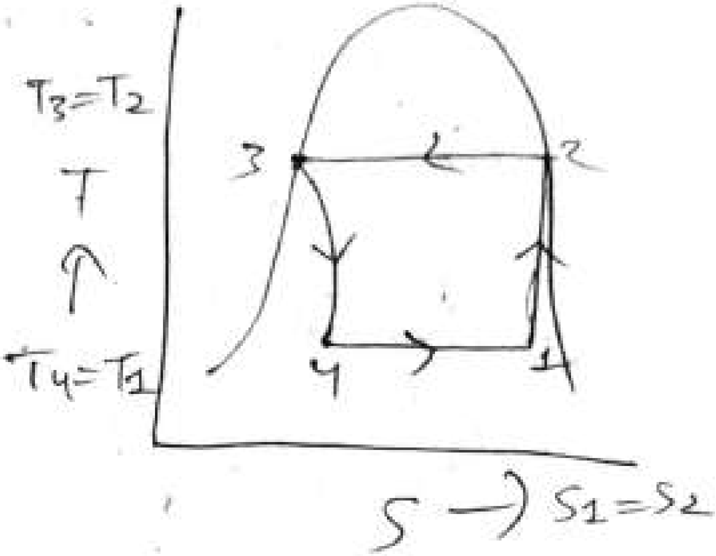
$x_4 = 0.19$

$W.D = 150$ KJ

Rate of ammonia circulation = 4.5 kg/min (hfg) L·H = 1325 KJ/kg

(Vg) Specific volume = 0.58 m³/kg





$h_1 = hf + (x_1 \times hfg)$

$= 117.69 + (0.85 \times 1325)$

$= 1243.94$ KJ/kg

$h_4 = hf + (x_4 \times hfg)$

$= 117.69 + (0.19 \times 1325)$

$= 369.44$ KJ/kg

$RE = h_1 - h_4 = 874.5$ kJ/kg

$C.O.P = \frac{RE}{WD} = \frac{874.5}{150} = 5.83$

Volume of the vapour entering the compressor per min

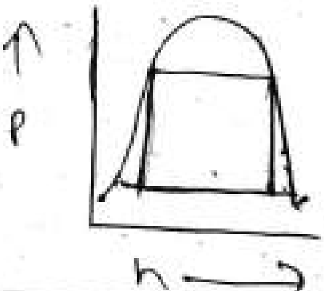
= Mass of Refrigerant per/min × S.V

= 4.5 kg/min × 0.58 m³/kg = 2.61 m³/min

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

Determine (i) C.O.P

(ii) Capacity of the refrigerator if the fluid flow is at a rate of 5 kg/min.



Ans:- Given data :-

Pressure (bar)	Sat temp (K)	Enthalpy		Entropy	
		Liquid	Vapour	Liquid	Vapour
60	295	151.96	293.23	0.554	[illegible].033
25	267	56.32	322.58	0.226	1.2964

$$COP = \frac{R.E}{WD} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$h_1 = h_f + x h_{fg})_{25\,bar}$$

x [illegible] $= s_1 = s_2$

$\Rightarrow 1.0332 = 0.226 + x \times 1.0204$

$\Rightarrow x_1 = 0.791$

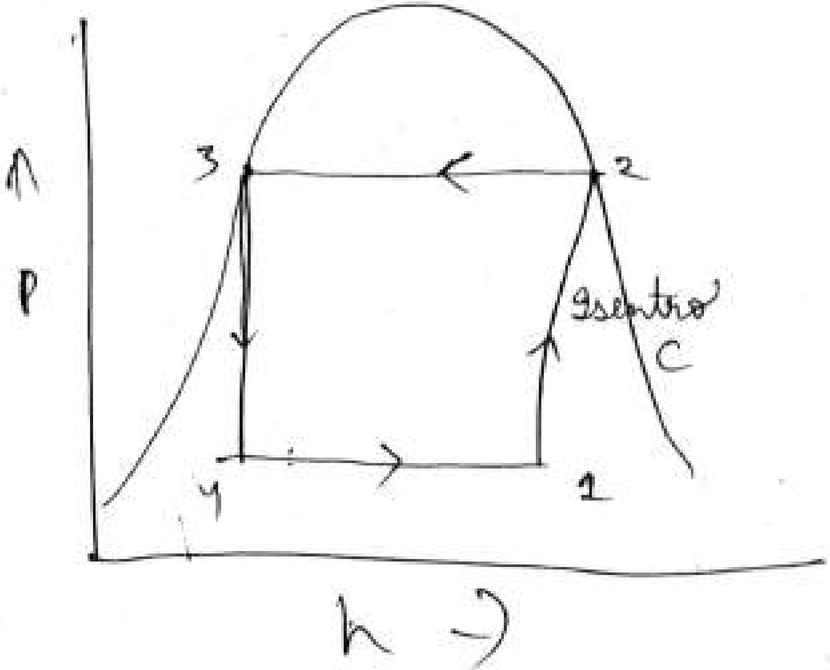
$h_1 = h_f + (x \times h_{fg})$ at 25 bar

$h_{fg} = 322.58 - 56.32$

$= 266.26$

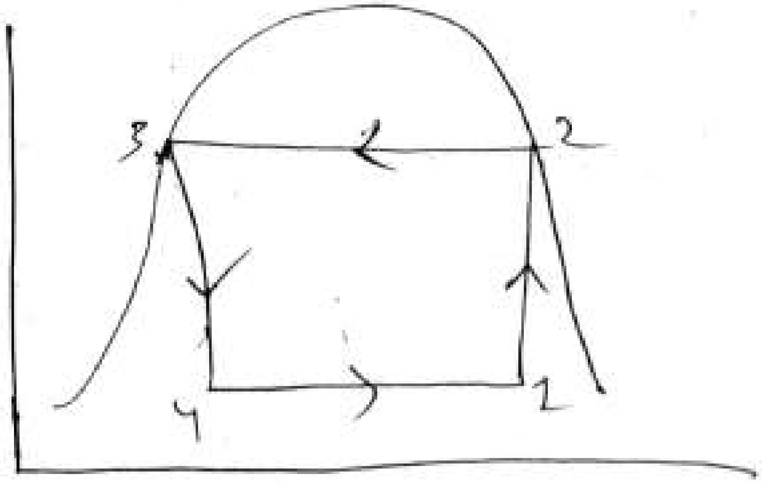
$56.32 + (0.791 \times 266.26)$

$h_1 = 266.93$ KJ/kg



$$C\cdot OP = \frac{RE}{W\cdot D}$$

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



$\therefore h_4 = (h_{f3})_{60\,bar}$

At 60 bar,

$h_{f3} = 151.96$

(Given)

$$C\cdot O\cdot P = \frac{RE}{W\cdot D} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$= \frac{266.93 - 151.96}{293.23 - 266.93}$$

$$= 4.36$$

(ii) Capacity of refrigerator -

Refrigerating effereect

$= h_1 - h_4 = 266.93 - 151.96$

$= 114.97$ KJ/kg

Rate of flow = 5 kg/min

$\Rightarrow 114.97 \times 5 = 574.85$ KJ/kg in a minute

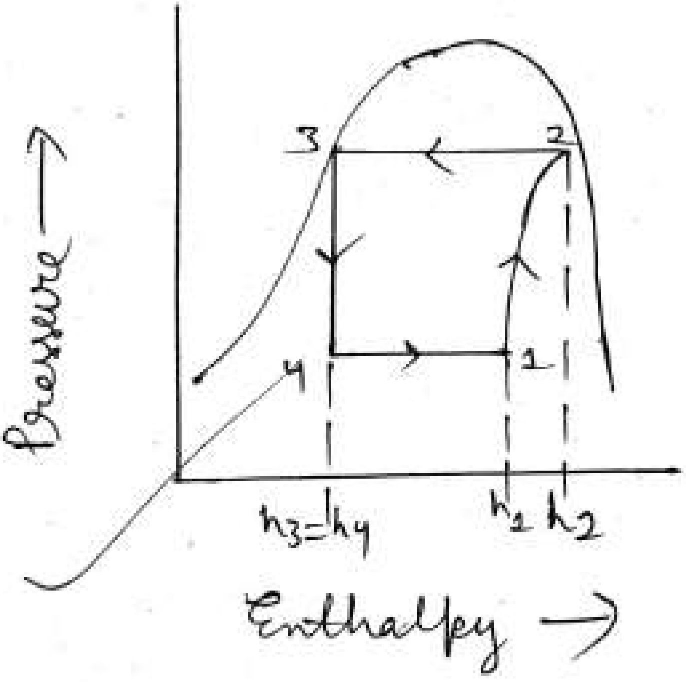
1 TR = 210 KJ/min

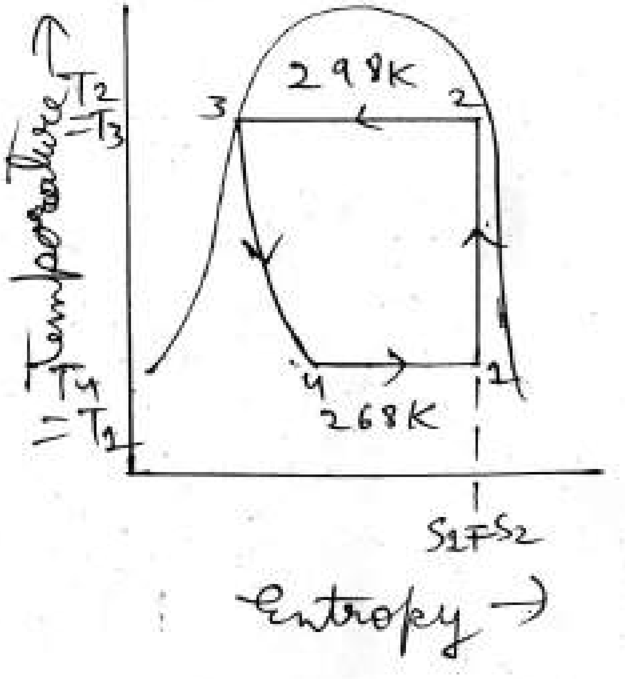
$\Rightarrow \text{Capacity} = \frac{574.85}{210}$

$= 2.73$ TR

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 are given for CO_2.

Temp °C	Liquid		Vapour		Latent heat KJ/kg (h_{fg})
	Enthalpy KJ/kg (h_f)	Entropy KJ/kg-K (S_f)	Enthalpy KJ/kg (h_g)	Entropy KJ/kg-K (s_g)	
25	164.77	0.5978	282.23	0.9918	117.46
−5	72.57	0.2862	321.33	1.2146	248.76





Given data

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

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

$\Rightarrow x_1 = 0.6$

$$C \cdot O \cdot P = \frac{R \cdot E}{W \cdot D}$$

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

$h_1 = h_{f_1} + x_1 * h_{fg_1}$

$= 72.57 + 0.6 \times 248.76$

$= 221.83$ kJ/kg

$h_4 = h_{f_3}$

$= 164.77$ kJ/kg

$h_2 = h_{f_2} + x_2 \times h_{fg_2}$

To find x_2 (dryness fraction at point 2)

$\boxed{s_1 = s_2}$

$s_1 = s_{f_1} + x_1 \times s_{fg_1}$

$= 0.2862 + 0.6 \times (s_g - s_f)$

$= 0.2862 + 0.6 \times (1.2146 - 0.2862)$

$= 0.843$

Since $s_1 = s_2$ therefore :-

$s_2 = 0.843$

$\Rightarrow s_2 = s_{f_2} + x_2 \times s_{fg_2}$

$\Rightarrow 0.843 = 0.5978 + x_2 \times (0.9918 - 0.5978)$

$\Rightarrow x_2 = 0.622$

Now

$h_2 = h_{f2} + x_2 \times (h_{fg2})$

$= 164.77 + 0.622 \times (117.46)$

$= 237.83$ kJ/kg

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

$$= \frac{221.83 - 164.77}{237.83 - 221.83}$$

$= 3.56$ (Ans)

[redacted]

Q1) A vapour compression refrigerator uses R-12 as refrigerant and the liquid evaporates in the evaporator at -15°C. The temperature of this refrigerant at the delivery from the compressor is 15°C when the vapour is condensed at 10°C. Find the coefficient of performance if

(i) there is no undercooling, and

(ii) the liquid is cooled by 5°C before expansion by throttling.

Temperature in °C	Enthalpy in KJ/kg		Speific entropy in KJ/kg K	
	Liquid	Vapour	Liquid	Vapour
−15	22.3	180.88	0.0904	0.7051
10	45.4	191.76	0.1750	0.6921

Ans:- Given data.

$T_1 = T_4 = -15°C = 258K$

$T_{2'} = T_3 = 10°C = 283K$

~~$T_2 = 15°C = 288K$~~

$C_{pv} = 0.64$ KJ/kg K

$C_{pl} = 0.94$ KJ/kg K

(i) Let x_1 = dryness fraction at point 1.

Entropy at point 1 = S_1

$S_1 = sf_1 + x \times sfg_1$

$= sf_1 + x_1 \times (sg_1 - sf_1)$

$= 0.904 + x_1 0.6147$

~~Entropy at point 2 = S_2~~

~~$S_2 = sf_2 + x_2 \times (sg_2 - sf_2)$~~

~~$= (0.1750) + x_2 \times (0.6921$~~

Entropy at point 2 = S_2

$$S_2 = S_2' + 2.3\, C_{pv} \log\left(\frac{T_2}{T_2'}\right)$$

$$= 0.6921 + 2.3 \times 0.64 \log\left(\frac{288}{283}\right)$$

$(\because S_2' = s_{g_2})$

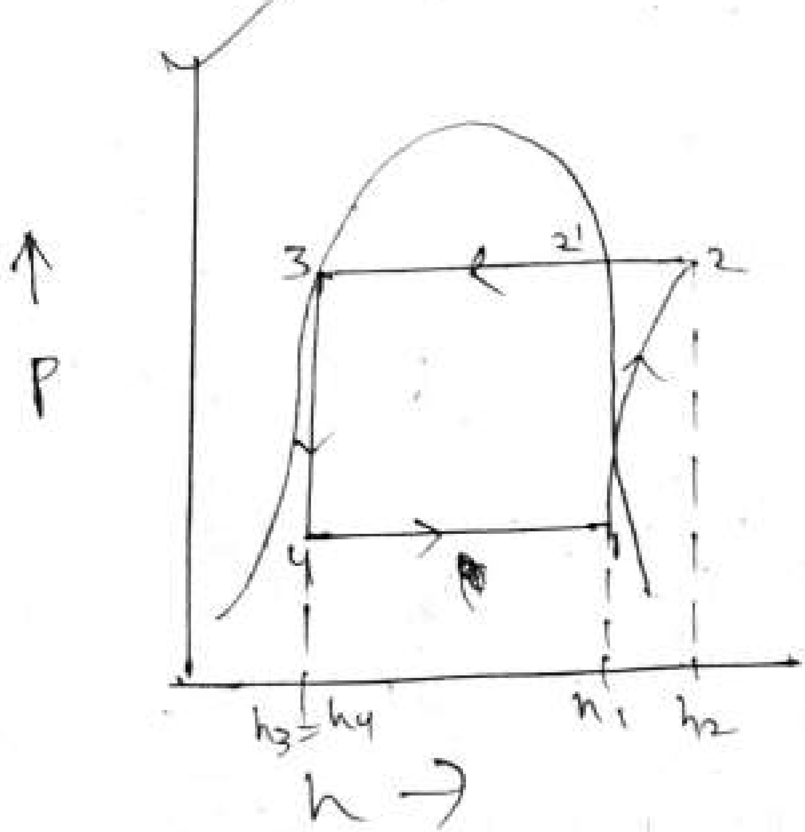
$$= 0.7032$$

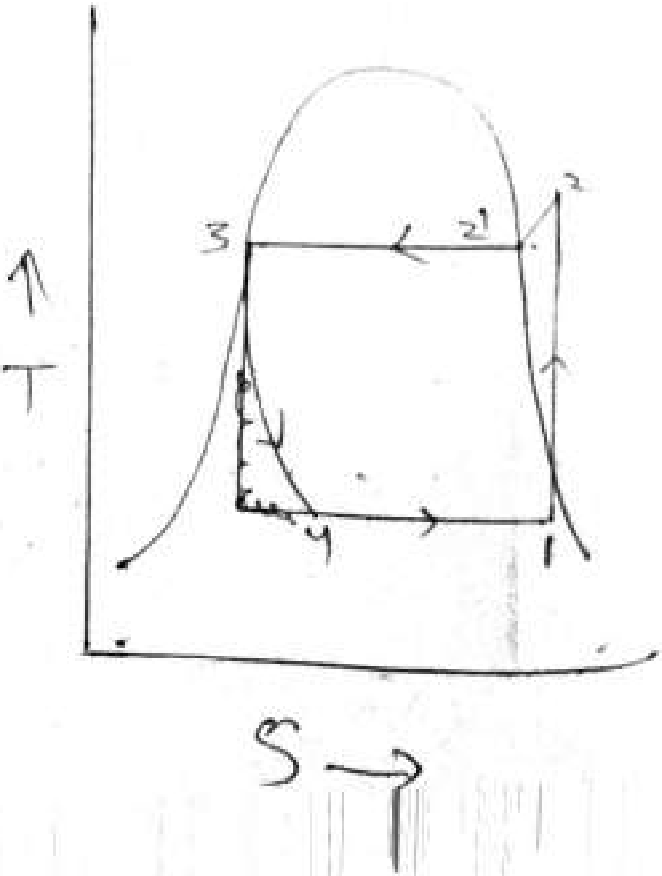
We know that $s_1 = s_2$

~~No 0.4722 x1 = 0.7032~~

$$0.0904 + x_1\, 0.6147 = 0.7032$$

$$\Rightarrow x_1 = 0.996$$





Now ·

$$h_1 = h_{f_1} + x_2 \times h_{fg_1}$$

$$= ~~hf~~\ 22.3 + 0.996 \times (180.88 - 22.3)$$

$$= 180.24 \text{ KJ/kg}$$

$$h_2 = h_2' + C_{P_v}(T_2 - T_2')$$

$$= 191.76 + 0.64(288 - 283)$$

$$(\because h_2' = h_{g_2})$$

$$= 194.96 \text{ KJ/kg}$$

$$h_4 = h_{f_3}$$

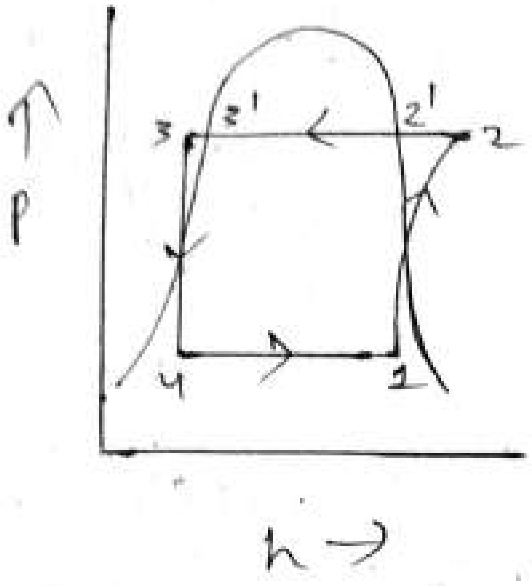
$$= 45.4$$

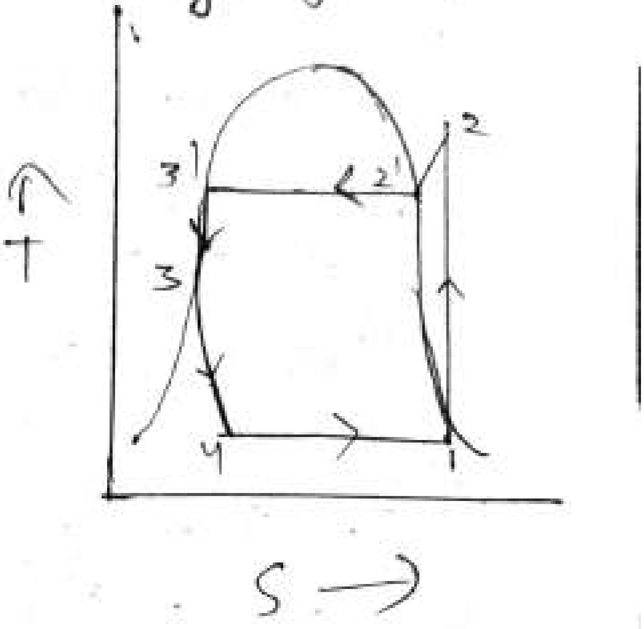
$$C.O.P = \frac{R.E}{W.D} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$= \frac{180.24 - 45.4}{194.96 - 180.24}$$

$$= 9.16$$

(ii) Coefficient of performance when there is an undercooling of 5°C





$h_4 = h_{f3}$

$h_{f3} = h_{f3'} - c_{pl} \times 5$ (degree of undercooling)

$= 45.4 - 0.94 \times 5$

$= 40.7$

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

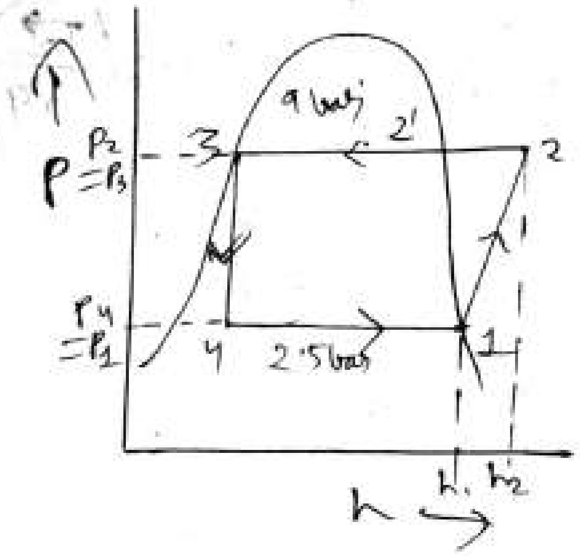
$$= \frac{180.24 - 40.7}{194.96 - 180.24}$$

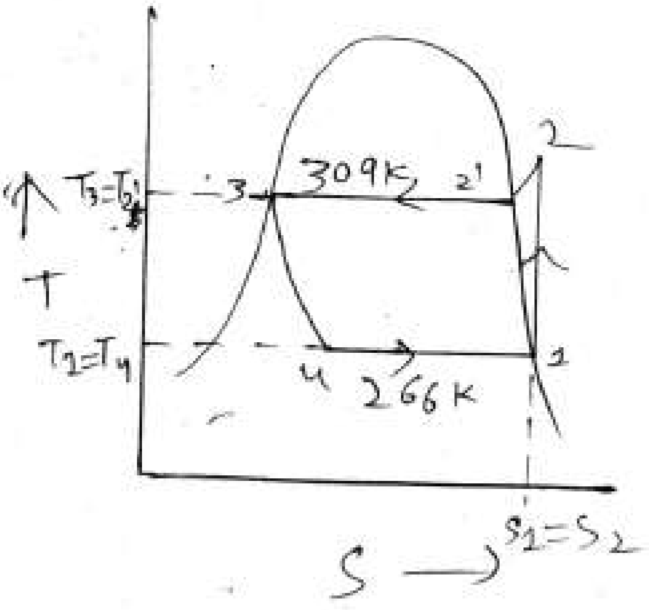
$= 9.47$

Q_2) A refrigeration machine using R-12 as refrigerant operates between the pressures 2.5 and 9 bar. The compression is isentropic and there is no undercooling in the condenser.

The vapour is in dry saturated condition at the beginning of the compression. Estimate the theoretical coefficient of performance. If the actual coefficient of performance is 0.65 of theoretical value, calculate the net cooling produced per hour. The refrigerant flow is 5 kg per minute. Properties of refrigerant are:-

Pressure	Sat temp, °C	Enthalpy, KJ/kg		Entropy of sat. vapour KJ/kg-K
		Liquid	Vapour	
9.0	36	70.55	201.8	0.6836
2.5	-7	29.62	184.5	0.7001





Given data.

$P_1 = P_4 = 2.5$ bar

$P_2 = P_3 = 9$ bar

$T_1 = T_4 = 266$ K

$T_{2'} = T_3 = 309$ K

$(C.O.P)_{actual} = 0.65 (C.O.P)_{theoretical}$.

$m = 5$ kg/min, $C_P = 0.64$ kJ/kg·K

$T_2 = ?$

$S_2 = S_{2'} \times 2.3 C_p \log\left(\frac{T_2}{T_{2'}}\right)$

$(S_2 = S_1)$ $S_1 = 0.7001$

so $S_2 = 0.7001$

$\Rightarrow 0.7001 = 0.6836 + 2.3 \times 0.64 \log\left(\frac{T_2}{309}\right)$

$\Rightarrow \log\left(\frac{T_2}{309}\right) = \frac{0.7001 - 0.6836}{2.3 \times 0.64}$

$\Rightarrow \log\left(\frac{T_2}{309}\right) = 0.0112$

$\Rightarrow \left(\frac{T_2}{309}\right) = 10^{0.0112} \quad (\log^{-1})$

$\Rightarrow \left(\frac{T_2}{309}\right) = 1.026$

$\Rightarrow T_2 = 1.026 \times 309 = 317 K$

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

$= 201.8 + 0.64(317 - 309)$

$\because (h_2' = h_{g_2})$

$= 206.92$ KJ/kg

$(C.O.P)_{theoretical} = \frac{h_1 - h_4}{h_2 - h_1}$

$= \frac{184.5 - 70.55}{206.92 - 184.5} \quad (\because h_4 = h_{f3})$

$(C.O.P)_{th} = 5.08$

$(C.O.P)_{actual} = 0.65 \times (5.08)$

$= 3.30$

$WD = h_2 - h_1 = 206.92 - 184.5$

$= 22.42$ kJ/kg

Net Cooling (R.E) = C.OP × W.D

$= 3.30 \times 22.42$

$= 73.98$ kJ/kg

R.E per hour $= 73.98 \times 5$

$= 369.9$

(1 TR = 210 kJ/min)

$\Rightarrow \frac{369.9}{210} = 1.76$

R.E per hour = 1.76 TR

?

Chapter-3

Vapour absorption Refrigeration System (VARS)

⇒ The vapour absorption refrigeration system is one of the oldest methods of producing refrigerating effect.

⇒ It may be used in both the domestic and large industrial refrigerating plants.

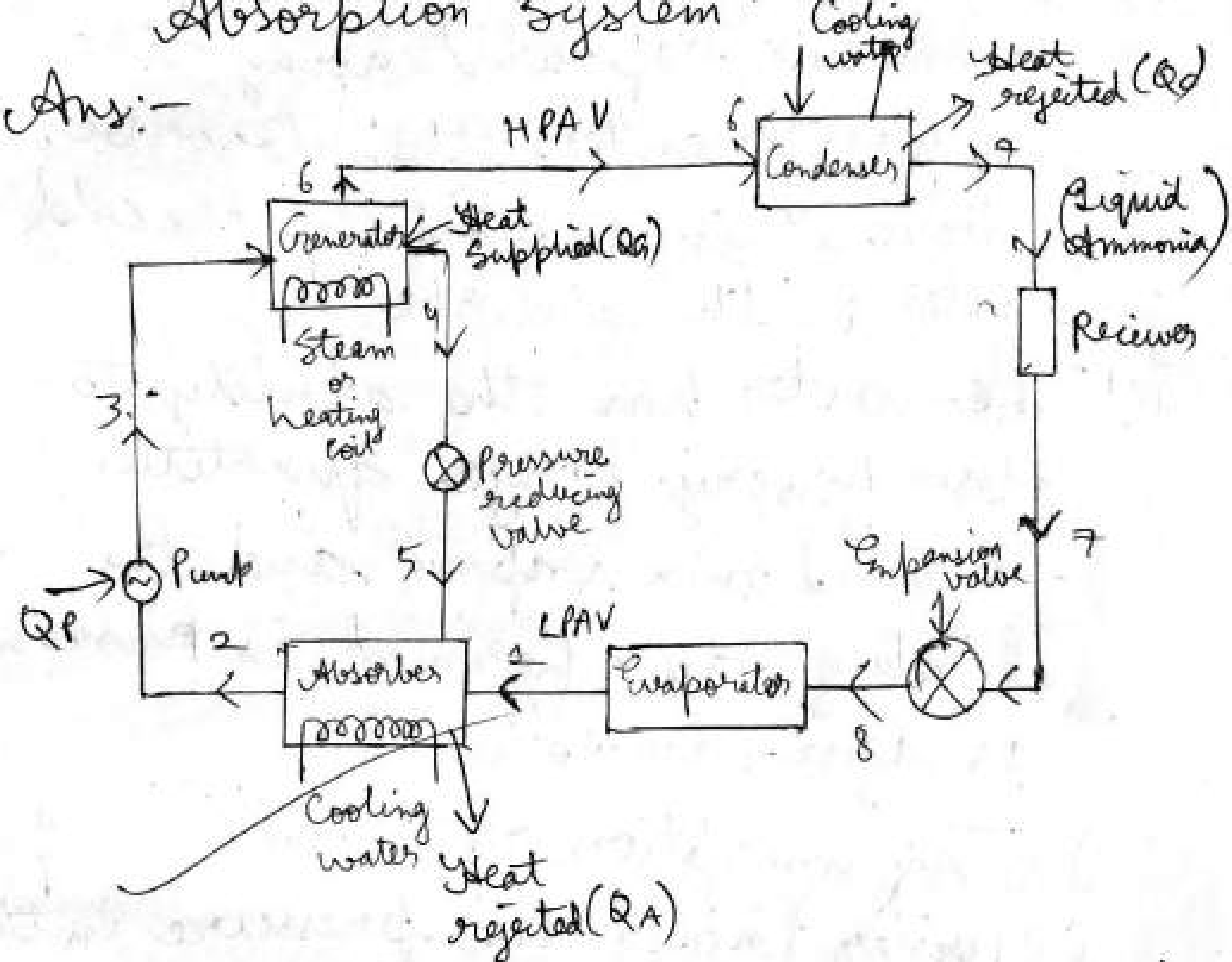
⇒ It uses heat energy, instead of mechanical energy as in vapour compression systems, in order to change the conditions of the refrigerant required for the operation of the refrigeration cycle.

⇒ In VARS, the compressor is replaced by an absorber, a pump, a generator and a pressure reducing valve.

⇒ The refrigerant commonly used in VARS is ammonia.

Q1) With neat sketch describe simple Absorption System.

Ans:-



<Simple Vapour Absorption System>

(i) The simple vapour absorption system, consists of an absorber, a pump, a generator and a pressure reducing valve to replace the compressor of vapour compression system.

(ii) The other components of the system are condenser, receiver, expansion valve and evaporator as in the vapour compression system.

(iii) In this system, the low pressure ammonia vapour leaving the evaporator enters the absorber where it is absorbed by the cold water in the absorber.

(iv) The water has the ability to absorb very large quantities of ammonia vapour and the solution, thus formed is known as aqua-ammonia.

(v) The absorption of ammonia vapour in water lowers the pressure in the absorber which in turn draws more ammonia vapour from the evaporator and thus raises the temperature of solution.

(vi) The strong solution thus formed in the absorber is pumped to the generator by the liquid pump.

(vii) The strong solution of ammonia in the generator is heated by

Some external source such as gas or steam.

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

(ix) The weak ammonia solution flows back to the absorber at low pressure after passing through the pressure reducing valve.

(x) The high pressure ammonia vapour from the generator is condensed in the condenser to a high pressure liquid ammonia.

(xi) This liquid ammonia is passed to the expansion valve through the receiver and then to the evaporator.

(xii) This completes the simple vapour absorption cycle.

Q2) Advantages of Vapour Absorption Refrigeration System over Vapour Compression Refrigeration System.

Ans:- (i) In the vapour absorption system the only moving part of the entire system is a pump, thus it's comparatively quieter and is subjected to little wear.

(ii) The VARS uses heat energy whereas VCRS uses mechanical energy.

(iii) Electricity is a neccesity in VCRS but in VARS no electricity is required as it operates on waste heat.

(iv) Load Variations do not affect the performance of a vapour absorption system whereas. performance is reduced in VCRS when partial loads are poor.

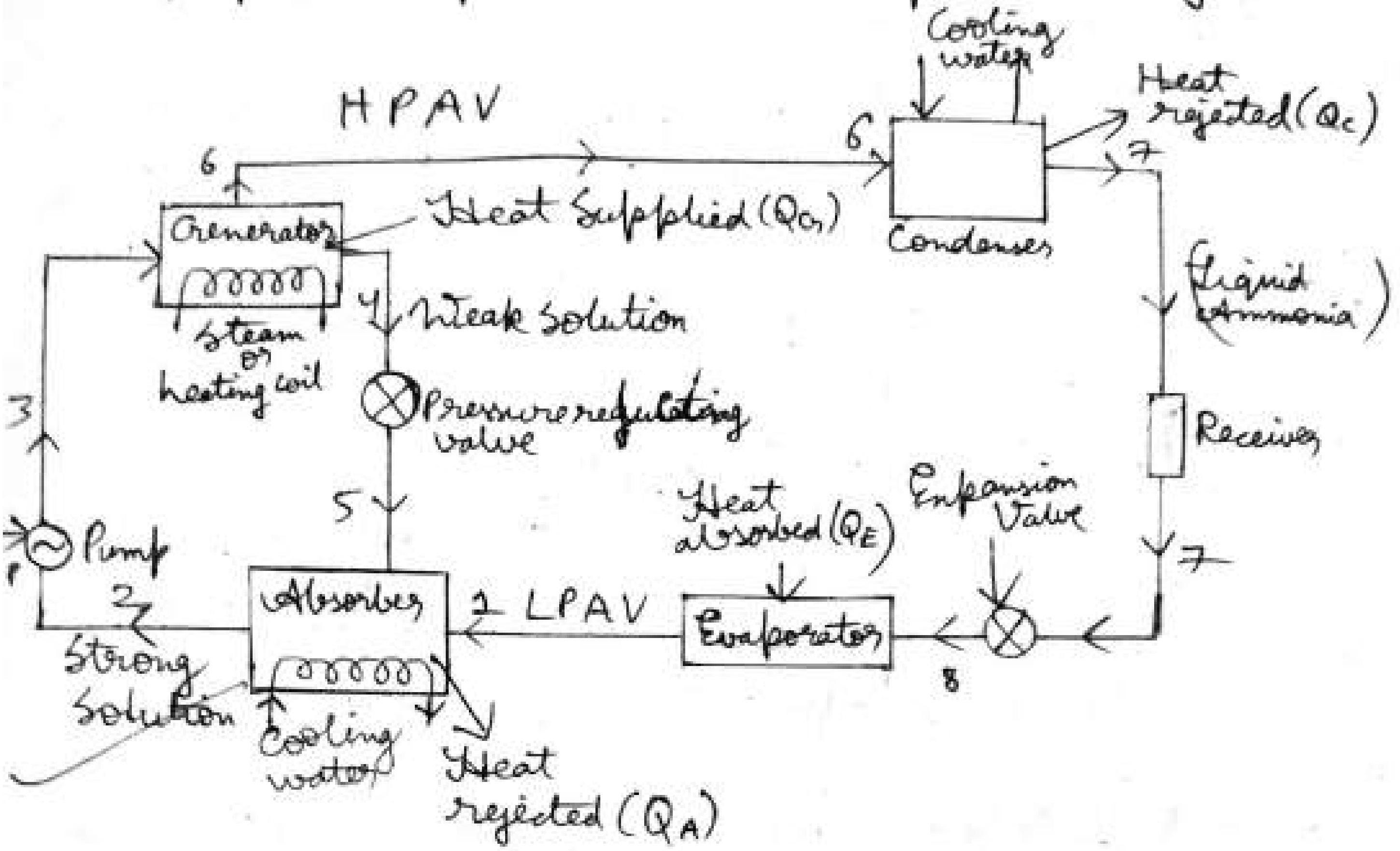
(v) In VARS the liquid refrigerant leaving the evaporator has no bad effect on the system but in

VCRS it is necessary to superheat the vapour refrigerant leaving the evaporator so that no liquid may enter the compressor.

(vi) The vapour absorption systems can be built in capacities well above 1000 tonnes of refrigeration each, which is the largest size for single compressor units.

(vii) The space requirements and automatic control requirements favour the absorption system more and more as the desired evaporator temperature drops.

Simple Vapour Absorption System



Coefficient of Performance of an Ideal Vapour Absorption Refrigeration System

a) Q_G = heat given to the refrigerant in the generator

b) Q_C = heat discharged to the atmosphere or cooling water from the condenser and absorber.

c) Q_E = heat absorbed by the refrigerant in the evaporator

d) Q_P = heat added to the refrigerant due to pumpwork.

Neglecting the heat due to pumpwork (Q_P), we have

$$Q_C = Q_G + Q_E$$ (According to the first law of thermodynamics

Let T_G = Temperature at which heat is given to the generator

T_C = Temperature at which heat is discharged to atmosphere

T_E = Temperature at which heat is absorbed in the evaporator.

In a perfectly reversible system, the initial entropy of the system must be equal to the entropy of the system after the change in it's condition.

Since VARS is considered as a perfectly reversible system

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

$$= \frac{Q_G + Q_E}{T_C} \quad (Q_C = Q_G + Q_E)$$

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

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

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

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

$\because$ Since $T_G > T_C > T_E$

therefore multiplying −ve we get.

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

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

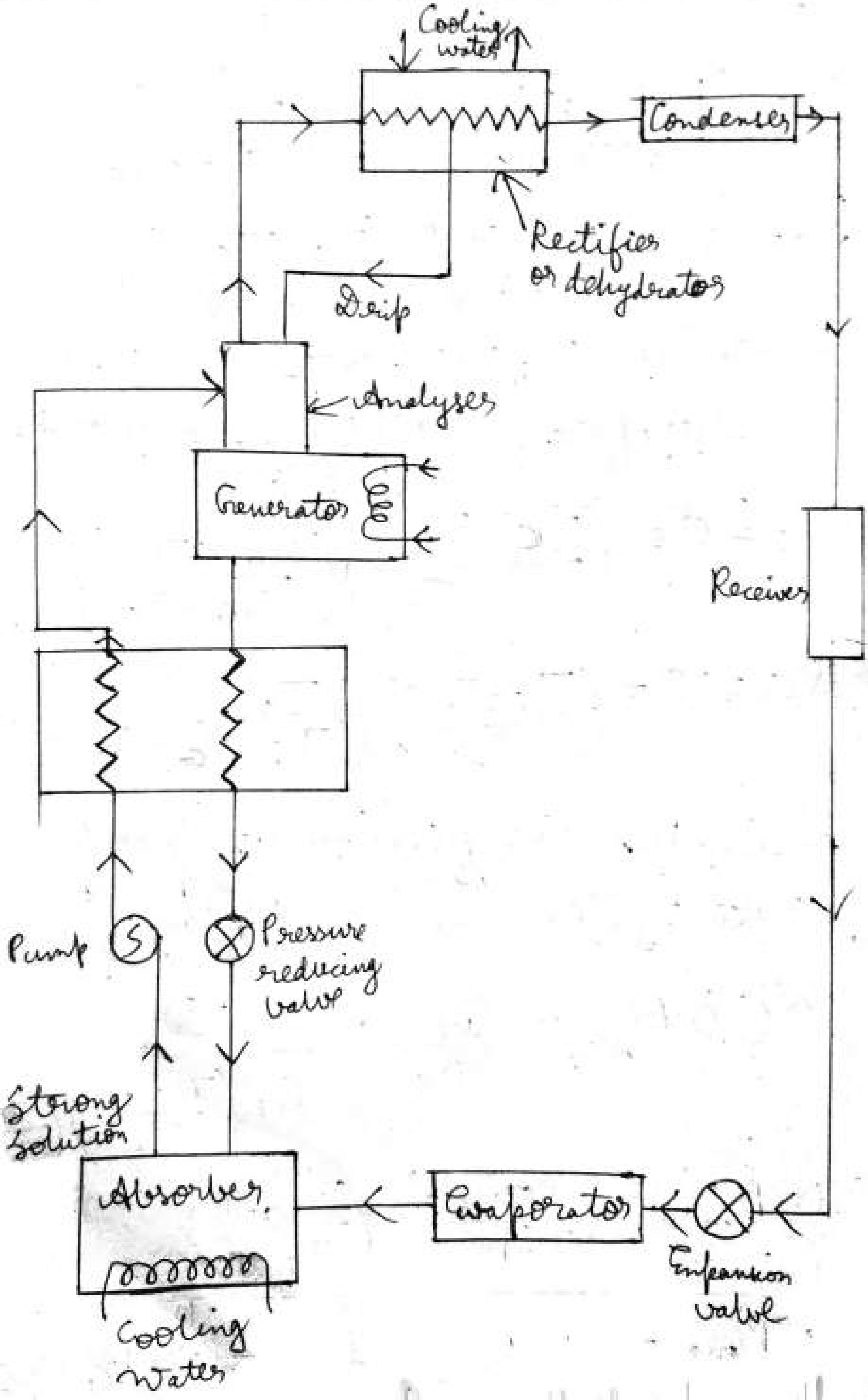
Maximum coefficient of performance of the system is given by

$$(C.O.P)_{max} = \frac{Q_E}{Q_G} = \frac{Q_E}{Q_E\left(\frac{T_C - T_E}{T_E}\right)\left(\frac{T_G}{T_G - T_C}\right)}$$

$$\Rightarrow (C.O.P)_{max} = \left(\frac{T_E}{T_C - T_E}\right)\left(\frac{T_G - T_C}{T_G}\right)$$

$$\boxed{\Rightarrow (C.O.P)_{max} = C.O.P_{(refrigerator)} \times \overset{\eta}{\cancel{C.O.P}}_{(\text{Heat Engine})}}$$

Practical vapour absorption system



(i) The simple ~~ator~~ vapour absorption system is not very economical. In order to make it practical, it is fitted with an Analyser, Rectifier and a Heat Exchanger.

(ii) When the low pressure ammonia vapour leaving the evaporator enters the absorber it is absorbed by the cold water present there thus forming a strong aqua-ammonia solution.

(iii) This strong solution is then pumped to the generator by the pump provided.

(iv) This strong solution of ammonia in the generator is heated by heating coils by which ammonia vapour is driven off leaving behind the hot weak solution which flows back to the absorber.

(v) The heat exchanger provided between the absorber and the generator then cools the weak hot solution returning to the absorber.

(vi) The heat removed from the weak solution raises the temperature of the strong solution going to the generator which in turn reduces the heat supplied to the generator and cooling required at the absorber making it more economical.

(vii) When Ammonia is vaporised in the generator, some water is also vaporised and will flow into the condenser which can freeze and choke the pipeline.

(viii) In order to remove these unwanted water particles, an analyser is used which may be an integral part of generator or attached externally.

(ix) In consists of a series of trays mounted above the generator to which the strong solution from the absorber introduced and flows downward over the trays into the generator.

(x) In this way, considerable liquid surface area is exposed to the vapour rising from the generator and most of the vapour

Condenser

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

(xii) It's function is to cool further the ammonia vapours leaving the analyser so that the remaining water vapours are condensed and only dry ammonia vapour flows to the condenser.

(xiii) the condensate from the rectifier is returned to the top of the analyser by a drip return pipe.

(xiv) Then the high pressure ammonia vapour is condensed in the condenser to a high pressure liquid ammonia.

(xv) This liquid ammonia is passed to the expansion valve through the receiver and then to the evaporator which turns it into low pressure vapour ammonia.

(xvi) This cycle is thus repeated.

Q 1) In a vapour absorption refrigeration system, heating, cooling and refrigeration take place at the temperatures of 100°C, 20°C and -5°C respectively. Find the maximum C.O.P of the system.

Ans:- Given data. $T_G = 100°C = 373\,K$

$T_C = 20°C = 293\,K$

$T_E = -5°C = 268\,K$

$$C.O.P_{(max)} = \left(\frac{T_E}{T_C - T_E}\right)\left(\frac{T_G - T_C}{T_G}\right)$$

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

$$\boxed{= 2.29}$$

Chapter-4

Refrigeration Equipments

Refrigerant compressor :-

Function :-

A refrigerant compressor is a machine which is used to compress the low pressure and low temperature vapour refrigerant from the evaporator and converted into high pressure and high temperature vapour refrigerant.

Classification of Compressor :-

1) According to method of compression
   a) Reciprocating compressor
   b) Rotary compressor
   c) Centrifugal compressor.
2) According to no of working strokes
   a) Single stage compressor.
   b) Double acting compressor

3) <u>According to no of stages</u>

a) Single stage
b) Multi stage

4) <u>According to the method of drive employed</u>

a) Direct drive compressors
b) Belt drive compressors.

5) <u>According to the location of the prime mover</u>

a) Semi-hermetic compressors.
b) Herimetric compressors.

<u>Important terms</u>

1) <u>Suction pressure</u> :- It is the absolute pressure of refrigerant at the inlet of a compressor

2) <u>Discharge pressure</u> :- It is the absolute pressure of refrigerant at the outlet of a compressor.

3) <u>Compression ratio</u> :- It is the ratio of absolute discharge pressure

to the absolute suction pressure. Since the absolute discharge pressure is always more than the absolute suction pressure, therefore, the value of compression ratio is more than unity.

⇒ The compression ratio may also be defined as the ratio of total cylinder volume to the clearance volume.

4) Suction volume :- It is the volume of refrigerant sucked by the compressor during its suction stroke. It is usually denoted by V_s.

5) Piston displacement volume or stroke volume or swept volume :-

It is the volume swept by the piston when it moves from it's top or inner dead position to bottom or outer dead centre position.

$$V_p = \frac{\pi}{4} \times D^2 \times L$$

D = diameter of cylinder, and
L = Length of piston stroke.

6) Clearance factor :- It is the ratio of clearance volume (V_c) to the piston displacement volume (V_p). Mathematically, clearance factor.

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

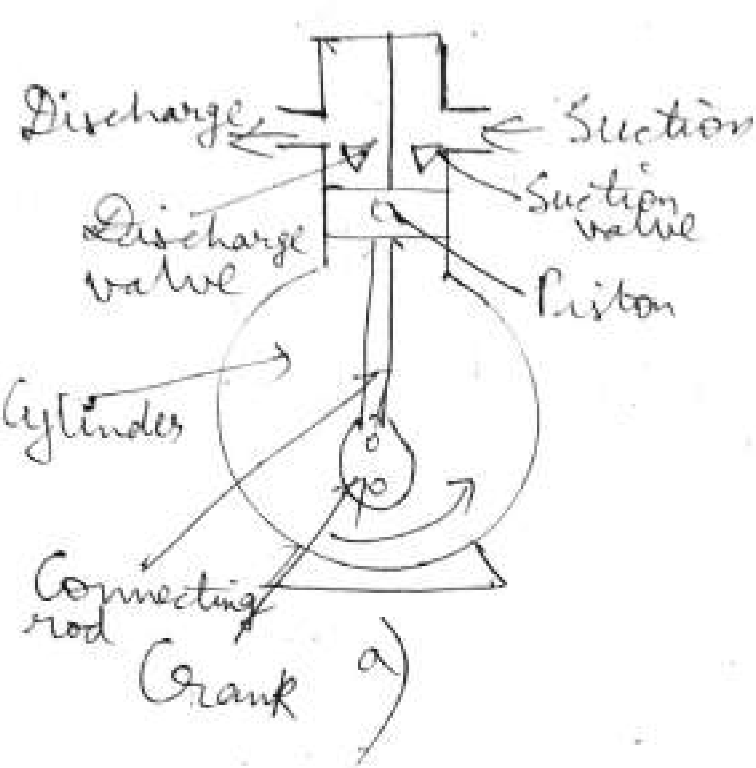
7) Compressor capacity :- It is the volume of the actual amount of refrigerant passing through the compressor in unit time. It is equal to the suction volume (V_s). It is expressed in m^3/s.

8) Volumetric efficiency :- It is the ratio of the compressor capacity or the suction volume (V_s) to the piston displacement volume (V_p). Mathematically, volumetric efficiency.

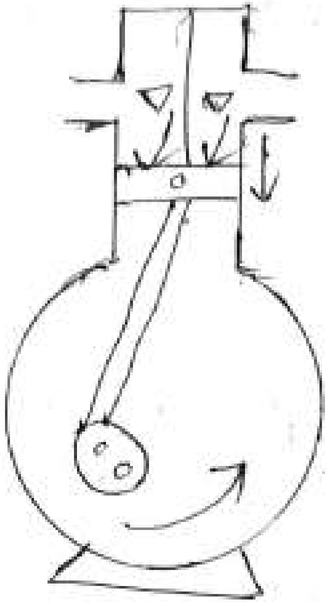
$$\eta_v = \frac{V_s}{V_p}$$

⇒ A good compressor has a volumetric efficiency of 70 to 80 percent.

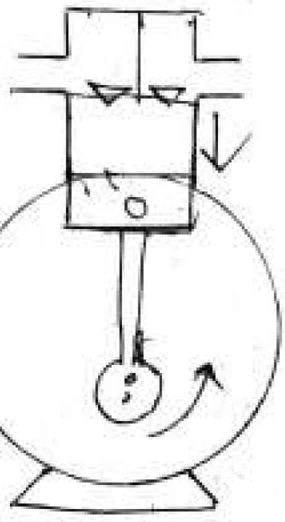
Principle & Working of reciprocating compressors :-



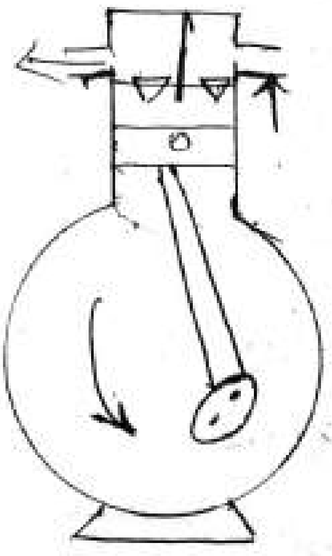
a)



b)



c)



d)

=) A reciprocating compressor consist of a piston and cylinder the piston is driven through a connecting rod & crank.

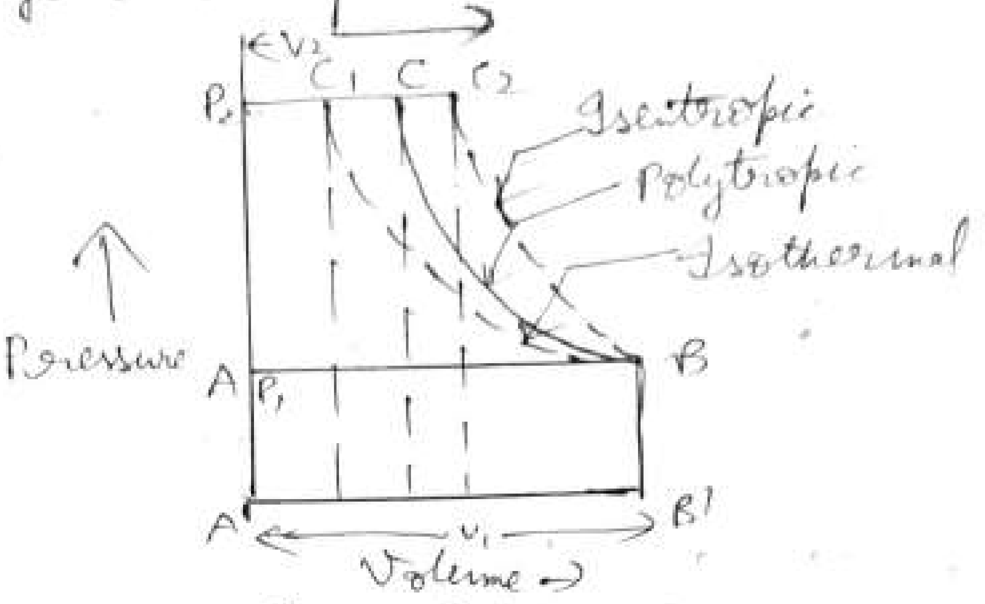
=) It consists of two valves inlet and outlet. These valves mounted on cylinder head and operating due to pressure difference.

=) The working of reciprocating compressor complete in two stroke of piston or one revolution of crank shaft.

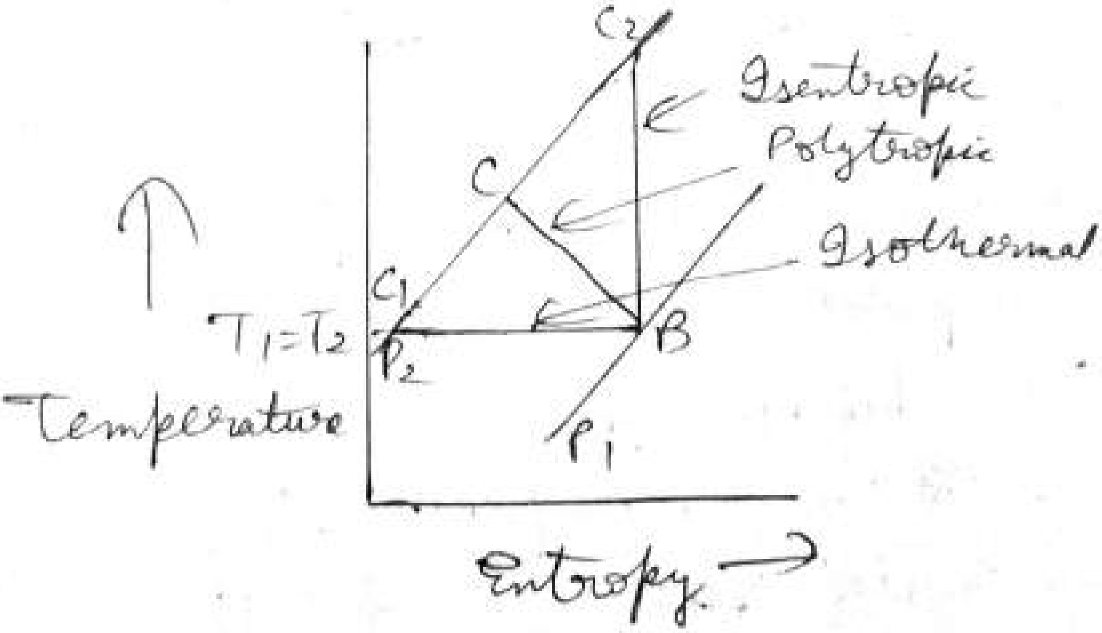
=) During suction stroke, the piston moves downward and inlet ~~[illegible]~~ valve open and outlet valve closed due to pressure difference between cylinder and surrounding. Then the low pressure seek in the engine cylinder through inlet valve.

=) Now, this stroke piston moves upward the slight increase in cylinder pressure will cause inlet valve closed and exhaust valve closed.

⇒ Now piston reaches the top, the pressure inside the cylinder will be high as compared to discharged valve. Then the discharge valve gas opened and the vapour refrigerant is discharged into the condenser and this cycle is repeated.



(P-V) diagram



(T-S) diagram

Hermetically Sealed Compressor

⇒ When the compressor and motor operate on the same shaft and are enclosed in a common casing, they are known as hermetic sealed compressors.

⇒ The hermetic sealed compressors are widely used for small capacity refrigerating systems such as in domestic refrigerators, home freezers and window air conditioners.

Advantages :-

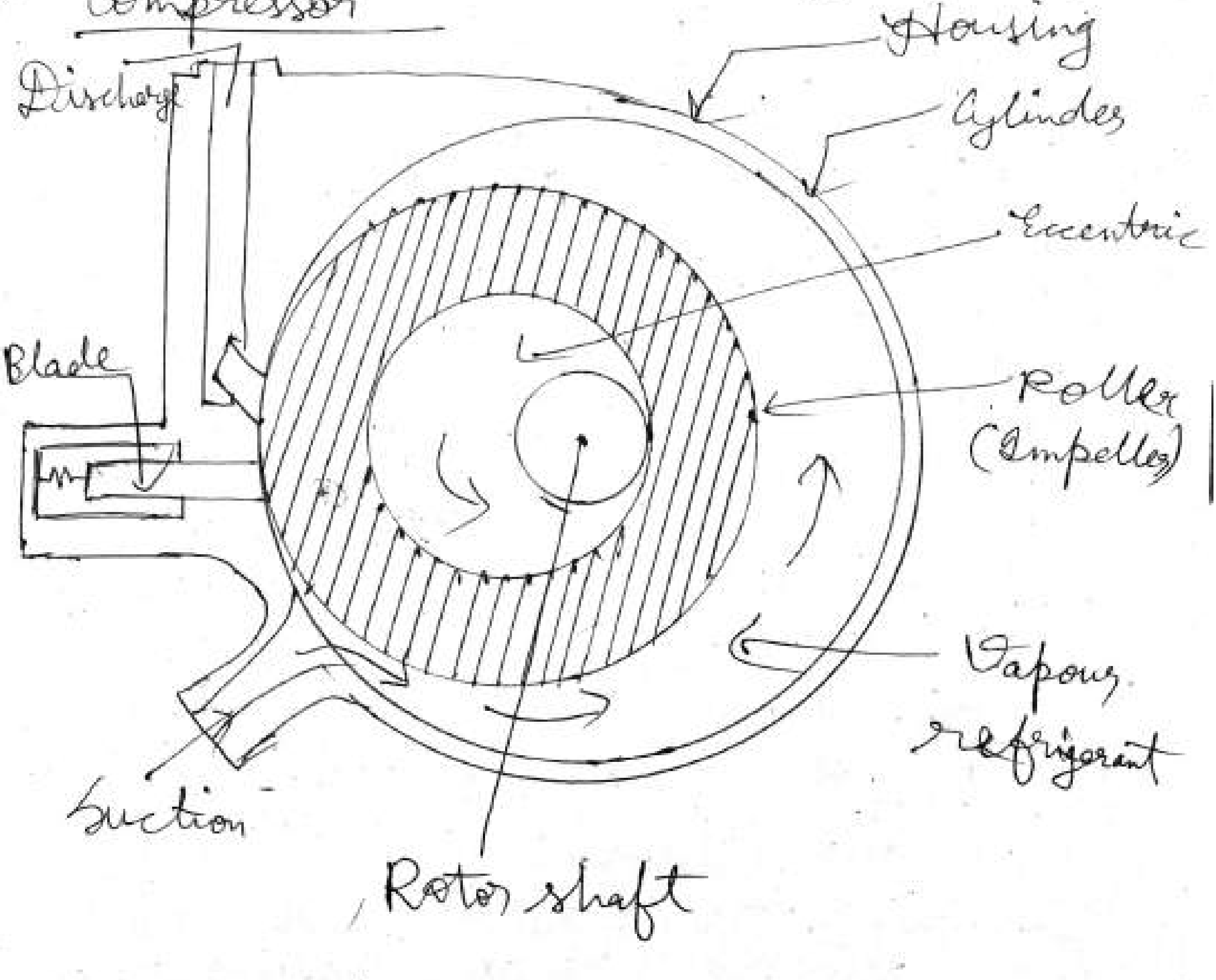
1) The leakage of refrigerant is completely prevented.
2) It is less noisy.
3) It requires small space because of compactness.
4) The lubrication is simple as the motor and compressor operate in a sealed space with the lubricating oil

Disadvantages :-

1) The maintenance is not easy because the moving parts are inaccessible.
2) A separate pump is required for evacuation and charging of refrigerant.

Rotary Compressors :-

1) Single stationary blade type rotary compressor



⇒ A stationary blade type rotary compressor consists of cylinder, roller, and a shaft and a spring loaded blade.

⇒ The centre of the shaft coincides with the centre of the cylinder.

⇒ Roller is in the closest possible contact with the wall of the cylinder and the point of contact runs around the cylinder as shaft and roller rotate.

⇒ The inlet is separated from the outlet by a spring loaded blade which remains in contact with the roller.

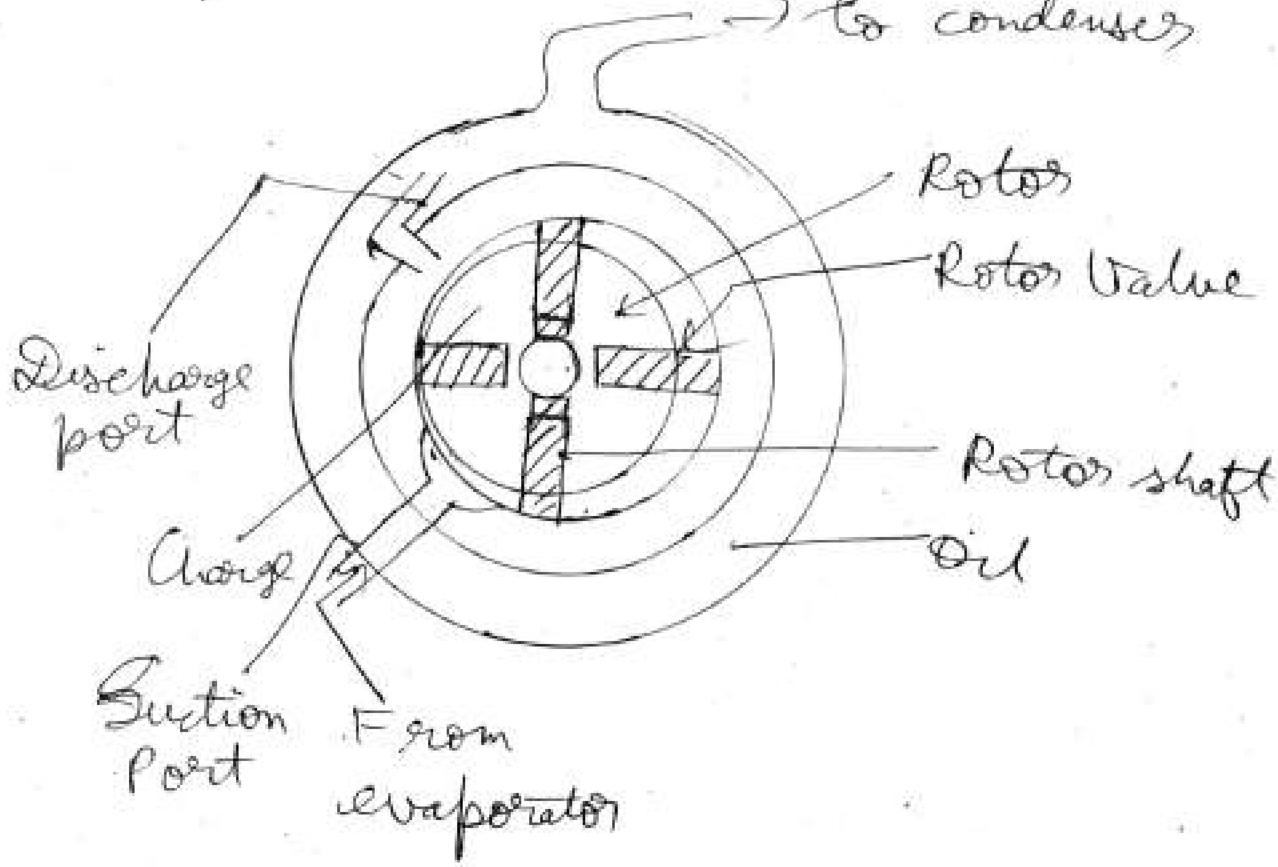
⇒ Due to the eccentrically between roller and cylinder the clearance between them is not uniform.

⇒ The whole assembly is placed in an air tight casing and submerged in an oil both.

⇒ When the space permits low pressure refrigerant vapour from the evaporator enters the cylinder.

⇒ As the roller rotates, this refrigerant vapour is compressed until it's pressure forces open the discharge valve and the high pressure vapour flows towards the condenser.

2) Rotating blade type rotary compressor



⇒ In this design the motor shaft is set off centre with the cylinder and is arranged co-axially with a rotor which is rotating around the inside of the cylinder.

⇒ Two or more vanes are recessed into slots in the rotor and these are thrown out by centrifugal force when the rotor rotates.

⇒ The vanes move in and out of the slots in the rotor and make effective contact with the cylinder.

⇒ The whole assembly is kept submerged in an oil bath inside the air tight casing.

⇒ The vanes making the contact with cylinder divide the clearance space between rotor and cylinder into sections.

⇒ The rotation of the rotor enables one of these to expand in size while another is being compressed.

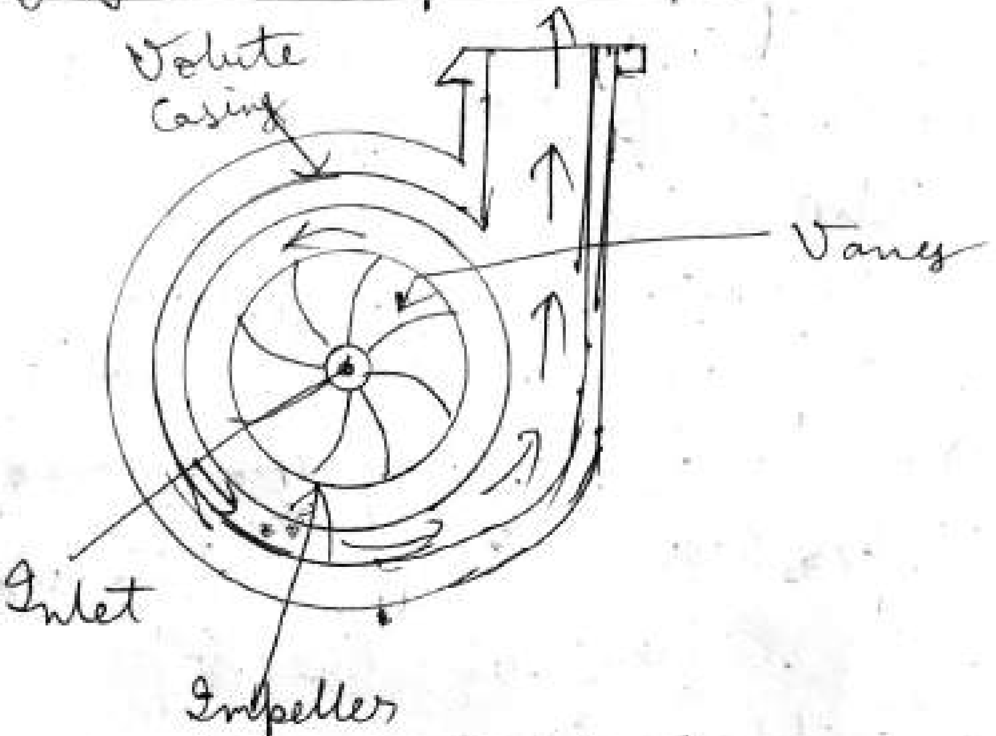
⇒ Low pressure refrigerant vapour from evaporator enters into the expanding section and gets compressed in the contacting section as the rotor rotates.

⇒ Compressed refrigerant vapour is forced out at high pressure into the condenser through the discharge valve.

⇒ These compressors are smaller in size and lighter in weight.

⇒ These compressors have the advantage of being quiet in operation and reasonably free from vibrations.

Centrifugal Compressor



⇒ The centrifugal compressor increases the pressure of low pressure vapour refrigerants to a high pressure by centrifugal force.

⇒ The centrifugal compressor is generally used for refrigerants that require large displacement and low condensing pressure, such as R-11 and R-113.

⇒ A single stage centrifugal compressor, in it's simplest form, consists of an impeller to which a number of curved vanes are fitted symmetrically;

⇒ The impeller rotates in an airtight ~~volute~~ casing with inlet and outlet points.

⇒ The impeller draws in low pressure vapour refrigerant from the evaporator.

⇒ When the impeller rotates, it pushes the vapour refrigerant from the centre of the impeller to its periphery by centrifugal force.

⇒ The high speed of the impeller leaves the vapour refrigerant at a high velocity at the vane tips of the impeller.

⇒ The kinetic energy thus attained at the impeller outlet is converted into pressure energy when the high velocity vapour refrigerant passes over the diffuser.

⇒ The diffuser is normally a vaneless type as it permits more efficient part load operation which is quite usual in any air conditioning plant.

⇒ The volute casing collects the refrigerant from the diffuser and it further converts the kinetic energy into pressure energy before the refrigerant leaves to the evaporator.

Advantages of Centrifugal compressor over reciprocating compressors

⇒ Since the centrifugal compressors have no valves, pistons, cylinders, connecting rod - etc, therefore the working life of these compressors is more as compared to reciprocating compressors.

⇒ These compressors operate with little or no vibration as there are no unbalanced masses.

⇒ The operation of centrifugal compressors is quiet and calm.

⇒ The centrifugal compressors run at high speeds (3000 R.P.M and above), therefore these can be directly compared to reciprocating compressors.

⇒ Because of the high speed, these compressors can handle large volume of vapour refrigerant, as compared to reciprocating compressors.

⇒ The centrifugal compressors are especially adapted for systems ranging from 50 to 5000 tonnes. They are also used for temperature ranges between −90°c to +10°c.

⇒ The efficiency of these compressor is considerably high.

⇒ The large size centrifugal compressors require less floor area as compared to reciprocating compressors.

Disadvantages

⇒ The main disadvantage in centrifugal compressors is surging. It occurs when the refrigeration load decreases to below 35 % of the rated capacity and causes severe stress conditions in the compressor.

⇒ The increase in pressure per stage is less as compared to reciprocating compressors.

⇒ The centrifugal compressors are not practical below 50 tonnes capacity load.

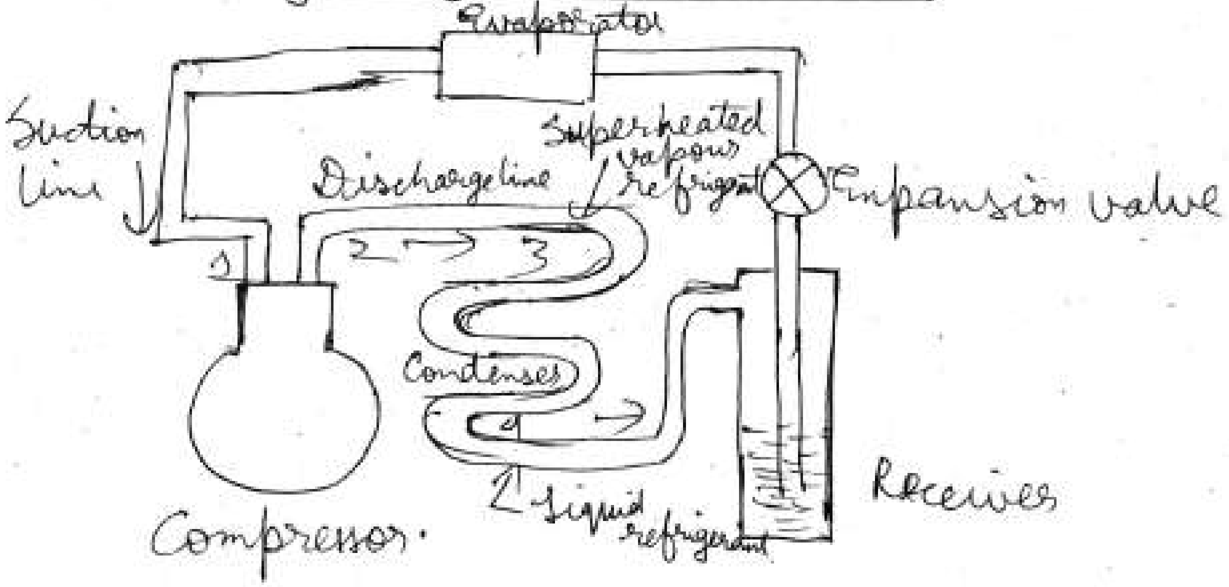
⇒ The refrigerants used with these compressors should have high specific volume.

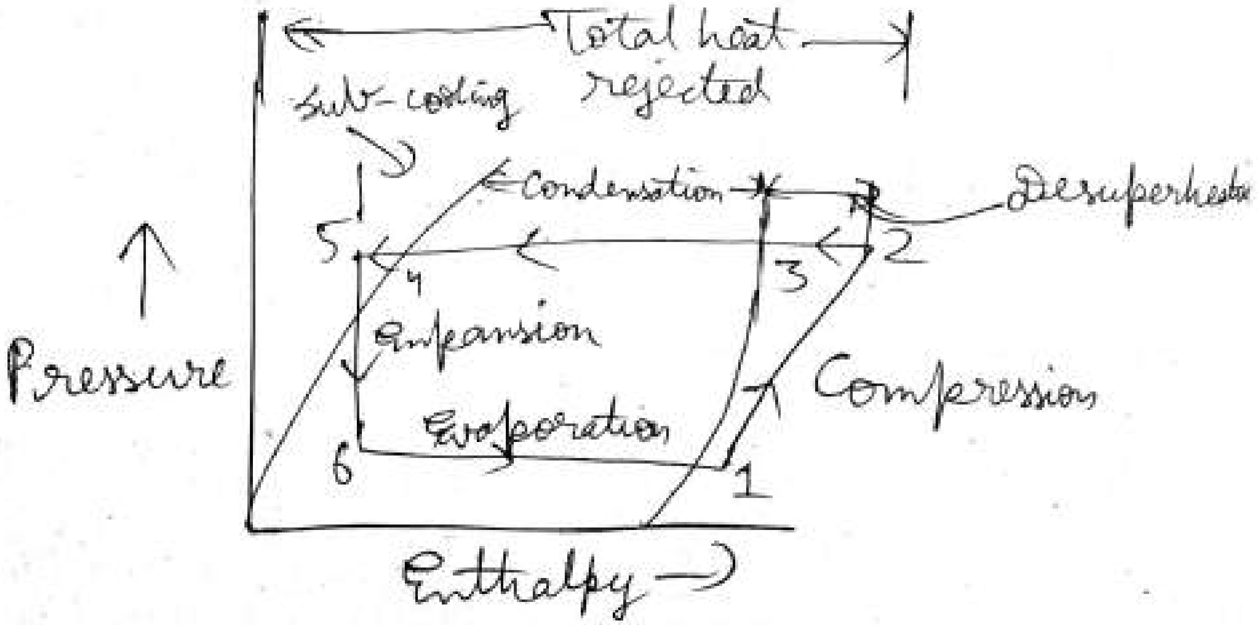
Condensers :-

→ The condenser is an important device used in the high pressure side of the refrigeration system.

⇒ It's function is to remove heat of the hot vapour refrigerant discharged from the compressor.

Working of a Condenser





⇒ First, the superheated vapour is cooled to saturation temperature corresponding to the pressure of the refrigerant. This is shown by line 2-3.

⇒ Now the saturated vapour refrigerant gives up it's latent heat and is condensed to a saterated liquid refrigerant. This process is called condensation. It is shown by the line 3-4.

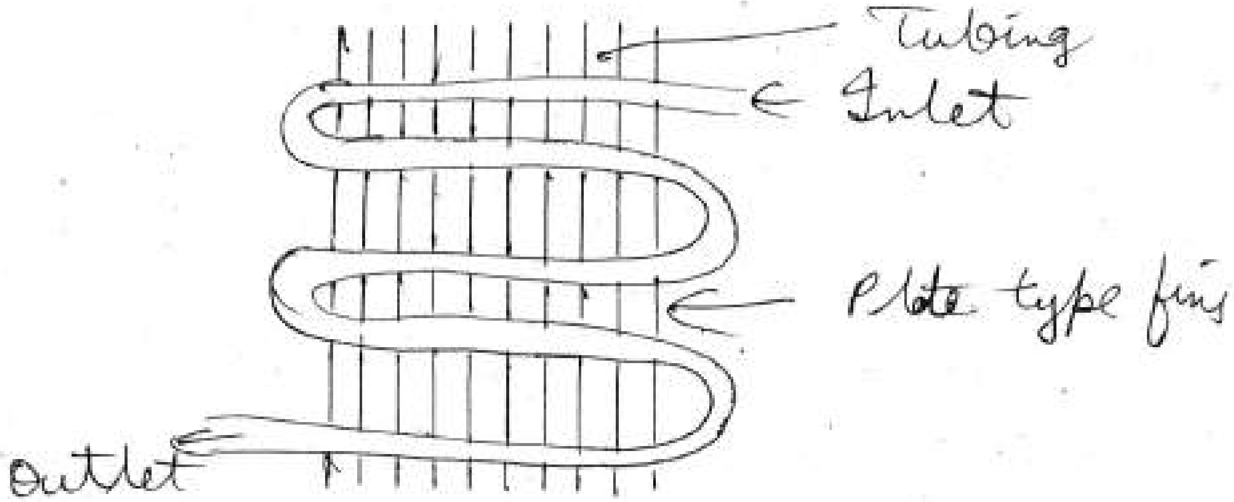
⇒ the temperature of the liquid refrigerant is reduced below it's saturation temperature in order to increase the refrigeration effect. This is shown by the line 4-5.

Types of ~~Ai~~ Condensers

According to condensing medium used, the condensers are classified into three groups.

1) <u>Air cooled condensers</u>

In these types of condensers, the heat removal is done by air.



It is divided into two types :-

a) Natural convection

⇒ The heat transfer from the condenser coils to the air is done by natural convection and no external force is applied.

b) Forced convection

⇒ It uses a fan to force the air over the condenser coils to increase it's heat transfer capacity.

⇒ It is divided into two types :-

(i) Base mounted air cooled condensers

It uses fan which is mounted on the same base ~~of~~ the compressor, motor, receiver and other controls.

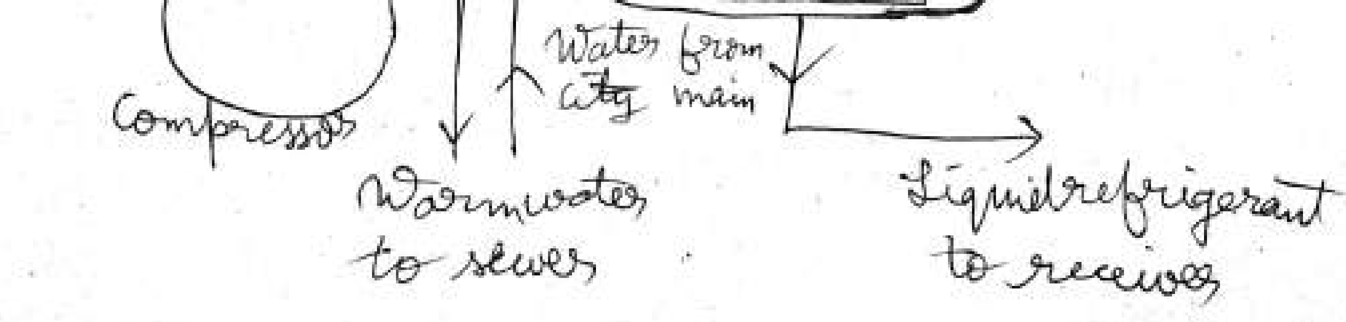
(ii) Remote air cooled condensers

These are used on systems above 10 tonnes and are available upto 125 tonnes. The systems above 125 tonnes usually have two or more condenserse. These multiple condensers can be located either inside or outside the building.

2) Water cooled condensers

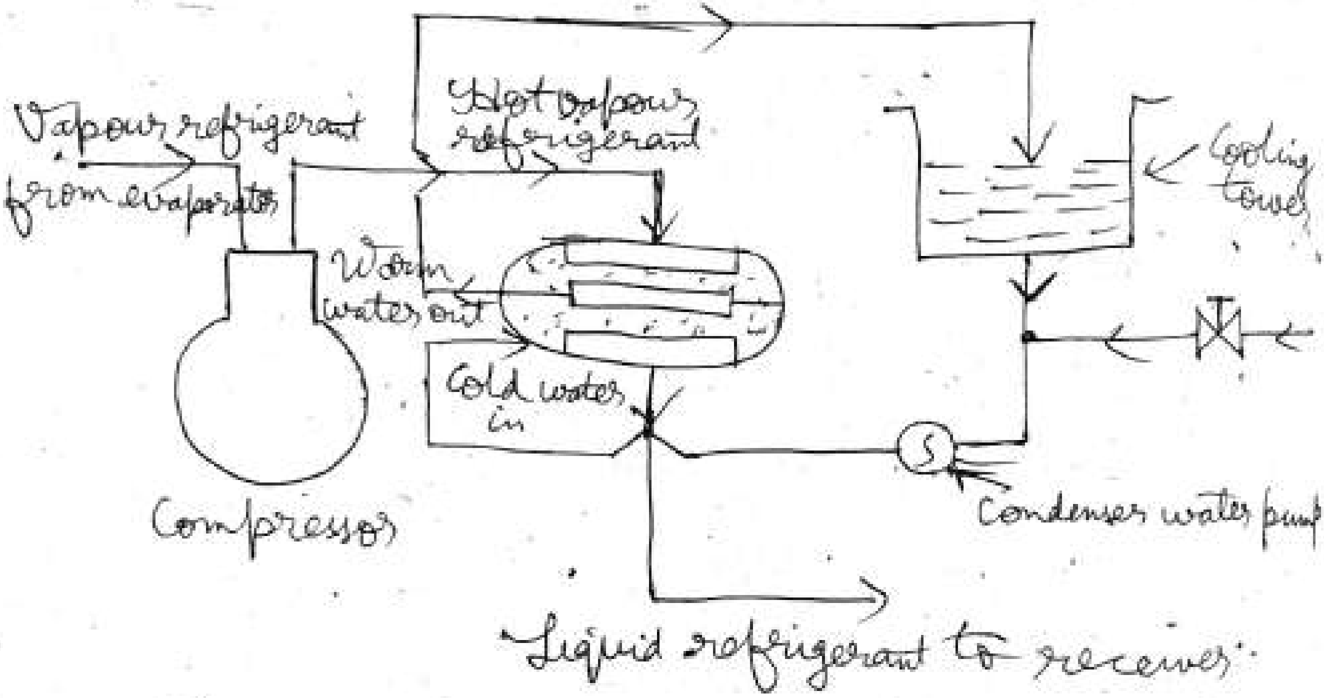
A water cooled condenser is one in which water is used as the condensing medium. These are classified into two types according to the type of water system they use:-

a) Waste water system



⇒ In this system, the water after circulating in the condenser is discharged to a sewer.

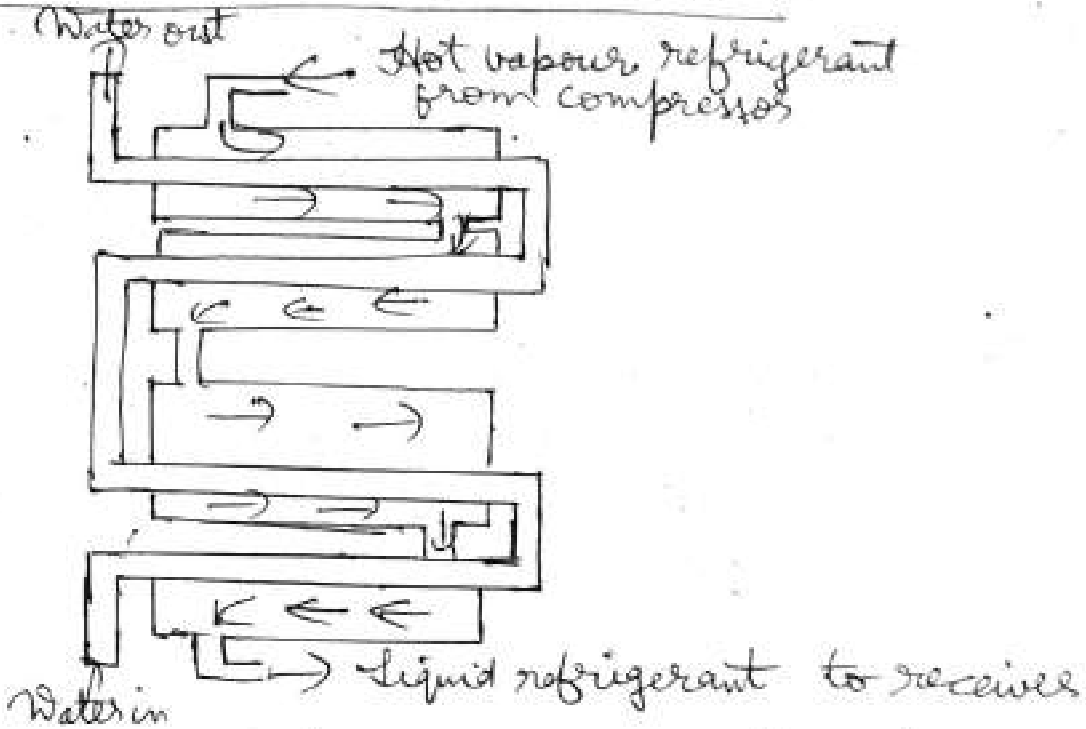
b) Recirculated water system :-



⇒ In this system, the same water is cooled again with a cooling tower or spray pond after getting discharged from the condenser and is used in the cycle again.

According to construction the water cooled condensers are divided into three types :-

a) Tube in tube condenser :-



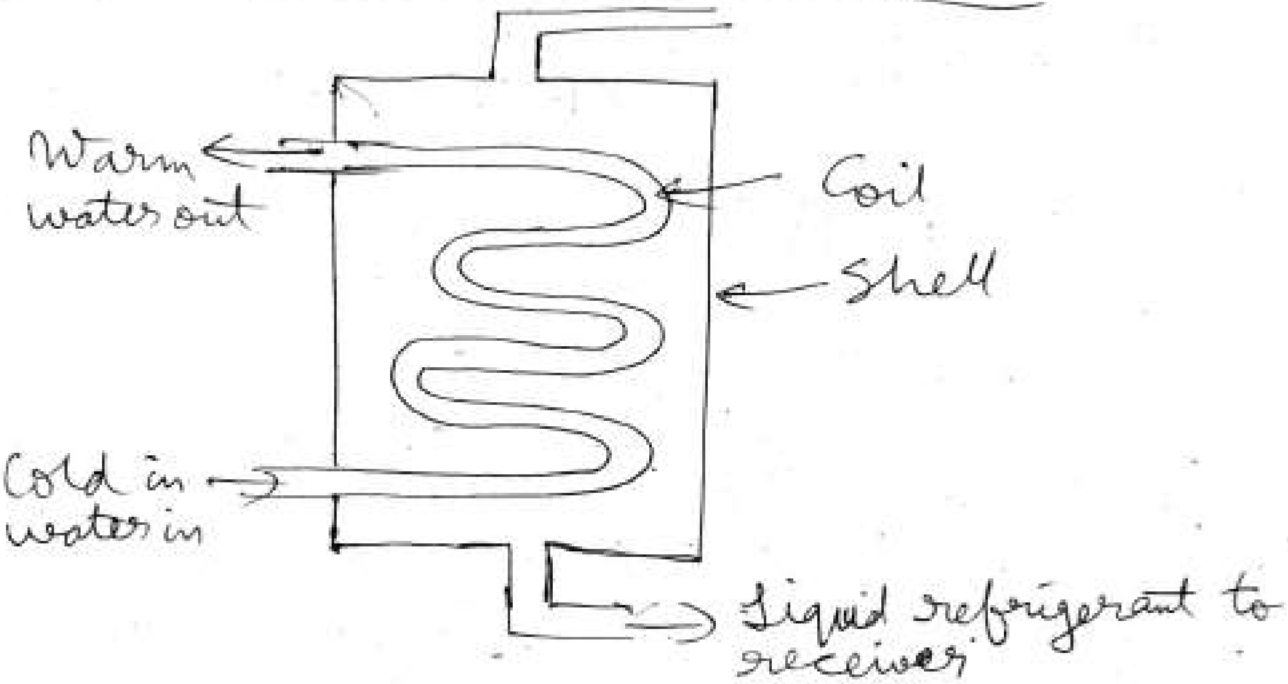
⇒ This consists of a water tube inside a large refrigerant tube. In this type of condenser, the hot vapour refrigerant enters at the top of the condenser. The water absorbs the heat from the refrigerant and the condensed liquid refrigerant flows at the bottom.

⇒ The cold water in the inner tubes may flow in either direction.

⇒ When the water flows in the opposite direction of refrigerant it is said to be <u>counter-flow system</u>.

⇒ When the water flows in the same direction of the refrigerant it is said to be parallel flow system

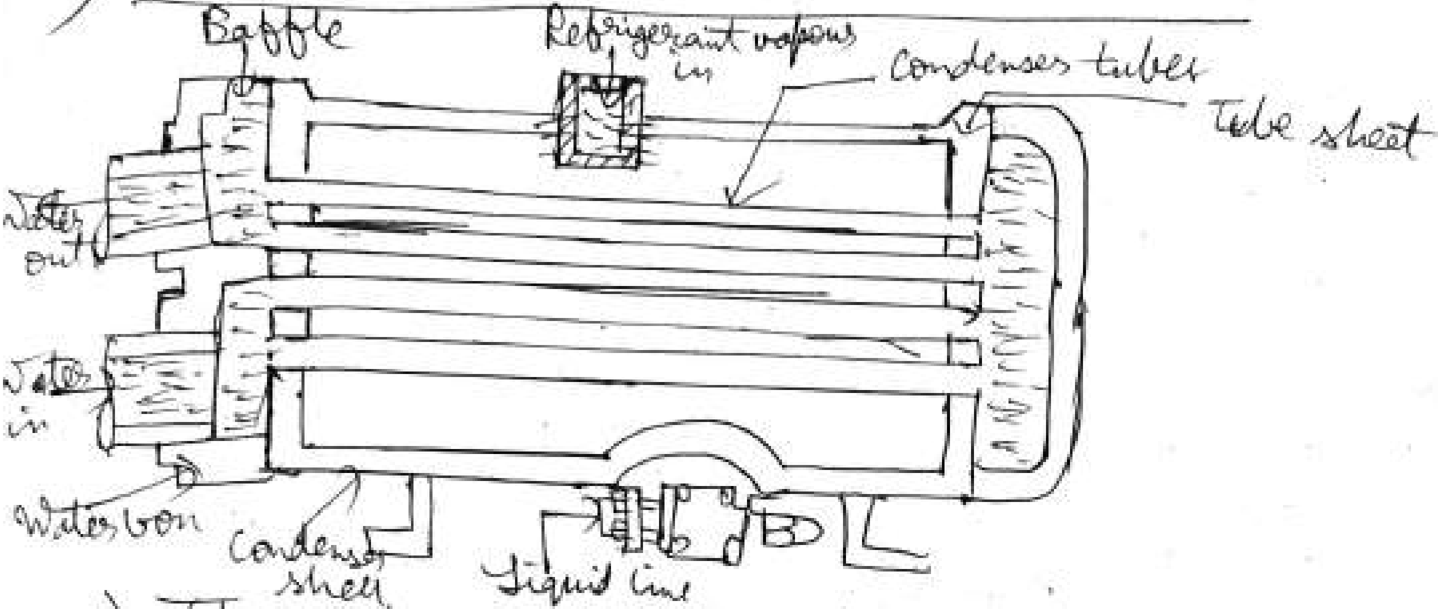
b) Shell and coil condensers:-



⇒ A shell and coil condenser consists of one or more water coils enclosed in a welded steel shell.

⇒ In this type of condenser, the hot vapour refrigerant enters at the top of the shell and surrounds the water coils. As the vapour condenses, it drops to the bottom of the shell which often serves as a receiver.

c) Shell and tube condensers :-



⇒ The shell and tube condenser, consists of a cylindrical steel shell containing a number of straight water tubes .

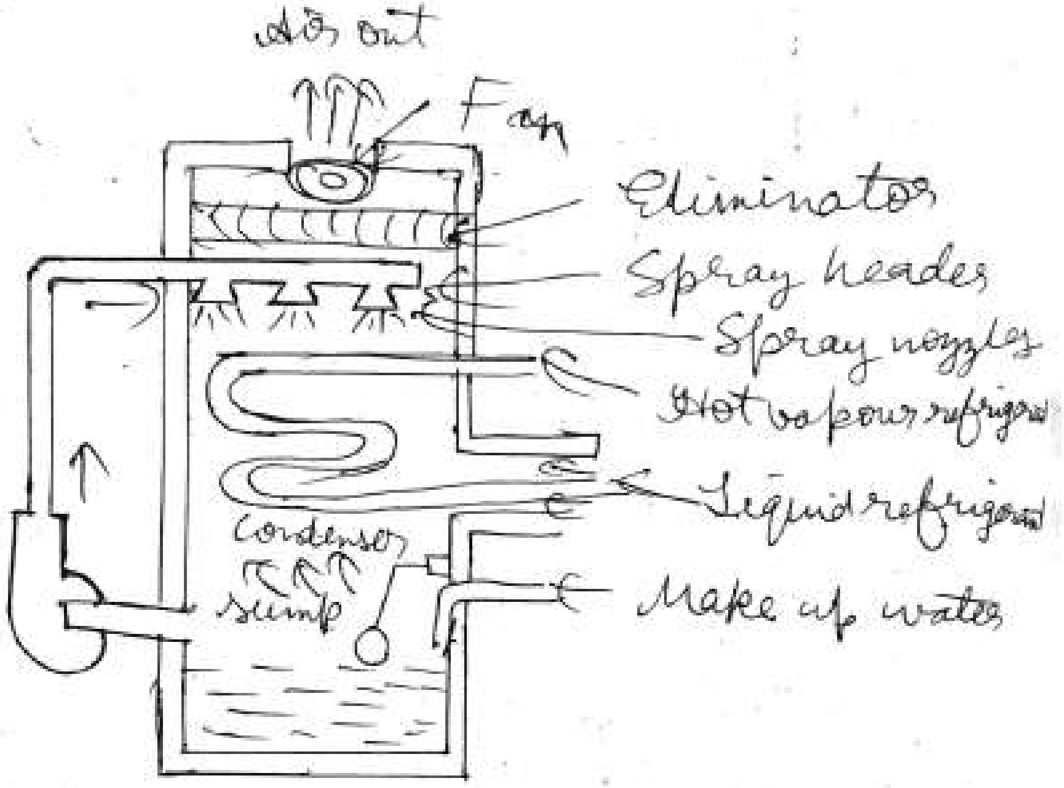
⇒ The tubes are expanded into grooves in the tube sheet holes to form a vapour-tight fit . The tube sheets are welded to the shell at both ends .

⇒ In this type of condenser, the hot vapour refrigerant enters at the top of the shell and condenses as it comes in contact with water tubes .

⇒ The condensed liquid refrigerant

drops to the bottom of the shell which often serves as a receiver.

3) Evaporative condensers



⇒ These condensers perform the combined functions of a water cooled condenser and a cooling tower. They use both air and water as a condensing medium.

⇒ In this operation, the water is pumped from the sump to a spray head and sprayed through nozzles over the condenser coils through which the hot vapour refrigerant from the compressor is passing.

⇒ The heat transfers from the refrigerant through the condensing tube walls and at the same time a fan draws air from the bottom side of the condenser and discharged out at the top.

⇒ The air causes the water from the surface of the condenser coils to evaporate and absorb the latent heat of evaporation from the remaining water to cool it.

Comparision between water cooled and air cooled condensers

Air cooled	Water cooled
(i) Initial cost and maintenance cost is low	(i) Initial and maintenance cost both are high.
(ii) There are no handling problems	(ii) These are difficult to handle.

(iii) They do not require piping arrangement.	(iii) Pipes are required to carry water.
(iv) No problem in disposing	(iv) There are problems in disposing waste water.
(v) No fouling effect takes place	(v) Fouling chances are very high
(vi) Low thermal conductivity	(vi) High thermal conductivity
(vii) These are used for low capacity plants	(vii) These are used for high capacity plants
(viii) Fan noise is present	(viii) There is no fan noise.
(ix) The distribution of air on condenser surface is not uniform	(ix) There is even distribution of water on the condensing surface.
(x) These have high flexibility	(x) These have very low flexibility

Heat Rejection factor

The load on the condenser per unit of refrigeration capacity is known as heat rejection factor.

Load on Condenser (Q_c) = Refrigeration Capacity + Workdone by compressor.

$$Q_C = R_E + W$$

∴ Heat Rejection Factor

$$HRF = \frac{Q_c}{R_E} = \frac{R_E + W}{R_E} = 1 + \frac{W}{R_E}$$

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

Fouling Factor

The water used in water - cooled condensers always contain a certain amount of minerals and other foreign materials depending upon it's source. The minerals form deposits inside the condenser water tubes.

This is called water fouling.

Cooling Tower

A cooling tower is an enclosed tower-like structure through which atmospheric air circulates to cool large quantities of warm water by direct contact.

Spray Ponds

A spray pond consists of a piping and spray nozzle arrangement suspended over an outdoor open reservoir or pond. It can also cool large quantities of warm water.

Types of cooling towers

1) Natural draft cooling tower

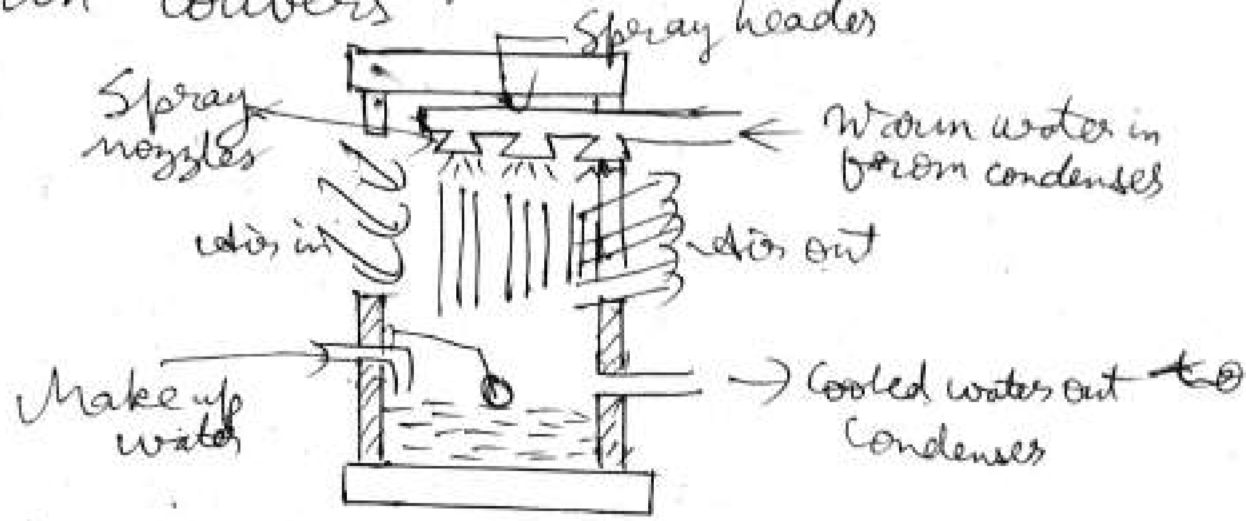
⇒ In this the air circulates through the tower by natural convection

⇒ These are divided into two types:-

(i) Spray type :-

⇒ The spray type cooling tower

consists of a box shaped structure with louvers.



⇒ 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.

⇒ It should be located in an open space or on the roof of a building where the air can blow freely through them.

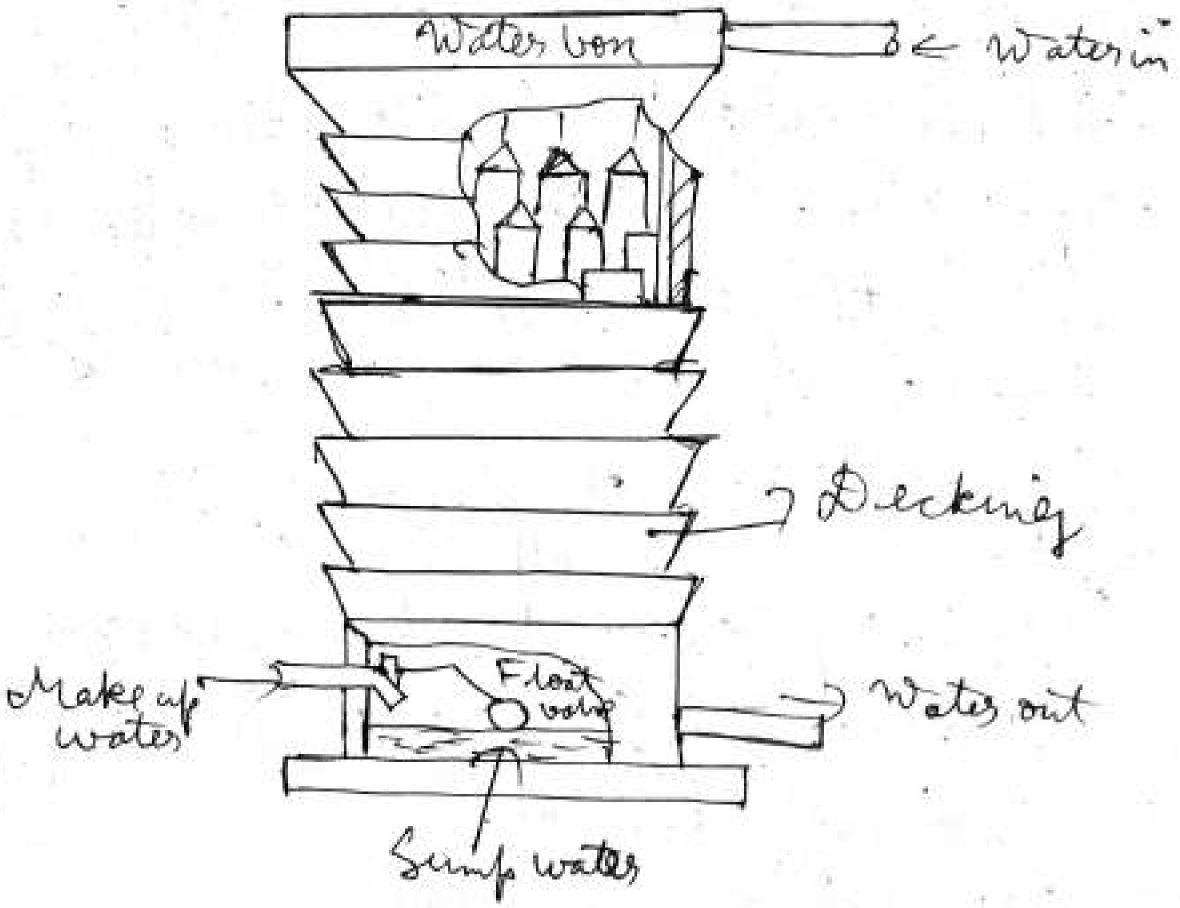
(ii) Splash deck type :-

⇒ The splash deck type cooling tower is similar to spray type cooling tower.

⇒ The water splashes on the decking from the holes in the bottom of a water box on the top of a tower.

⇒ The object of decking is to increase the rate of heat transfer by exposing a large amount of wetted surface to the air.

⇒ The decking also helps to break up the water into small droplets and slows down the fall of water to the bottom of tower.



2) Mechanical draft cooling tower:-

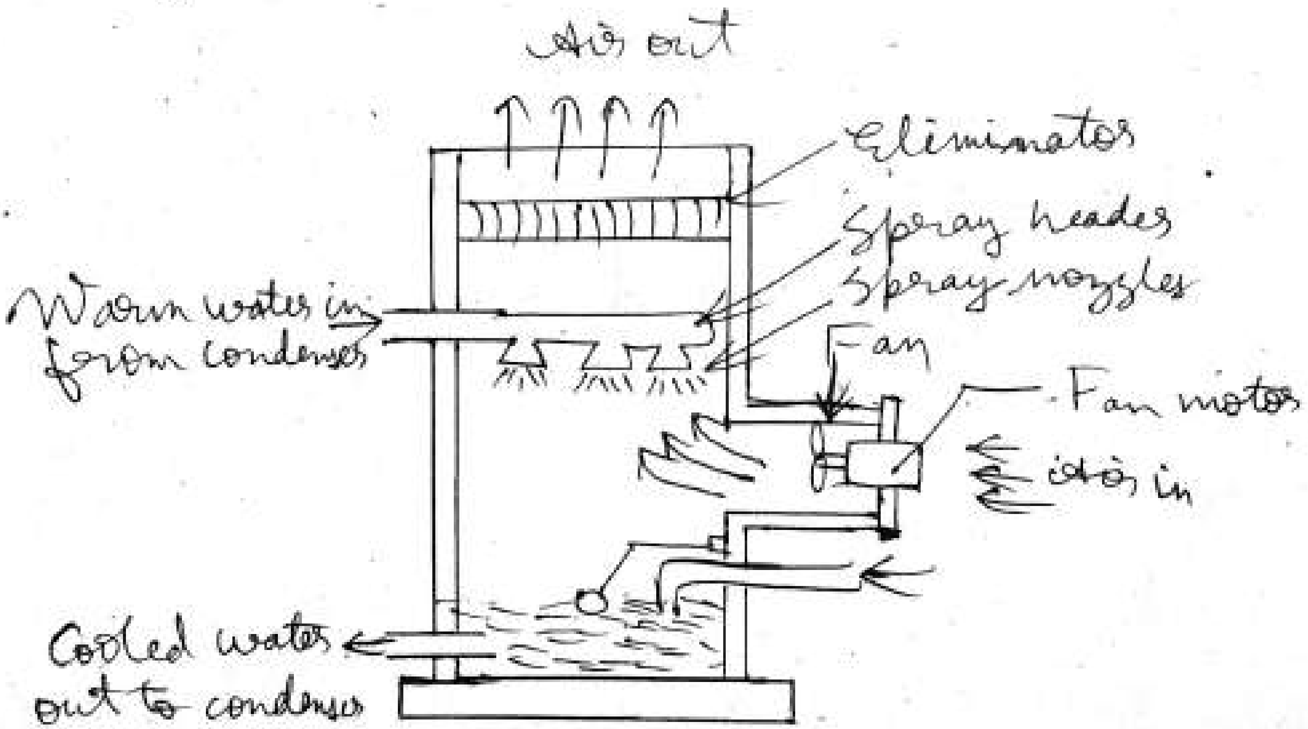
⇒ The mechanical draft cooling towers are similar to atmospheric natural draft cooling towers except the fans are used to force the air through them.

⇒ These are divided into two types:-

(i) Forced Draft:-

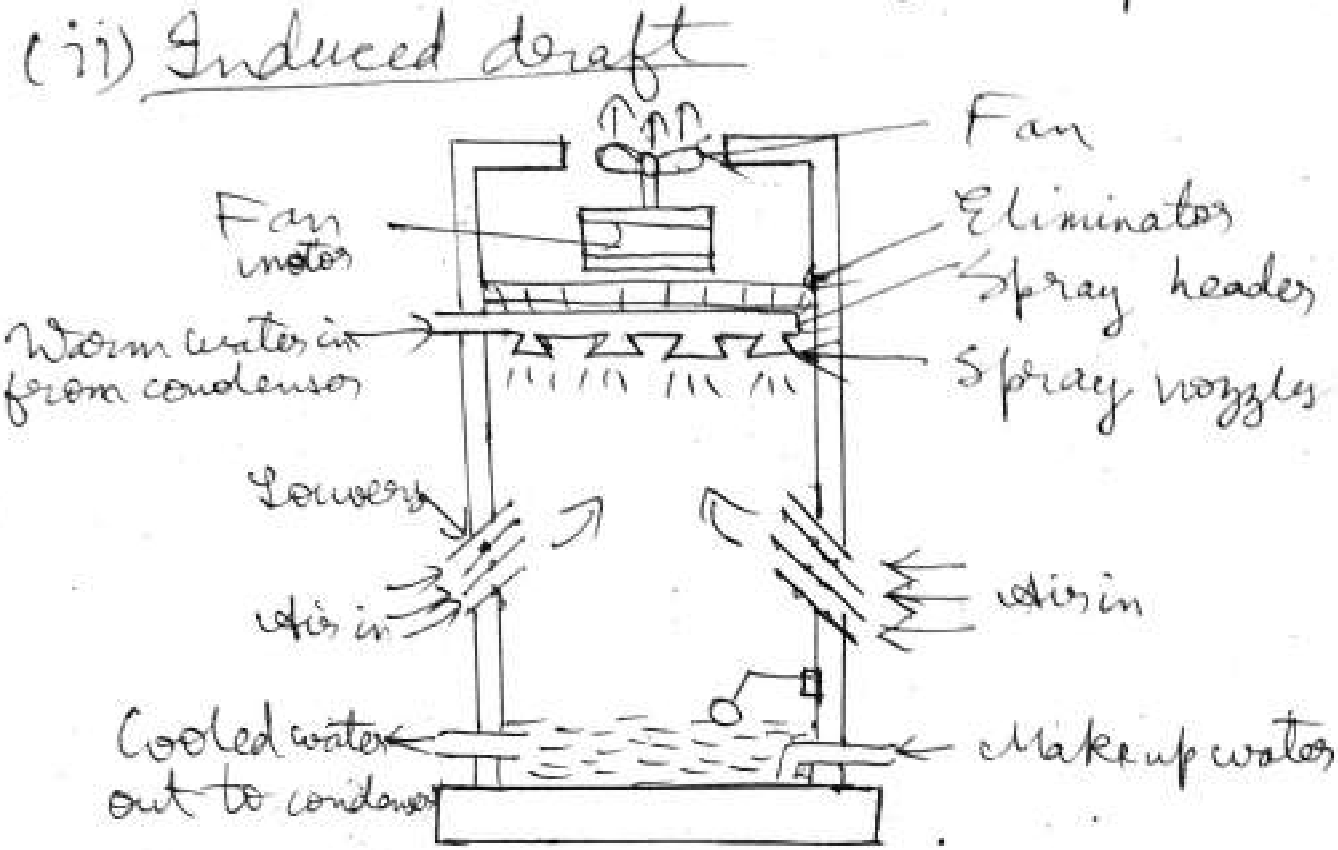
⇒ In the forced draft cooling tower, a fan forces the air through the spray nozzles.

⇒ The air is forced through the help of a propeller fan near the bottom of the tower.



⇒ The condenser warm water is cooled by means of evaporation.

(ii) Induced draft



⇒ The induced draft cooling tower uses a fan to suck the air

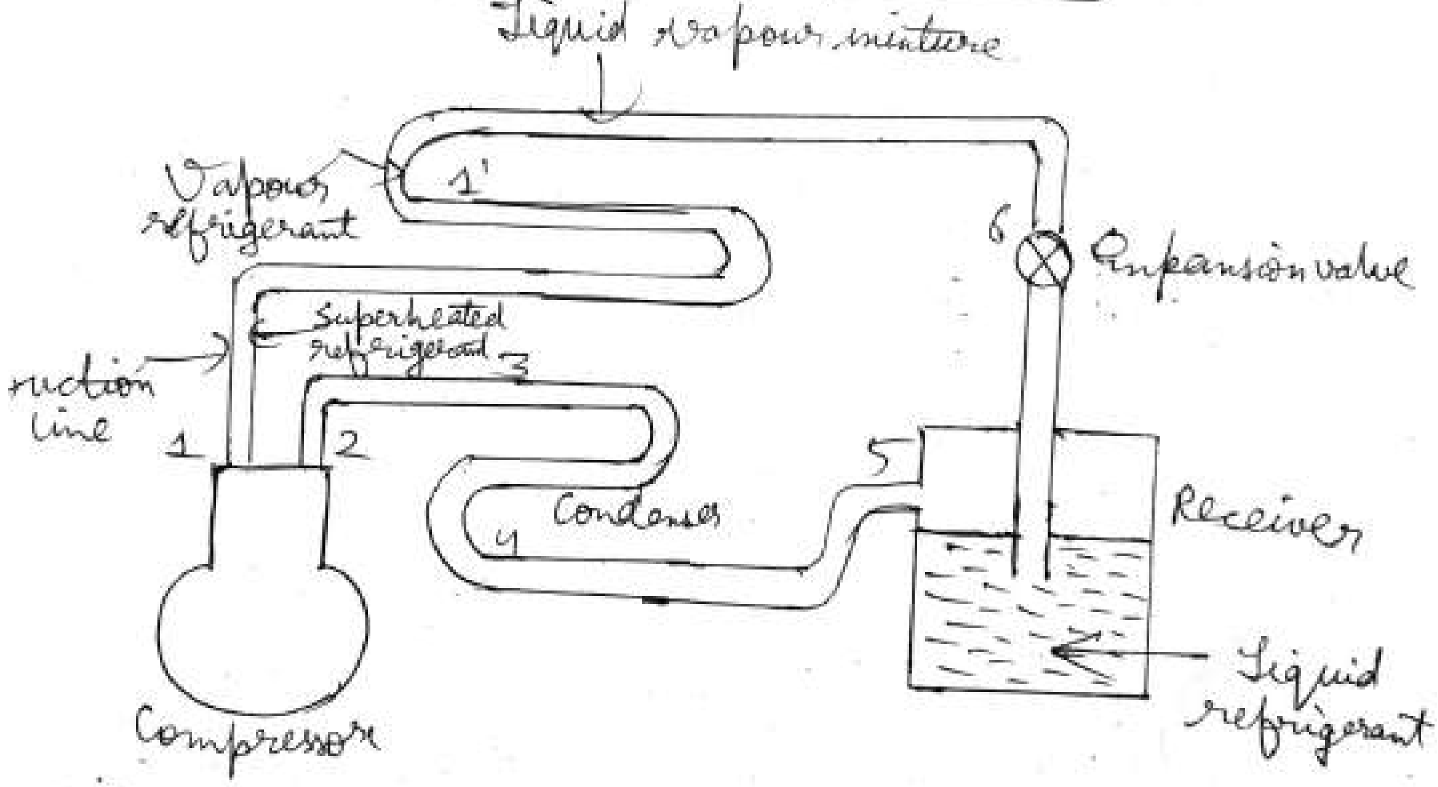
⇒ These are similar to forced draft cooling towers except that the fans are located at the top instead of at the bottom and draw the air upward through the tower.

Evaporators

⇒ The evaporator is an important device used in the low pressure side of a refrigeration system.

⇒ The refrigerant boils in it by extracting heat from the surrounding medium.

Working of an Evaporator



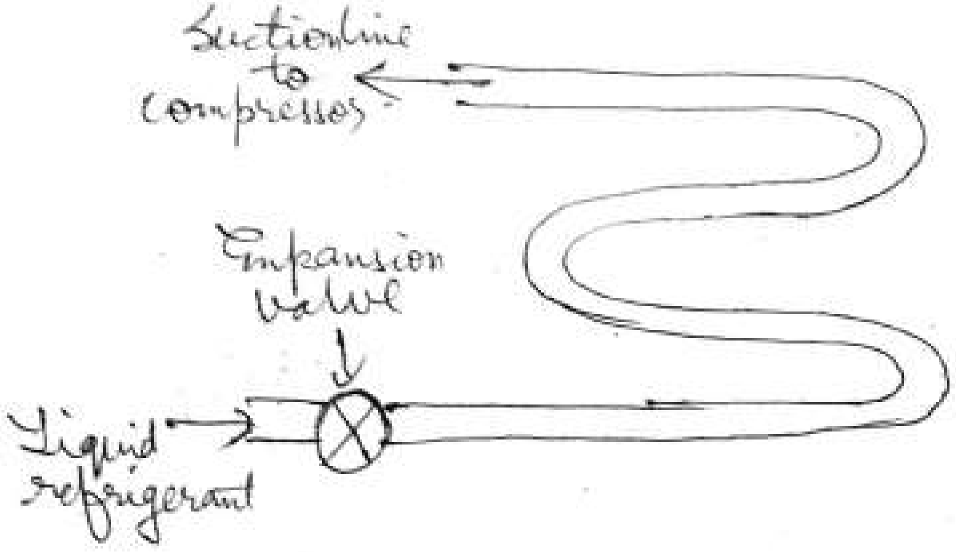
⇒ The liquid refrigerant from the expansion valve enters into the evaporator coil at a temperature below the temperature of evaporator.

⇒ It extracts heat from evaporator and produce coldness.

⇒ The products placed in evaporator or fluids flowing through the evaporator coil are cooled.

Classification of Evaporators

1) Bare tube Coil Evaporator



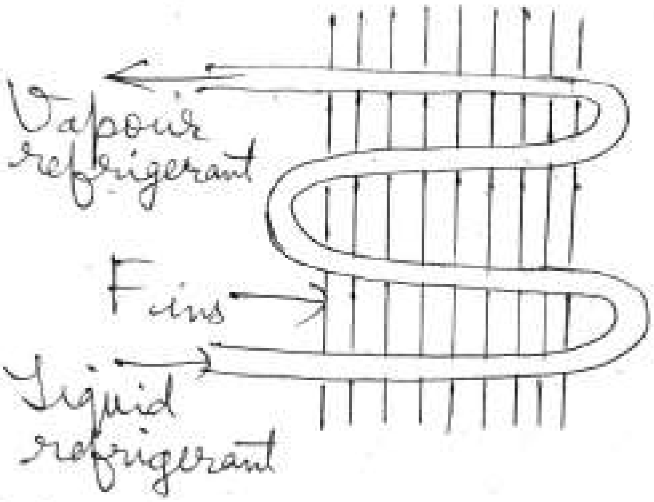
⇒ The bare tube coil evaporators are also known as prime-surface evaporators.

⇒ It has a very simple construction hence it is easy to clean and defrost.

⇒ It offers relatively little surface contact area which can be increased by extending the length of the tube.

⇒ These are limited to applications where the low temperatures are under 0°C.

2) Finned Evaporators



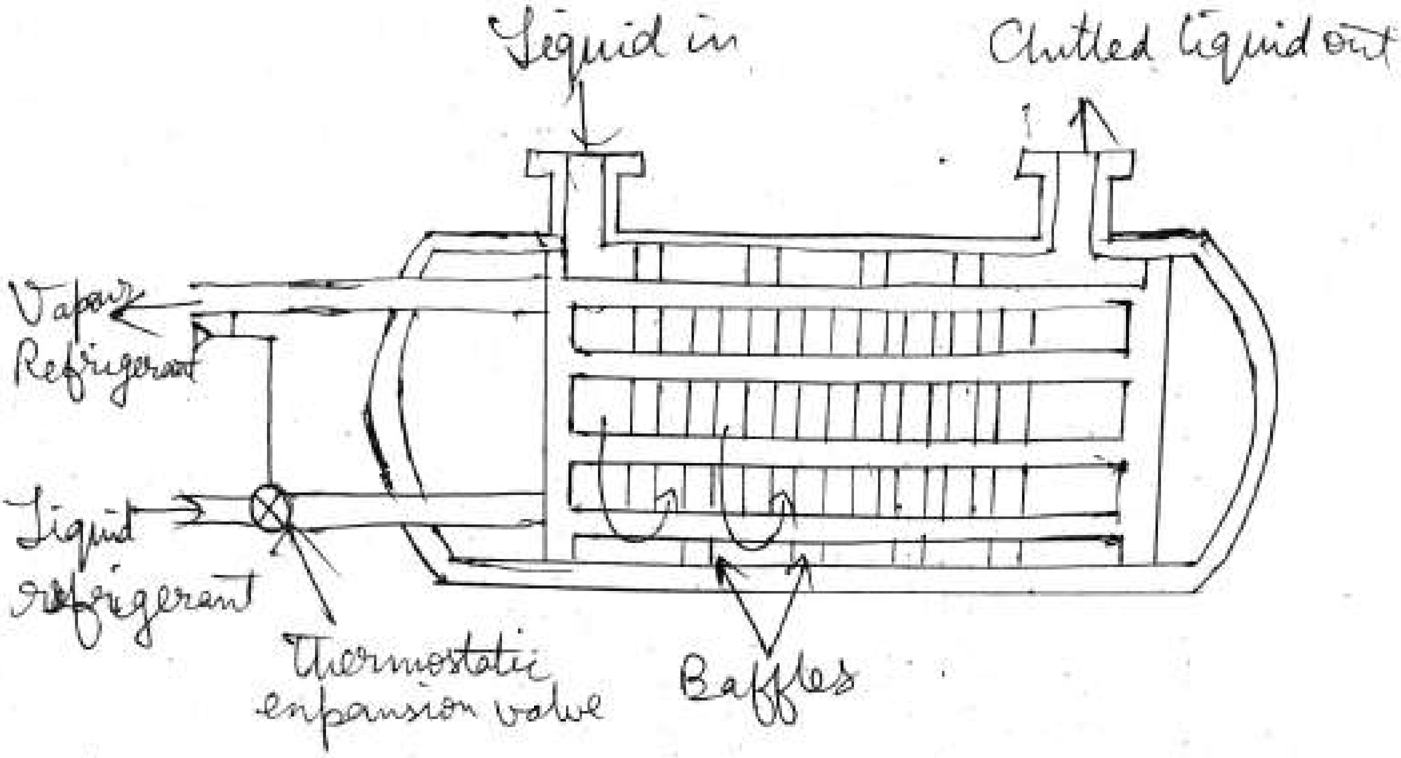
⇒ It consists of bare tubes or coils over which the metal plates or fins are fastened.

⇒ The metal fins are constructed of thin sheets of metal having good thermal conductivity.

⇒ Since the fins increase the contact surfaces for heat transfer, therefore the finned evaporators are also called extended surface evaporators.

⇒ These are designed for applications where the temperature is above 0°C.

3) Shell and tube Evaporators



- ⇒ These are similar to shell and tube condensers.
- ⇒ These consists of a number of horizontal tubes enclosed in a cylindrical shell. The inlet and outlet headers with perforated metal tube sheets are connected at each end of the tubes.
- ⇒ These evaporators are generally used to chill water or brine solutions.

Chapter-5

Refrigerant Flow Controls, Refrigerants and Application of Refrigerants

Expansion Valves:-

⇒ The expansion device is an important device that divides the high pressure side and the low pressure side of a refrigerating system.

⇒ It is found between the condenser and the evaporator.

Function:-

The expansion device has the following functions:-

⇒ It reduces the pressure of the refrigerant from high to low before being fed to the evaporator.

⇒ It controls the flow of refrigerant according to load on evaporator.

⇒ It maintains the desired pressure difference between the high and low pressure sides of the system.

Types of Expansion Devices

(i) Capillary Tube

⇒ The capillary tube is as an expansion device in small capacity hermetic sealed refrigeration units.

⇒ It is a copper tube of small internal diameter and of varying length dependending upon the application.

⇒ The inside diameter of the tube used in refrigeration work is generally about 0.5 mm to 2.25 mm and the length varies from 0.5 m to 5 m.

⇒ A small filter drier is used on some systems to provide additional freeze-up application.

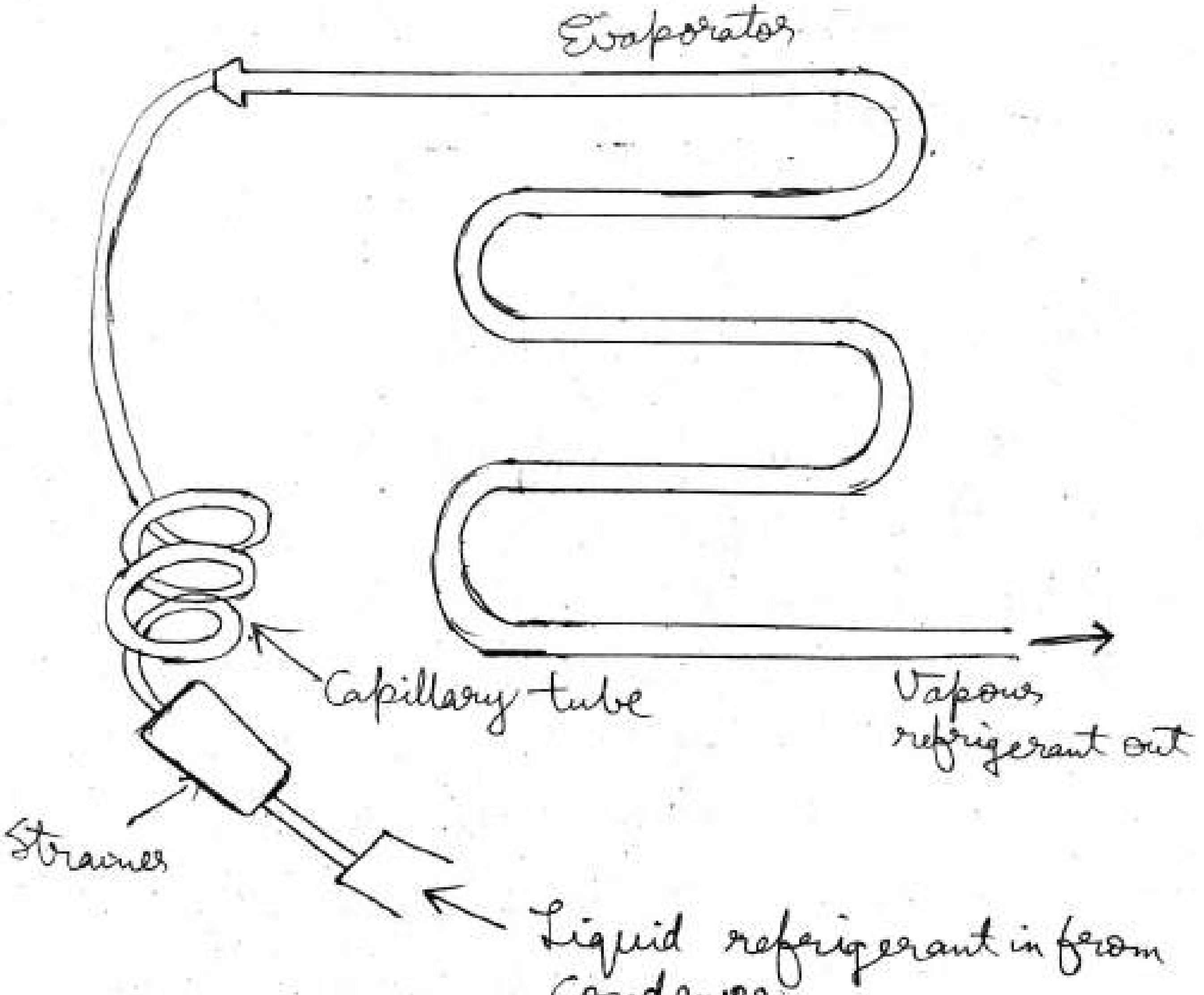
⇒ The refrigeration system using capillary tube the following advantages.

1) It's cost is less than other

expansion devices.

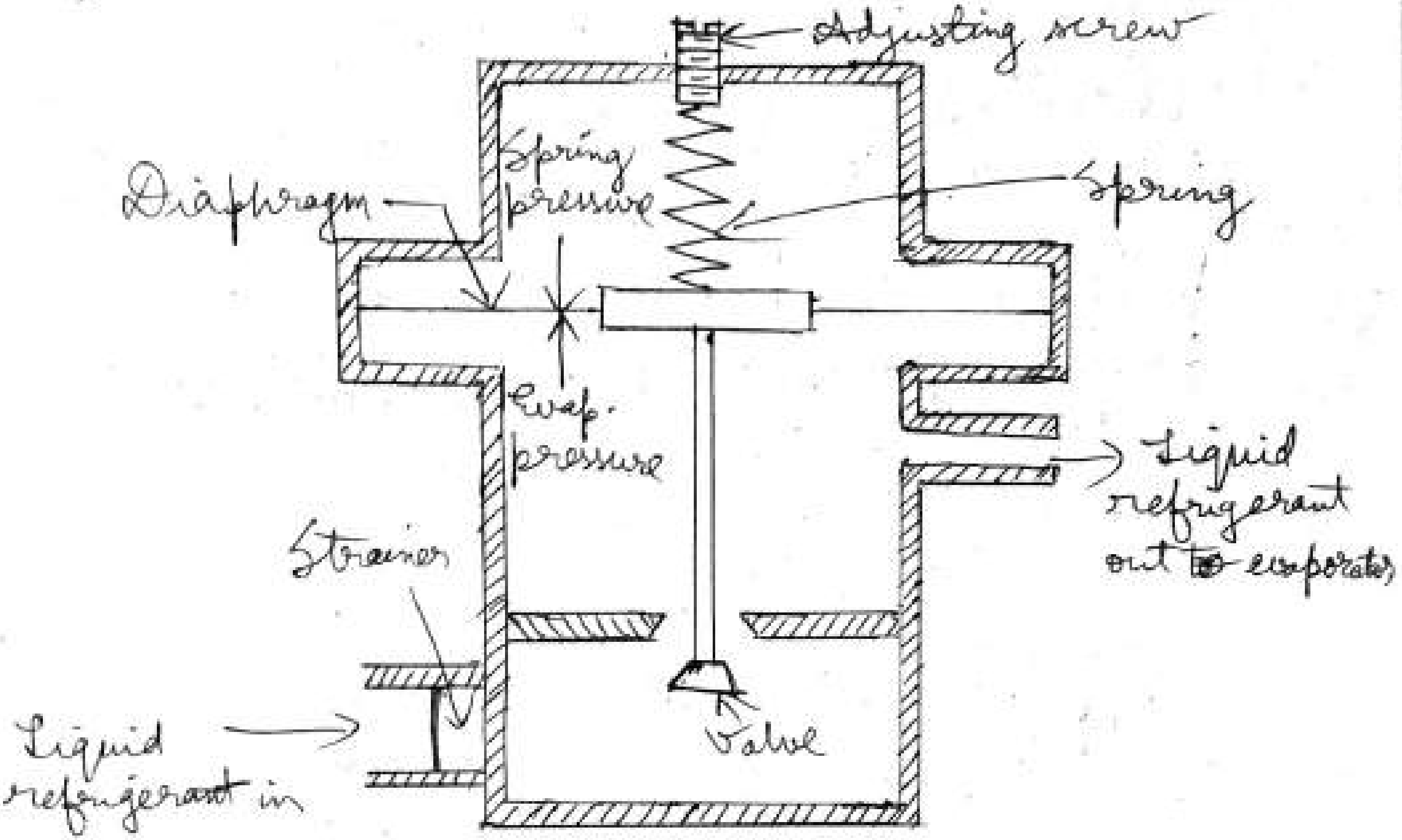
2) The refrigerant charge is critical, therefore no receiver is necessary.

3) The refrigerant continues to flow into the evaporator and equalises the pressure even after the compressor stops therefore the load on the compressor is reduced.



Capillary tube

(ii) Automatic Expansion Valve



=) The automatic expansion valve is also known as constant pressure expansion valvebecause it maintains constant evaporator pressure regardless of the load on the evaporator.

=) The automatic expansion valve, consists of a needle valve and a seat, a metallic diaphragm or bellows, spring and an adjusting screw.

=) The opening and closing of the valve with respect to the seat depends upon two opposing forces acting on the diaphragm:

1) The spring pressure and atmospheric pressure on top of the diaphragm
2) The evaporator pressure acting below the diaphragm.

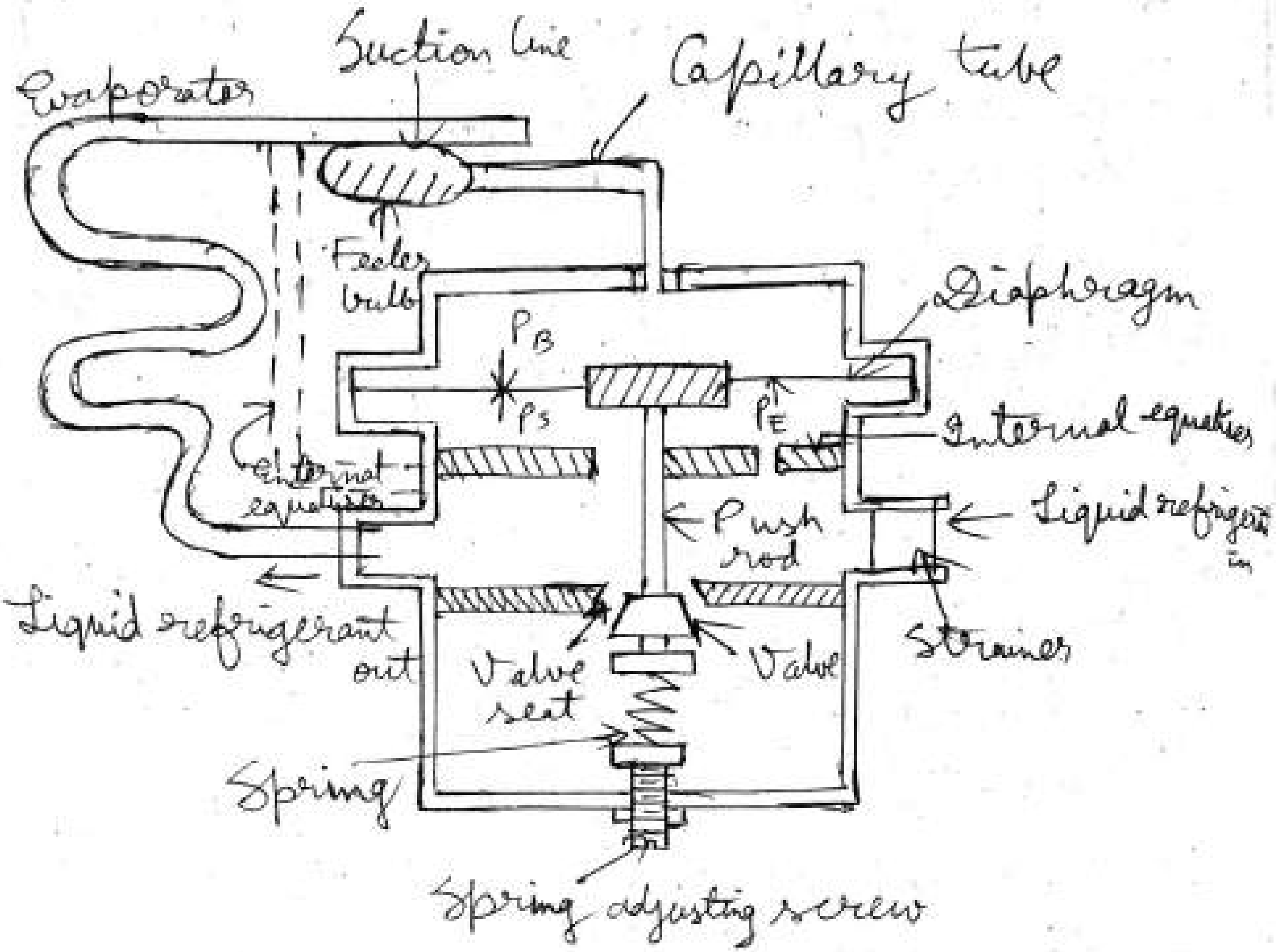
⇒ When the compressor is running, the valve maintains an evaporator pressure in equilibrium with the spring pressure and the atmospheric pressure.

⇒ Any increase in evaporator pressure ($p_e > p_s$) pushes the diaphragm up, causing the valve to move in closing direction and admit less refrigerant.

⇒ Any decrease in evaporator pressure ($p_e < p_s$) results in the movement of diaphragm downwards, so that the valve opens more and admits more refrigerant.

⇒ At correct spring setting ($p_s = p_e$), the amount of fluid flowing through the valve exactly balances the compressor pumping capacity at designed suction pressure.

(iii) Thermostatic expansion valve



⇒ The thermostatic expansion valve, consists of a needle valve and a seat, a metallic diaghragm, spring and an adjusting screw.

⇒ In addition to ~~this~~, it has a feeler or thermal bulb which is mounted on the suction line near the outlet of the evaporator coil. It is partially filled with the same liquid refrigerant as used in the refrigeration system.

⇒ Any change in temperature of the refrigerant will cause a change in pressure in the feeler bulb which will be communicated to the top of diaphragm.

⇒ The evaporator pressure and spring force act beneath the diaphragm in closing direction of the valve whereas pressure exerted by power fluid above the diaphragm acts in the opening direction

⇒ Any increase in heat load or decrease in refrigerant will increase the superheat and the pressure on the top of the diaphragm, moving it to open the valve to a closed position.

⇒ Under normal operating conditions the valve achieves a balanced condition ($P_b = P_s + P_e$) where the refrigerant flow balances the heat load.

⇒ Thermostatic expansion valve is most suitable for comparatively high evaporator temperature operation and is the mostly used form of expansion device in air conditioning and refrigeration systems.

⇒ The thermostatic expansion valve serves the following functions:-

(i) To reduce the pressure of the liquid refrigerant from the condenser pressure to evaporator pressure - throttling action.

(ii) To allow the ~~flow~~ flow of liquid refrigerant to the evaporator according to load requirements of the evaporator so as to prevent the starving of evaporator or flooding the compressor.

Refrigerants

The refrigerant is a heat carrying medium which during their cycle in the refrigeration system absorbs heat from a low temperature system and discards the heat so absorbed to a higher temperature system.

Classification of Refrigerants

The refrigerants are mainly classified into two groups:-

1) Primary refrigerants.
2) Secondary refrigerants.

⇒ The refrigerants which directly take part in the refrigeration system are called primary refrigerants.

⇒ The refrigerants which are first cooled by primary refrigerants and then used for cooling purposes are known as secondary refrigerants.

The primary refrigerants are further classified into four groups:-

(i) Halo-carbon or organic

⇒ This group contains refrigerants having one or more of three halogens (chlorine, fluorine, bromine)

=) These are all synthetically produced and are available in the market under trade names of Freon, Genetron, Isotron and Aretron.

=) Few enamples of Halo-carbons are R-11, R-12, R-13, R-134a etc

(ii) Azeotrope

⇒ Azeotrope is a stable minture of refrigerants whose vapour and liquid phases retain identical compositions over a wide range of temperatures

⇒ Some common Azeotropes are R-500, R-502, R-503, R-504.

(iii) Inorganic Refrigerants

=) Inorganic compounds were used before the introduction of halo-carbon refrigerants and are the oldest form of refrigerants.

=) They possess encellent properties but are highly tonic and flammable.

⇒ Some examples of Inorganic compounds are R-717 (Ammonia), R-729 (Air), R-744 (CO_2), R-764 - etc

(iv) <u>Hydro-Carbons</u>

⇒ Hydrocarbon refrigerants are used in low temperature applications and are made from carbon and hydrogen.

⇒ They are highly flammable and explosive but possess satisfactory thermodynamic properties.

⇒ Their use are limited to chemical and refining industries only.

⇒ Some examples of hydro-carbons are R-170 (Ethane), R-290 (Propane), R-600 (Butane), R-600a (Isobutane), R-1120 - etc.

Secondary Refrigerants

⇒ Water and Brines are widely used as secondary refrigerants.

Water

⇒ Water is used as a refrigerant where the temperature is to be maintained above the freezing point of water i.e 0°c

⇒ The water is first cooled by a primary refrigerant and is then allowed to be circulated through the tubes by means of a pump.

Brine

⇒ These are used as a secondary refrigerant where the temperature to be maintained is below the freezing point of water such as in an ice plant.

⇒ It is a solution of salt in water because addition of salt in water reduces the freezing temperature of ~~water~~ solution than that of water.

⇒ Ex:- $NaCl$, $CaCl_2$ - etc.

Desirable properties of an Ideal Refrigerant

1) Low boiling and freezing point
2) High critical pressure and temperature.
3) High latent heat of vaporisation.
4) Low specific heat of liquid and high specific heat of vapour.
5) Low specific volume of vapour.
6) High thermal conductivity.
7) Non-corrosive to metal
8) Non-flammable and non-explosive.
9) Non-toxic
10) Low cost.
11) Easily and regularly available
12) Easy to liquify at moderate pressure and temperature.
13) Easy of locating leaks by odour or suitable indicator.
14) Mixes well with oil.
15) High co-efficient of performance
16) Ozone friendly.

Designation of Refrigerant

⇒ The refrigerants are internationally desegned as 'R' followed by certain numbers.

⇒ A refrigerant followed by a two digit number indicates that a refrigerant is derived from methane base while three-digit number represents ethane base.

⇒ The first digit on the right is the number of fluorine (F) atoms, second digit is hydrogen (H) atoms + 1, and the third digit is number of carbon (C) atoms − 1.

⇒ When the number of carbon atoms is zero it is omitted.

⇒ The general chemical formula for the refrigerant, either for methane or ethane base is given by $\boxed{C_mH_nCl_pF_q}$ in which $\boxed{n+p+q=2m+2}$

where m = No of carbon atoms
n = No of hydrogen atoms
p = No of chlorine atoms
q = No of fluorine atoms.

⇒ The number of refrigerant is given by $\boxed{R(m-1)(n+1)q}$.

1) Dichloro-difluoro-methane

No of chlorine atoms, $p = 2$

No of fluorine atoms, $q = 2$

No hydrogen atoms, $n = 0$

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

$\Rightarrow 0 + 2 + 2 = 2m + 2$

$\Rightarrow m = 1$

No of Carbon atoms = 1

Chemical Formula = CCl_2F_2

No of Refrigerant = $R(m-1)(n+1)q$

$\Rightarrow R(1-1)(0+1)2$

$\Rightarrow R\text{-}12$

2) Dichloro-tetrafluoro ethane

$p = 2, q = 4, n = 0$

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

$0 + 2 + 4 = 2m + 2$

$\Rightarrow m = 2$

Chemical formula = $C_2Cl_2F_4$

No of refrigerant = $R(2-1)(0+1)4$

$= R\text{-}114$

3) Dichloro-trifluoro-ethane

$p = 2, q = 3, n = 1$

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

$1 + 2 + 3 = 2m + 2$

$\Rightarrow m = 2$

Chemical formula $= C_2HCl_2F_3$

No of refrigerant $= R(2-1)(1+1)3$

$\Rightarrow$ R-123

4) R-22

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

$\Rightarrow m - 1 = 0$

$\Rightarrow m = 1$

$n + 1 = 2$

$\Rightarrow n = 1$

$p = 2$

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

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

$\Rightarrow q = 1$

Therefore chemical formula

$= CHClF_2$ (Monochloro difluoromethane)

5) R-114

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

$m-1=1$

$\Rightarrow m=2$

$n+1=1$

$\Rightarrow n=0$

$p=4$

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

$\Rightarrow (0+4+q)=2\times2+2$

$\Rightarrow q=2$

Therefore, $C_2Cl_2F_4$

Dichloro-tetrafluoro-ethane

Thermodynamic Properties of Refrigerants

1) Boiling temperature :-

⇒ The boiling temperature of the refrigerant at atmospheric pressure should be low.

⇒ If the boiling temperature of refrigerant is high at atmospheric pressure, the compressor should operate at high vaccum.

⇒ The high boiling temperature reduces the capacity and operating cost of system.

2) Freezing temperature :-

⇒ The freezing temperature of a refrigerant should be well below the operating evaporator temperature

⇒ It is below -35° C in most of the refrigerants.

3) Evaporator and condenser pressure:-

⇒ Both the pressures should be positive and be as near to the atmospheric pressure as possible in order to prevent leakage of air and moisture into the refrigerating system.

⇒ Too high evaporating and condensing pressures would require stronger refrigerating equipment resulting in higher initial cost.

4) Critical temperature and pressure:-

⇒ The critical temperature of a refrigerant is the highest temperature at which it can be condensed to a liquid regardless of a higher pressure.

⇒ It should be above the highest condensing temperature that might be encountered or else excessive power consumption results.

5) <u>Co-efficient of performance and power requirements</u>

⇒ For a ideal refrigerant operating between −15°C evaporator temperature and 30°C condenser temperature, the theoretical co-efficient of performance for the reversed Carnot cycle is 5·74.

⇒ Practically, all common refrigerants have approximately the same co-efficient of performance and power requirement.

6) <u>Latent heat of vaporisation</u>

⇒ A refrigerant should have a high latent heat of vaporisation at the evaporator temperature.

⇒ 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.

7) Specific Volume

⇒ The specific volume of the refrigerant vapour at evaporator temperature indicates the theoretical displacement of the compressor.

⇒ The reciprocating compressors are used with refrigerants having high pressures and low volumes of suction vapour.

⇒ The centrifugal compressors are used with refrigerants having low pressures and high volumes of suction vapour.

⇒ The rotary compressors are used with refrigerants having intermediate pressures and volumes of the suction vapour.

Chemical properties of Refrigerants

1) Flammability :-

⇒ It is the ability of a refrigerant to catch fire with ease.

⇒ Hydro-carbon refrigerants are highly flammable and Ammonia becomes explosive when mixed with air in the ratio of 16 to 25 %.

⇒ The halo-carbon refrigerants are neither flammable nor explosive.

2) Toxicity :-

⇒ Toxicity is the property of a refrigerant to be poisonous or harmful towards atmosphere.

⇒ It may be of primary or secondary importance depending on the application

⇒ Some non-toxic refrigerants becomes toxic when mixed with certain percentage of air.

3) Solubility of water

⇒ Refrigerant should be soluble in water at right amount or else ice may form which chokes the expansion valve.

⇒ This may be avoided by proper dehydration of the refrigerating unit before charging

4) Miscibility

⇒ The ability of a refrigerant to mix with oil is called miscibility.

⇒ The freon group of refrigerants are highly miscible while inorganic refrigerants are non-miscible.

⇒ The non-miscible refrigerants require larger heat transfer surfaces due to poor heat conduction properties of oil.

5) Effect on perishable materials

=) 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.

=) Freon group of refrigerants have no effect upon dairy products, meats, vegetables and furs.

=) Methyl chloride vapours have no effect upon furs, flowers, eating foods or drinking beverages.

=) Ammonia dissolves easily in water and becomes alkaline in nature therefore it reacts with products that are acidic in nature.

Commonly used Refrigerants

1) R-11 (Trichloro-monofluore methane)(CCl_3F)

=) It is a synthetic chemical powder which can be used as a refrigerant.

=) It is stable, non-flammable and non-tonic and is a low pressure refrigerant.

=) It has a low side pressure of 0.202 bar at -15°C and high side pressure of 1.2606 bar at 30°C

=) The latent heat is 195 KJ/kg at -15°C and the boiling point is 23.77°C at Atmospheric pressure.

=) It is used for large centrifugal compressors of 200TR and above.

2) R-12 (Dichloro difluoro methane) (CCl_2F_2)

=) It is a colourless, odourless, non-tonic, non-corrosive, non-irritating and non-flammable refrigerant.

=) It has a boiling point of -29°C at atmospheric pressure.

=) It has a pressure of 0.82 bar at 15°C and a pressure of 6.4 bar at

30°C.

⇒ It has a latent heat of 159 KJ/kg at 15°C.

⇒ It is used in refrigerators, freezers, water coolers, room and window air-conditioning units etc.

3) R-22 (Monochloro-difluoro-methane) ($CHClF_2$)

⇒ It is a synthetic refrigerant used for fast freezing units which maintain a temperature of -29°C to -40°C.

⇒ It's boiling point is -41°C at atmospheric pressure and has a latent heat of 216.5 KJ/kg at -15°C.

⇒ The normal head pressure of R-22 at 30°C is 10.88 bar and the evaporator pressure is 1.92 bar at -15°C

⇒ The refrigerant is stable and is non-toxic, non-corrosive, non-irritating and non-flammable.

⇒ It is used in reciprocating and centrifugal compressors and has also been successfully used in air-conditioning units in household refrigerators.

4) R - 134a (Tetrafluoro ethane) (CF_3CH_2F)

⇒ It is considered as the most preferred substitute for refrigerant R-12.

⇒ It has a boiling point of -26.15°C.

⇒ It has no chlorine atom therefore this refrigerant has zero ozone depleting potential (ODP) and has 74% less global warming potential compared to R-12.

⇒ Since the molecules of R-134a are smaller therefore a very sensitive leak detector is used to detect leaks.

⇒ It is now-a-days widely used in car-air-conditioners.

5) R - 717 (Ammonia) (NH_3)

⇒ It is one of the oldest and most widely used of all refrigerants.

⇒ It is a colourless gas and is toxic, flammable and explosive in nature.

⇒ It's boiling point is -33.3°C and melting point is -78°C.

⇒ It's latent heat of vaporisation is at −15°C which is 1315 KJ/kg.

⇒ The condenser pressure for R-717 is 10.78 bar at 30°C.

⇒ The condensers for R-717 are usually of water cooled type.

⇒ It's greatest application is found in large and commercial reciprocating compression systems where high toxicity is secondary.

Substitute for CFC

⇒ The Chloro Fluoro carbon (CFC) refrigerants have been linked to the depletion of ozone layer and have a global warming effect.

⇒ Due to this reason certain substitutes are being looked for to replace CFCs.

⇒ Two of the chemical classes under consideration for replacing CFCs are hydrochlorofluorocarbons (HCFCs). and hydro-fluoro-carbons (HFCs).

=) HCFCs contributi to ozone depletion but to a much lesser extent than CFCs.

=) Therefore HFCs have lowest ozone depletion potential in addition to less global warming potential.

=) At present the following substitutes are available :-

1) R-123 (CF_3CHCl_2) for R-11 (CCl_3F)
2) R-134a (CF_3CH_2F) and R-152a (CH_3CHF_2) for R-12.
3) R-143a (CH_3CF_3) and R-125 (CHF_2CF_3) for R-502.
4) R-290 (C_3H_8) and R-600a (C_4H_{10}) as an additional substitute for R-12.

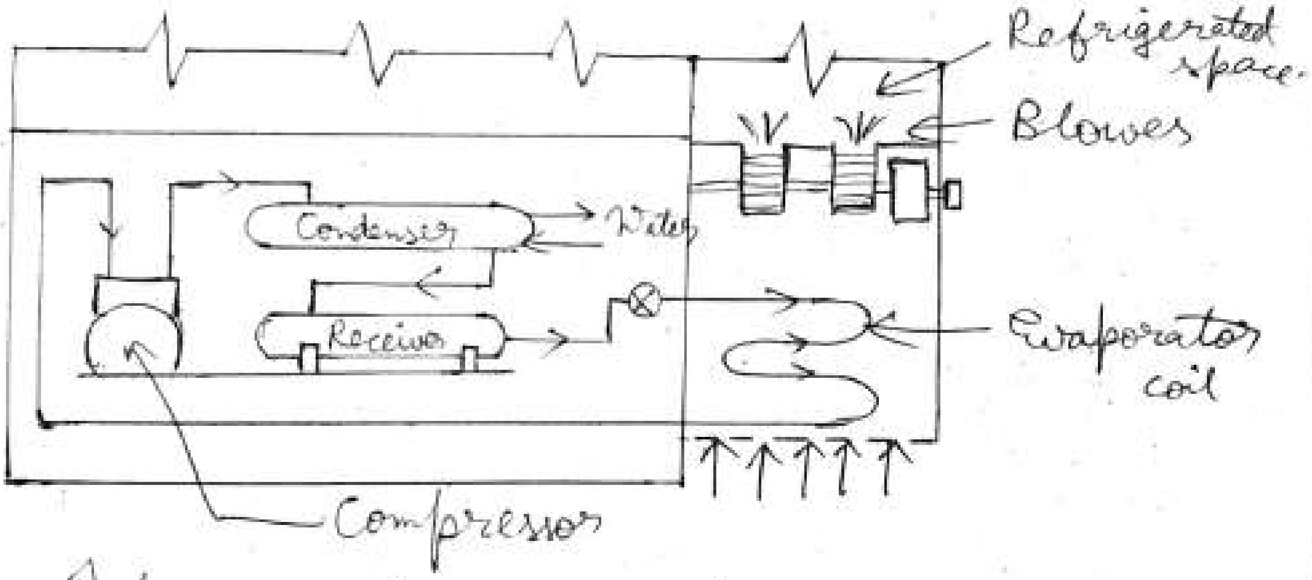
Applications of Refrigeration

Certain applications of refrigeration are:-

(i) Cold Storage

⇒ It is a space designed to store perishable food stuff within well defined temperature and humidity.

⇒ It is used to preserve fish, meat, fruits, vegetables and medicines.



⇒ It works on vapour compression system.

⇒ It prevents the spoilage of perishable commodities and make them available in all the seasons and in places where they are not harvested.

(ii) Dairy refrigeration

⇒ Milk and dairy products are very essential for human nutrition and development and has a very increasing demand worldwide.

⇒ Although it is a highly nourishing food, raw fresh milk is highly liable to rot and can easily spoiled by the growth of micro-organisms.

⇒ Therefore a refrigeration system is used for processing of milk.

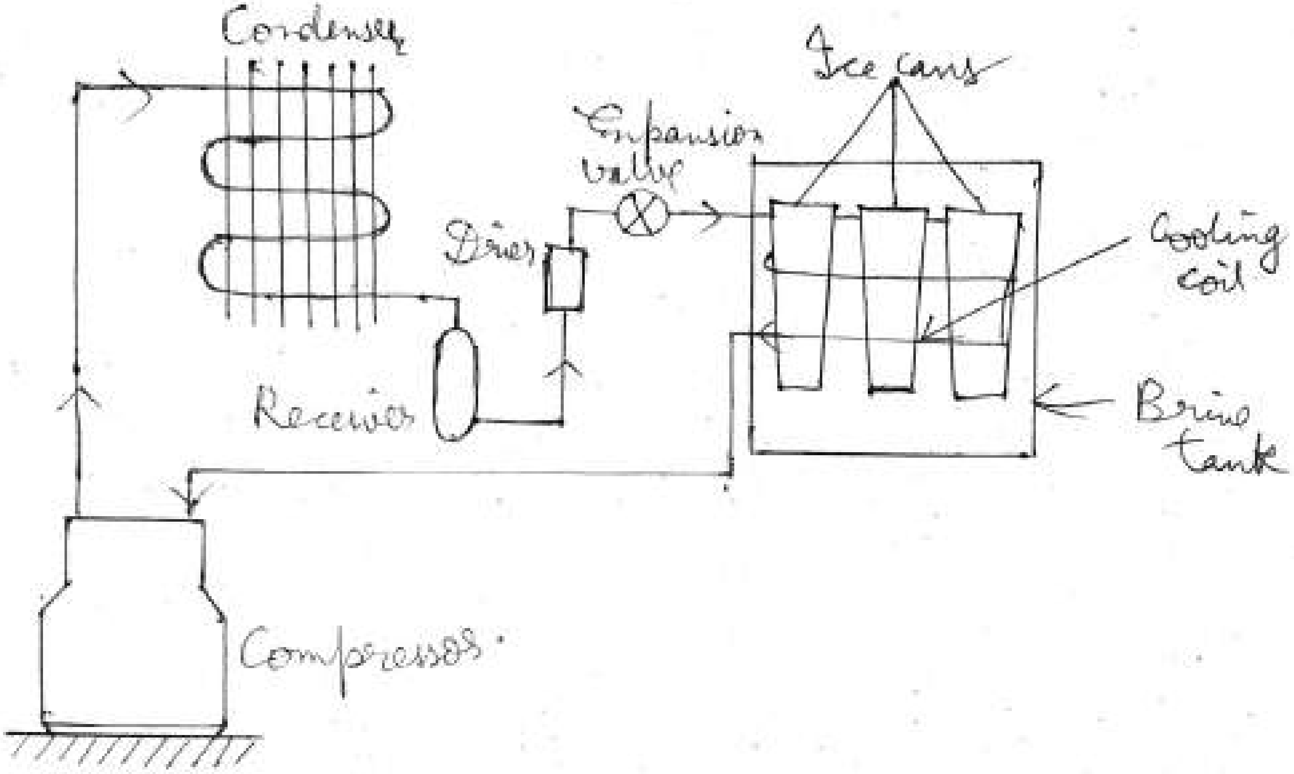
⇒ and to keep it preserved until it is delivered.

(iii) Ice plant

⇒ Ice is produced artificially from clean water by chilling. Ice making plant consists of a vapour compression system with Ammonia as a refrigerant.

⇒ It also uses brine to prevent heat transfer from surrounding to it

⇒ The ice produced through it is widely used to chill cold drinks, or transport dairy products or perishable commodities such as fishes, fruits - etc.



(iv) Water cooler

⇒ The purpose of a water cooler is to make cold water available at a constant temperature irrespective of the ambient temperature

⇒ They are meant to produce cold water at about 7°C to 13°C (≈280 K to 286 K) for quenching the thirst of people.

⇒) Water coolers are classified as
(i) Storage type
(ii) Instantaneous type.

⇒) In a storage type water cooler, a cooling coil is wrapped around the water storage tank and cold water is available in the tank at all times.

⇒) In an instantaneous cooler, cooling coil is wrapped around the pipeline. Water is cooled to the desired temperature by the time it reaches the tank.

(v) Frost Free refrigerator

⇒) A Frost Free refrigerator offers an even distribution of cool air within the refrigerator by means of electric fans.

⇒) Since this technology prevents the formation of ice, no defrosting is necessary.

PSYCHROMETRY AND PROPERTIES

-> In this psychrometry chapter the properties of mixture of air and water vapour are studied.

Dry Air :- The dry air is considered as a mixture of nitrogen and oxygen neglecting the small percentages of other gases.

Moist Air :- It is a mixture of dry air and water vapour.

water vapour -The water vapour present in air is known as moisture.

Dry Bulb Temperature :- The temperature of air measured by ordinary thermometer is known as dry bulb temperature (DBT).

wet Bulb Temperature :-The temperature measured by the thermometer when its bulb is covered with wet cloth and is exposed to a current of moving air is known as wet bulb temperature. The difference between DBT and WBT is known as WBD.

Dew point temperature ;-The temperature of the air is reduced by continuous cooling then the water vapour in the air will start condensing at a particular temperature. The temperature at which the condensing starts is known as dew point temperature. DPT is the steam table saturation temperature corresponding to the partial pressure of water vapour.

specific humidity :- It is the mass of water vapour present per kg of dry air.

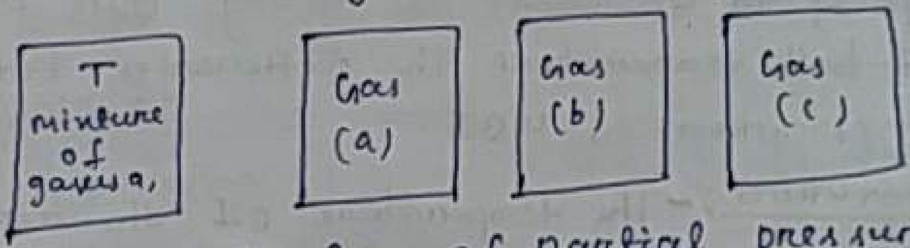
Absolute humidity :-The weight of water vapour present in unit volume of air is known as absolute humidity.

degree of saturation :- The degree of saturation is defined as the ratio of mass of water vapour associated with unit mass of dry air to mass of water vapour associated with unit mass of dry ai saturated at the same temperature.

Relative Humidity :- The relative humidity is defined as the ratio of actual mass of water vapour in a given volume to the mass of water vapour if the air is saturated at the same tempera

* Dalton's Law of partial pressure :-

It states that the total pressure of a mixt of gases is equal to the sum of the partial pressures exerted by each gas.



As per Dalton's law of partial pressure

$$\boxed{P_t = P_a + P_b + P_c}$$

If this law is applied to the moist air which contains dry air and water vapour, then

$$\boxed{P_t = P_a + P_v}$$

P_t = Total pressure of moist air
P_a = partial pressure of dry air
P_v = partial pressure of water vapour.

Specific Humidity :-

It is the mass of water vapour present per kg of dry air.

$$\omega = \frac{\text{mass of water vapour in mixture}}{\text{mass of dry air in mixture}}$$

$$\boxed{\omega = \frac{m_v}{m_a}}$$

$$\boxed{m_a = \frac{P_a V}{R_a T}} \qquad \boxed{m_v = \frac{P_v V}{R_v T}}$$

$$\omega = \frac{\left(\frac{P_v V}{R_v T}\right)}{\left(\frac{P_a V}{R_a T}\right)} = \frac{P_v V}{R_v T} \times \frac{R_a T}{P_a V} = \left(\frac{R_a}{R_v}\right) \times \left(\frac{P_v}{P_a}\right)$$

$$R_a = \frac{K}{M_a} \quad , \quad R_v = \frac{K}{M_v}$$

$$\omega = \left(\frac{K/M_a}{K/M_v}\right) \times \frac{P_v}{P_a}$$

$$= \left(\frac{M_v}{M_a}\right) \times \left(\frac{P_v}{P_a}\right)$$

$$= \left(\frac{18}{29}\right) \times \left(\frac{P_v}{P_a}\right)$$

$$\boxed{\omega = 0.622 \times \left(\frac{P_v}{P_t - P_v}\right)}$$

Relative Humidity :(ϕ) :-

$$\phi = \frac{\text{mass of water vapour in a given volume}}{\text{mass of water vapour in same volume if saturate}}$$

$$= \left(\frac{m_v}{m_{vs}}\right) = \frac{\left(\frac{P_v V}{R_v T}\right)}{\left(\frac{P_{vs} V}{R_v T}\right)} = \left(\frac{P_v}{P_{vs}}\right).$$

$$\boxed{\phi = \frac{P_v}{P_{vs}}}$$

Degree of Saturation : (μ) :-

$$\mu = \frac{\text{mass of water vapour associated with unit mass of dry air}}{\text{mass of water vapour associated with saturated unit mass of dry air.}}$$

$$\boxed{\mu = \frac{\omega}{\omega_s}}$$

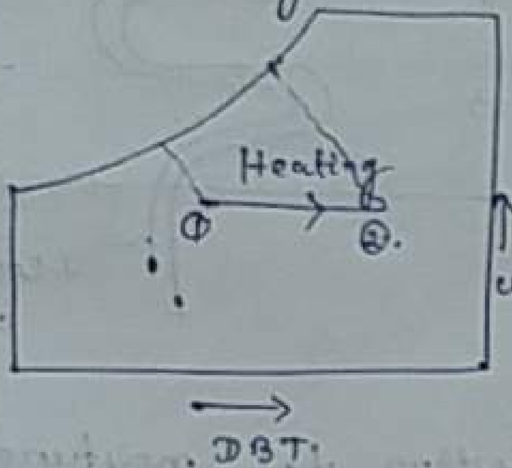
$$\mu = \frac{\cancel{0.622}\left(\frac{P_v}{P_t - P_v}\right)}{\cancel{0.622}\left(\frac{P_{vs}}{P_t - P_{vs}}\right)}$$

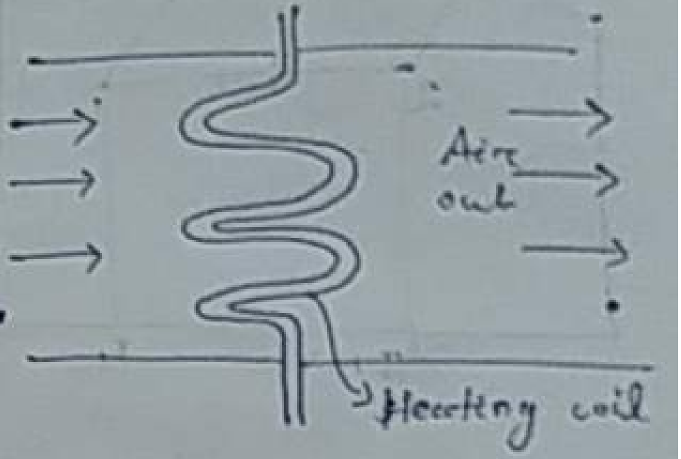
$$\boxed{\mu = \frac{P_v\,(P_t - P_{vs})}{P_{vs}\,(P_t - P_v)}.}$$

PSYCHROMETRIC PROCESS :-

① **Sensible Heating** :- Heating of air without addition of moisture is termed as sensible heating.

→ The heating can be achieved by passing the air over the heating coil.



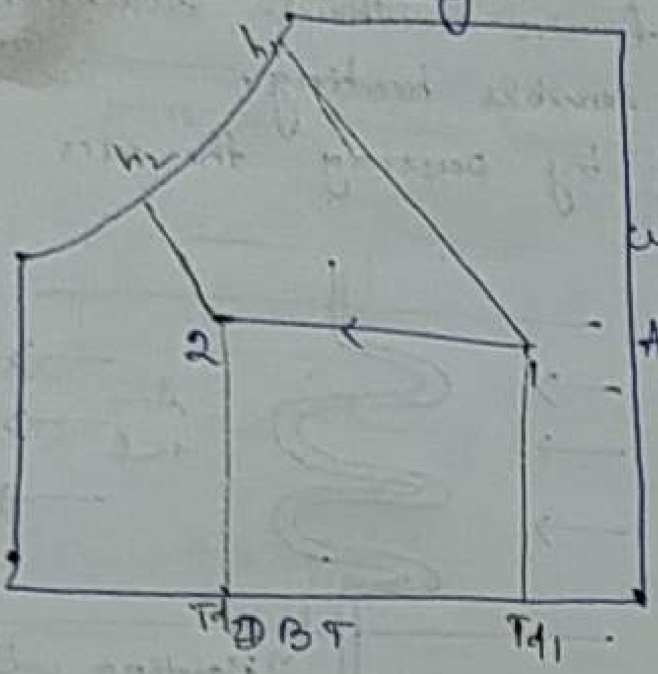


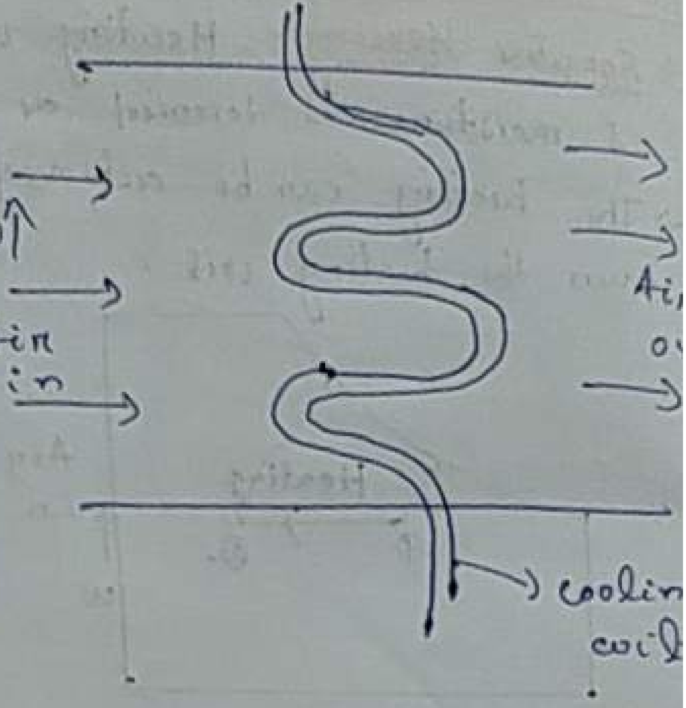
→ In this process the dry bulb Temperature (DBT) increases. specific humidity remains constant.

→ enthalpy value in this process increases and wet bulb temperature increases.

→ Relative humidity value decreases in this process.

Sensible cooling :-





- → Cooling of air without rejecting the moisture from the air is termed as sensible cooling.
- → This process is represented in the psychrometric chart by the line (1-2) from right to left.
- → The heat rejected by air during sensible cooling may be obtained from the psychrometric chart by the enthalpy difference $(h_1 - h_2)$.
- → In this sensible cooling process the specific humidity remains constant.
- → The dry bulb temperature reduces from t_{d_1} to t_d
- → The relative humidity value increases from ϕ_1 to ϕ_2.
- → heat rejected can be calculated by using the following formula.

$$\boxed{q = h_1 - h_2}$$

Scanned By CamNScan

$$q = C_{pa}(T_{d1} - T_{d2}) + W C_{ps}(T_{d1} - T_{d2}).$$

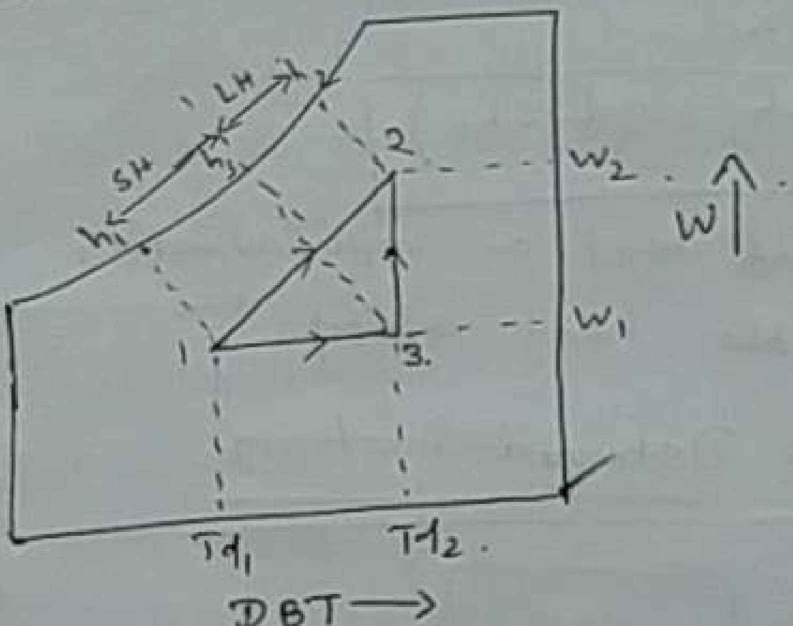
$$= (C_{pa} + W C_{ps})(T_{d1} - T_{d2})$$

$$\boxed{q = C_{pm}(T_{d1} - T_{d2})}$$

C_{pm} is called humid specific heat.

$$\boxed{C_{pm} = 1.022 \text{ KJ/kgK}}$$

Heating and Humidification :-



→ This process is generally used in winter air conditioning to warm and humidify the air.

→ When air is passed through a humidifier having spray water temperature higher than the dry bulb temperature of the entering air, the unsaturated air will reach the condition of saturation and thus the air becomes hot.

→ The process of heating and humidification is shown in (1-2).

→ Air enters at condition 1 and leaves at condition 2.

→ In this process both dry bulb temperature and specific humidity increases.

→ The final relative humidity of the air can be higher or lower than that of the entering air.

Total heat added

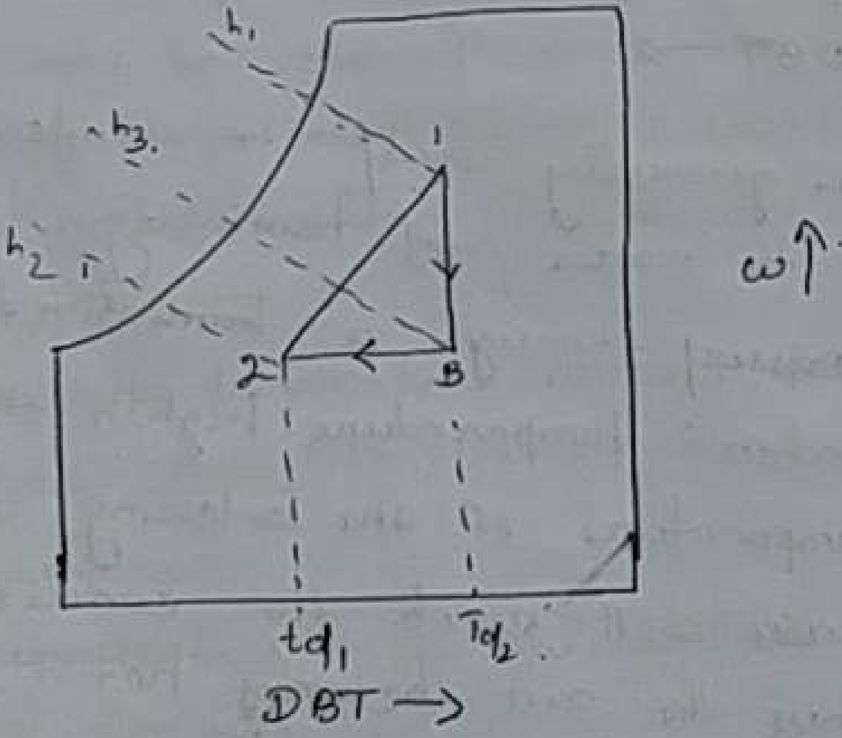
$q = h_2 - h_1$

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

$h_2 - h_3$ = Latent heat of vapourisation

$h_3 - h_1$ = sensible heat added.

Cooling and Dehumidification



→ This process is generally used in summer air conditioning to cool and dehumidify the

→ In this process the dry bulb temperature reduces and specific humidity decreases.

→ The final relative humidity of the air is generally higher than that of the entering air.

→ The dehumidification is possible if the effective surface temperature of the cooling coil is less than that of the dew point temperature of the air entering the coil.

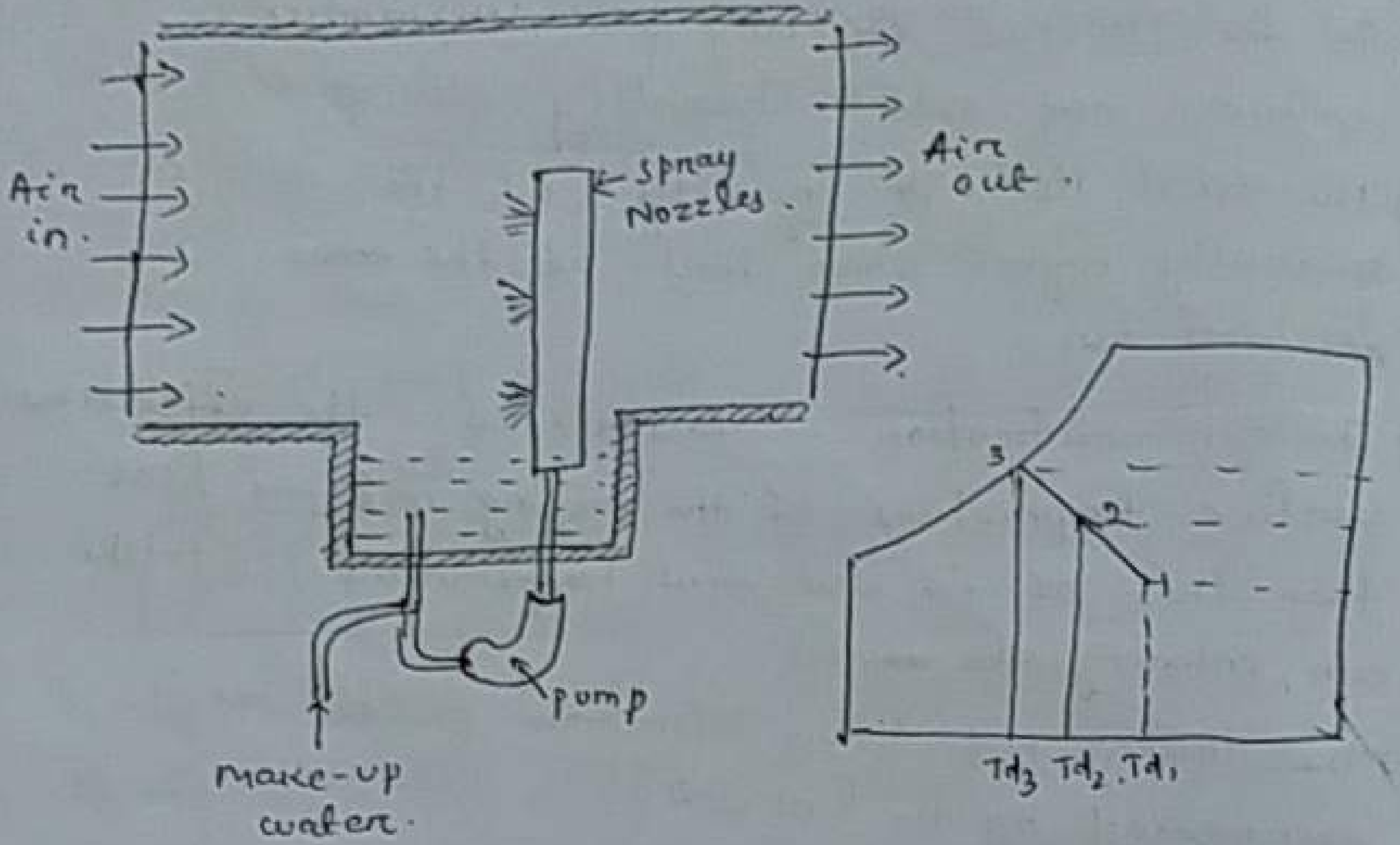
→ The cooling and dehumidification process is represented by the line (1-2).

→ The total removed in the process is given by

$$q = (h_1 - h_2) = (h_1 - h_3) + (h_3 - h_2).$$

$$\boxed{q = (LH) + SH\ .}$$

Cooling with Adiabatic Humidification :-



→ When the air is passed through an insulated chamber, having sprays of water maintained at a temperature (t_1) higher than the dew point temperature of the entering air (t_{dp_1}), but lower than its dry bulb temperature (t_{d_1}) of entering air.

→ The temperature of the spray water is equal to the wet bulb temperature(t_{wp}) of the entering air.

→ In this process air is getting cooled and humidified. Since no heat is supplied or rejected from the spray water, so the adiabatic saturation happens. In this process wet bulb temperature remains constant.

Scanned By CamNScan

→ It is represented by the line (1-3) on the psychrometric chart. Though perfect cooling is not possible always, so the final condition of air is at point '2'.

→ effectiveness of the spray chamber is given by

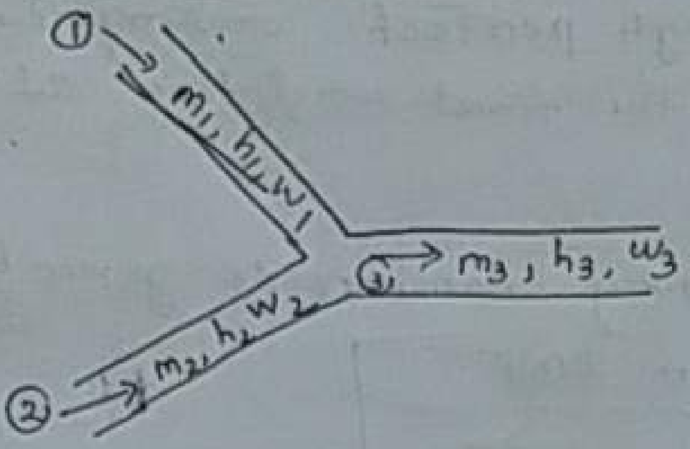
$$\boxed{\eta_H = \frac{\text{Actual drop in DBT}}{\text{ideal drop in DBT}}}$$

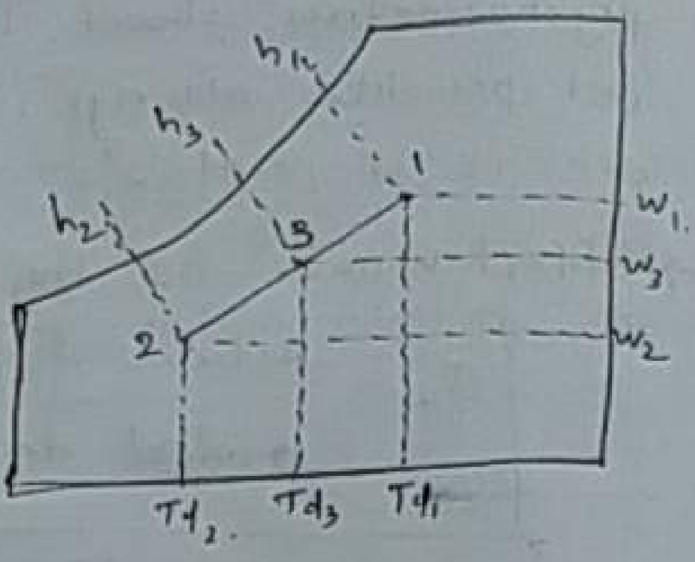
$$\Rightarrow \boxed{\eta_H = \frac{T_{d_1} - T_{d_2}}{T_{d_1} - T_{d_3}}}$$

also it can be represented by the difference between the specific humidity.

$$\boxed{\eta_H = \frac{\omega_1 - \omega_2}{\omega_1 - \omega_3}}$$

Adiabatic Mixing of two Air streams :-





Consider two air streams ① and ② mixing adiabatically as shown in the above figure.

m_1 = mass of air entering at ①

h_1 = enthalpy of air entering at ①

w_1 = specific humidity of air entering at ①.

m_2, h_2, W_2 = mass, enthalpy and specific humidity of air which are entering at point ②.

m_3, h_3, w_3 = mass, enthalpy and specific humidity of air at point ③.

→ For mass balance

$$\boxed{m_1 + m_2 = m_3} \quad \text{——} ①$$

→ For energy balance

$$\boxed{m_1h_1 + m_2h_2 = m_3h_3} \quad \text{——} ②.$$

For mass balance of water vapour

$$\boxed{m_1 W_1 + m_2 W_2 = m_3 W_3} \quad \text{---} ③$$

Now substituting the value of m_3

$$m_1 h_1 + m_2 h_2 = m_3 h_3$$

$$\Rightarrow m_1 h_1 + m_2 h_2 = (m_1 + m_2) h_3$$

$$\Rightarrow m_1 h_1 + m_2 h_2 = m_1 h_3 + m_2 h_3$$

$$\Rightarrow m_1 (h_1 - h_3) = m_2 (h_3 - h_2)$$

$$\Rightarrow \boxed{\frac{m_1}{m_2} = \frac{h_3 - h_2}{h_1 - h_3}}$$

Now substituting the value of m_3 in eq^n ③.

$$m_1 W_1 + m_2 W_2 = m_3 W_3$$

$$\Rightarrow m_1 W_1 + m_2 W_2 = (m_1 + m_2) W_3$$

$$\Rightarrow m_1 W_1 + m_2 W_2 = m_1 W_3 + m_2 W_3$$

$$\Rightarrow m_1 (W_1 - W_3) = m_2 (W_3 - W_2)$$

$$\Rightarrow \boxed{\frac{m_1}{m_2} = \frac{W_3 - W_2}{W_1 - W_3}.}$$

So $\boxed{\frac{m_1}{m_2} = \frac{h_3 - h_2}{h_1 - h_3} = \frac{W_3 - W_2}{W_1 - W_3}}$

Human Comfort -

It is that condition of mind, which expresses satisfaction with the enviornment (cold or hot).

The human body works best at a certain temp.

Effective temperature —

The degree of warmth or cold (temperature) felt by human body depends mainly on the following three factors:

a. Dry bulb temp.

b. Relative humidity

3. Air velocity

→ Effective temperature is defined as that index which corelates the combined effects of dry bulb temp, relative humidity and air velocity on the human body.

→ The value of effective temp. is equal to the temperature of still saturated air (i.e 5 to 8 m/min air velocity)

→ ~~2~~. The practical application of effective temp. is presented by Comfort Chart.

Factors affecting Optimum Effective temperature

① Climatic and seasonal difference:

→ The people living in colder climates feel comfortable at a lower temp. than those having in warmer region

→ In winter season the optimum effective temp. is 19°c and in summer season the optimum effective temp. is 22°C.

② **Clothing :**

→ The person with light clothings need less optimum temperature than a person with heavy clothings.

③ **Age and Sex :**

→ The women of all ages require higher effective temp. (0.5°c) than men.

→ The children also need higher effective temprature than adults.

④ **Duration of Stay -**

→ If the ~~stat~~ stay in a room (i.e in bank) is shorter, then effective temp. is required higher than for long stay (i.e in office)

⑤ **Kind of activity -**

→ When the activity of person is heavy such as the people working in a factory, dancing hall, then low effective temp. is needed than for the people sitting in a cinema hall.

⑥ **Density of Occupants :**

→ The effect of body radiant heat from person to person in ~~adu~~ auditorium is large which require a slight lower effective temperature.

Comfort Chart :

→ A chart which relates effective temp, dry bulb temp, wet bulb temp. and air movement to human comfort

→ In this Chart, the dry bulb temp is taken as abscissa and the wet bulb temperature as ordinates.

→ The study of the chart reveals that the several combinations of wet and dry bulb temperatures with different relative humidities will produce the same effective temperature.

→ The comfort chart shows the range for both summer and winter condition within which a condition of comfort exists for people.

→ For winter condition the comfort chart indicates an effective temp. of 20°C ~~of~~ for 97.7% people and for summer condition the comfort chart indicates an effective temp. of 21.6°C ~~of 98~~ for 98% people.

→ For comfort condition the women requir 0.5°C higher effective temp. than men.

→ The greater the degree of activity, the lower the effective temp. necessary for comfort.

→ The effective temp. is 21°C for still air velocity i.e 6 m/min at 24°C dry bulb temp. and 16°C wet bulb temp. condition.

CHAPTER -7

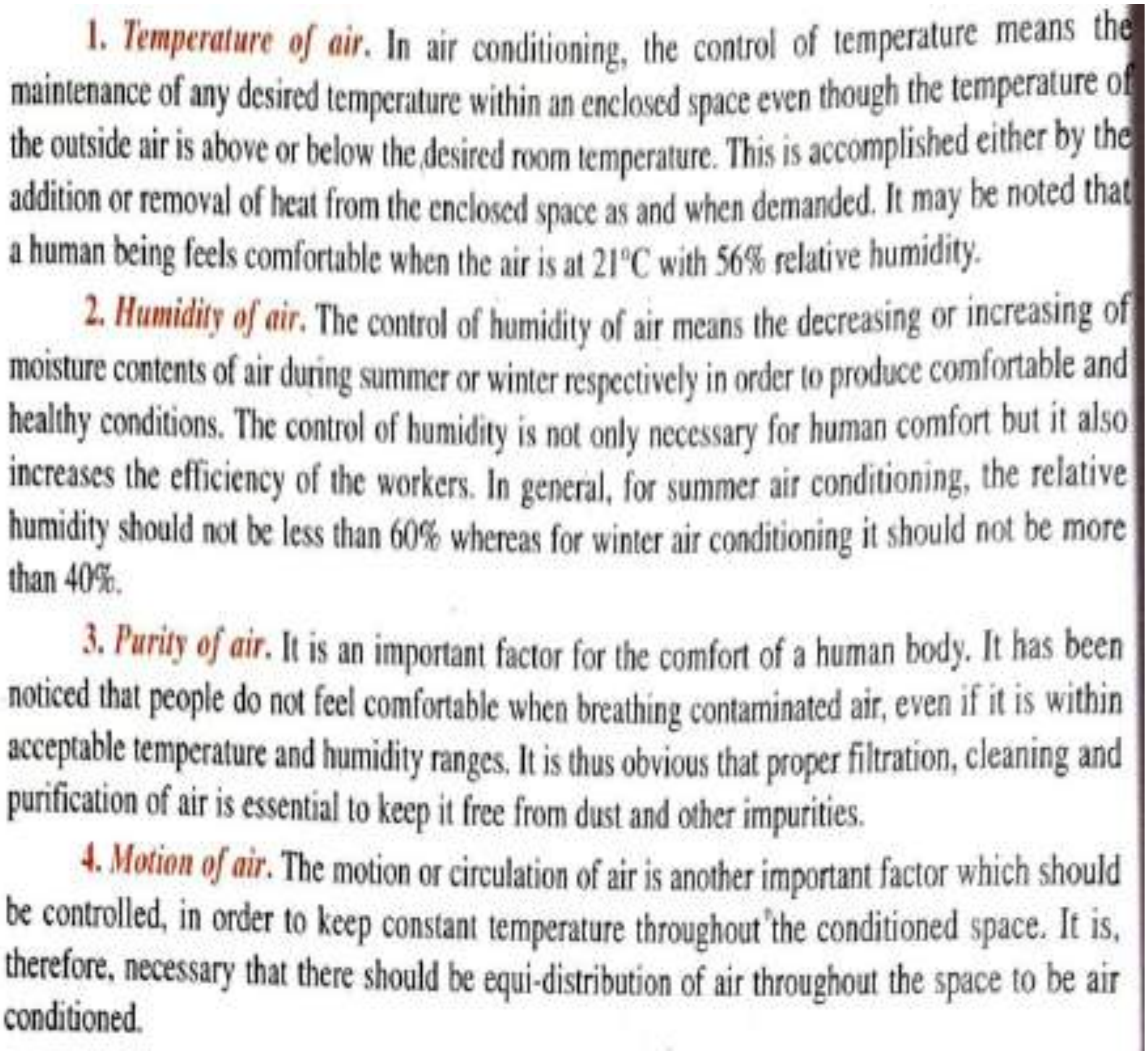
AIR CONDITIONING SYSTEMS

Air conditioning is the process of removing heat and moisture from the interior of an occupied space to improve the comfort of occupants. Air conditioning can be used in both domestic and commercial environments. This process is most commonly used to achieve a more comfortable interior environment, typically for humans

Factors affecting comfort air conditioning:

Following are the Factors affecting Comfort Air conditioning:

1. Temperature
2. Humidity
3. Purity of air
4. Motion of air.



1. *Temperature of air.* In air conditioning, the control of temperature means the maintenance of any desired temperature within an enclosed space even though the temperature of the outside air is above or below the desired room temperature. This is accomplished either by the addition or removal of heat from the enclosed space as and when demanded. It may be noted that 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 respectively in order to produce comfortable and healthy conditions. The control of humidity is not only necessary for human comfort but it also increases the efficiency of the workers. In general, for summer air conditioning, the relative humidity should not be less than 60% whereas for winter air conditioning it should not be more than 40%.

3. *Purity of air.* It is an important factor for the comfort of a human body. It has been noticed that people do not feel comfortable when breathing contaminated air, even if it is within acceptable temperature and humidity ranges. It is thus obvious that proper filtration, cleaning and purification of air is essential to keep it free from dust and other impurities.

4. *Motion of air.* The motion or circulation of air is another important factor which should be controlled, in order to keep constant temperature throughout the conditioned space. It is, therefore, necessary that there should be equi-distribution of air throughout the space to be air conditioned.

Equipments Used in an Air Conditioning System

Following are the main equipments or parts used in an air conditioning system :

1. *Circulation fan*. The main function of this fan is to move air to and from the room.

2. *Air conditioning unit*. It is a unit which consists of cooling and dehumidifying processes for summer air conditioning or heating and humidification processes for winter air conditioning.

3. *Supply duct*. It directs the conditioned air from the circulating fan to the space to be air conditioned at proper point.

4. *Supply outlets*. These are grills which distribute the conditioned air evenly in the room.

5. *Return outlets*. These are the openings in a room surface which allow the room air to enter the return duct.

6. *Filters*. The main function of the filters is to remove dust, dirt and other harmful bacteria from the air.

Classification of Air Conditioning Systems

The air conditioning systems may be broadly classified as follows :

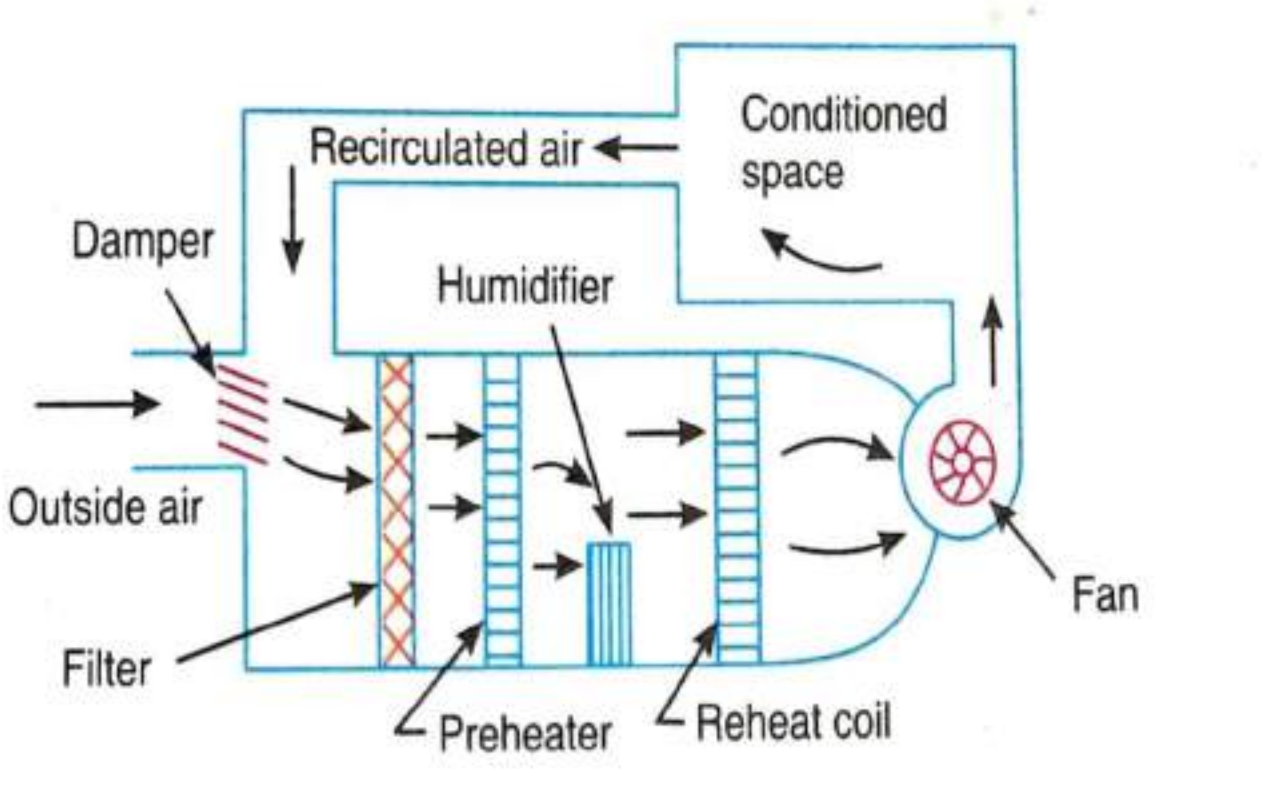
1. *According to the purpose*
   - (*a*) Comfort air conditioning system, and
   - (*b*) Industrial air conditioning system.
2. *According to season of the year*
   - (*a*) Winter air conditioning system,
   - (*b*) Summer air conditioning system, and
   - (*c*) Year-round air conditioning system.
3. *According to the arrangement of equipment*
   - (*a*) Unitary air conditioning system, and
   - (*b*) Central air conditioning system.

Winter Air Conditioning System:

In winter AC System, the inlet is heated by the heater, and in winter season due to less present in the air, we also need to add the moisture particle to the air, generally, a humidification system is added to maintain the moisture quantity.

Working of Winter Air Conditioning System:

In winter air conditioning, the air is heated and is accompanied by humidification.



Winter air conditioning system

---

1. The outside air flows through a damper and mixes up with the recirculated air which is obtained from the conditioned space.

2. The mixture here passes through a filter to remove dirt, dust, and other impurities.

3. The air now passes through a preheat coil to prevent possible freezing of water due to which dry bulb temperature increases to a very high value and the relative humidity drops to a low value.

4. This air is being pumped into the humidifier.

So, humidification of air (addition of moisture) is done and then the air is made to pass through a reheat coil to bring the air to the designed dry bulb temperature.

5. Now the conditioned air is supplied to the conditioned space by mea fan. From the conditioned space, a part of the used air is exhausted to the atmosphere by the exhaust fans or ventilators.

The remaining part of the air known as recirculated air is again conditioned

6. Initially, the relative humidity is 60% in the winter season, so to reduce it, a process of reheating is done where it is reduced to 20%.

So it is again humidified due to which it reaches a point of 80% or 100% RH where the DBT is very low.

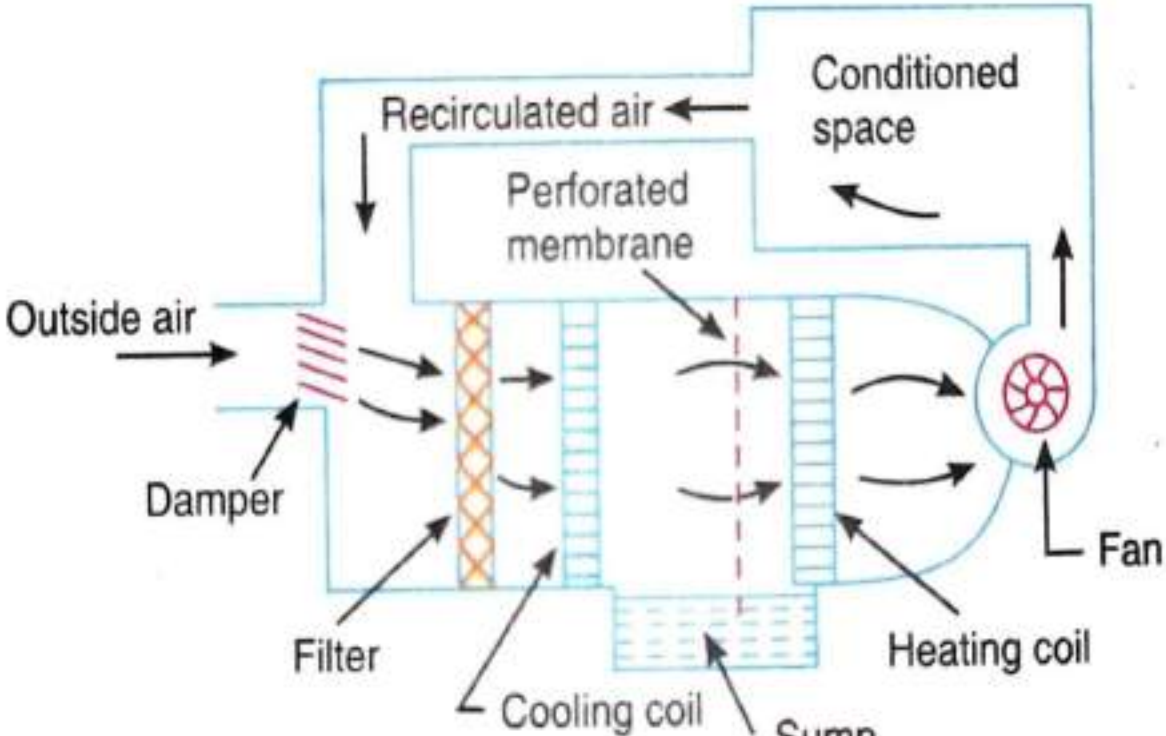
So in order to get the desired dry bulb temperature, again the process of reheating is done where the desired percentage 40% RH is also obtained.

7.A damper is used in order to control the area and have an intake of the required amount of air.

Summer Air Conditioning System:

Initially, during summer, the dry bulb temperature is high and the relative humidity of air is low.

Relative humidity should not be less than 60% according to the comfort conditions for summer air conditioning.



Summer air conditioning system

Working of Summer air conditioning system:

1. The outside air(atmospheric air) flows through the air filter to remove impurities or dust particles present in the air. The air now passes through a cooling coil.

2. The coil has a temperature much below the required dry bulb temperature of the air and very high relative humidity in the conditioned space.

So the cooled air is pumped into a dehumidifier, where it loses its moisture in the conditioned space.

3. After that, the air is made to pass through a heating coil which heats the air slightly.

This is done to bring the air to the designed DBT and relative humidity(RH).

4. Now the conditioned air is supplied to the conditioned space by a fan.

From the conditioned space, a part of the used air is exhausted to the atmosphere by the exhaust fans or ventilators.

The remaining part of the used air is again conditioned.

5. The outside air is sucked and it is made to mix with the recirculated air to make up for the loss of conditioned air through exhaust fans or ventilation from the conditioned space.