LECTURE NOTES

ON

REFRIGERATION AND AIR CONDITIONING

PREPARED BY

MS. CHINMAYEE JAYASHING

(DEPT. OF MECHANICAL ENGG.)

GOVERNMENT POLYTECHNIC, PURI

UNIT-I 7.8.2023

AIR REFRIGERATION CYCLE

Refrigeration and air conditioning:-

Refrigeration:-

Refrigeration may be defined as the process of achieving and maintaining a temperature below that of surrounding.

Application:-

It is used for reservation of food products by storing that low temperature.

Air condition:-

It is a system or process for controlling the temperature humidity and sometimes the purity of air.

Application:-

It is used in an office, lab, house etc.

Difference between refrigerator and air condition

Refrigerator	Air conditioner
(i) It is the process which controls temperature of air only.	(i) It is the process which controls temperature, humidity and sometimes purity of air.
(ii) It provides comfort to products	(ii) It provides comfort to human beings.
(iii) It is used for fridge.	(iii) It is use office, lab. house.

8.8.2023

Refrigerant:-

It is the working fluid which is used to extract heat from the system.

EX:- R-12, R-32, R134A, R600, R290.

Refrigeration effect:-

It is the amount of heat which is required to extract in order to provide and maintain the lower temperature than that of surrounding.

IMP

Unit of Refrigeration

→ The unit refrigeration is expressed in tonnes of refrigeration.

→ A tonne of refrigeration is defined as the amount of heat produce / refrigeration effect produce by the uniform melting of one tonne of ice at 0°c in 24 hours.

$$1\ TR = 1000\ kg \times 335\ kJ/kg \text{ in } 24 \text{ hours}$$

$$= \frac{1000 \times 335}{24 \times 60} = 232.63\ kJ/min$$

In actual practice 1 TR is taken as equivalent to 210 kJ/min

$$= \frac{210}{60} = 3.5\ kJ/sec$$

$$= 3.5\ KW.$$

9.8.2023

Coefficient of performance of a refrigerator

It is the ratio of is extracted (refrigerating effect) in the refrigerator to the workdone on the refrigerant. Mathematically,

$$COP = \frac{\text{Refrigerating effect / Desired effect}}{\text{Workdone}}$$

$$COP = \frac{Q}{W_{net}}$$ (unitless)

Note:-

→ The coefficient of performance is the reciprocal of efficiency.

→ The value of COP is always >1

Relative COP :- <1

It is the ratio between actual COP to the theoritical COP.

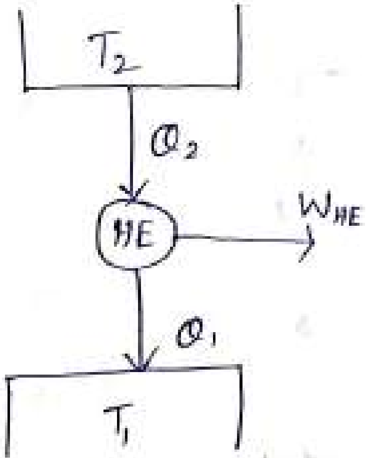
Q.1 Find the COP of a refrigerator if the work input is 150 W/kg and the refrigeration effect produce these 450 W/kg.

Ans: $$COP = \frac{\text{Refrigerating effect}}{\text{Workdone}}$$

$$= \frac{Q}{W_{net}} = \frac{450}{150} = 3.$$

2 marks

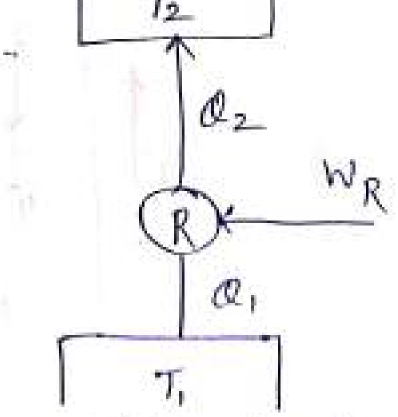
* Difference between a heat engine, refrigerator and heat pump.



(Heat engine)

$\eta = \frac{W}{Q}$

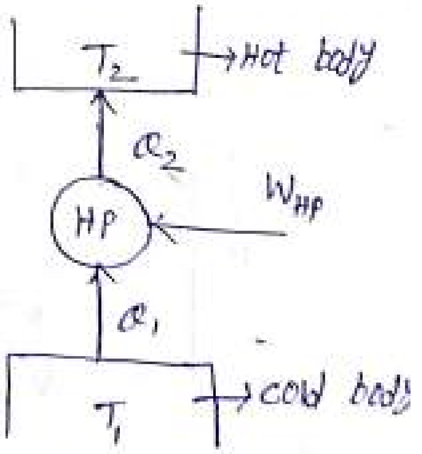
$\eta = \frac{Q_2 - Q_1}{Q_2}$



(Refrigerator)

$COP = \frac{Q}{W}$

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



(Heat pump)

$COP = \frac{Q}{W}$

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

Relation

$$\frac{1}{\eta} = (COP)_R + 1 = (COP)_{HP}$$

Q.2

A machine working on carnot cycle operates between two temperature when the machine is operated at heat pump the cop is 5. Find out the cop of refrigerator.

Ans: $(COP)_R + 1 = (COP)_{HP}$

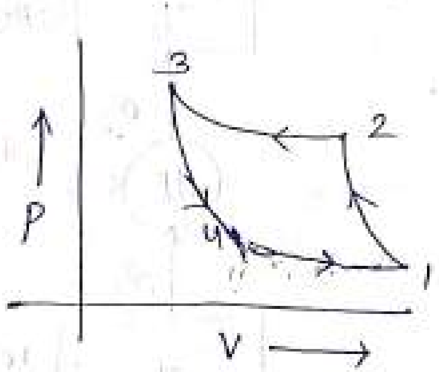
$\Rightarrow (COP)_R = (COP)_{HP} - 1$

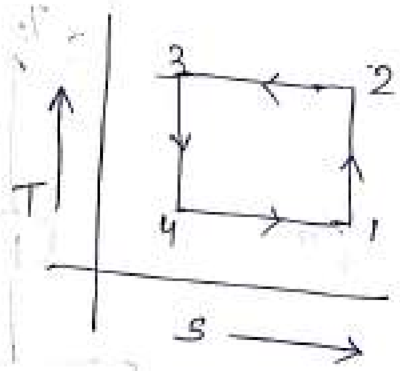
$\Rightarrow (COP)_R = 5 - 1 = 4.$

Ideal refrigeration cycle or reverse carnot cycle

An air refrigeration system working on reverse carnot cycle will have highest possible cop.

The refrigerator working on reverse carnot cycle is not possible to construct how ever it is used as standard of comparision.





These are four processes in this cycle.

process (1-2) :- Isentropic compression

→ The air is compressed isentropically on the process (1-2), during this process the pressure of air increases from P_1 to P_2.

→ specific volume decreases from V_1 to V_2 and temperature increases from T_1 to T_2. During isentropic compression no heat is absorbe or rejected on the air.

process (2-3) :- Isothermal compression

→ The air is now compressed isothermally i.e $T_2 = T_3$, during this process the pressure of air increases from P_2 to P_3 and

→ specific volume decreases from V_2 to V_3.

→ During isothermal compression the heat rejected by the air.

$Q_{Rejected} = T_2 (S_2 - S_3)$

process (3-4) :- Isentropic expansion

This air is now expanded isentropically in the process 3-4, during this process the pressure decreases from P_3 to P_4 and specific volume increases from V_3 to V_4 and temperature decreases from T_3 to T_4.

process (4-1) :- Isothermal expansion

This air is now expanded isothermally ($T_4 = T_1$) in the process (4-1), During this process the pressure decreases from P_4 to P_1 and specific volume increases from V_4 to V_1. During this process the heat is absorb by the air

$Q_{absorb} = T_4 (S_1 - S_4)$

COP of reverse carnot cycle:-

$$COP = \frac{\text{Desired effect}}{W_{net}}$$

$$= \frac{Q_A}{Q_R - Q_A}$$

$$= \frac{T_4 (S_1 - S_4)}{T_2(S_2 - S_3) - T_4(S_1 - S_4)}$$

$$= \frac{T_4 (S_2 - S_3)}{T_2(S_2 - S_3) - T_4(S_2 - S_3)}$$

$$= \frac{T_4 (S_2 - S_3)}{T_2 - T_4 (S_2 - S_3)}$$

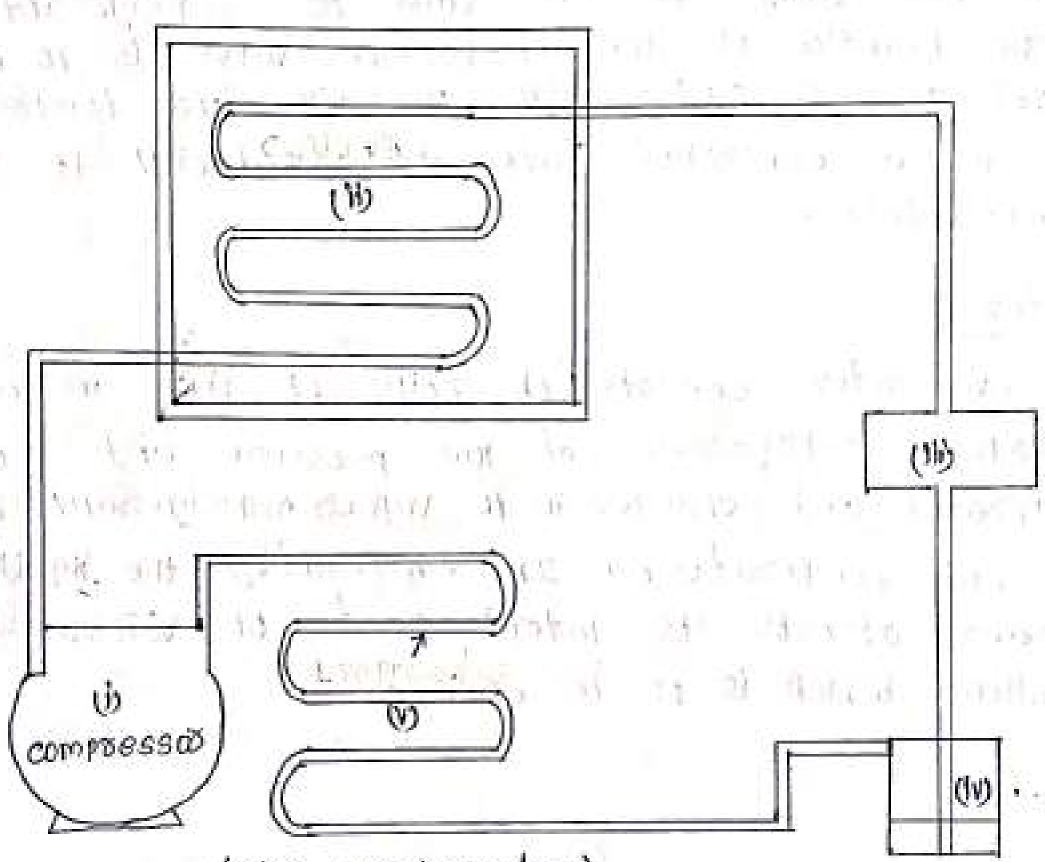
$$= \frac{T_4}{T_2 - T_4}$$

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

12.08.2023

Components of Air refrigeration cycle

An air refrigeration cycle consist of following different components. These are :-
(i) compressor
(ii) condenser
(iii) Receiver
(iv) Expansion valve
(v) Evaporator.



(Air Refrigerator)

(i) Compressor :-

The low pressure and temperature vapour refrigerant from evaporator is draw in to the compressor through the inlet or suction valve 'A', where it is compressed to a high pressure and temperature. The high pressure and temperature vapour refrigerant is discharged in to the condensor, through the delivery or discharge valve 'B'.

(ii) Condenser :-

The condenser or cooler consists of coils or pipe in which the high pressure and temperature vapour refrigerant is cooled and condensed the refrigerant, while passing through the condenser gives up its latent heat to the surrounding condensing medium which is normally air or water.

(iii) Receiver :-

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

(iv) Expansion valve :-

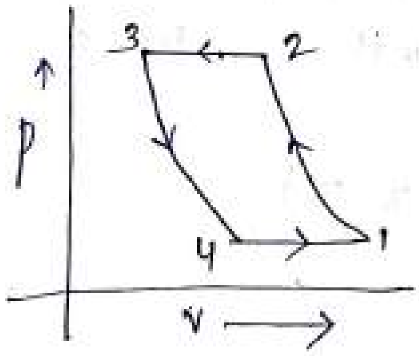
It is also called throttle valve or refrigerant control valve. The function of the expansion valve is to allow the liquid refrigerant under high pressure and temperature to pass at a controlled rate after reducing its pressure and temperature.

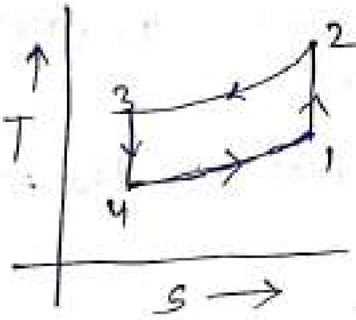
(v) Evaporator :-

An evaporator consists of coils of pipe in which the liquid-vapour refrigerant at low pressure and temperature is evaporated and change in to vapour refrigerant at low pressure and temperature. In evaporating the liquid vapour refrigerant absorbs its latent heat of vapourisation from the medium which is to be cooled.

16.8.2023

⊛ Reverse Brayton cycle / Bell-coleman cycle / Reverse Joule cycle





This cycle consist of four different process i.e two isentropic process and two isobaric process.

Process 1-2 :- (Reversible adiabatic compression / isentropic)

In this process the air from the evaporator drawn in to the compressor there it is compress isentropically. During this process the pressure increases from P_1 to P_2, Temperature increases T_1 to T_2 and volume decreases from V_1 to V_2.

Process 2-3 :- (constant pressure heat rejection)

The compressed air from the compressor is now passed through the condenser. where it is cooled at a constant pressure ($P_2 = P_3$) and temperature reduces from T_2 to T_3. The specific volume also reduces V_2 to V_3.

The amount of heat rejected during this process

$$\Rightarrow Q_R = C_P(T_2 - T_3)$$

Process (3-4) :- (Isentropic expansion)

Now the cooled air is drawn in to the expansion cylinder (expansion valve) where it is expanded isentropically from pressure P_3 to P_4, and temperature also reduces from T_3 to T_4 and the specific volume of refrigerant increases from V_3 to V_4.

Process (4-1) :- constant

The cool air from the expansion valve passes through the evaporator, where the heat is added to it. During this process the temperature increases from T_4 to T_1, the specific volume also increase

The amount of heat absorbed => $Q_A = C_p(T_1 - T_4)$

COP of the cycle

we know that, $COP = \frac{\text{desired effect}}{W_{net}}$

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

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

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

we know that, ~~$\left(\frac{T}{P}\right)^{\frac{\gamma-1}{\gamma}}$ = constant~~

For isentropic process 1-2 => $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$

process 3-4 => $\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$ $\left\{\because P_2 = P_3,\ P_1 = P_4\right\}$

$$\Rightarrow \frac{T_2}{T_1} = \frac{T_3}{T_4} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \quad \text{----- (2)}$$

$$\Rightarrow \frac{T_2}{T_3} = \frac{T_1}{T_4} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \quad \text{----- (3)}$$

putting the value of $\frac{T_2}{T_3}$ in eqn (1)

we get $\Rightarrow$ $COP = \dfrac{T_4\left(\frac{T_1}{T_4}-1\right)}{T_3\left(\frac{T_1}{T_4}-1\right) - T_4\left(\frac{T_1}{T_4}-1\right)}$

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

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

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

putting the value of $\frac{T_3}{T_4}$ from eqn (2)

we get, $\Rightarrow COP = \dfrac{1}{\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1}$

$$\Rightarrow COP = \frac{1}{r^{\frac{\gamma-1}{\gamma}} - 1}$$

where, r = compression ratio

$$r = \frac{P_2}{P_1}$$

18.08.23

① A refrigerator working on Bell-coleman cycle operates between pressure 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 $pv^{1.4}$ is constant. determine the COP of the constant.

Ans: Given data

$P_1 = 1.05$ bar

$P_2 = 8.5$ bar

$T_1 = 10°C = 283$ K

$T_3 = 30°C = 303$ K

$\gamma = 1.4$

$$r_c = \frac{P_2}{P_1} = \frac{8.5}{1.05} = 8.09$$

$$COP = \frac{\text{desired effect}}{W_{net}}$$

$$= \frac{1}{(r_c)^{\frac{\gamma-1}{\gamma}} - 1} = \frac{1}{(8.09)^{\frac{1.4-1}{1.4}} - 1} = 1.22$$

or

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

we know, $\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$ $\left(\because \begin{matrix} P_3 = P_2 \\ P_4 = P_1 \end{matrix}\right)$

$$\Rightarrow \frac{T_3}{T_4} = \left(\frac{8.5}{1.05}\right)^{\frac{1.4-1}{1.4}}$$

$$\Rightarrow \frac{T_3}{T_4} = 1.81$$

$$\Rightarrow 303 = 1.81\, T_4$$

$$\Rightarrow T_4 = \frac{303}{1.81} = 167.40$$

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

$$= \frac{167.40}{303 - 167.40} = 1.23.$$

② A refrigerating plant working on bell-coleman cycle, the air is compressed from 1 bar to 5 bar. The initial temperature is 10°c. After compression the air is cooled up to 20°C in a cooler, before expanding to 1 bar. Determine the COP of the plant and the net refrigerating effect. Take $C_p = 1.005$ kJ/kgK, $C_v = 0.718$ kJ/kgK.

Ans: Given data,

$P_1 = 1$ bar $\quad C_p = 1.005$ kJ/kgK

$P_2 = 5$ bar $\quad C_v = 0.718$ kJ/kgK

$T_1 = 10°C = 283K$

$T_3 = 20°C = 293K$

$$\therefore \gamma = \frac{C_p}{C_v} = \frac{1.005}{0.718} = 1.399 = 1.4$$

$$r_c = \frac{P_2}{P_1} = \frac{5}{1} = 5.$$

$$COP = \frac{1}{(r_c)^{\frac{\gamma-1}{\gamma}} - 1} = \frac{1}{(5)^{\frac{1.4-1}{1.4}} - 1} = 1.71.$$

OR

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

$$\therefore \frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow \frac{T_3}{T_4} = \left(\frac{5}{1}\right)^{\frac{1.4-1}{1.4}}$$

$\Rightarrow \frac{T_3}{T_4} = 1.58$

$\Rightarrow T_4 = \frac{293}{1.58} = 185.44\,K$

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

$= \frac{185.44}{293 - 185.44} = 1.72.$

19.08.23

⊛ open air rebrigeration cycle :-

In an open air rebrigeration cycle, the air is directly led to the space to be cooled, allowed to circulate through the cooler and then return to the compressor to start the another cycle.

Disadvantages of open air rebrigeration cycle :-

→ The air is suppied to the rebrigerator at atmospheric pressure, therebore volume of the air handled by the compressor and expander is large.

→ In the open cycle system the moisture is regularly carried away by the air circulated through the space.

⊛ Closed air rebrigeration cycle :-

→ In closed air rebrigeration cycle, the air is passed through the pipes and dibberent components of the system.

→ This air is used bor absorbing heat brom the space which is to be cooled.

Advantages :-

→ Smaller size of compressor and expander are required.

→ The operating pressure ratio in the system can be reduced, so that COP of the cycle increases.

Chapter at a glance

$1\ TR = 1000\ kg \times 335\ kJ/kg$ in 24 hours

$= 232.63\ kJ/min\ /\ 210\ kJ/min$

$= 3.5\ kJ/s$

$= 3.5\ kW$

COP of refrigerator $= \dfrac{\text{Refrigerating effect / desired effect}}{\text{workdone}}$

$$= \frac{Q}{W_{net}} = \frac{Q_1}{Q_2 - Q_1}$$

COP of heat engine =

COP of heat engine $= \dfrac{Q}{W} = \dfrac{Q_2}{Q_2 - Q_1}$

Relation $\Rightarrow \dfrac{1}{\eta} = (COP)_R + 1 = (COP)_{HP}$

COP of reverse carnot cycle $= \dfrac{T_1}{T_2 - T_1}$

COP of Bell-Coleman cycle $= \dfrac{T_4}{T_3 - T_4}$, or $\dfrac{1}{(r)^{\frac{\gamma-1}{\gamma}} - 1}$

compression ratio $(r) = \dfrac{P_2}{P_1}$.

21.08.23

UNIT-2

Simple vapour compression refrigeration system (VCRS)

A vapour compression refrigeration system is an improved type of air refrigeration system in which the ~~refrige~~ working substance is refrigerant. It condense and evaporates at temperature and pressure close to atmospheric condition.

The refrigerant use does not leave the system but circulated through out the system.

First vapour compression system was developed by - Jacob perkins in 1834.

Application:-

- It is generally used for industrial and domestic purpose.

Advantages:-

- It has smaller size for given capacity of refrigeration.
- It has less running cost.
- It can be employed over a large range of temperature.
- The COP is quiet high.

Disadvantages:-

- The initial cost is high.
- The prevention of ~~the~~ leakage of refrigerant is the major problem in VCRS.

Types of VCRS

There are many types of vapour compression refrigeration ~~etc~~ system. The following are important from the subject point of view.

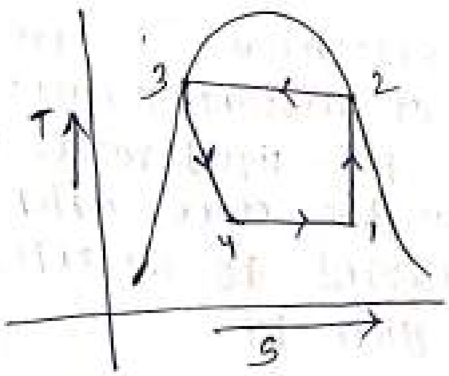
(i) cycle with dry saturated vapour after compression.
(ii) cycle with wet vapour after compression.

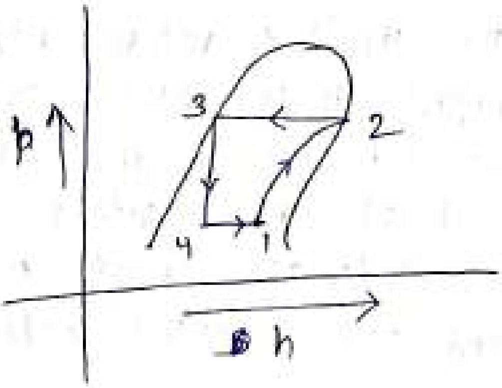
(iii) cycle with superheated vapour after compression.
(iv) cycle with superheated vapour before compression.
(v) cycle with undercooling or sub-cooling of refrigerant.

22.08.23

~~vapour compr~~

(i) cycle with dry saturated vapour after compression





A vapour compression cycle with dry saturated vapour after compression is shown TS and ph diagram. At point 1 let T_1, P_1, S_1 and h_1 be the temperature, pressure, entropy and enthalpy of vapour refrigerant respectively. The four processes of the cycle as follows

process (1-2):- Isentropic compression

The vapour refrigerant at low pressure P_1 and temperature T_1 is compressed isentropically to dry saturated vapour. As a result of which pressure and temperature rises from P_1 to P_2 and T_1 to T_2 respectively.

The workdone during isentropic compression per kg of refrigerant is given by $\Rightarrow W = h_2 - h_1$

process (2-3):- Isobaric heat rejection or condensation

The high pressure and temperature of vapour refrigerant from the compressor is passed through the condenser, where it is completely condensed. (In this process the heat rejected is latent heat). $P_2 = P_3$, $T_2 = T_3$.

process (3-4) :- Isenthalpic expansion

The liquid refrigerant is expanded by throttling process (isenthalpic) through the expansion valve. During this process pressure and temperature decreases from P_3 to P_4 and T_3 to T_4.

process (4-1) :- evaporation / vapourising / constant pressure heat addition

The liquid + vapour mixture or refrigerant is evaporated and changed in to vapour refrigerant at constant pressure and temperature. During this evaporation the liquid vapour refrigerant absorbs ~~heat~~ latent heat from the space which is to be cooled. The heat which is absorbed by the refrigerant is called refrigerating effect. and is given by

$$RE = h_1 - h_4$$

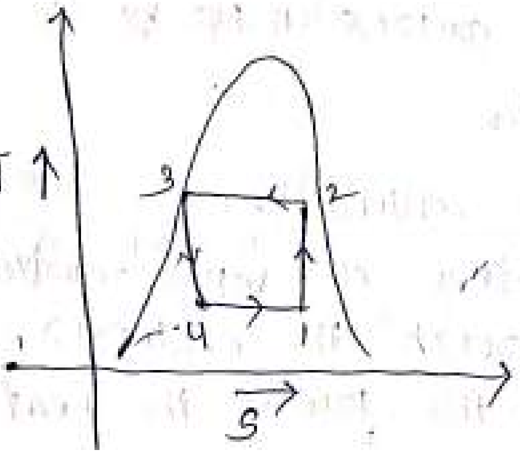
$$COP = \frac{\text{desired effect}}{\text{workdone}}$$

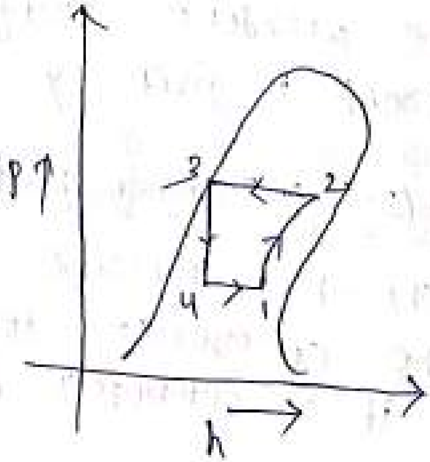
$$= \frac{RE}{W} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$\Rightarrow COP = \frac{h_1 - h_4}{h_2 - h_1} \quad \text{or} \quad \frac{h_1 - h_3}{h_2 - h_1}.$$

23.08.23

(ii) cycle with wet vapour after compression

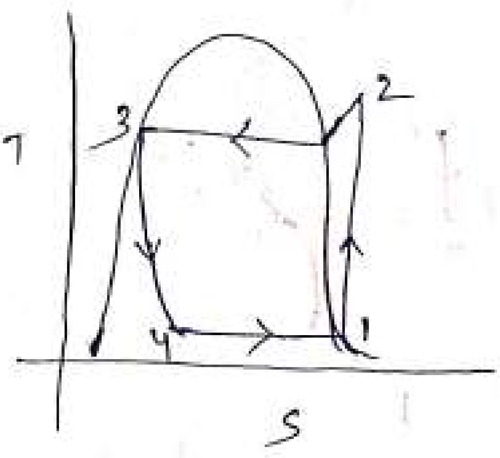


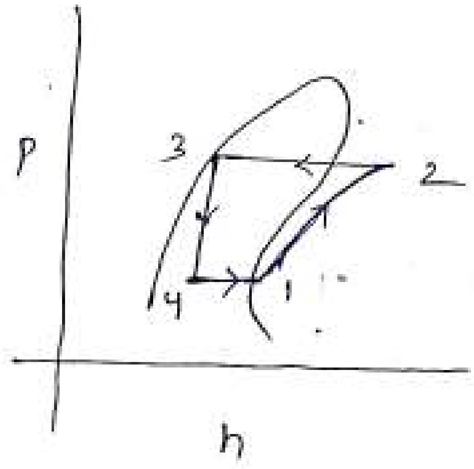


$$COP = \frac{RE}{W}$$

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

(iii) cycle with superheated vapour after compression

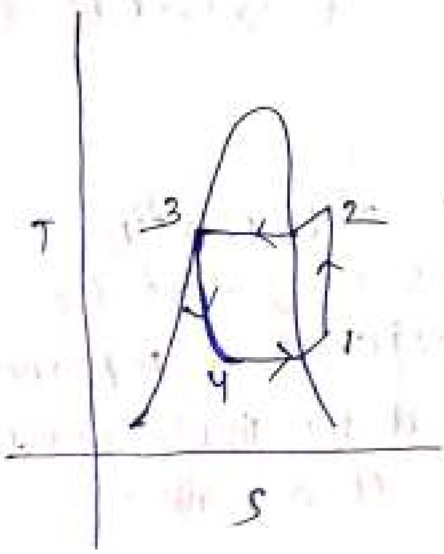


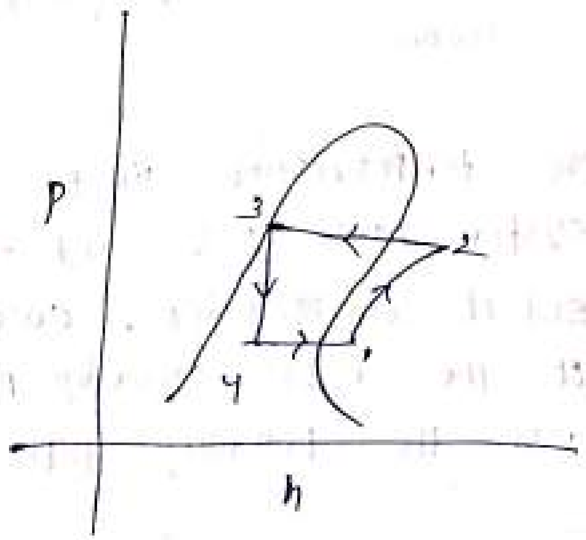


$$COP = \frac{RE}{W}$$

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

(iv) cycle with superheated vapour before compression

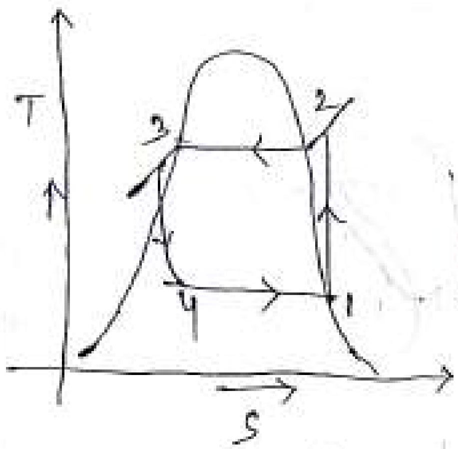


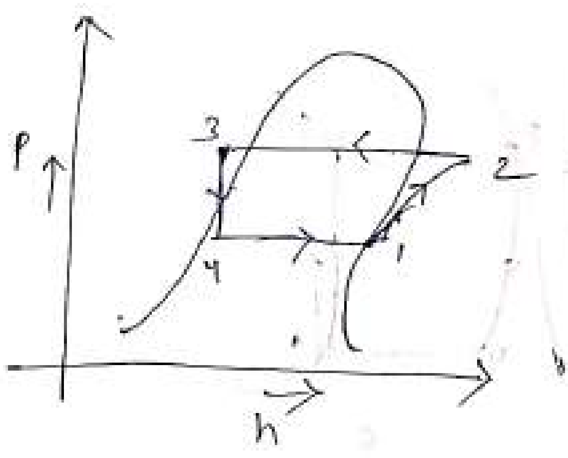


$$COP = \frac{RE}{W}$$

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

(v) cycle with undercooling and subcooling of refrigerant





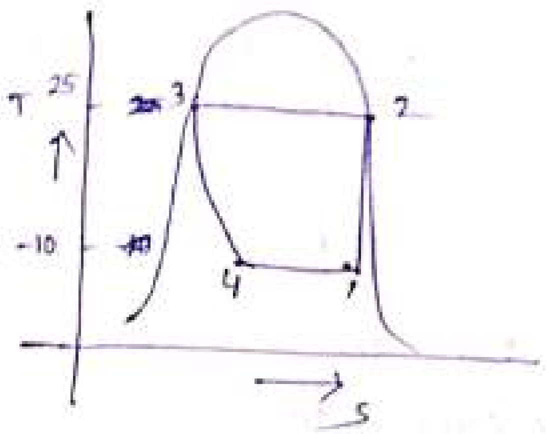
29.08.23

	Enthalpy	Entropy
wet steam	$h = h_f + x h_{fg}$	$S = S_f + \frac{x h_{fg}}{T}$ $S = S_f + S_{fg}$
saturated steam	$h = h_g$	$S = S_g$
superheated steam	$h = h_g + C_p(T_{sup} - T_{sat})$	$S = S_g + 2.3 C_p \log\left(\frac{T_{sup}}{T_{sat}}\right)$

① The temperature limits of an ammonia refrigerating system are $-25°C$ and $-10°C$. If the gas is dry at the end of compression, calculate the co-efficient of performance of the cycle assuming no undercooling of the liquid ammonia. Use the following table for properties of ammonia :-

Temperature	Liquid heat (kJ/kg) (h_f)	Latent heat (kJ/kg) (h_{fg})	Liquid entropy (kJ/kg K) (S_f)
25	298.9	1166.94	1.1242
-10	135.37	1297.68	0.5443

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



$h_2 = h_{f_2} + x h_{fg_2}$

$= 298.9 + 1 \times 1166.94$

$= 1465.84$

For process (3-4) isenthalpic process

$\Rightarrow h_3 = h_4 = 298.9$

$S_2 = S_{f_2} + \frac{x h_{fg_2}}{T_2}$

$\Rightarrow S_2 = 1.1242 + \frac{1 \times 1166.94}{298}$

$\Rightarrow S_2 = 5.04$

process (1-2) isentropic compression

$S_2 = S_1$

$S_2 = S_f + \frac{x h_{fg}}{T}$

$\Rightarrow S_2 = 0.5443 + x \times \frac{1297.68}{263}$

$\Rightarrow 5.04 = 0.5443 + x \times \frac{1297.68}{263}$

$\Rightarrow x = 5.04 - 0.5443 \times \frac{263}{1297.68}$

$\Rightarrow x = 0.91$

$h_1 = h_{f_1} + x\, h_{fg_1}$

$= 135.37 + 0.91 \times 1297.68$

$= 1316.25$

$\therefore COP = \dfrac{h_1 - h_4}{h_2 - h_1}$

$= \dfrac{1316.25 - 298.9}{1465.84 - 1316.25} = 6.80$ (Ans).

(*) **Process**

(i) Plot the TS diagram

(ii) Given data,

T_1 (Low)	T_2 (High)
x_1	x_2
h_f	h_f
h_g	h_g
S_f	S_f
S_g	S_g

(iii) What to find

Note:- process (1-2) :- isentropic compression

$\Rightarrow S_1 = S_2$

process (3-4) :- isenthalpic

$\Rightarrow h_3 = h_4$.

② Find the theoritical COP foo a CO_2 machine wooking between temperature range of 25°c to -5°c. The dryness fraction of CO_2 during the suction stooke is 0.6.

T_2 (25°C)	T_1 (-25°C)
x_2 = ?	x_1 = 0.6
h_f = 164.77	h_f = 72.57
s_f = 0.5978	s_f = 0.2862
h_g = 282.23	h_g = 321.33
s_g = 0.9918	s_g = 1.2146
h_{fg} = 117.46	h_{fg} = 248.76

01.09.23

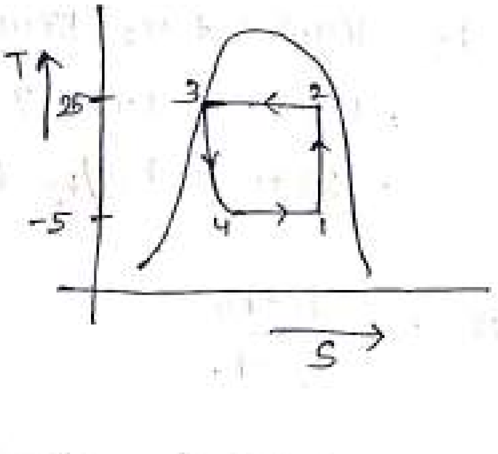
Ans: Given data,

	h_f	s_f	h_g	s_g	h_{fg}
25°C	164.77	0.5978	282.23	0.9918	117.46
-25°C	72.57	0.2862	321.33	1.2146	248.76

T_1 = -5°c = 268 K

T_2 = 25°c = 298 K

x_1 = 0.6.



$h_1 = h_{f_1} + x\, h_{fg_1}$

$= 72.57 + 0.6 \times 248.76$

$= 221.826$ kJ/kg

$h_4 = h_3 = h_f = 164.77$ kJ/kg.

$h_2 = hf_2 + x_2 hfg_2$

$\Rightarrow h_2 = 164.77 + x_2 \times 117.46$

During Isentropic process

$\Rightarrow S_1 = S_2$

$$S_1 = Sf_1 + \frac{x_1 hfg_1}{T_1}$$

$$= 0.2862 + \frac{0.6 \times 248.76}{268}$$

$$= 0.8431$$

$$S_2 = Sf_2 + \frac{x_2 hfg_2}{T_2}$$

$$\Rightarrow 0.8431 = 0.5978 + x_2 \frac{117.46}{298}$$

$$\Rightarrow x_2 \left(\frac{117.46}{298}\right) = 0.8431 - 0.5978$$

$$\Rightarrow x_2 = 0.622$$

$$\therefore h_2 = 164.77 + x_2 \times 117.46$$

$$= 164.77 + 0.622 \times 117.46$$

$$= 237.83 \text{ KJ/kg}$$

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

$$= \frac{221.826 - 164.77}{237.83 - 221.826}$$

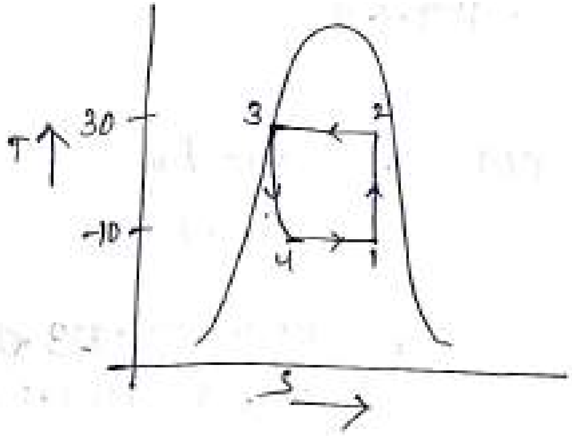
$$= 3.56 \text{ (Ans)}$$

③

Temp	h_f	h_{fg}	s_f	s_g
30°C	323.08	1145.80	1.2037	4.8942
-10°C	135.37	1297.68	0.5443	5.4770

$x_2 = 0.95$

Ans:



During isentropic process

$s_1 = s_2$

$\Rightarrow s_2 = s_{f_2} + \frac{x_2 h_{fg_2}}{T_2}$

$= 1.2037 + \frac{0.95 \times 1145.80}{303}$

$= 4.7961$

$\Rightarrow s_1 = s_{f_1} + \frac{x_1 h_{fg_1}}{T_1}$

$\Rightarrow 4.7961 = 0.5443 + \frac{x_1 \times 1297.68}{263}$

$\Rightarrow \frac{x_1 \times 1297.68}{263} = 4.7961 - 0.5443$

$\Rightarrow x_1 = \frac{4.2518 \times 263}{1297.68} = 0.86$

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

$= 135.37 + 0.86 \times 1297.68$

$= 1251.3748$ kJ/kg

Due to (3-4) isenthalpic process

$h_4 = h_3 = h_f = 323.08$

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

$= 323.08 + 0.95 \times 1145.80$

$= 1411.59$

$\therefore$ COP $= \dfrac{h_1 - h_4}{h_2 - h_1}$

$= \dfrac{1251.3748 - 323.08}{1411.59 - 1251.3748}$

$= 5.79$ (Ans).

11.09.2023

UNIT-3

Vapour Absorption Refrigeration system

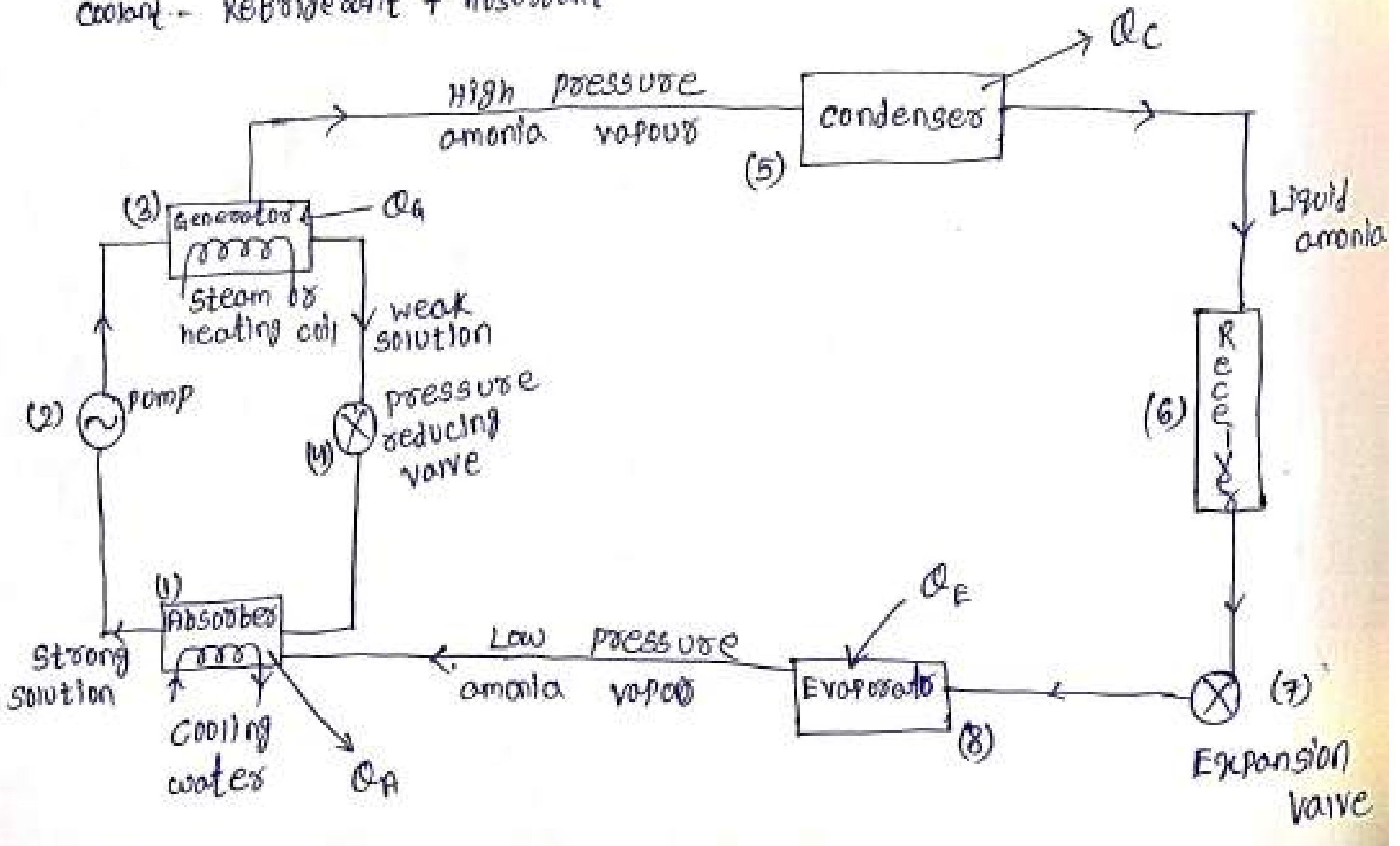
- The vapour absorption refrigeration system is one of the oldest method of producing refrigerating effect. It was first discovered by Michel Faraday in 1824.
- The first vapour absorption machine was developed in 1860.

The vapour absorption system uses heat energy instead of mechanical energy as in VCRS in order to change the refrigerant condition required for the operation of refrigeration cycle.

In VARS the compressor is replaced by an absorber, a pump, a generator and a pressure reducing valve. These components perform same function as that of a compressor in VCRS.

Simple vapour absorption system:-

Coolant - Refrigerant + Absorbant



The simple vapour absorption system consist of an absorber, a pump, a generator and a pressure reducing valve to replace the compressor of VCRS. The other components of the system are condensor, receiver, expansion valve and a evaporator.

→ In this system the low pressure amonia vapour leaving from the evaporater enters the absorber where it is absorbed by the cold water. The water has the ability to absorb large quantity of amonia thus aqua-amonia is formed.

→ The absorption of amonia vapour in water lowers the pressure in the absorber. which in term draws more amonia from the evaporater. During this process the temperature of the solution rises.

→ some form of cooling arrangement is employed in the absorber to remove the heat. It is necessary in order to increase the absorption capacity of water because at higher temperature water absorbs less amonia.

→ The strong solution thus formed in the absorber is pumped to the generator by liquid pump. The pump increases the pressure of the solution up to 10 bar.

→ The strong solution of amonia in the generator is heated by some external source (gas / steam). During the heating process the amonia vapour is driven of the solution at high pressure leaving behind hot weak amonia solution in the generator.

→ This weak amonia solution flows back to the absorber at low pressure after passing through the pressure reducing valve.

→ The high pressure amonia vapour from the ~~generator~~ rectifier is condensed in the condensor to form high pressure liquid amonia.

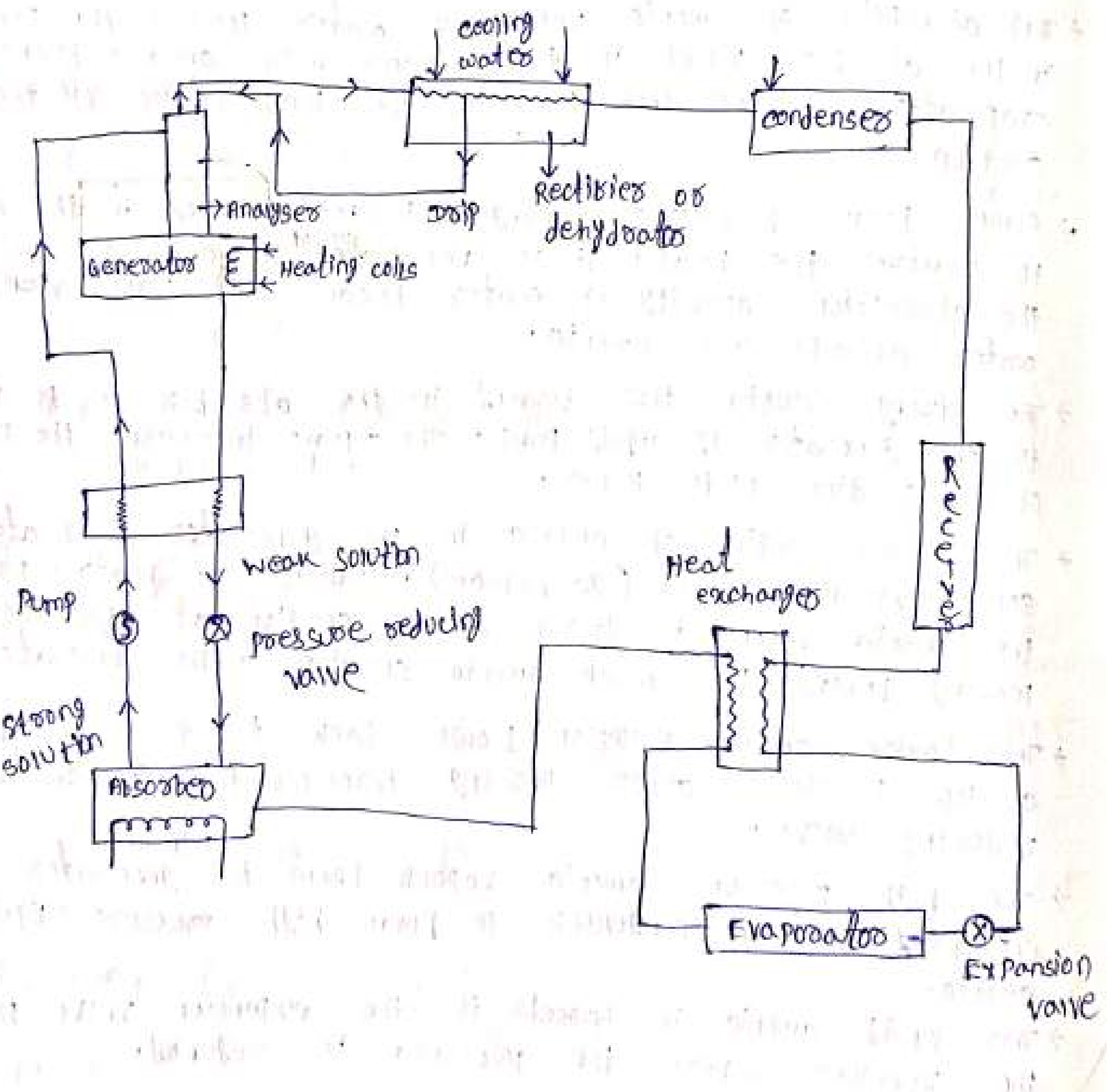
→ This liquid amonia is passed to the expansion valve through the receiver where the pressure is reduced.

→ The low pressure liquid amonia is then passed to the evaporator where it can absorb the heat from the space which is meant to be cooled.

→ This completes the simple vapour absorption system.

13.09.23

⊛ Practical Vapour Absorption Refrigeration System



The simple VARS is not very economical in order to make the system more practical it is fitted with an analyser, a rectifier and two heat exchanger. These accessories helps to improve the performance and working of the plant.

7) Analyser :-

When amonia is vapourised in the generator some water will also vapourised and will through in to the condenser along with amonia vapour. If these unwanted water particles are not remove before entering in to the condenser they will enter into the expansion valve and choke the pipe line.

→ The analyser is consist of a series of trays mounted above the generator. The strong solution from the generator and water from the rectifier is introduced at the top of the analyser. In this way the vapour is cooled and most of the water vapour condensed. That's why mainly amonia vapour leaves the top of the analyser.

(ii) Rectifier :-

In case of water vapour are not completely removed in the analyser. A closed type vapour cooler called rectifier is used. It is generally a water cooled pipe. Its function is to coll the further amonia vapour leaving the analyser. so that the remaining water vapour condensed. Thus only dry amonia vapour's flow in to the condenser.

25.09.23

Heat exchanger :-

1) → The heat exchanger provided between the pump and generator is used to cool the weak hot solution from the generator.

4 → The heat exchanger provided between the condenser and evaporator may be also called liquid sub-cooler.

→ In this heat exchanger the liquid refrigerant leaving from the condenser is sub-cooled by low temperature amonia vapour from the evaporator.

COP of ideal VARS :-

In this system net refrigeration effect is the heat absorbed by the refrigerant in the evaporator. The total energy supply to the system is the sum of workdone by the pump and heat supplied in the generator.

$$COP = \frac{\text{Desired effect}}{W_{net}}$$

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

Let, Q_G = The heat given to the refrigerant in the generator

Q_C = The heat is discharge to the atmosphere or cooling water from the condenser of absorber.

Q_E = The heat absorb by the refrigerant in the evaporator.

Q_P = Heat in added to the refrigerant due to the pump work.

$$COP = \frac{Q_E}{Q_P + Q_G} \quad \text{------ (i)}$$

26.09.23

From the first law of thermodynamic we found

$Q_G + Q_P + Q_E = Q_C$.

Neglecting the heat added due to pump work, we get

$$Q_C = Q_G + Q_E \quad \text{------ (ii)}$$

$$\therefore COP = \frac{Q_E}{Q_G}.$$

since the VARS can be considered as a perfectly reversible system, Therefore the initial entropy of the system must be equal to the entropy of system after the change in its condition.

$$\frac{Q_G}{T_G} + \frac{Q_E}{T_E} = \frac{Q_C}{T_C} \qquad \left(\because s = \frac{dQ}{T}\right)$$

putting the value of Q_C from eqn (ii)

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

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

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

$$\Rightarrow Q_G\left(\frac{1}{T_G} - \frac{1}{T_C}\right) = Q_E\left(\frac{1}{T_C} - \frac{1}{T_E}\right)$$

$$\Rightarrow Q_G\left[\frac{T_C - T_G}{T_G T_C}\right] = Q_E\left[\frac{T_E - T_C}{T_C \cdot T_E}\right]$$

$$\Rightarrow Q_G = Q_E\left[\frac{T_E - T_C}{\cancel{T_C} T_E}\right] \times \left[\frac{T_G \cancel{T_C}}{T_C - T_G}\right]$$

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

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

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

$$\boxed{COP = \frac{T_E}{T_E - T_E} \times \frac{T_C - T_G}{T_G}}$$

$$\boxed{COP = \frac{T_E}{T_E - T_E} \times \frac{T_G - T_C}{T_G}}$$

① In a vapour absorption refrigeration system heating, cooling and refrigeration takes place at the temperature of 100°c, 20°c and -5°c. Find the cop of the system.

Ans: $T_G = 100°c = 373$ K

$T_C = 20°c = 293$ K

$T_E = -5°c = 268$ K

$$COP = \frac{T_E}{T_E - T_E} \times \frac{T_G - T_C}{T_G}$$

$$= \frac{268}{293 - 268} \times \frac{373 - 293}{373}$$

$= 2.31$ (Ans)

(*) Difference between VCRS and VARS.

VCRS	VARS
1. Energy input is mechanical i.e from an electric motor.	1. Energy input is thermal.
2. In VCRS refrigerant is compressed.	2. In VARS refrigerant is heated then absorbed.
3. It includes five simple parts to complete one cycle. a. compressor b. condenser c. Receiver d. Expansion valve e. Evaporator	3. In VARS compressor is alone replaced by a. absorber b. pump c. Generator d. pressure reducing valve
4. There is only water vapour as refrigerant.	4. water vapour is disolved in amonia.
5. The COP is very high.	5. COP is lower as compared to VCRS.
6. Due to high pressure chance of leckage is high.	6. No leckage of refrigerant.
7. VCRS is more noisy due to compressor.	7. VARS is less noisy.
8. It has high operating cost.	8. It has low operating cost as compared to VCRS.
9. Part load performance is low.	9. No effect of variation of load.
10. It is used home cooling appliances.	10. It is used in bigger tonnage plant.

27·09·23

② Find the ideal COP of the vapour absorption system in which heating, cooling and refrigeration take place at temp. of 197°C, 17°C and −3°C respectively.

Ans: Given data

$T_G = 197°C = 470\,K$

$T_C = 17°C = 290\,K$

$T_E = -3°C = 270\,K$

$$COP = \frac{T_E}{T_C - T_E} \times \frac{T_G - T_C}{T_G}$$

$$= \frac{270}{290-270} \times \frac{470-290}{470}$$

$$= 5.17$$

③

UNIT-4

03.10.23

Refrigeration Equipments

Refrigerant compressors :-

It is a machine used to compress the vapour refrigerant from the evaporator and to raise its pressure, so that the corresponding saturation temperature also increase. since the compression of refrigerant requirs some work to be done It therefore compressor must be driven by some prime mover.

Classification of compressor :-

ⓐ According to the method of compressor :-

1. Reciprocating compressor
2. Rotary compressor
3. Centrifugal compressor

ⓑ According to the no. of working stroke :-

1. single acting compressor
2. Double acting compressor

ⓒ According to the no. of stage :-

1. single stage compressor
2. Multi stage compressor

ⓓ According to the method of drive employed :-

1. Direct drive compressor
2. Belt drive compressor

ⓔ According to the location of prime mover :-

1. Semi Hermitic compressor
2. Hermitic compressor.

Important terms related to compressor

The following important terms are frequently used in this chapter.

Suction pressure :-

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

Discharge pressure :-

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

Compression ratio :-

It is the ratio of absolute discharge pressure to the absolute suction pressure.

It is also defined as total cylinder volume to the clearance volume.

Suction volume / swept volume / piston displacement volume / stroke volume

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

It is the volume swept by the piston when it moves from TDC to BDC.

Mathmatically, $V_s = A \times l$

$$= \frac{\pi}{4} \times d^2 \times l$$

where, d = diameter of the cylinder

l = stroke length or length of the

Clearance factor :- (c)

It is the ratio of clearance volume to swept volume.

Mathmatically, $c = \frac{V_c}{V_s}$

compressor capacity :- (CC)

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

Mathmatically, $CC = V_s$

volumetric efficiency :-

It is the ratio of compressor capacity to the swept volume.

Mathmatically, $\eta_v = \frac{CC}{V_s}$

(*) Receprocating compressor

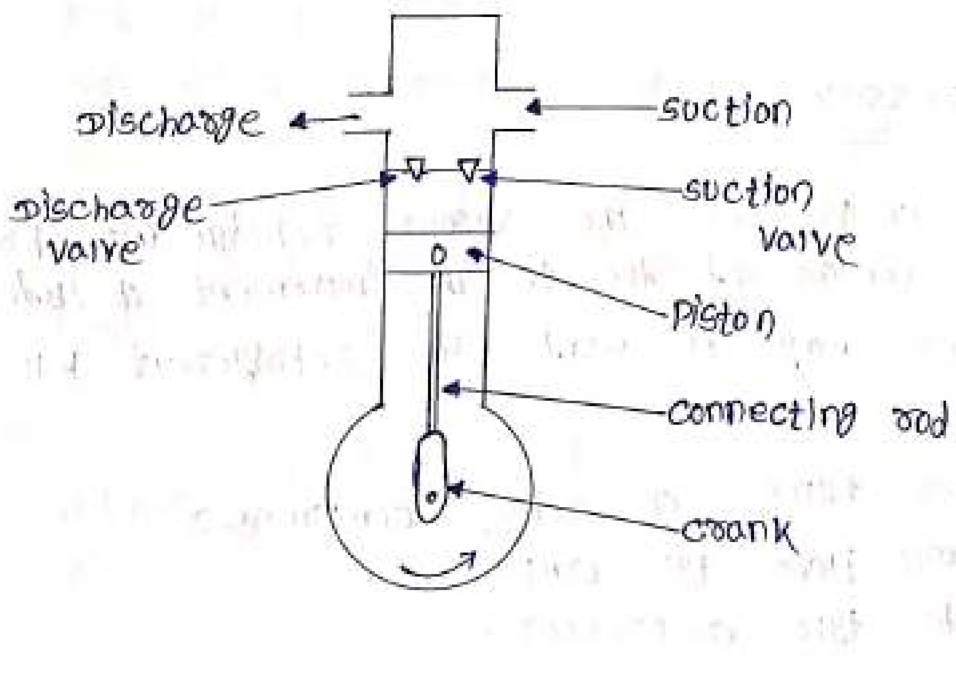
→ The compressors in which the vapour refrigerant is compressed by the receprocating motion of the piston are called receprocating compressor.

→ These compressors are used for refrigerants which have comparatively low volume and a large differential pressure.

→ The refrigerants are R-717, R-12, R-22 and R-40.

→ The two types of receprocating compressor used generally. These are :- (i) single acting vertical compressor

(ii) Double acting horizontal compressor



Let us consider from the above figure the piston is in at the top of the cylinder (called TDC).

→ TDC = Top Dead center

BDC = Bottom Dead center

→ In this time the suction and discharge valves are closed.

→ When the piston moves downward during suction stroke, the refrigerant left in the clearance space expands.

→ In this stroke the volume of the cylinder (above the piston) increases and the pressure inside the cylinder decreases.

→ When the pressure become slightly less than the suction pressure or atmospheric pressure then the suction valves get opened and the vapour refrigerant flows in to the cylinder. The flow contineous untill the piston reaches the bottom dead center.

→ After piston reach the BDC due to the spring action the piston moves upward direction. (BDC to TDC)

→ The stroke is called compression and during this stroke the volume of the cylinder decrease and pressure increases.

→ When the pressure inside the cylinder become greater than that of atmospheric pressure or on the top of the discharge valve then the discharge valve get opened and the vapor refrigerant is discharged in to the condensor and the cycle is repeated.

⊛ Rotary compressor

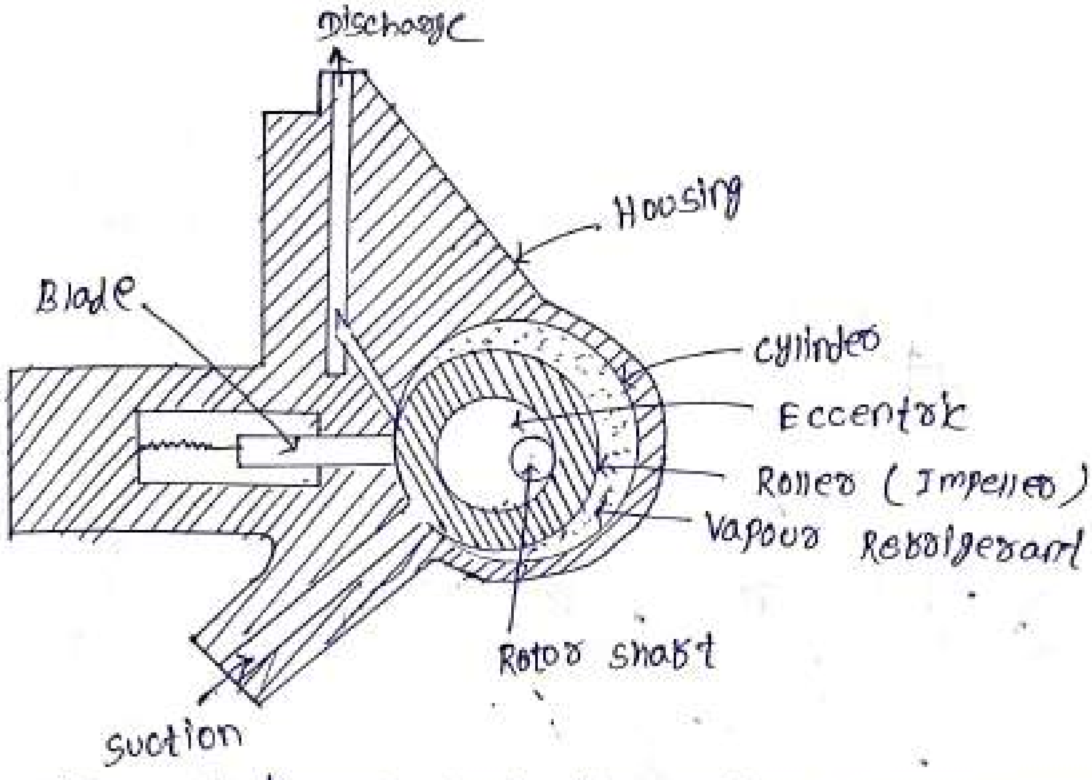
→ In a rotary compressor the vapour refrigerant from the evaporator is compressed due to the movement of blades.

→ The compressor may be used with refrigerant R 12, R22, R 114, amonia.

→ There are two types of rotary compressor

(1) Single stationary blade type compressor.

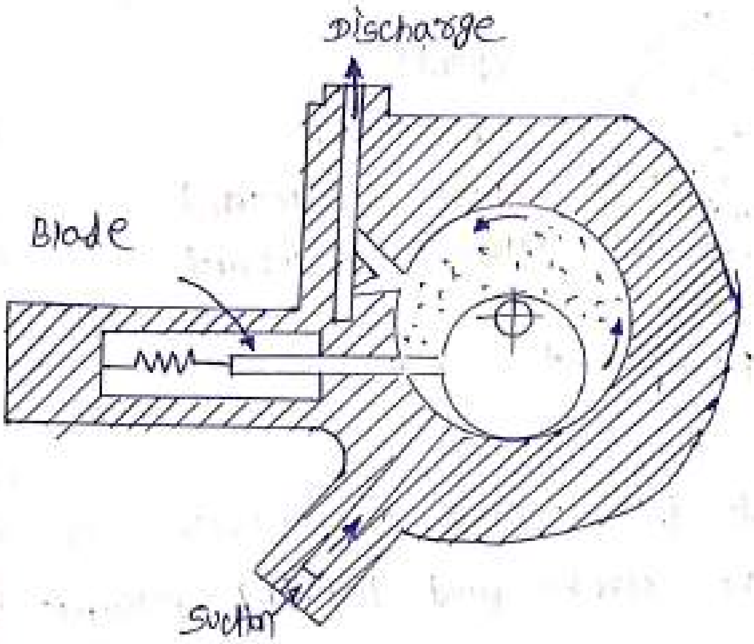
(2) Rotating blade type compressor.



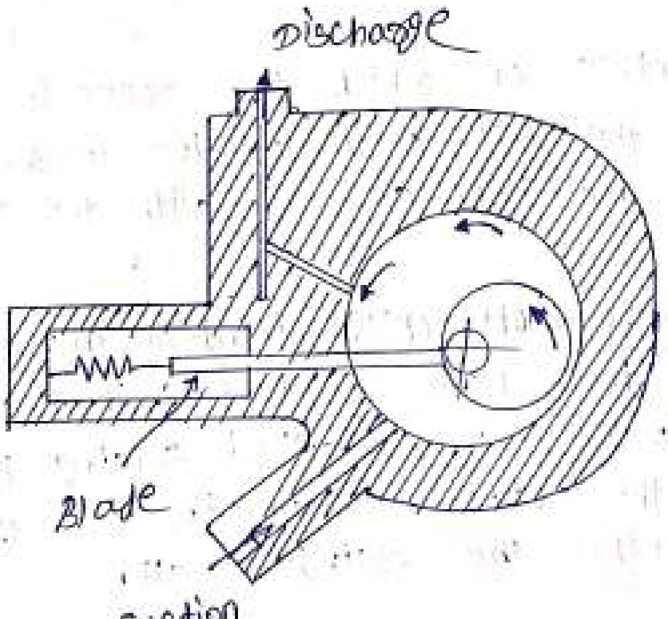
single stationary blade type rotary compressor
(a) completion of intake stroke and begining of compressor.

(1) single stationary blade type compressor

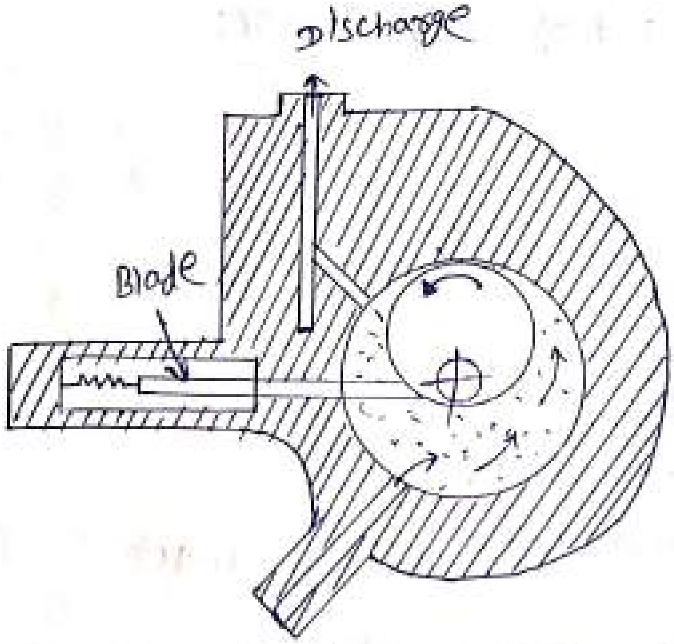
- A single stationary blade type rotary compressor is shown in the above figure.
- It consists of a stationary cylinder, a roller (or impeller) and a shaft.
- The shaft has an eccentric on which the roller is mounted.
- A blade is set in to the slot of a cylinder in such a manner that is always maintains constant with the roller by means of a spring.
- The blade moves in and out of the slot to follow the rotor when it rotates. Since the blade separates the suction and discharge part, therefore it is called sealing blades.
- When the shafts rotate the roller also rotates so that the blade is always touches the cylinder wall.



[b] compression stroke continued and new intake stroke started.



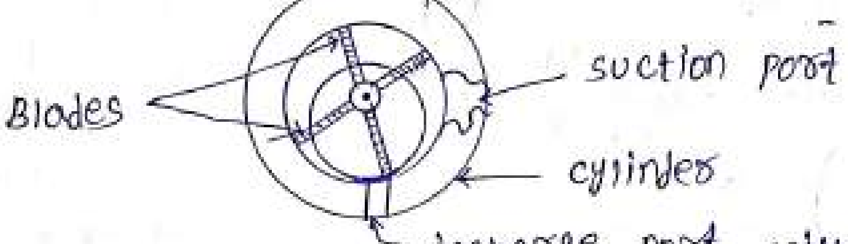
[c] compression continued and new intake stroke continued.



[d] compressed vapour discharged to condenser and new intake stroke continued.

- Fig [a] and [d] shows the various position of roller as the vapour refrigerant is compressed fig [a] shows the completion of intake stroke. (i.e the cylinder is full of low pressure and temp. vapour refrigerant) and the begining of compression stroke.
- When the roller rotates, the vapour refrigerant ahead of the roller is being compressed and the new intake from the evaporator is drawn in to the cylinder as shown in fig [b].
- As the roller rotates the vapour refrigerant ahead of the roller is being compressed and the new intake from the evaporater is drawn in to the cylinder while the compressed refrigerant is discharged to condenser. A new charge of refrigerant is drawn in to the cylinder.
- In this way the vapour refrigerant with low pressure and temperature is gradually compressed with high pressure and temperature.

② Rotating blade type rotary compressor



→ The rotating blade type rotary compressor consists of a cylinder and slotted rotor containing a number of blades.

→ The center of the rotor is eccentric with the center of cylinder.

→ The blades are forced against the cylinder wall by the centrifugal action during the rotation of the motor.

→ The low pressure and temperature vapour refrigerant from the operator is drawn through the suction port.

→ As the rotor turns, the suction vapour refrigerant entrapped between the two adjacent blades is compressed.

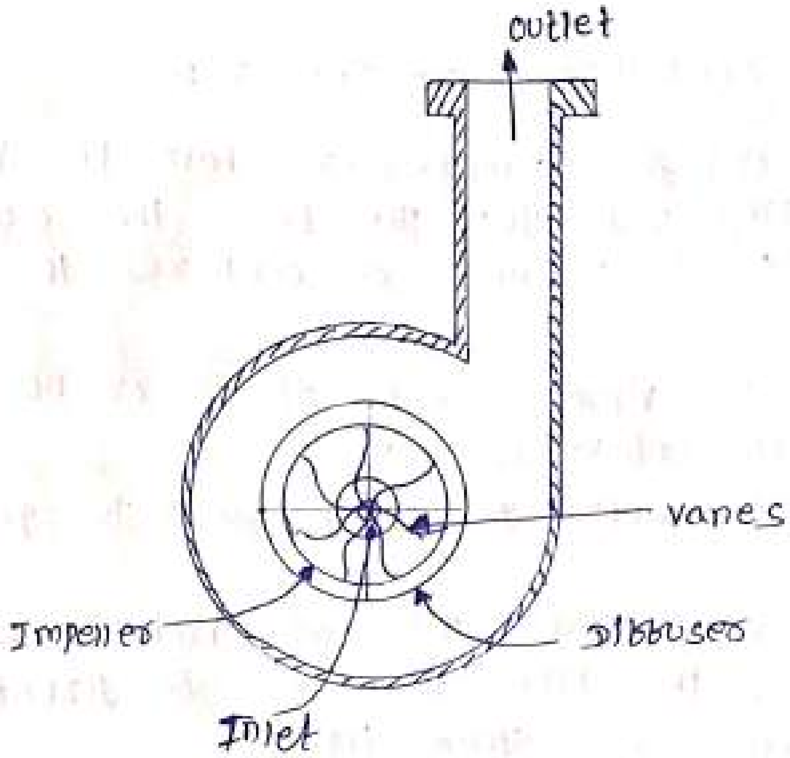
→ The compressed refrigerant at high pressure and temp is discharged through the discharge port to the condenser.

(*) Centrifugal compressor

→ The centrifugal compressor for refrigeration system was designed and developed by, Dr. Willis H. Carrier in 1922.

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

→ The refrigerant are generally used are R-11, R-12 and R-113.



- A single stage centrifugal compressor in its simplest form consists of impeller to which a number of curved vanes are fitted symmetrically.
- The impeller rotates in an air tight 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 center 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 in to 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 it furthers the kinetic energy to pressure energy before it leaves the refrigerant to the evaporator.

Advantages of centrifugal compressor :-

- 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 compressor.
- These compressors vibrates with little or no vibration as there are no unbalanced masses.
- The operation of centrifugal compressors is quite and calm.
- The centrifugal compressor runs at high speeds (3000 rpm and above), therefore those can be directly connected to electric motors or steam turbine.
- Because of high speed, these compressors can handle large volume of vapour refrigerant, accompared to reciprocating compressor.
- The efficiency of these compressor is considerably high.
- The large size centrifugal compressor require less floor area as compared to reciprocating compressor.

Disadvantages of centrifugal compressor :-

- The main disadvantages in centrifugal compressor is surging. It occurs when the refrigeration load decreases to below 35 percent of the rated capacity and causes severe stress conditions in the compressor.
- The increase in pressure per stage is less as compared to reciprocating compressor.
- The centrifugal compressors are not practical below 50 tonnes capacity load.
- The refrigerants used with these compressors should have high specific volume.

→ According to the locations of prime movers compressor can be classified in to three types.

(i) Hermitic compressor
(ii) semihermitic compressor
(iii) open compressor

(i) Hermitic compressor :-

When the electric motor is together with the compressor in the same housing is called hermitic compressor.

(ii) semihermitic compressor :-

When the motor is together with the compressor in the same chamber, but this chamber can be opened, being fastened by screw and seals.

(iii) open compressor :-

When the electric motor is not together with the compressor is called open compressor.

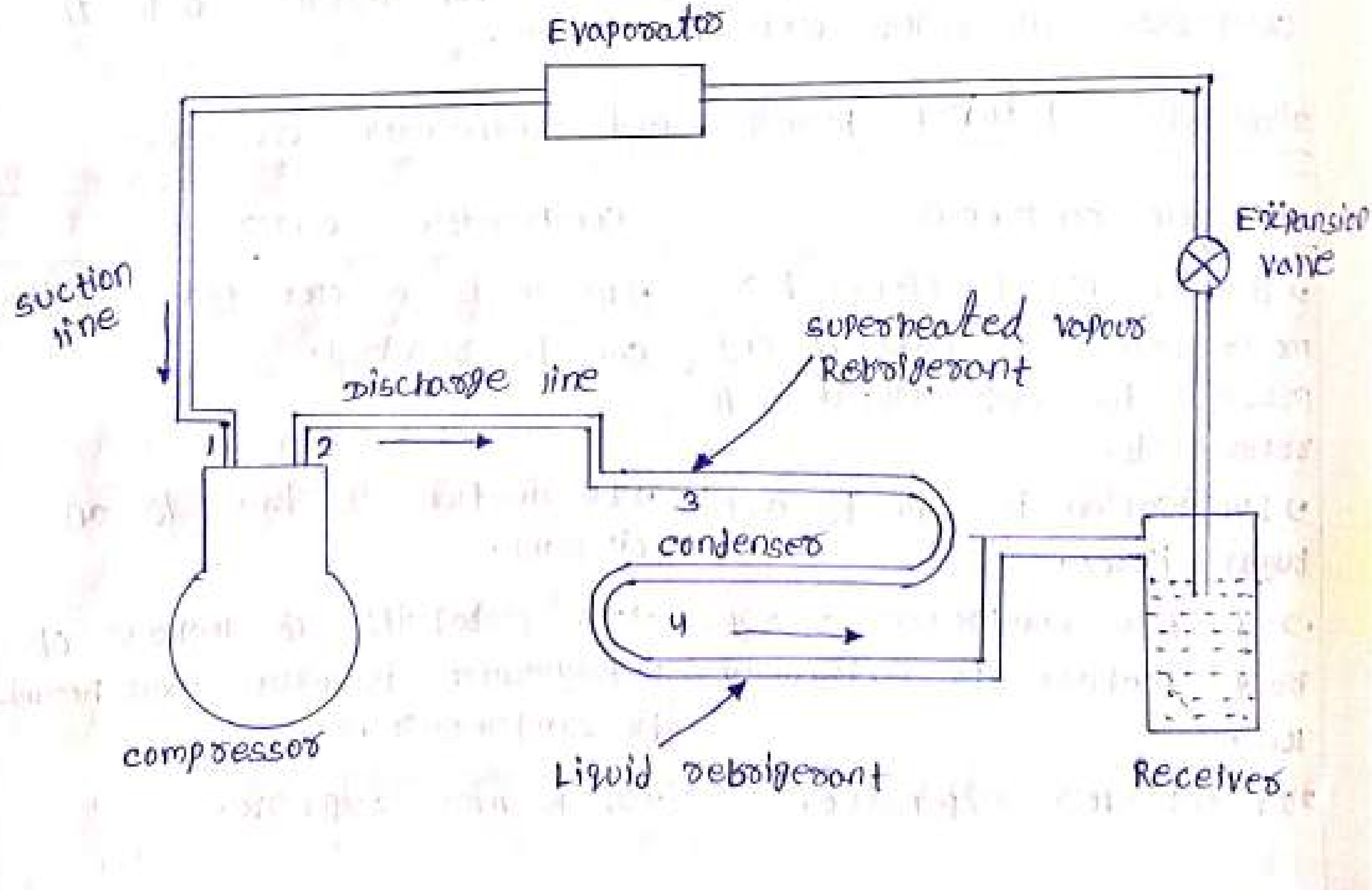
Difference between hermitic and semihermitic compressor

Hermitic compressor	semihermitic compressor
• It can not be opened for maintainance in case of any problem the only solution is to replace it.	• As it is a open type, so it can be repaired.
• Lubrication is done by centrifugal force.	• Lubrication is done by an oil pump.
• In this compressor refrigerant leakase is extremely low.	• In probability of leakage of refrigerant is more than hermitic compressor.
• It is less expensive.	• It is more expensive.

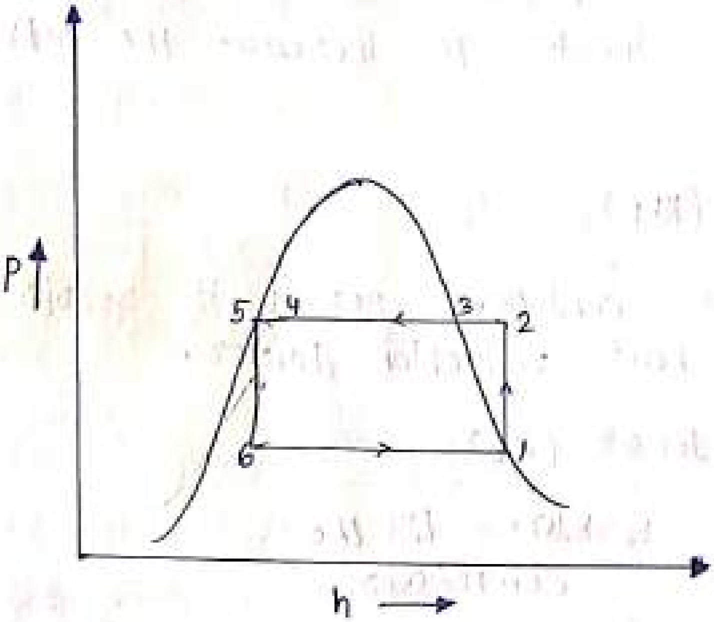
CONDENSER

- The condenser is an important device used in the high pressure side of a refrigeration system.
- It's function is to remove heat from the hot refrigerant from the condenser.
- The heat from the hot refrigerant in a condenser is first removed by transfering it to wall of compressor and then by cooling medium.
- The cooling medium may be air or water or combination of air and water.
- The selection of condenser upon the capacity of the refrigeration system. the type of refrigerant used and the type of cooling medium available.

Working of a condenser



→ The working of a condenser may be set understood by considering a simple refrigerating system.
→ The corresponding P-h diagram showing three stages of a refrigerant cooling.



process (1-2) = compression
(2-3) = Desuperheating
(3-4) = condensing or condensation
(4-5) = subcooling
(5-6) = Expansion
(6-1) = Evaporation

→ The compressor draws in the superheated vapour refrigerant that contains the heat it absorbed in the evaporator.
→ The compressors adds more heat to the superheated vapour.
→ The highly superheated vapour from the compressor is pumped to the condenser through the discharge line.
→ The condenser cools the refrigerant in three stages.
→ First of all the superheated vapour is cooled to saturation temperature (called desuperheating) corresponding to the pressure of the refrigerant.

→ The desuperheating occurs in the discharge line and in the first few coils of the condenser.
→ Now the saturated vapour refrigerant gives up its latent heat and is condensed to a saturated liquid refrigerant. The process is called condensation.
→ The temp. of the liquid refrigerant is reduced below its saturation temperature inorder to increase the refrigeration effect.

Heat rejection factor (HRF)

2 Marks

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

The load on the condenser (Q_c)

$$Q_c = \text{Refrigeration capacity} + \text{workdone by the compressor}$$

$$= R_E + W$$

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

$$\left(\because COP = \frac{R_E}{W}\right)$$

(*) Classification of condenser

① Air cooled condenser
② water cooled condenser
③ Evaporative condenser

① Air cooled condenser :-

→ Air cooled condenser is one in which the removal of heat is done by ~~water~~ air.

⇒ It consists of steel or copper tubing through which the refrigerant flows. Generally copper tubes are used because of its excellent heat transfer ability.

⇒ The condenser with steel tubes are used in amonia refrigerating system.

⇒ The tubes are usually provided with plate type fins to increase the surface area for heat transfer and made up of alluminium because of light weight.

Types of air cooled condenser

(a) Natural convection air cooled condenser

(b) Forced convection air cooled condenser

(a) Natural convection air cooled condenser :-

In this type of condenser, that the heat is transfer from the condenser coils to the air by natural convection.

It is only used in small capacity application i.e domestic refrigerator, water air cooler and A.C.

(b) Forced convection air cooled condenser :-

In this type of condenser, fan is used to force the air over the condensers coil to increase heat transfer capacity.

The forced convection condensers may be devided in to two groups.

(i) Base mounted air cooled condenser.

(ii) Remote air cooled condenser.

② Water cooled condenser :-

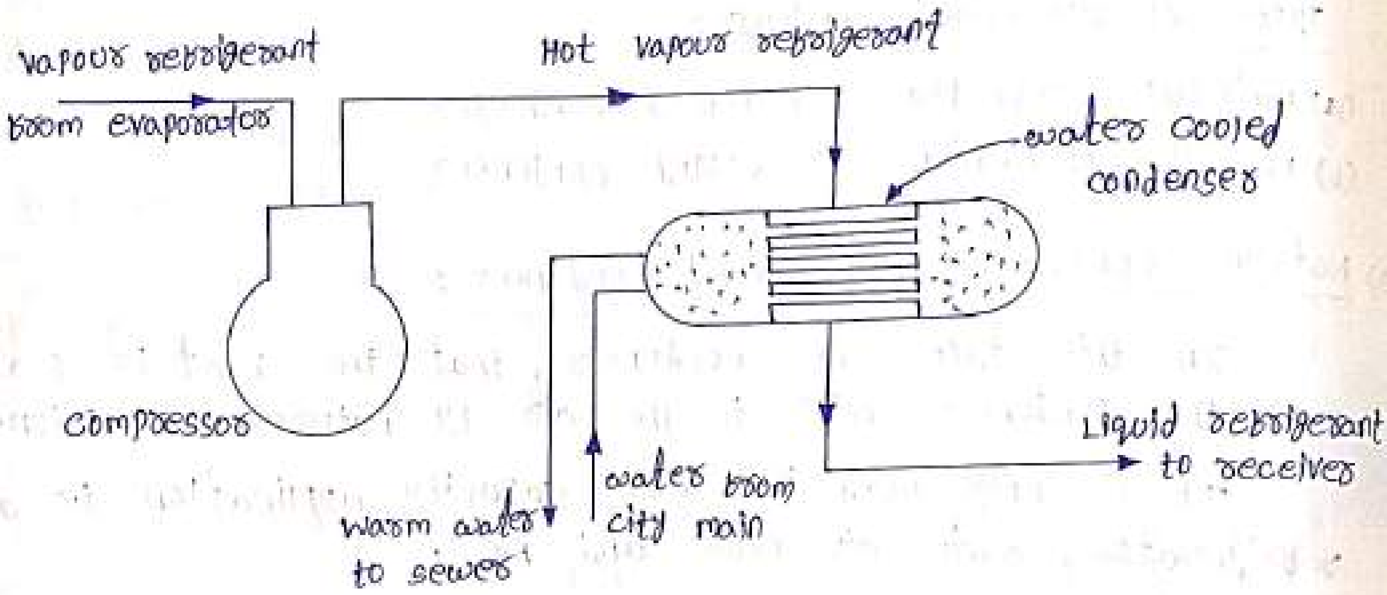
⇒ Water cooled condenser is one in which water is used as condensing medium. These condensers are commonly used in commercial and industrial refrigerating units.

⇒ The water-cooled condenser may use either of following two water systems.

(a) Waste water system:-

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

→ This system is used on small units and in locations where large quantity of fresh inexpensive water are available.



(b) Recirculated water system:-

→ In this system the same water circulating in the condenser is cooled and used again and again. Thus this system requires some type of water cooling devices.

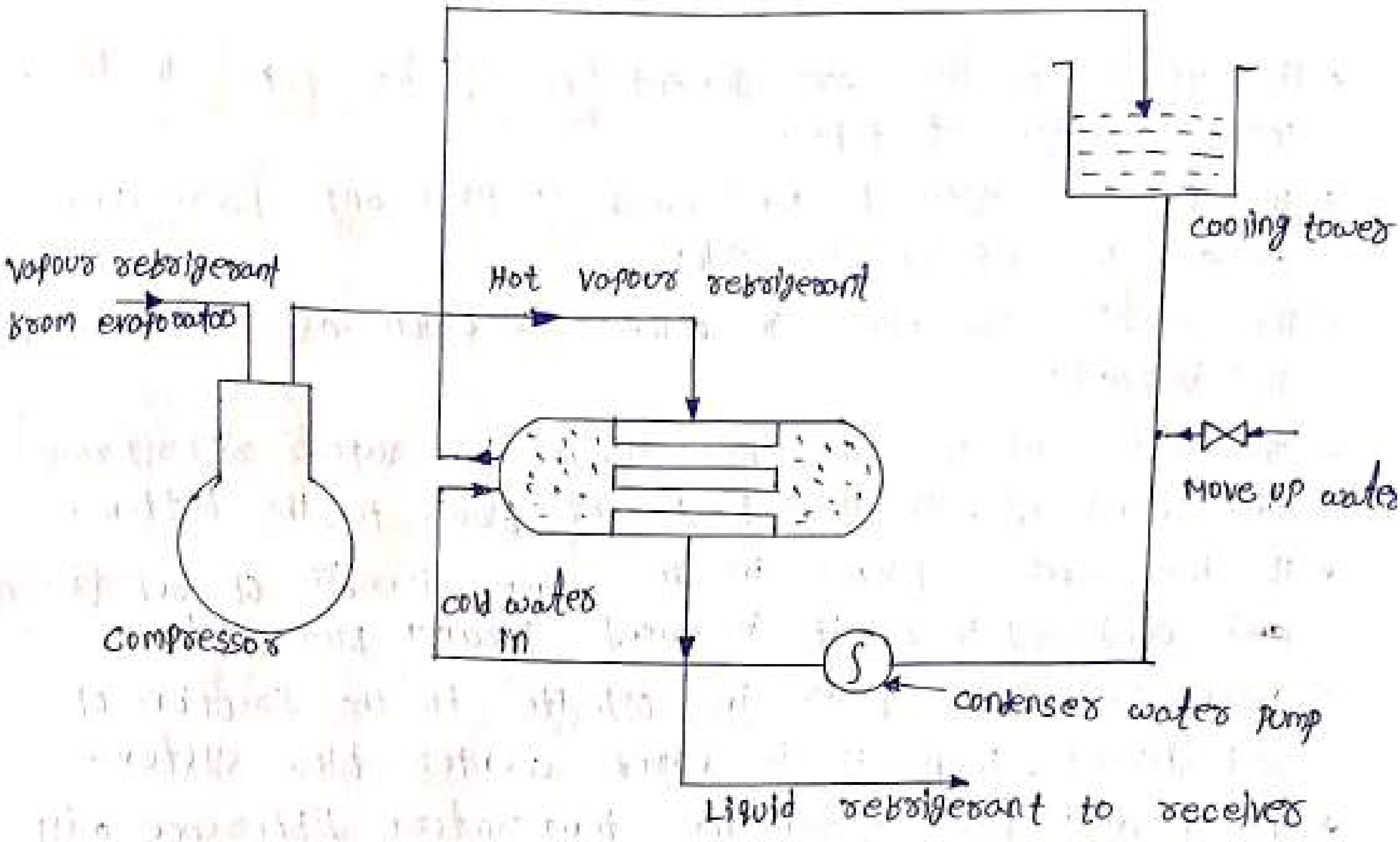
→ The cooling water tower and spray ponds are the most common cooling devices used in recirculated water system.

→ According to the construction of condenser water cooled condensers are classified in to three types.

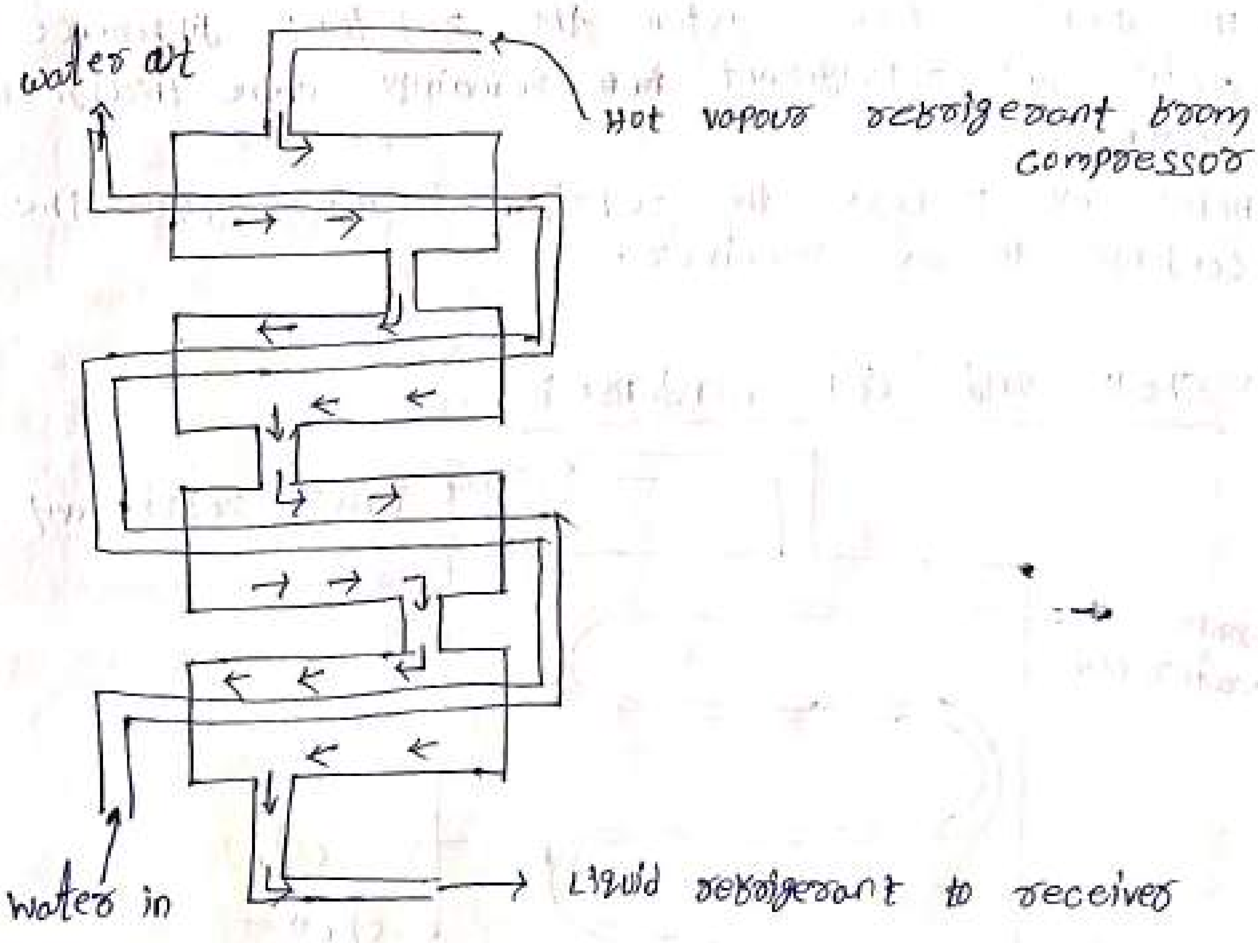
(i) Tube in tube or double tube condenser.

(ii) shell and coils condenser.

(iii) shell and tube condenser.



(i) Tube in tube or double tube condensers water out



→ It consists of an arrangement of water tube inside a large refrigerant tube.

→ In this arrangement the vapour refrigerant from compressor enters the top of the tube.

→ The water also flows in other direction as the flow of refrigerant.

→ The water absorbs the heat from the vapour refrigerant and condensed, liquid refrigerant flows to the bottom.

→ If the water flows in the same direction of refrigerant ~~and condensed~~ then it is called parallel flow system.

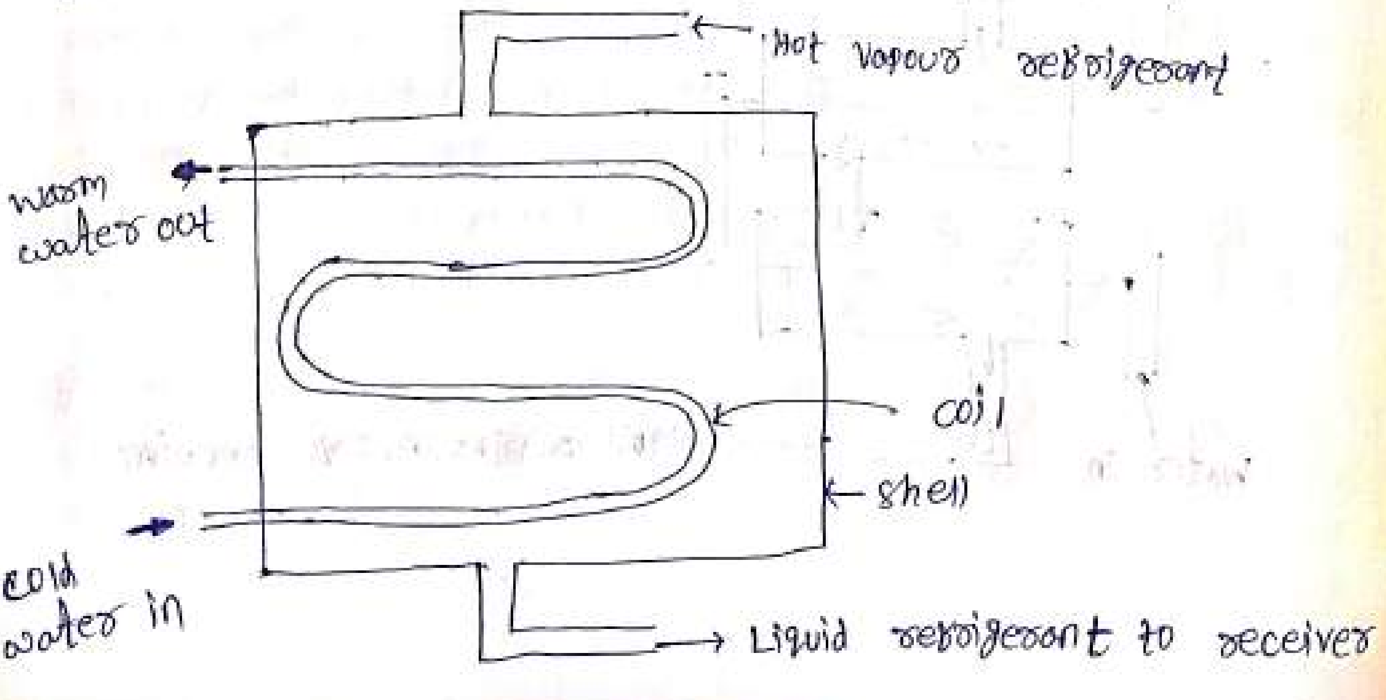
→ When the water flows in opposite to the direction of refrigerant, then it is called counter flow system.

→ In parallel flow system the temperature difference will be minimum at outlet and maximum at inlet, so heat transfer rate decreases.

→ In counter flow system the ~~ref~~ temp. difference between water and refrigerant ~~from~~ remainy same throughout the system.

→ After all process the refrigerant leaves from the condensor to the receiver.

(ii) Shell and coil condenser



→ In this type of condenser consists of one or more number of coils enclosed in a shell.

→ The coil may be finned or bored.

→ The coils can be arranged both horizontally as well as vertically.

→ The coil inside the shell is allowed to expanding contracting with temp. rise or fall.

→ The spring action of coil helps it to withstand temperature strain.

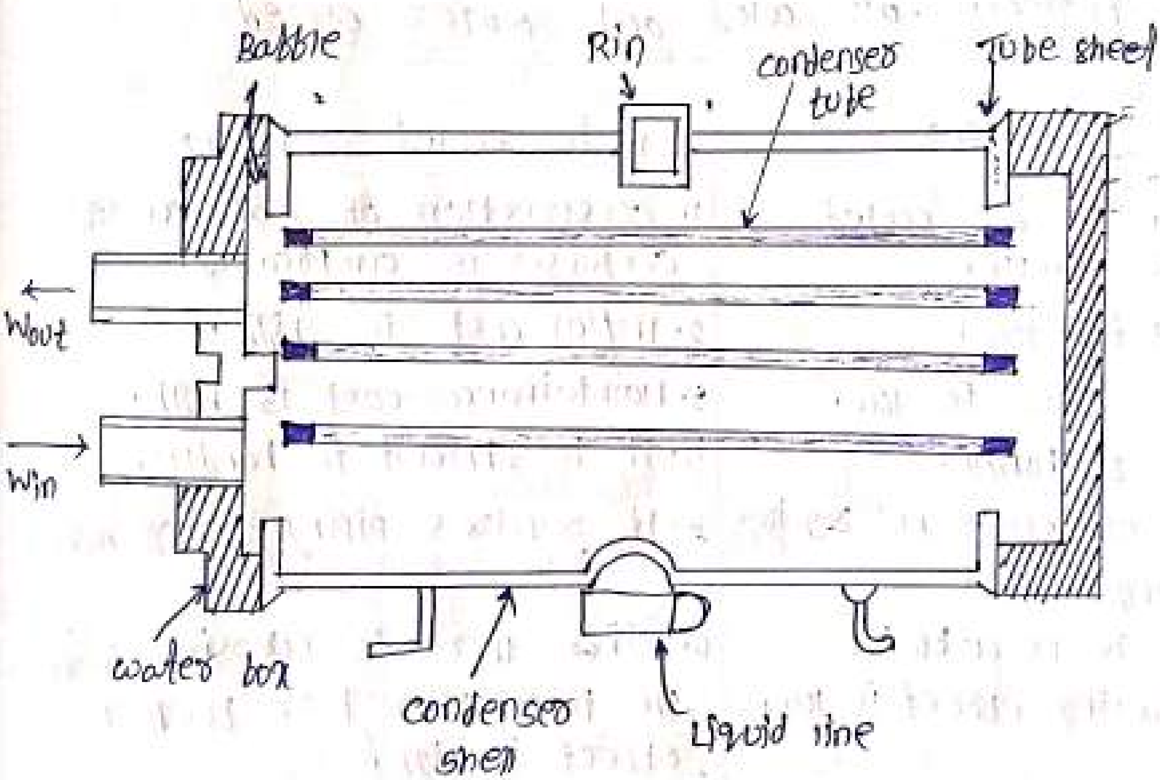
→ The hot refrigerant enters in to the shell at top.

→ The warm refrigerant then surrounds the water coil and the water absorbs the heat.

→ The condensed refrigerant then drop to the bottom of shell.

→ Because of the coils are completely enclosed by welded steel then the mechanical cleaning of coils is impossible, the coils are cleaned with chemical.

(iii) Shell and tube condenser



→ Shell and tube is the most common type of condenser in large chemical processing plants.

→ In this type of condenser a number of straight water tubes are enclosed a large cylindrical shell.

→ The shell may be with or without fins.
→ The common material for shell is steel and copper.
→ In case of ammonia refrigerant we use steel tube because ammonia the copper.
→ Grooved tube sheet is welded at both ends of the cylinder.
→ The water tubes are extended to the groove of tube sheet to achieve vapour tight fit.
→ Intermediate supports are provided to avoid bending of water tube.
→ The hot refrigerant enters the shell at top. Refrigerant rejects heat to the water when it contacts with water tubes.
→ Finally the condensed refrigerant drops to the bottom of shell.

Difference between air cooled and water cooled

Air-cooled condenser	Water-cooled condenser
1. Construction of air cooled condenser is simple.	1. Construction of water-cooled condenser is complicated.
2. Initial cost is low.	2. Initial cost is high.
3. Maintainance cost is low.	3. Maintainance cost is high.
4. It is easy to handle.	4. It is difficult to handle.
5. Air-cooled condenser not requires piping arrangement.	5. It requires piping arrangement.
6. Since there is no corrosion therefore fouling effect is low.	6. Since there is corrosion inside the tube, therefore fouling effect is high.
7. These condensers are used for low capacity. (less than 5 TR).	7. These condensers are used for high capacity.

9. Fan noise is more.	9. Fan noise is not.
10. Air-cooled condensers are high flexibility.	10. Water-cooled condensers are low flexibility.

Evaporator

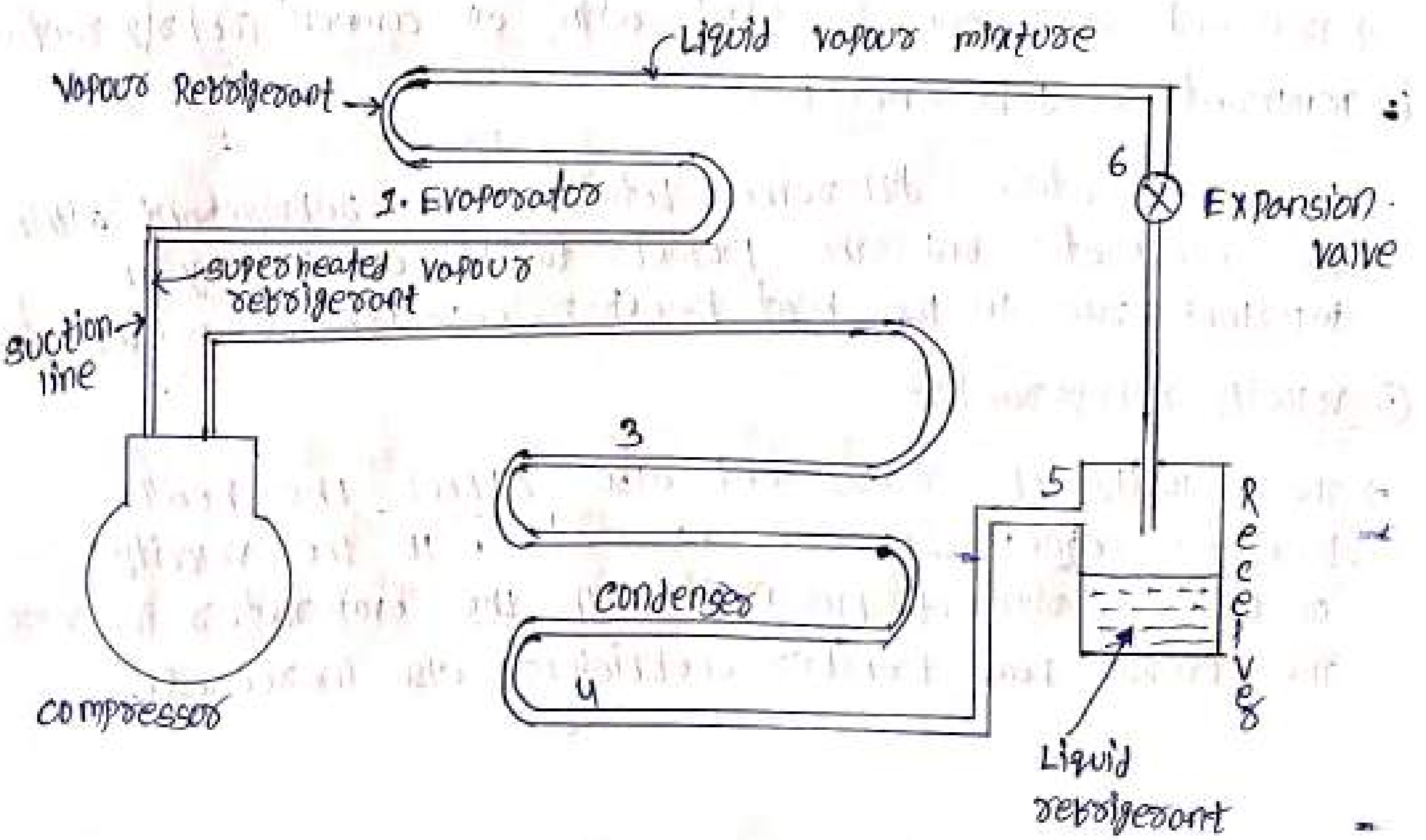
→ Evaporator is an important device which is used in the low pressure and low temperature side of a refrigeration system.

→ The liquid from the expansion valve enters in to the evaporator, where it boils and changes in to vapour.

→ The function of an evaporator is to absorb heat from the surroundings which is to be cooled by means of refrigerant.

→ The temp. of the boiling refrigerant in the evaporator must always be less than that of the surroundings medium so that the heat flows to the refrigerant.

Working of Evaporator



→ The liquid refrigerant at low pressure enters the evaporator at point 6.

→ As the liquid refrigerant passes through the evaporator coil, it continually absorbs heat through the coil walls, from the medium being cooled.

→ During this refrigerant continues to boil and evaporate.

→ Finally at point 7 all the liquid refrigerant has evaporated and only vapour refrigerant remains in the evaporator coil.

→ The liquid refrigerants ability to convert absorbed heat to latent heat is now used up.

④ Factors affecting the heat transfer capacity of an evaporator

① Material:-

→ In order to have rapid heat transfer in an evaporator, the material used for the construction of an evaporator coil should be a good conductor.

→ Since the metals are best conductor of heat, therefore they are always used for evaporators.

→ Iron and steel can be used with all common refrigerant.

② Temperature difference:-

→ The temperature difference between the refrigerant within the evaporator and the products to be cooled play an important role in the heat transfer capacity of an evaporator.

③ Velocity refrigerant:-

→ The velocity of refrigerant also affect the heat transfer capacity of an evaporator. If the velocity of the refrigerant flowing through the evaporator increases, the overall heat transfer coefficient also increases.

→ But this increased velocity will cause greater pressure lose in the evaporator.

④ Thickness of the evaporator coil wall :-

→ The thickness of the evaporator coil wall also affects the heat transfer capacity of the evaporator.

→ In general, the thicker the wall, the slower is the rate of heat transfer.

→ Since the refrigerant, in the evaporator is under pressure, therefore the evaporator wall must be thick enough to withstand the effect of the pressure.

⑤ Contact surface area :-

→ An important factor affecting the evaporator capacity is the contact surface available between the walls of evaporator coil and the medium being cooled.

→ The amount of contact surface, in turn depens ~~of~~ basically on the physical size and shape of the evaporator coil.

Marks

Capacity of an evaporator

The capacity of an evaporator is defined as the amount of heat absorbed by its over a given period of time.

It is denoted by 'Q'.

$Q = UA(T_2 - T_1)$ W or J/s

where, U = overall heat transfer coefficient in, W/m² °C.

A = Area of evaporator surface in, m².

T_2 = Temperature of medium to be cooled (or temperature outside the evaporator), °C.

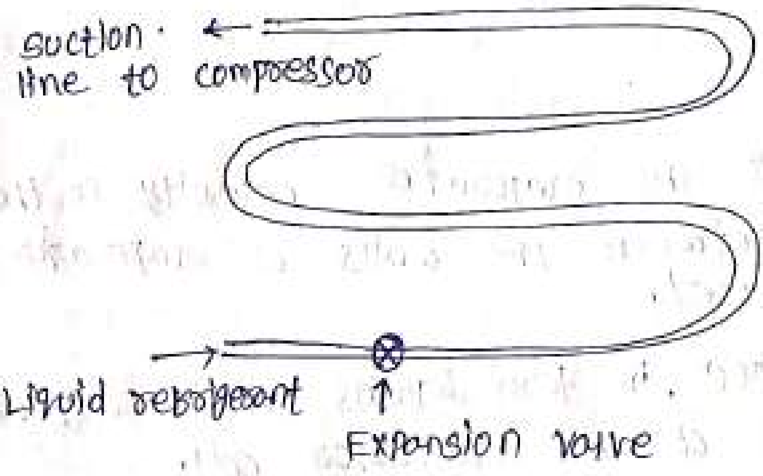
T_1 = saturation temp of the refrigerant at evaporator pressure (or temp. inside the evaporator).

(*) Types of Evaporator

According to the type of construction

a. Bare tube coil evaporator.
b. Finned tube evaporator.
c. Plate evaporator.
d. Shell and tube evaporator.

(a) Bare tube coil evaporator:-



- → Bare tube evaporator is the simplest type evaporator.
- → The bare tube coil evaporator is also known as prime surface evaporator.
- → Because of the simple construction, the bare tube coil is easy to clean and defrost.
- → Bare tube evaporators are usually constructed either of steel pipe or copper tubing pipes.
- → Bare tubes evaporators are available in number of size, shapes and designs.
- → Effective length and diameter of the tube are governed by the capacity of expansion valve.
- → The copper tubing is used for small evaporators where the refrigerant other than ammonia.

→ The steel pipes are used with the large evaporator where ammonia is used as the refrigerant.

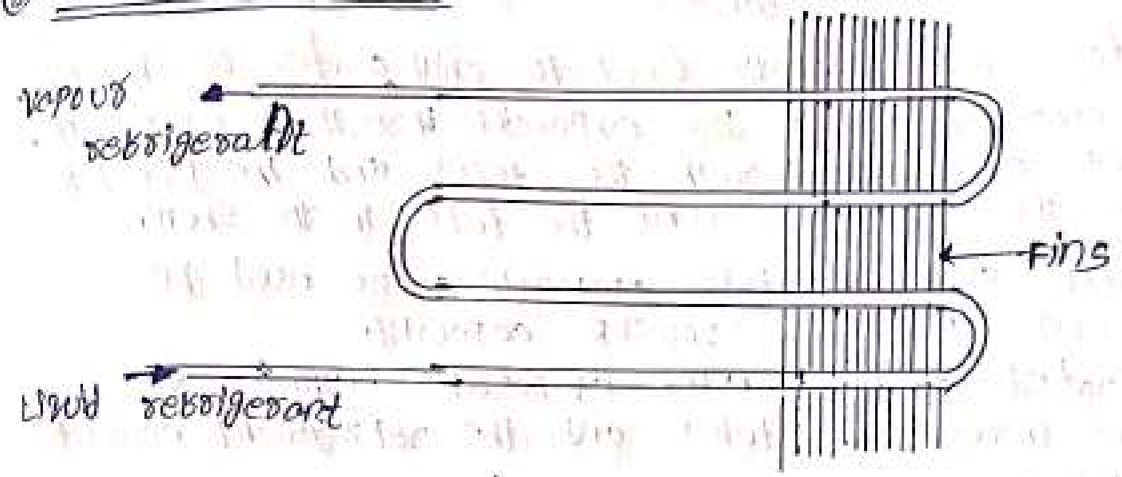
→ The atmospheric air blows over the bare tube evaporator and the chilled air leaving it used for the cooling purpose.

Application

→ Bare tube evaporator are most frequently used for cooling applications.

→ They are widely used in domestic refrigerator because they are easier to clean.

(b) Finned Evaporator :-



→ The finned evaporator consists of bare tubes or coils over which the metal plate or fins are fastened.

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

→ The shape, size or spacing of the fins can be adopted to provide best rate of heat transfer for a given applications.

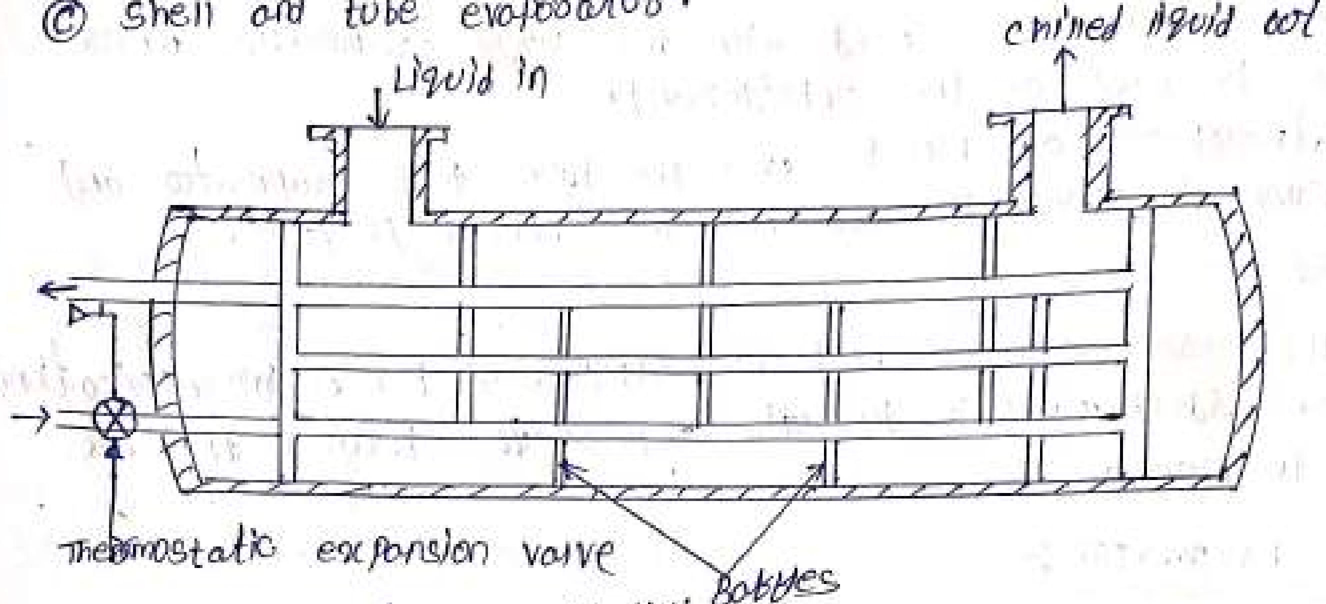
→ Since the fins are greatly increase the contact surface for heat transfer, therefore the finned evaporators are called extend surface evaporator.

→ The finned type evaporator is more effective then the bare tube evaporator.

Application :-

→ The finned evaporator mostly used in the air conditioner (window split, packaged and the central air conditioning system).

© Shell and tube evaporator.



→ These evaporators are generally used to chill water or brine.

→ When it is operated as a dry expansion ~~through the~~ evaporator, the refrigerant circulate through the tubes and the liquid to be cooled fills the space around the tube in the shell.

→ The dry expansion shell and tube evaporators are used for refrigerating unit of 2 to 200 TR capacity.

→ When the operated as a flooded evaporator. The water or brine flows through the tubes and the refrigerant circulate around the tube.

→ The flooded shell and tube evaporator are used for refrigerating units of 10 to 5000 TR capacity.

2 marks
Fouling factor

The water used in water cooled condenser always contains certain amount of minerals, foreign particles and impurities. These materials deposite inside the condenser water tubes which reduce the heat transfer rate and restrict the water flow, this is called water fouling.

06.11.23

UNIT-5

REFRIGERANT FLOW CONTROLS, REFRIGERANTS AND APPLICATION OF REFRIGERANT

Refrigerant

Refrigerant is a heat carrying medium or the working fluid in a refrigeration cycle.

→ The natural ice and the mixture of salt and ice where the first refrigerant.

→ In 1834 ether, amonia, supher dioxide, methyle chloride and carbon dioxide are used as refrigerant in refrigerating machines.

Classification of Refrigerant

Refrigerants

- Primary refrigerant
  - → Halo carbon
  - → Azeotrope
  - → Inorganic
  - → Hydrocarbon
- Secondary refrigerant

5 Marks

Desire properties of an ideal refrigerant

A refrigerant is said to be ideal if it has all the following properties.

(i) Low boiling and freezing point

(ii) High critical pressure and temperature

(iii) High latent heat of vapourisation

(iv) Low specific heat of liquid and high specific heat of vapour.
(v) Low specific volume of vapour.
(vi) High thermal conductivity.
(vii) Non-corrosive to metal.
(viii) Non-flamable and non-explosive.
(ix) Non-toxic.
(x) Low cost.
(xi) Easy and regularly available.
(xii) Easy to liquify at moderate pressure and temperature.
(xiii) Easy of locating leacks by odour (smell) or suitable indicator.
(xiv) Mixes well with oil.
(xv) ozone friendly.
(xvi) High COP.

Ex :- air.

07.11.23

Designation system for refrigerant

The refrigerants are internationaly designated as are followed by certain numbers. The general chemical formula for the refrigerant is given as $C_mH_nCl_pF_q$.

m = no. of carbon atoms
n = no. of hydrogen atoms
p = no. of chlorine atoms
q = no. of florine atoms

The number assigned to hydro-carbon and halocarbon refrigerant have special meaning.

→ The first digit on the right side is the no. of florine atom

→ The second digit from the right side is one more than the no. of hydrogen atom present in the refrigerant.

→ The third digit from the right is one less than the no. of carbon atom present in the refrigerant.

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

8.11.23

Naming

① $R_{(m-1)(n+1)(q)}$

$CH_2Cl_2 \rightarrow R_{30}$

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

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

$\Rightarrow 4 = 4$

$R_{\underline{0}\,\underline{3}\,\underline{0}}$

② $CH_3Cl \rightarrow R_{40}$

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

$\Rightarrow 3 + 1 + 0 = 2 \times 1 + 2$

$\Rightarrow 4 = 4$

$R_{\underline{0}\,\underline{4}\,\underline{0}}$

③ $CF_3CHCl_2 \rightarrow R_{123}$

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

$\Rightarrow 1 + 2 + 3 = 2 \times 2 + 2$

$\Rightarrow 6 = 6$

$R_{\underline{1}\,\underline{2}\,\underline{3}}$

④ R_{113}

R _ _ _

$m = 2$, $n = 0$, $q = 3$

$C_2F_3Cl_3 = C_2Cl_3F_3$

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

$\Rightarrow 0 + p + 3 = 2 \times 2 + 2$

$\Rightarrow p + 3 = 6$

$\Rightarrow p = 3$

⑤ R_{011} – CCl_3F

R _ _

$m = 1$, $n = 0$, $q = 1$

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

$\Rightarrow 0 + p + 1 = 2 \times 1 + 2$

$\Rightarrow p + 1 = 4$

$\Rightarrow p = 3$

⑤ R_{115} — $C_5Cl_{10}F$

R
— — —

$q = 2$, $n = 20$, $m = 5$

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

$0+p+2 = 2\times5+2$

$\Rightarrow p+2 = 12$

$\Rightarrow p = 10$

⑥ R_{115} — C_2ClF_5

$m = 2$, $n = 0$, $q = 5$

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

$\Rightarrow 0+p+5 = 2\times2+2$

$\Rightarrow p+5 = 6$

$\Rightarrow p = 1$

⑦ $CHCl_2F$ — R_{21}

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

$\Rightarrow 1+2+1 = 2\times1+2$

$\Rightarrow 4 = 4$

R
— 2 1

⑧ $CHClF_2$ — R_{202}

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

$\Rightarrow 1+1+2 = 2\times1+2$

$\Rightarrow 4 = 4$

R
— 2 0 2

⑨ R_{114} — $C_2Cl_2F_4$

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

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

$\Rightarrow 0+p+4 = 2\times2+2$

$\Rightarrow p+4 = 6$

$\Rightarrow p = 2$

R
— —

UNIT-6

14.11.23

Psychrometry

The psychrometry is the branch of engineering science which deals with the study of moist air. (dry air mixed with water vapour) or humidity).

→ It also includes the study of behaviour of dry air and water vapour mixture under various set of conditions.

Psychrometric terms

1. **Dry air :-**

The pure dry air is a mixture of no. of gases such as nitrogen, oxygen, carbon dioxide, hydrogen etc.. The nitrogen and oxygen have the major portion of dry air.

2. **Moist air :-**

It is the mixture of dry air and water vapour. The amount of water vapour present in the air depends upon the absolute temp. and pressure of the mixture.

3. **Saturated air :-**

It is the mixture of dry air and water vapour when the air has diffused maximum amount of water vapour in to it.

4. **Degree of saturation :-**

It is the ratio of actual mass of water vapour in a unit mass of dry air to the mass of water vapour in the same mass of dry air when it is saturated at the same temperature.

5. **Humidity :-**

It is the mass of water vapour present in 1 kg dry air. It's unit is g/kg of dry air or kg/kg of dry air.

Absolute humidity

It is the mass of water vapour present in one m^3 of dry air. It's unit is g/m^3 of dry air, kg/m^3 of dry air.

Relative humidity (RH)

It is the ratio of actual mass of water vapour in a given volume of moist air to the mass of water vapour in the same volume of saturated air.

2 marks

Dry bulb temperature (t_d or t_{db})

It is the temp. of air recorded by thermometer when it is not affected by moisture in the air.

Wet bulb temperature (t_w, t_{wb})

It is the temp. of air recorded by thermometer when its bulb is surrounded by a wet cloth exposed to the air.

Dew point temperature

It is the temp. of air recorded by thermometer when the moisture present in it begins to condense.

or

Dew point temp. is the saturation temp. corresponding to the partial ~~vapour~~ of water vapour.

Wet bulb depression

It is the difference between dry bulb temp. and wet bulb temp. at any point.

$(D_{BT} - W_{BT})$

Dew point depression

It is the difference between dry bulb temp. and dew point temperature.

$(D_{BT} - D_{PT})$.

16.11.23

Psychrometer

It consist of a dry bulb thermometer and a wet bulb thermometer mounted side by side in a protective case and attached to a handle.

2 marks

(*) ## Dalton's law of partial pressure

It states that the total pressure exerted by the mixture of air and water vapour is equal to the sum of pressures which is constituent (air, water vapour separately) would exert, if it occupied the same space by itself.

Mathematically, $\Rightarrow P_b = P_a + P_v$

where, P_b = partial pressure of mixture of air and water vapour.

P_a = partial pressure of dry air.

P_v = partial pressure of water vapour.

(*) ## Psychrometric Relation

Humidity ratio (W)

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

Put, $R_a = 0.287$ kJ/kg K

$R_v = 0.461$ kJ/kg K

we know that

$$\frac{m_v}{m_a} = \frac{P_v V_v / R_v T_v}{P_a V_a / R_a T_a} \quad (\because T_v = T_a)$$

$$\frac{m_v}{m_a} = \frac{P_v V_v R_a}{P_a V_a R_v} \quad (\because V_a = V_v)$$

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

$$\Rightarrow W = \frac{m_v}{m_a} = \frac{0.287}{0.461} \times \frac{P_v}{P_a}$$

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

$$\boxed{W = 0.622 \frac{P_v}{P_b - P_v}}$$

<u>Specific humidity (W_s)</u>

$$W_s = W_{max} = 0.622 \frac{P_s}{P_b - P_s}$$

<u>Degree of saturation (μ)</u>

$$\mu = \frac{W}{W_s} = \frac{P_v}{P_s} \left[\frac{1 - \left(\frac{P_s}{P_b}\right)}{1 - \left(\frac{P_v}{P_b}\right)} \right]$$

Relative humidity (ϕ)

$P_b = P_{atm} = 1.0132$ bar

P_v =

P_s : pressure of saturated air.

$$\phi = \frac{m_v}{m_s} = \frac{P_v}{P_s}$$

$$\phi = \frac{\mu}{1-(1-\mu)\frac{P_s}{P_b}}$$

20.11.23

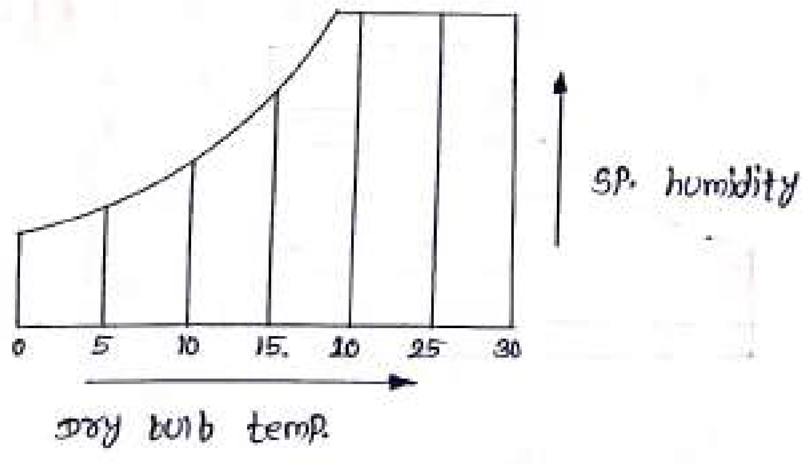
psychrometric chart

It is graphical representation of various thermodynamic properties of moist air.

- The psychrometric chart is very useful for finding out the properties of air which is required in the field of air conditioning. These are dry bulb temperature, wet bulb temperature, Dew. bulb temperature, specific humidity, Relative humidity, enthalpy, specific volume and vapour pressure of moist air.
- In psychrometric chart dry bulb temperature is taken as x-axis and specific humidity is taken as y-axis.

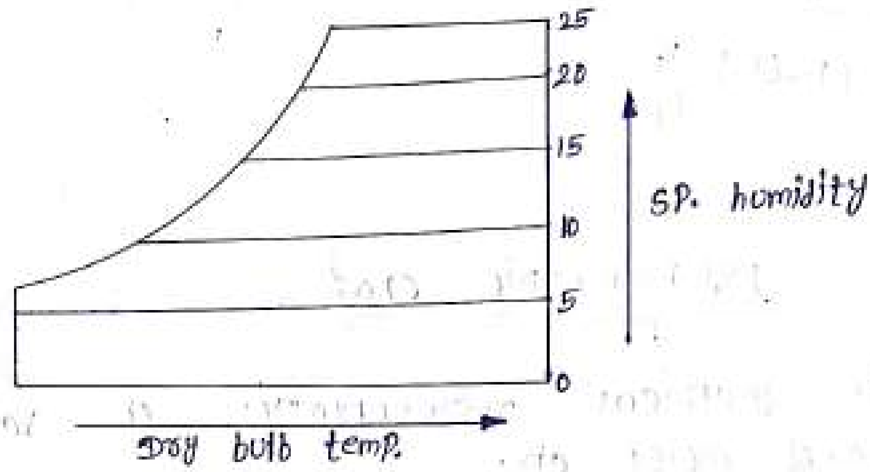
Dry bulb temp. :-

The line are vertical and parallel to y-axis and uniformly spaced. DBT varies from -6° to 45°C.



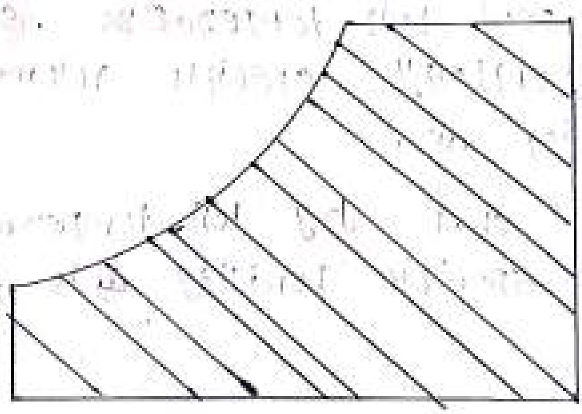
specific humidity

The specific humidity lines are horizontal, parallel to x-axis and uniformly spaced.



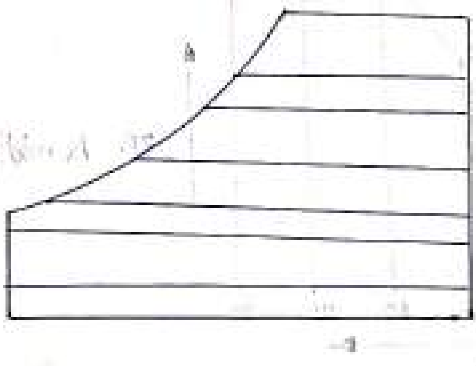
wet bulb temp.

This lines are inclined straight and non-uniformly spaced.



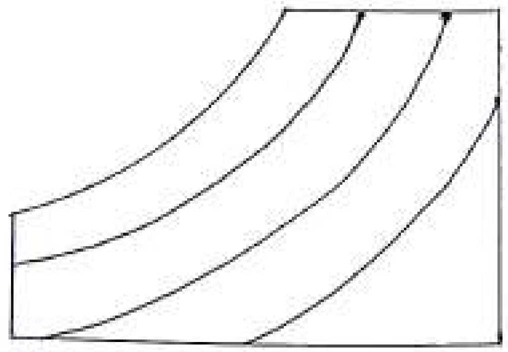
Dew point line

The lines are parallel to horizontal axis and non-uniformly spaced.



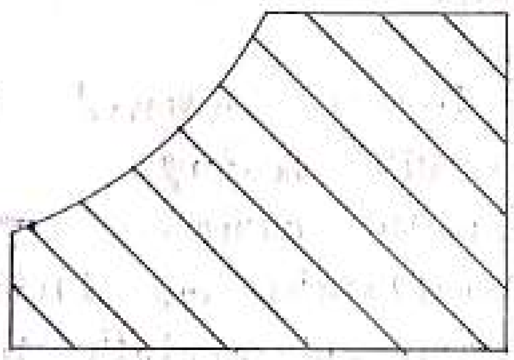
Relative humidity

The relative humidity lines are curve lines followed by the saturation curve.



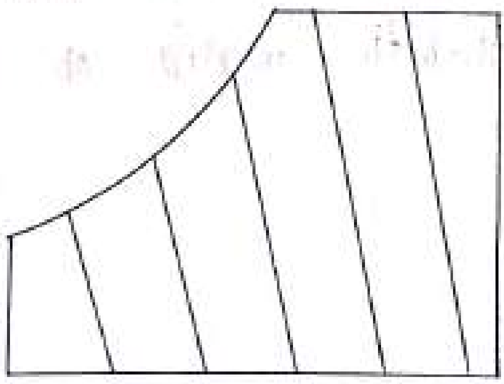
Enthalpy

The enthalpy lines are inclined straight line and uniformly spaced.



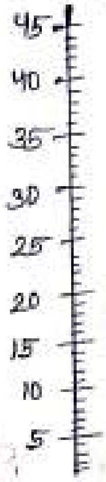
Specific volume

The specific volume lines are obliquely inclined straight line and uniformly spaced.



Vapour pressure line

The vapour pressure lines are horizontal uniformly spaced. Generally it is not showing in the psychrometric chat but a scale showing pressure in mm of Hg at the left side of the chat is called vapour pressure line.



22.11.23

5 marks

Psychrometric process

The Psychrometric process involved in air conditioning are as follows

(i) sensible heating ✓
(ii) sensible cooling ✓
(iii) Humidification and dehumidification ✓
(iv) cooling and adiabatic humidification
(v) cooling and dehumidification by water injection
(vi) Heating and humidification
(vii) Humidification by steam injection
(viii) Adiabatic chemical dehumidification
(ix) Adiabatic mixing of air stream

2 marks

Sensible heat factor (SHF)

It is the ratio of ~~tota~~ sensible heat to total heat.

Mathematically, $SHF = \frac{SH}{\text{Total heat}}$

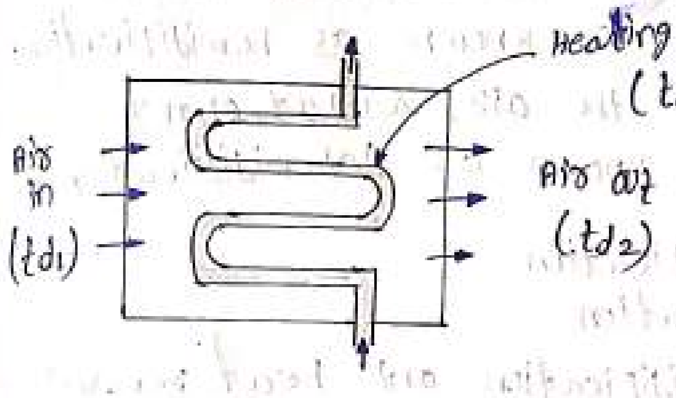
$= \frac{SH}{SH + LH}$

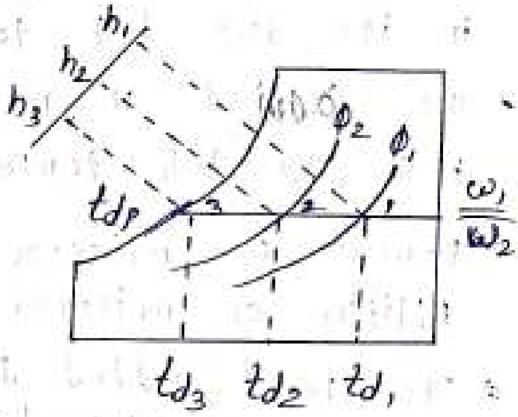
$SH = m_a(h_3 - h_2)$

$LH = m_a(h_1 - h_3)$

(i) Sensible heating :- (SH)

The heating of air without any change in specific ~~volume~~ humidity, is known as sensible heating.





(ii) sensible cooling :-

The cooling of air without any change in its specific humidity, is know as sensible cooling.

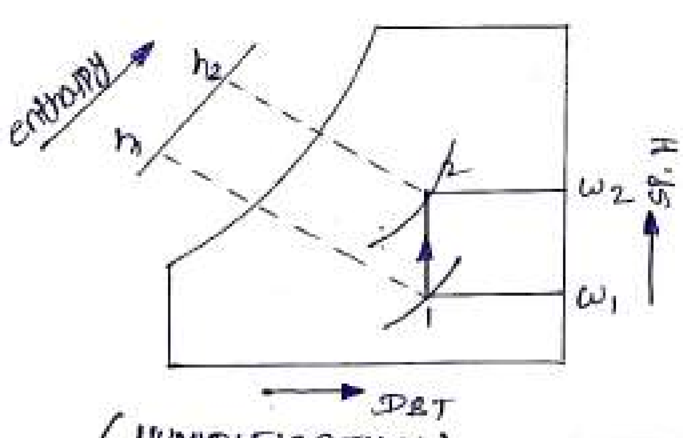
(iii) Humidification and dehumidification :-

- The addition of moisture to the air, without change in its dry bulb temperature is known as humidification.
- The substract of moisture from the air, without change its dry bulb temperature is known as dehumidification.
- Removal of moisture - Dehumidification
  Addition of moisture - Humidification
- The heat added during humidification and heat removal during dehumidification is given by

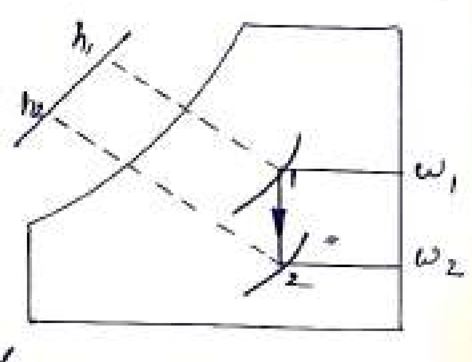
$$LH = h_2 - h_1$$

$$= h_{fg}(\omega_2 - \omega_1)$$

where h_{fg} = latent heat of vapourisation at dry bulb temp (t_{d1})



(HUMIDIFICATION)



(DEHUMIDIFICATION)