Refrigeration and Airconditioning

Refrigeration :

Refrigeration is a process in which by the action of refrigerant a close confinement is produced whose temperature is lower than the temperature of surrounding and this lower temperature has to be maintained.

Mechanism of Refrigeration :

- In refrigeration heat is to be abstracted from low temperature body and reject to high temp. atmosphere but it can't be possible to transfer the heat from low temperature body to high temperature atmosphere without any source or medium.
- Initially the refrigerant is at liquid state and is maintained at a temperature lowe than or equal to temperature of body and is at its saturation condition.
- Due to this the liquid refrigrant abstract the heat from the body and body gets cool down.
- The liquid refrigerant since at its saturation condition therefore abstracting the heat it becomes vapour. This process of heat abstraction is a process of evaporation and is known as desired effect.
- Now the vapour refrigerant is maintained at a temperature higher than or equal to temperature of the atmosphere and at its saturation condition.

- The vapour refrigerant rejects its heat into atmosphere. Since the vapour refrigerant is at its saturation therefore after rejecting the heat it get condensed into vapour.
- This process of heat rejection is a process of condensation.
- In this way cycle continues and refrigeration is continuously achieved.
- Process of evaporation and condensation takes place almost all refrigeration system except air refrigeration system.

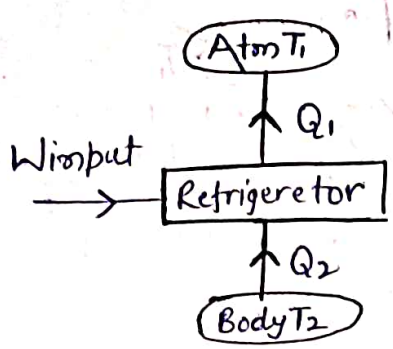
Air Refrigeration System

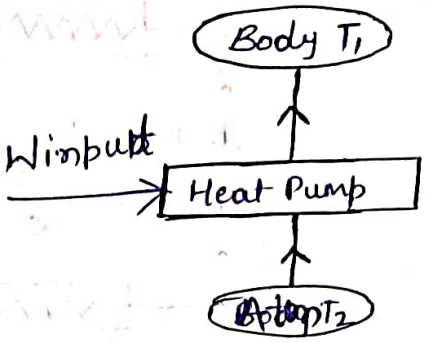
The refrigeration system in which air is used as refrigerant in place of any chemical refrigerant then such refrigeration system is called air refrigeration system.

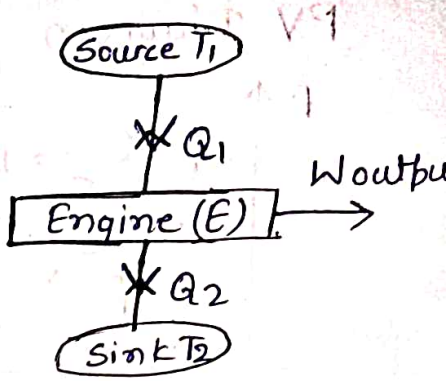
- It is based on reversed carnot cycle.
- If any machine working on reversed carnot cycle then it can be either refrigerant or heat pump.
- The working principle of both are same that it to transfer the heat from low temperature to high temperature

Refrigerator :- It abstract the heat from low temperature body and transfer the heat to high temperature body or atmosphere.

Heat Pump :- It abstract the heat from low temperature atmosphere and transfer it to high temperature body.







COP

- Just like efficiency COP is also ratio of output with input but in thermodynamics efficiency is considered for those machine which works between high temperature to low temperature and COP is considered for those machine which works between low temperature to high temperature.
- Since refrigerator and heat pump both works from low temperature to high temperature hence the ratio of output to input for them are cosidered as COP instead of efficiency
- $COP = \frac{Output}{Input}$.

$$\boxed{[COP]_{Pump} = 1 + [COP]_R}$$

COP of Refrigerator

$$[COP]_R = \frac{Output}{Input} = \frac{\text{Desired effect}}{\text{Work supplied}}$$

$$= \frac{\text{Heat abstracted from body } (T_2)}{-(\text{Heat supplied to refrigerator} - \text{Heat rejected to refrigerator})}$$

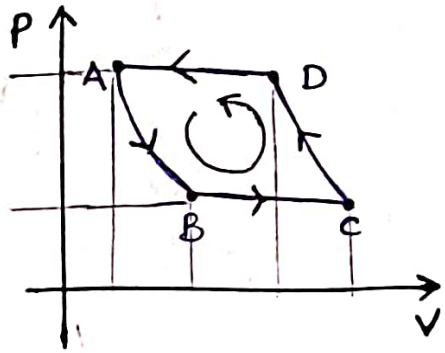
$$[COP]_R = \frac{Q_2}{-(Q_2 - Q_1)} = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}.$$

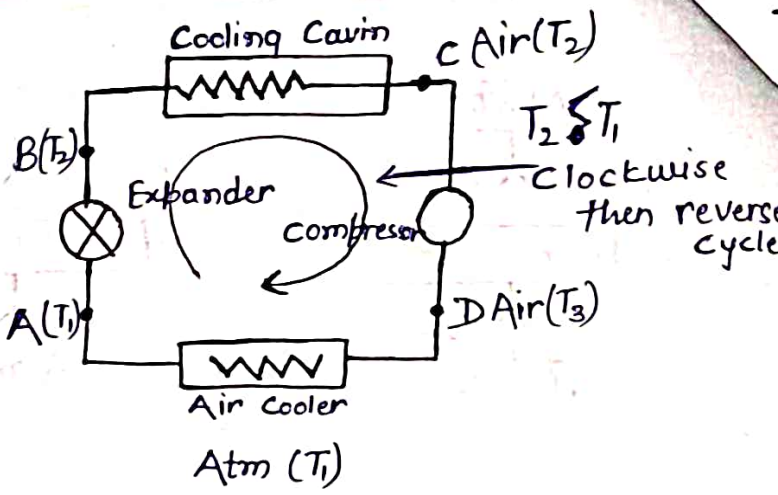
COP of Heat Pump

$$[COP]_{Pump} = \frac{Output}{Input} = \frac{\text{Desired effect}}{\text{Work supplied}} = \frac{\text{Heat supplied to body } (T_1)}{[\text{Heat supplied to pump} - \text{Heat rejecte to pum}}$$

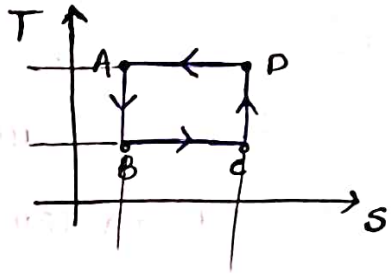
$$[COP]_{pump} = \frac{Q_1}{-(Q_2 - Q_1)} = \frac{Q_1}{Q_1 - Q_2} = \frac{T_1}{T_1 - T_2}.$$

PV Diagram





TS Diagram



A-B .. Isentropic Expansion
$P\downarrow V\uparrow T\downarrow$, S = Constant

B-C .. Isothermal Process
$V\uparrow S\uparrow P\downarrow$, T = constant

C-D .. Isentropic Compression
$P\uparrow V\downarrow T\uparrow$ S = contant

D-A .. Isothermal Process
$V\downarrow P\uparrow S\downarrow$ T = constant.

- Air Refrigerator based on Reversed carnot cycle;

- Let initially air is at high temperature T1. is at point A enters into expander undergoes reversible adiabatic expansion (isentropic expansion), due to which its volume increases temperature fall to T2, which is equal to the body.
- At point B the cold atmospheric air enters into the cooling cabin where it abstract the heat from the body at the contant temperature T_2. Due to which volume of air increases and entropy of air also increases, but body gets cool down. This is our desired process known as refrigerating effect.
- At point C, this air enters into the compressor where it is undergoes reversible adiabatic compression (isentropic compression), due to which it volume decreases and temperature of air rises to T_1, equals to temp. of atm.
- At point D, this compressed air enters into air cooler where it rejects its heat into surrounding at contant temperature T_1 due to which its volume reduces and entropy reduces.

Unit of Refrigeration :

- The unit of refrigeration is termed as tonnes of refrigeration and expressed as T.R..
- "It is defined as the amount of heat abstracted to produce 1 TON of ice that is 1000 kg of ice from water at 0 degree celsius in 1 day that is in 24 hours."
- Generally its value is 14000 kJ/hr, 210 kJ/min, 3.5 kJ/sec (3.5)
  It is also expressed as 12000 BTU/HR.

Numerical ;

1. An inventor claim to have developed a refrigerating unit which maintain a refrigerated space at -5°c which is operating in a room where temperature is 26°c has C.O.P. of 8.4 . Find out whether his claim is right or wrong.

$$T_2 = -5 + 273$$
$$= 268 \text{ K}$$
$$T_1 = 26° + 273$$
$$= 299 \text{ K}$$
$$COP_R = \frac{T_2}{T_1 - T_2} = \frac{268}{299-268} = \frac{268}{31} = 8.64$$

Hence the inventor claim is wrong.

2. A refrigerating machine working on reversed carnot cycle consume 5.5 kJ/sec for producing refrigerating effect of 940 kJ/min for maintaining region at temp. of ~~940~~ ~~kJ~~ -38°c . Determine
   1. C.O.P of refrigerating machine
   2. Higher temp. of cycle
   3. Amount of heat deliver in kJ/min when this machine is used as heat pump.

Work supplied, $W_S = 5.5$ kJ/sec

$R_N = 940$ kJ/min $= Q_2$

$T_2 = -38°C$

$= -38 + 273$

$= 235K$

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

$$= \frac{\text{Desired effect}}{\text{work supplied}}$$

$$= \frac{R_N}{W_S} = \frac{940}{5.5 \times 60} = \underline{\underline{2.84}}$$

$$COP_R = T_2/T_1 - T_2$$

$$\Rightarrow 2.84 = \frac{235}{(T_1 - 235)}$$

$$\Rightarrow 2.84 T_1 - 2.84 \times 235 = 235$$

$$\Rightarrow T_1 = \frac{235 + 2.84 \times 235}{2.84}$$

$$\Rightarrow T_1 = \underline{\underline{317.74 K}}$$

$$Q_1 = W_S + Q_2$$

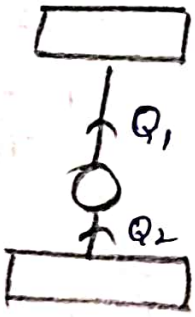
$$Q_1 = 5.5 \times 60 + 940 = \underline{\underline{1270 \text{ kJ/min}}}$$

3. A refrigerating machine is operated on reversed carnot cycle working between temp limit of 35°c and -15°c. The capacity of machine is 12 T.R. Determine

1. C.O.P.
2. Heat rejected from system in kJ/hr
3. Power Required.

$T_1 = 35° + 273 = 308\ K$

$T_2 = -15° + 273 = 258\ K$



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

$$= \frac{258}{308-258} = \frac{258}{50} = \underline{5.16}$$

$Q_2 = 12\ T.R$

$= 12 \times 14000\ kJ/hr$

$= 168000\ kJ/hr$

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

$$5.16\,[Q_1 - 168000] = 32558$$

$$\Rightarrow Q_1 = \frac{168000 + 5.16 \times 168000}{5.16}$$

$$\Rightarrow Q_1 = \underline{13953488\ kJ/hr}$$

$$\text{Power} = \frac{R_v(Q_2)}{W_s}$$

$$W_s = \frac{168000}{5.16 \times 3600}$$

$$= \underline{0.9043\ kW}$$

4. A reversed carnot cycles is used for heating & cooling purpose. If the work supplied is 9.5 kW & C.O.P. is 3.6 for cooling purpose, calculate,

1. T_1/T_2
2. Refrigerating effect in T.R.
3. C.O.P of heating.

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

$$\frac{1}{COP_R} = \frac{T_1 - T_2}{T_2}$$

$$\Rightarrow \frac{T_1}{T_2} = \frac{1}{COP_R} + 1 = \frac{1}{3.6} + 1 = \underline{\underline{0.782}}$$

$$\therefore \frac{R_N}{W_S} = COP_R$$

$$\Rightarrow R_N = 3.6 \times 95 \text{ kJ/sec}$$

$$= 3600 \times 3.6 \times 95 \text{ kJ/hr}$$

$$= \frac{3600 \times 3.6 \times 95}{14000 \times 10 \times 10} \text{ TR}$$

$$= \underline{\underline{8.9942 \text{ TR}}}$$

$$COP_P = 1 + COP_R$$

$$= 1 + 3.6 = \underline{\underline{4.6}}$$

Qn. 5. Ice is formed at 0°c from water at 20°c the temp. of brine is -8°c. Findout the amount (kg) of ice provided per kw-hr assume the system works on reverse carnot cycle. The latent heat of ice is 335 kJ/kg. Specific heat of water is 4.18 kJ/kg-k.

$$\because T_2 = -8 + 273 = 265 \text{ K}$$

$$T_1 = 20 + 273 = 293 \text{ K}$$

$$COP_R = \frac{T_2}{T_1 - T_2} = \frac{265}{293 - 265} = \frac{265}{28} = \underline{\underline{9.464}}$$

$$COP_R = \frac{R_N}{W_S}$$

$$R_N = 9.464 \times 3600 \text{ kJ} = 34071.4 \text{ kJ}$$

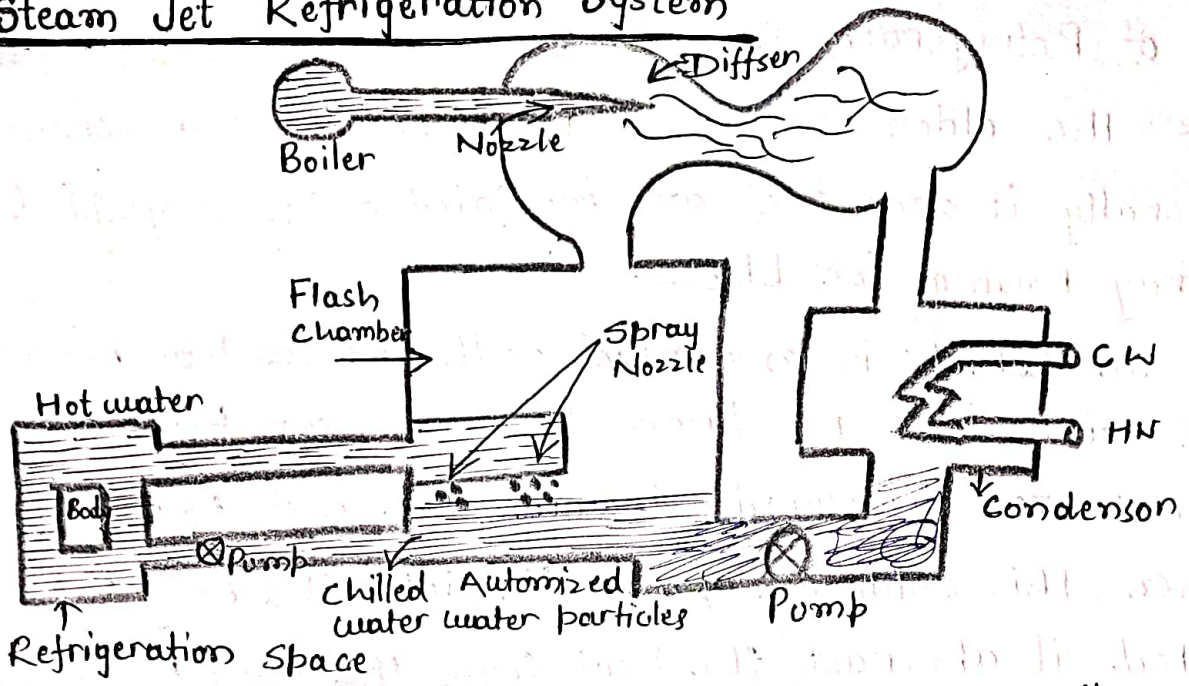
Qabstractrated to produce 1kg of ice at 0° from water 20°c,

$$Q_S = 1 \times 4.18 \times 20 \quad , \quad Q_L = 1 \times 335$$

$$Q_T = 4.18 \times 20 + 335 = 418.6 \text{ kJ}.$$

mass of ice = $\frac{R_N}{Q_T}$ = $\frac{34071.4}{418.6}$ = 81.4 kg

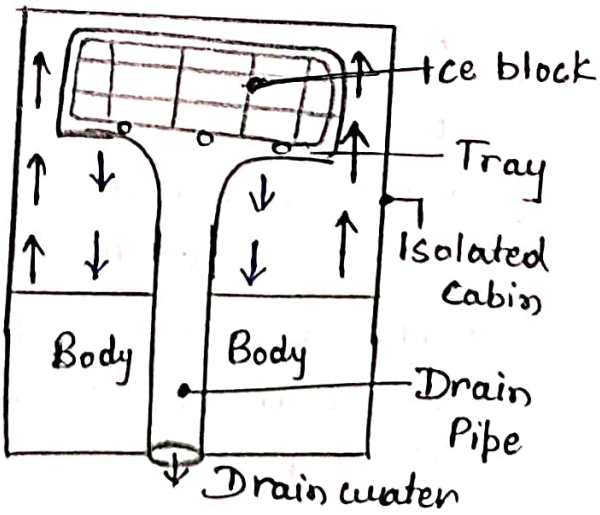
Steam Jet Refrigeration System



- This system of refrigeration uses the principle of boiling the water at the temperature below 100° C which is achieved by lowering the atmospheric pressure that is by creating vaccum.
- If pressure reduces boiling point also reduces, for example water boils at 2°c when atmospheric pressure is 0.006 bar.
- In this system steam from the boiler enters into the diffuser through nozzle. with a very high velocity.
- The high velocity steam jet expriences an induction action on surrounding vapour and air molecules present in the flash chamber. This creates vaccume in the flash chamber.
- The bottom layer of water supplies its heat to upper layer of water in flash chamber the upper layer of water uses this heat as latent heat and become vapour, while the bottom layer of water after rejecting the heat becomes chilled water.
- This chilled water goes into the refrigerated space where it abstract the heat from the body to be cooled and thus produces the cooling effect.

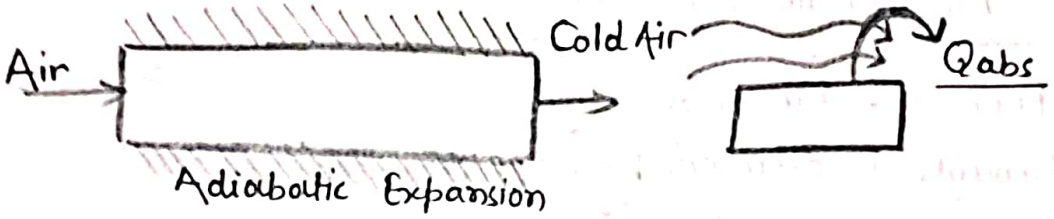
Methode of Refrigeration :-

- It is the oldest method of refrigeration.
- Generally it consist of an insulated cabinet equipped with a tray having ice blocks.
- The air which is in contact with the ice tray becomes cold air, since we know that cold air being denser so it moves downward towards the body to be cooled.
- When this cold air passes through the body to be cooled it abstract the heat from the body, the body gets cool down.
- Now the air after abstracting the heat become hot air, since hot air is rarer hence it moves upward towards the ice block tray.
- The ice block in the absorbs this heat which causes the ice to melt but in small amount.
- The melted ice in form of water is further drained.
- In this way cycle continues and body gets cool down by help of ice.
- Since the heat is abstracted from the body the help of ice blocks hence it is known as ice refregeration system



- The chilled water after abstracting the heat becomes hot water and recirculated in the flash chamber through spray nozzle in form of atomized water particle which ready to vapourise.
- Make up water is supplied to the flash chamber by condenso

Refrigeration by Expansion of Air



As we know that temperature of air can be easily reduced when it undergoes adiabatic expansion. According to first law of thermodynamics,

$$dQ = du + dw$$

$$dQ = du + dw$$

$$m c_v (T_f - T_i) = -dw$$

$\because$ In expansion $dw > 0$

$\therefore (T_f - T_i) < 0.$

$$\boxed{T_f < T_i}$$

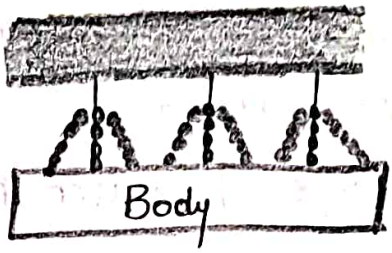
$\therefore$ Air become cold air after adiabatic expansion and when this cold air passes through the body to be cooled it abstracts the heat, due to which body gets cooled down and refrigeration is achieved.

Evaporative Refrigeration;

- Evaporation is a process in which liquid gets transform into vapour by gaining some heat energy.
- In this process when the atomized liquid particles generall water comes in contact with any body the atomized water particle abstract the heat and becomes vapou which a process of evaporation.

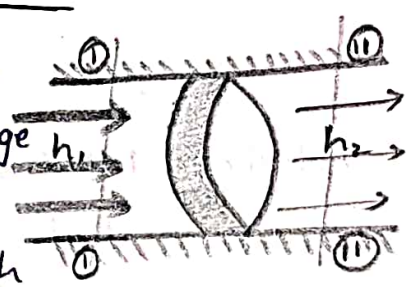
- When heat is abstracted from body it get cool down this process of heat abstraction is basically refrigeration.

- Such refrigeration process which takes place through evaporation is called evaporative refrigeration.



Refrigeration by Throttling of Grasses

Throttling Process : When any gas passes through restricted passage its pressure reduces but it enthalpy remains constant such process is called throttling process.



According to steady fluid energy equation;

$$h_1 + \cancel{\frac{V_1^2}{2g}} + \cancel{gz_1} + \cancel{Q}^{0} = h_2 + \cancel{\frac{V_2^2}{2g}} + \cancel{gz_2} + \cancel{W_s}^{0}$$

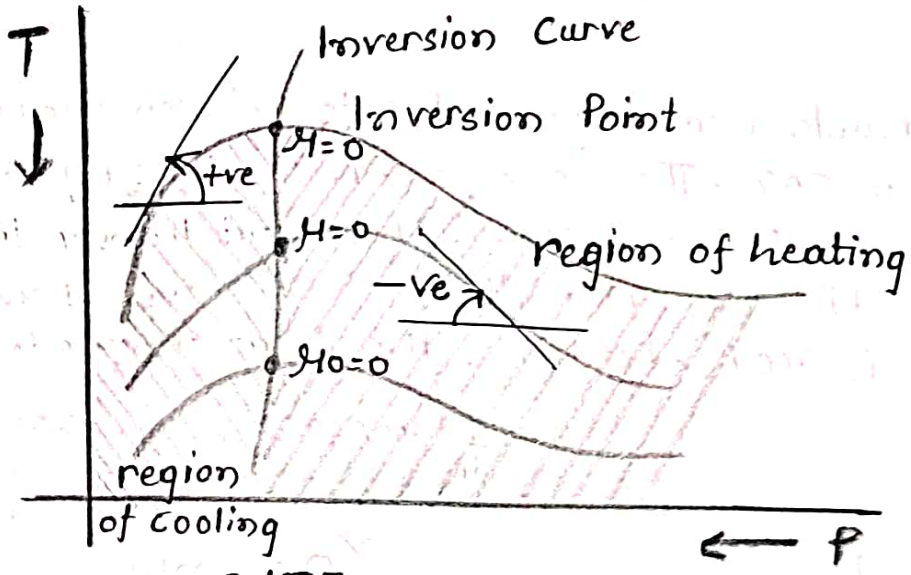
$$\boxed{h_1 = h_2} \Rightarrow C_p(T_1 - T_0) = C_p(T_2 - T_0)$$

$$\boxed{T_1 = T_2}$$

"Throttling Process is a free expansion process, and due to having its sudden or quick, it is irreversable in nature."

For Ideal gas, when undergoes throttling process its temperature remains constant, but the real gas, when undergoes throttling process its temperature may increase or decrease, which can be studied by Joule Thompson equation.

To predict the behaviour Joule and Thompson concluded on experiment on different gasses.



$$\left[\frac{dT}{dP}\right]_h = \text{Joule Thompson Coefficient}$$

- $\left(\frac{dT}{dP}\right)_h$ is known as slope at any point curve and is known as Joule Thompson coefficient. It is represented by μ.
- The curve of each gases has a point where $\mu = 0$ such points is called "inversion point" and locus of such inversion point for different gases is called inversion curve.

CASE - I

- If throttling is done in region of infront of inversion curve $\mu < 0$; $\frac{dT}{dP} < 0$, on decreasing pressure temp. will increase.

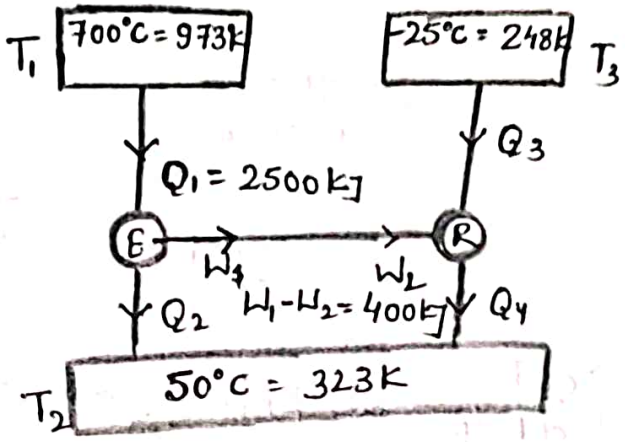
CASE - II

- If throttling of gas is done in region behind of inverson curve $\mu > 0$; $\frac{dT}{dP} > 0$, on decreasing pressure temp. will decrease.

- Thus when any gas undergoes throttling process from a point beyond inversion curve its temperature reduces and when this reduced temperature gas passes over the body it abstract the heat and produce refrigerating effect.

Numerical

Qn. 6. A reversable heat engine operates between two reservoir at temp. 700°c to 50°c. The engine drives a refrigerator which operates between 50°c to −25°c. The heat transfer to the engine is 2500 kJ while net workoutput of combined heat engine & refrigerator is 400 kJ. Determine the heat transfer to reservoir at 50°c.



for engine,

$$\eta_e = 1 - \frac{T_2}{T_1}$$

$$= 1 - \frac{323}{973}$$

$$= 1 - 0.331$$

$$= 0.668 = 66.8\%$$

$$\eta_e = \frac{\text{Output}}{\text{Input}} = \frac{W_1}{Q_1}$$

$$W_1 = Q_1 \times \eta_e$$

$$= 2500 \times 0.668 = 1670 \text{ kJ}$$

$$W_2 = W_1 - 400 = 1670 - 400 = 1270 \text{ kJ}.$$

$$W_1 = Q_{supp.} - Q_{Rejected}$$

$$= Q_1 - Q_2$$

$$1670 = 2500 - Q_2$$

$$Q_2 = 830 \text{ kJ}$$

$$COP_R = \frac{T_3}{T_2 - T_3} = \frac{248}{323 - 248} = \frac{248}{75} = 3.306$$

$$COP_R = \frac{Q_3}{W_2} \Rightarrow 3.306 = \frac{Q_3}{830} \Rightarrow Q_3 = 4191 \text{ kJ}$$

$$W_2 = -[Q_{sup.} - Q_{rej}]$$

$$830 = Q_4 - Q_3 \Rightarrow$$

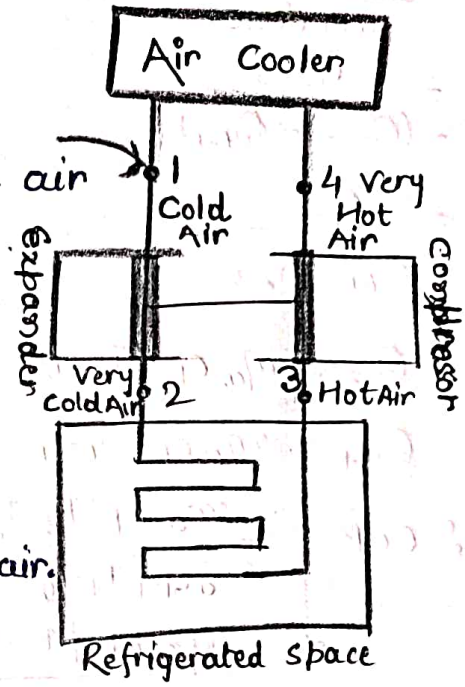
$$Q_4 = 830 + 4191 = 5461 \text{ kJ}.$$

∴ Heat transfer at reservoir, $Q_2 + Q_4 = 5461 + 830$

$$= 6291 \text{ kJ}$$

Air refrigeration system working in Bell-Coleman cycle.

- It is also known as Reversed Joule or Reversed Brayton cycle.
- The working medium is Air.



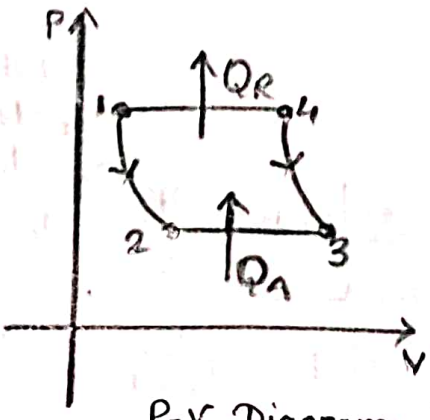
$V \propto T \Rightarrow P = C$.

At point 1; The cold atmospheric air enters into the expander where reversible adiabatic expansion, ie isentropic expansion takes place. Due to which the temperature & pressure of atmospheric air drops and cold air becomes very cold air.

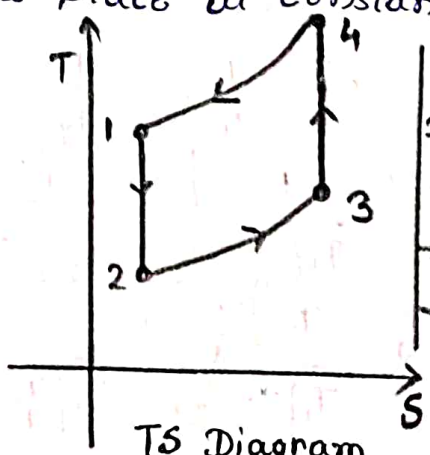
At point 2; This very cold air enters into the refrigerated space where it abstract the heat from the body. Due to this the body gets cool down but the air becomes hot air with its volume and entropy both increases. However this process of heat transfer takes place at constant pressure.

At point 3; This hot air enters into compressor where reversible adiabatic compression takes place. Due to which temperature and pressure of hot air increases and air becomes very hot air.

At point 4; The air enters into air cooler where this hot air transfer/reject its heat into surrounding and air become cold air. This process of heat takes place at constant pressure.



P-V Diagram



TS Diagram

$W_{comp} > W_{exp}$

$m_a c_p (T_4 - T_3) > m_a c_p (T_1 - T_2)$

$T_4 - T_3 > T_1 - T_2$

$$COP = \frac{\text{Output}}{\text{Input}}$$

$$= \frac{\text{Desired effect}}{\text{work done}}$$

$$= \frac{Q_{2-3}}{-(Q_{2-3} - Q_{4-1})}$$

$$= \frac{Q_{2-3}}{Q_{4-1} - Q_{2-3}}$$

$\because$ $Q_{2-3} = m_a c_p (T_3 - T_2)$

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

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

$$= \frac{m_a c_p [T_3 - T_2]}{m_a c_p [T_4 - T_1 + T_2 - T_3]} = \frac{T_3 - T_2}{[T_4 - T_1] - [T_3 - T_2]}$$

$$\Rightarrow \frac{T_2 \left[\frac{T_3}{T_2} - 1\right]}{T_1 \left[\frac{T_4}{T_1} - 1\right] - T_2 \left[\frac{T_3}{T_2} - 1\right]}$$

$\because$ Process 1-2 : reversible adiabatic expansion

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

Process 3-4 : reversible adiabatic compression

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

$\because$ $P_1 = P_4$ & $P_2 = P_3$

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

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

then, $$\frac{T_2 \left[\frac{T_3}{T_2} - 1\right]}{T_1 \left[\frac{T_4}{T_1} - 1\right] - T_2 \left[\frac{T_3}{T_2} - 1\right]}$$

$$\Rightarrow \frac{T_2 \left[\frac{T_3}{T_2} - 1\right]}{T_1 \left[\frac{T_3}{T_2} - 1\right] - T_2 \left[\frac{T_3}{T_2} - 1\right]} = \frac{T_2}{T_1 - T_2}.$$

$$\because \boxed{COP = \frac{T_2}{T_1 - T_2}}.$$

Where,
T_2 = Temp. air leaving expander
T_1 = Temp. air entering expander

Deviding by T_2

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

$$\left[r_p = \frac{P_1}{P_2}\right].$$

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

Note : When expansion and compresion is polytropic process;

In process 1-2 ; ~~Wcomp~~ $PV^{n_1} = C$

In process 2-3 ; $PV^{n_2} = C$

$\because W_{comp.} = \frac{n_2}{n_2 - 1}(P_4 V_4 - P_3 V_3) = \frac{n_2}{n_2 - 1}[mRT_4 - mRT_3]$

$W_{exp.} = \frac{n_1}{n_1 - 1}(P_1 V_1 - P_2 V_2) = \frac{n_1}{n_1 - 1}[mRT_1 - mRT_2]$

$\because$ Total workdone $= W_{comp.} + W_{exp.} = \frac{n_2}{n_2 - 1}[mRT_4 - mRT_3] + \frac{n_1}{n_1 - 1}[mRT_1 - mRT_2]$

then, $COP = \frac{R_N}{WD}$

Qn. 7. In an open dense air refrigeration system 1kg of air at pressure of 1.05 bar and temperature of 20°c is compressed to 6 bar. It is then cooled to 27°c in air cooler before entering into expander. Assume both expansion and compression are isentropic. Determine

1. Refrigerating effect per kg of air
2. C.O.P take $C_{pa} = 1.005$ kJ/kgK $\gamma = 1.4$

$P_3 = 1.05$ bar $= P_2$

$T_3 = 20°c = 20 + 273 = 293$ K

$P_4 = 6$ bar $= P_1$

$T_1 = 27° = 27 + 273 = 300$K

$C_{pa} = 1.005$ kJ/kg-K

$\gamma = 1.4$

$R_N = Q_{2-3}$
$= m_a C_{pa} \times (T_3 - T_2)$
$= 1 \times 1.005 \times (293 - 182.32)$
$= 111.23$ kJ/kgK

$\because COP = \frac{T_2}{T_1 - T_2} = \frac{182.32}{(300 - 182.32)} = 1.54$

$\because$ 1-2 reversable adiabatic expansion,

$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow T_2 = 300\left[\frac{1.05}{6}\right]^{\left[\frac{0.4}{1.4}\right]}$

$= 182.32$ K

3-4 revesible adiabatic compression

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

$\Rightarrow 293 \left(\frac{1.05}{6}\right)^{\frac{0.4}{1.4}} = T_4$

$\therefore T_4 = 292.205$K

Qn. 8. 500 kg of air is circulated per hour in a refrigerating sy working on Bell coleman cycle. The air is drawn from the cold cold chamber is at temperature 8°c and 1 bar pressure and then compressed isentropically to 5 bar. It is then cooled at this pressure to temperature 28°c and then lead into expander where it is expand isentropically. Determine

1. Heat rejected in air cooler (in kJ/min)
2. COP take $\gamma = 1.4$ $C_{pa} = 1.005$ kJ/kg-k.

Given,

$m_a = 500$ kg/hr

$T_3 = 8°C = 281K$

$P_3 = 1$ bar $= P_2$

$P_4 = 5$ bar $= P_1$

$T_1 = 28°C = 301$ K

$\because$ P_{1-2} reversible adiabatic expansion

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

$$T_2 = \left(\frac{1}{5}\right)^{\left(\frac{0.4}{1.4}\right)} \times 301$$

$$= 190.046 \text{ K}$$

$$\therefore COP = \frac{T_2}{T_1 - T_2} = \frac{190.046}{301 - 190.046} = 1.712$$

P_{3-4} reversible adiabatic compressi n

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

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

$$= 281 / (5)^{\frac{0.4}{1.4}}$$

$$\Rightarrow 294.22 \text{ K}$$

$$= 444.05 \text{ K}$$

Heat rejected in air cooler,

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

$$= \frac{500}{60} \times 1.005 (294.05 - 301)$$

$$= 1198.04 \text{ kJ/min}.$$

Qn. 9. An open air cycle operated by refrigeration system has refrigerating effect of 6 T.R. with cooler pressure 11 bar and the refrigerating space is at pressure 1.05 bar. The temperature of air leaving the cooler is 38°c and the air leaving the room is 16°c. Calculate

1. mass of air circulated per min
2. Compressor displacement (m^3/min) V_3
3. Expander displacement (m^3/min) V_2

Given,

$R_N = 6\ T.R. = 6 \times 14000\ kJ/hr$

$P_4 = P_1 = 11\ bar$

$P_2 = P_3 = 1.05\ bar$

$T_1 = 38°C = 311\ K$

$T_3 = 16°C = 289\ K$

∵ 1-2 reversible adiabatic expansion

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

$\Rightarrow \left(\frac{1.05}{11}\right)^{\frac{0.4}{1.4}} \times 311 = T_2$

$\Rightarrow T_2 = 158.95\ K$

∴ 3-4 reversible adiabatic compression

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

$\Rightarrow \left(\frac{11}{1.05}\right)^{\frac{0.4}{1.4}} \times 289 = T_4$

$\Rightarrow T_4 = 565.43\ K$

∴ $R_N = 840000 = Q_{2-3} = m_a\ C_{Pa}\ T_3 - T_2$

$m_a = \frac{840000}{1.005\ [289 - 158.95]}$

$= \frac{633.19}{60}\ kg/min = 10.55\ kg/min$

- Compressor displacement (m^3/min) V_3

At point 3, $P_3 V_3 = m_a R T_3$

$V_3 = \frac{10.55 \times 287 \times 289}{1.05 \times 10^5} = 8.35\ m^3/min$

- Expander displacement (m^3/min) V_2

At point 2, $P_2 V_2 = m_a R T_2$

$V_2 = \frac{10.55 \times 287 \times 158.95}{1.05 \times 10^5} = 4.59\ m^3/min$

Qn. 10. A refrigerator working on Bell Coleman Cycle. The air is drawn in the compressor from cold cabin at pressure 1.03 bar and temp. 12°c and then compressed isentropically to 5.5 bar. The air is then cooled at this pressure to 22°c. The polytropic expansion is given as $PV^{1.25} = c$. Calculate

1. Workdone per kg
2. Refrigerating effect per kg
3. COP
4. R_N in TR for mass flow rate 90 kg/hr.

given,

$P_3 = 1.03$ bar $= P_2$

$T_3 = 12°c = 285$ K

$P_4 = 5.5$ bar $= P_1$

$T_1 = 22°c = 295$ K

1-2 Reversible adiabatic expansion

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{1.25-1}{1.25}} \qquad [\because PV^{1.25} = c]$$

$$\Rightarrow T_2 = 295 \times \left[\frac{1.03}{5.5}\right]^{\frac{0.25}{1.25}} = \underline{211.01 \text{ K}}$$

3-4. Reversible adiabatic compression

$$\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow T_4 = \left(\frac{5.5}{1.03}\right)^{\frac{0.4}{4}} \times 285 = \cancel{459.48 \text{ K}} = 459.94 \text{ K}$$

$$\cancel{\therefore COP = \frac{T_2}{T_1 - T_2} = \frac{211.01}{295 - 211.01} = 2.512}$$

If expansion & compression become polytropic,

$$\text{Workdone} = \frac{n_2}{n_2 - 1}\left[mRT_4 - mRT_3\right] - \frac{n_1}{n_1 - 1}\left[mRT_1 - mRT_2\right]$$

$$= \frac{1.4}{0.4}\left[1 \times 287 \times 463 - 1 \times 287 \times 295\right] - \frac{1.25}{0.25}\left[1 \times 287 \times 295 - 1 \times 287 \times 211.0\right]$$

$$= 170765 - 120525.65$$

$$= 50240.65 = \underline{50.24 \text{ kJ/kg}}$$

$$R_N = Q_{2-3} = m_a C_{p_a}(T_3 - T_2) = 1 \times 1.005 \times (285 - 211.01)$$

$$= \underline{74.32 \text{ kJ/kg}}$$

$$COP = \frac{R_N}{WD} = \frac{74.32}{50.24} = \underline{\underline{1.47}}$$

R_N in TR, $m_a = 90$ kg/hr

$$R_N = m_a C_p (T_3 - T_2)$$

$$= 90 \times 1.005 [285 - 211.01]$$

$$= 6693.3 \text{ kJ/hr}$$

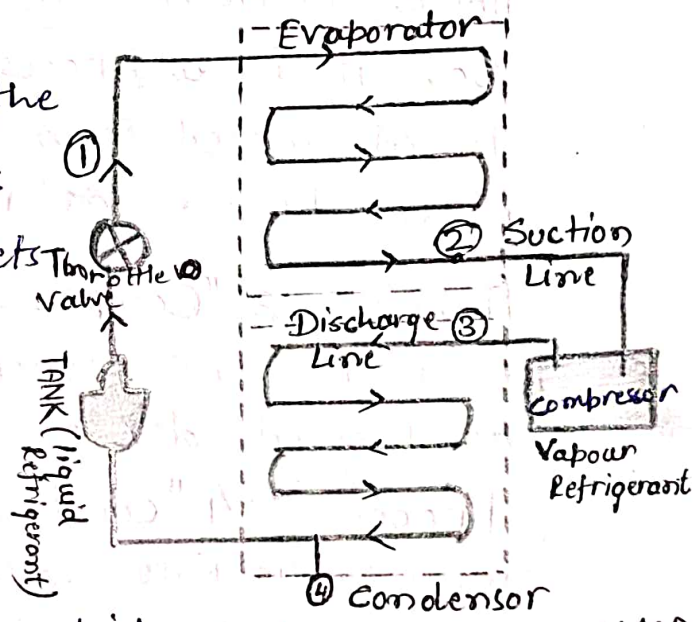
$$= \frac{6693.3}{14000} \text{ TR}$$

$$= 0.478 \text{ TR}$$

UNIT - 2 Vapour Compression Refrigeration System

Vapour compression Refrigeration

- Out of all refrigeration system V.C.R system is one of the most important refrigeration system from domestic utility point of view.
- In this system the working medium is vapour refrigerant which redily evaporates and condense to change its phase during heat transfer.
- During evaporation the liquid refrigerant abstract the heat from the body to be cool. The heat is used as latent heat by refrigerant and change its phase from liquid to vapour.
- Now during condensation the vapour refrigerant rejects its heat to atmosphere and gets liquify into liquid.



Block Diagram of VCR

Vapour Compression Refrigeration Components :-

1. Refrigeration Tank : It is used to store high pressure high temperature liquid refrigerant coming from condensor.
2. Throttle Valve : It is an expansion device in which the liquid refrigerant coming from tank undergoes throtting process due to which pressure and temp. of refrigerant reduces.

3. Evaporator : It provide large heat transfer surface area through which heat is abstracted by the liquid refrigerant from the body kept in refrigerating space.

4. Compressor : It compresses the vapour refrigerant coming from evaporator due to which its pressure and temp. rises.

5. Condensor : It provide the large heat transfer surface area through which the vapour refrigerant reject heat into surrounding and get liquify.

Process 1-2 "Evaporation" :— The liquid refrigerant at its saturation when enters into evaporator, it abstract the heat from the body to be cool. Due to which the liquid refrigerant get transform into vapour refrigerant. So, it is a process of evaporation and since heat is abstracted from the body hence it is our desired process known as refrigerating effect.

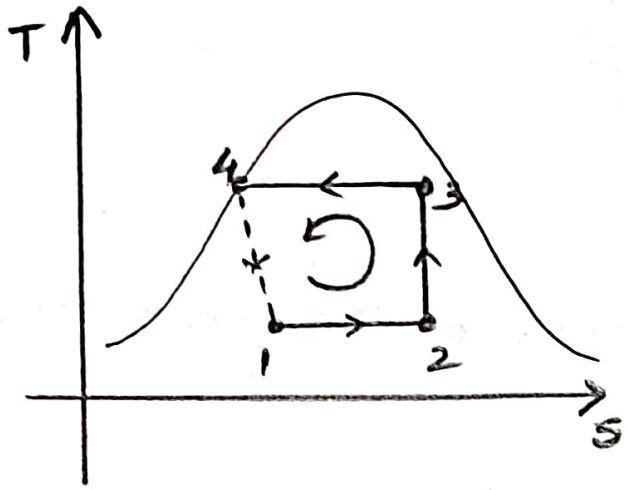
Process 2-3 "Compression" : — Now the vapour refrigerant enters into compressor through suction line where it is compressed due to which its pressure & temp. rises.

Process 3-4 "Condensation" : - The compressed refrigerant now enters into condensor through discharge line where it rejects its heat into atmosphere and get liquify which is a process of condensation.

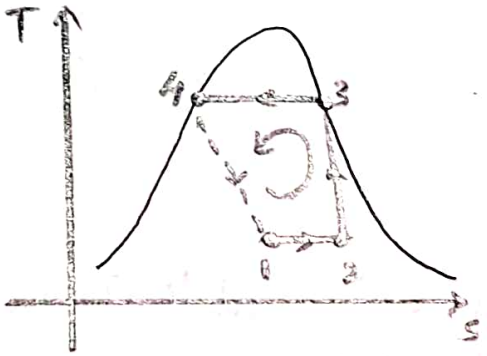
Process 4-1 "Throttling" : — The liquid refrigerant stored in a tank is at high pressure and high temperature undergoes throttling process. A type of expansion process in throttling valve which reduces the pressure and temperature of liquid refrigerant.

T-S Diagram:

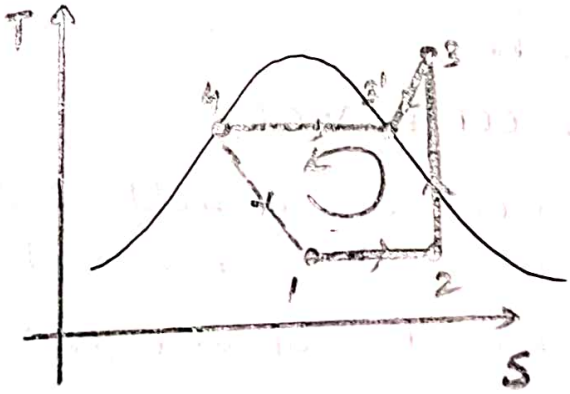
1. Vapour is wet at the end of compression



2. Vapour is completly dry at the end of compression

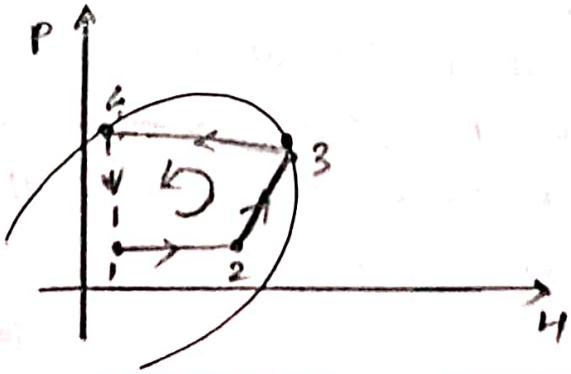


3. Vapour is superheated at the end of compression

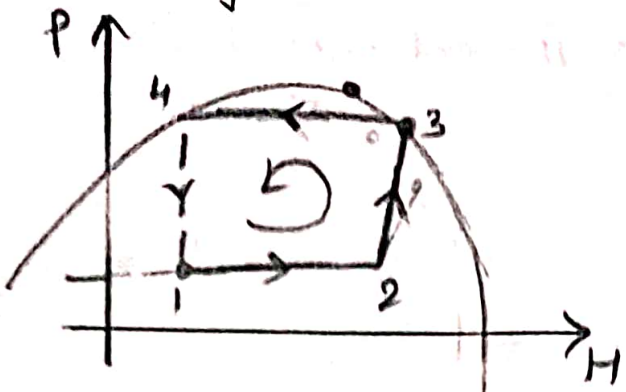


P-H Diagram

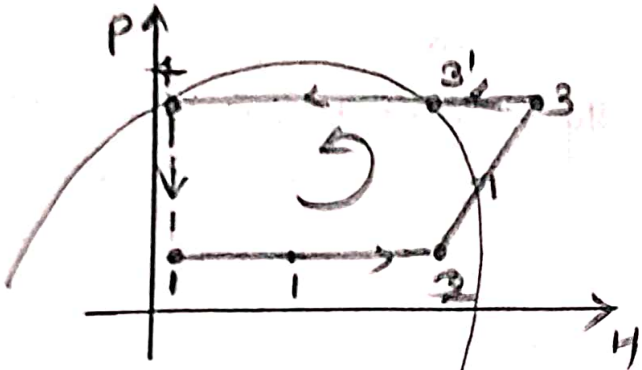
1. Vapour is wet at the end of compression



2. Vapour is dry at the end of compression



3. Vapour is superheated at the end of compression



$$COP = \frac{R_N}{W_d}$$

$$= \frac{\text{Amount of heat abstracted } (1-2)}{\text{Workdone } (2-3)}$$

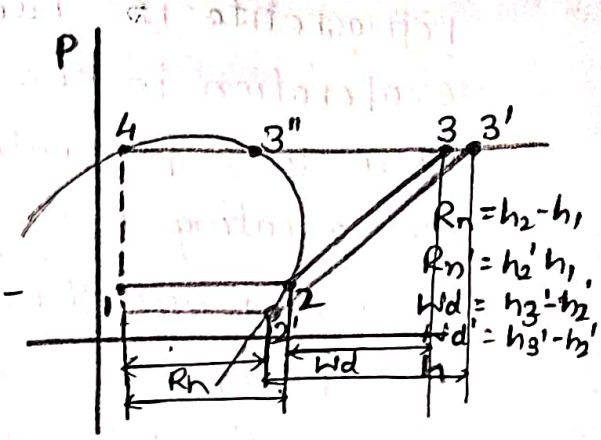
$$\boxed{COP = \frac{h_2 - h_1}{h_3 - h_2}}.$$

Factors affecting the COP in V.C.R.

- It is very much advisable and desirable that the vapour refrigerant entering into compressor must be dry.
- The pressure at which the vapour refrigerant enters into compressor is called suction Pressure and at this pressure evaporation takes place hence called evaporator pressure.
- The pressure at which the vapour refrigeration is discharged from compressor is called discharged pressure and at this pressure condensation will takes place hence it is called condencing pressure.

The following factor on which C.O.P depends are :-

a. Suction Pressure
b. Discharge Pressure
c. Superheating
d. Sub cooling

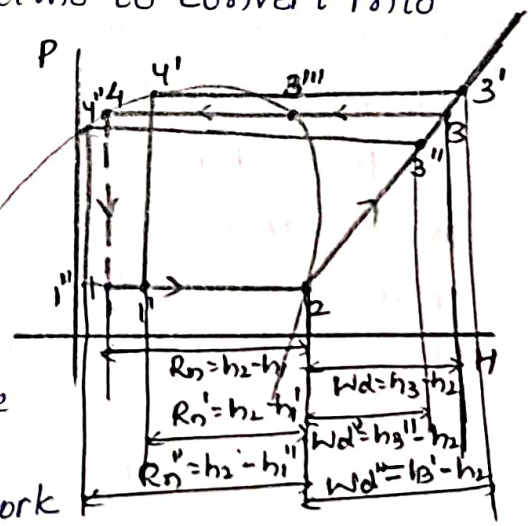


Suction Pressure

On decreasing the suction pressure :-
On decreasing the suction pressure from the graph we can conclude that new $R_n' = h_2' - h_1$ will be less than original $R_n = h_2 - h_1$. ie R_n decreases and to achieve this new R_n' work required $h_3'' - h_2'$ will be more than the original work done $h_3 - h_2$ work done increases.

- $COP = \frac{R_N \downarrow}{W_d \uparrow}$, This overall COP will decrease.
- This it is advisable never to decrease suction pressure.

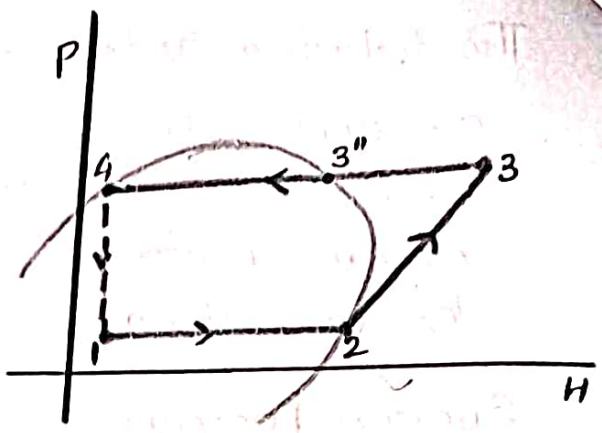
"Never increase the suction pressure, because if suction pressure increases, saturation temperature also increases, due to which liquid refrigerant will takes more time to convert into vapour which is not desirable."



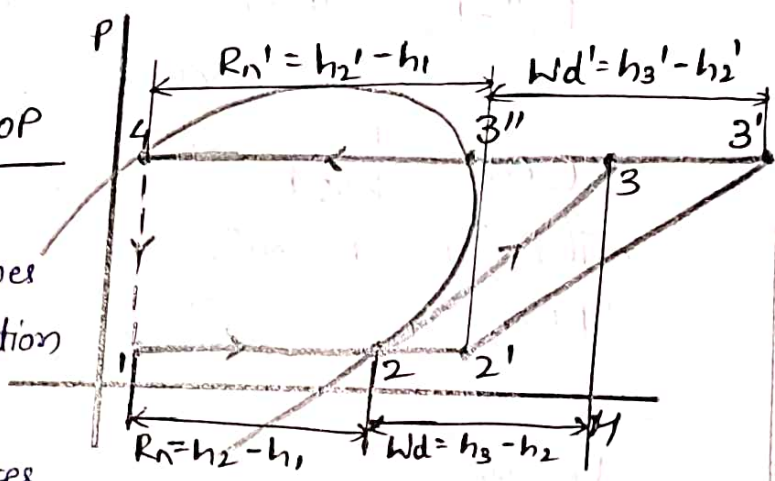
Discharge Pressure

- On increasing the discharge pressure the new $R_n' = h_2 - h_1'$ will be less than original $R_n = h_2 - h_1$, ie R_n will decrease and new workdone $W_d = h_3'' - h_1$ will be more than the original workdone $W_d = h_3 - h_1$, ie work done will increase this indicates the overall C.O.P will reduce. Therefore it is advisable not to increase the discharge pressure.
- On decreasing the discharge pressure, saturation temp. decreases this cause the delay in condensation process which is not desireable.

Effect of Superheating in COP



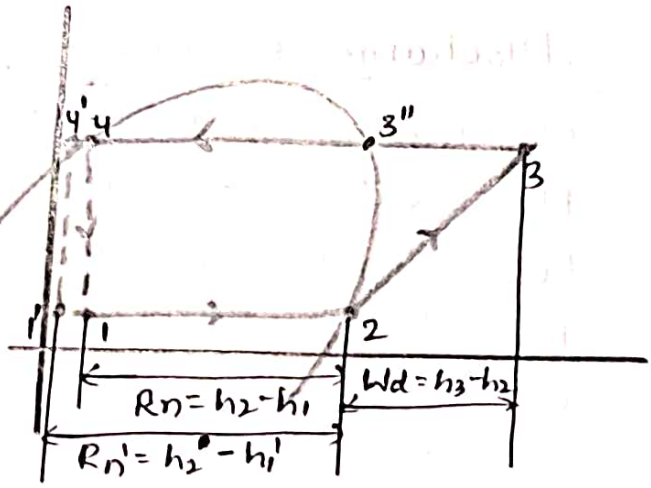
- It is a process in which the refrigerant is heated beyond evaporation in the evaporator.
- Due to superheating the new refrigerating effect $R_n' = h_2' - h_1$ will increase than original $R_n = h_2 - h_1$ and the new workdone $W_d' = h_3' - h_2'$ will also increases the original workdone $W_d = h_3 - h_2$.
- But it is found that rate of increase in work done will be more than rate of increase in R_n hence overall C.O.P will reduce.



↑ Effect of Superheating ↑

Effect of sub-cooling in COP

- It is a process in which the condensed refrigerant undergoes further cooling beyond condensation in the condensor.
- Sub cooling will be always takes place in condensor.
- After sub cooling the new refrigerating effect $R_n' = h_2 - h_1'$ will be more than original $R_n = h_2 - h_1$, ie R_n will increase while the workdone remains same this will increase the overall C.O.P.



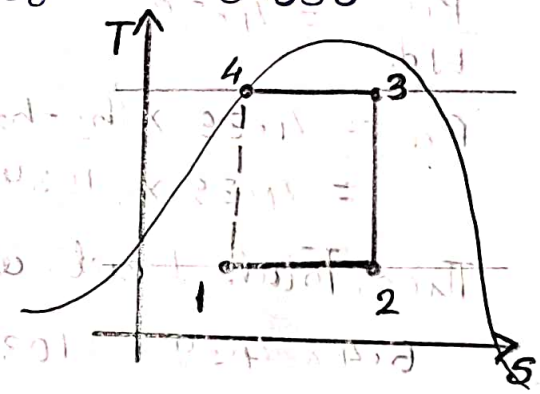
↑ Effect of subcooling ↑

Numerical

Qn. 1. A refrigerating plant work between temp. limit of $-5°c$ and $25°c$. The working fluid is NH3 has dryness fraction of 0.62 at the entry of compressor. If the machine has elective C.O.P of 55%, Calculate

1. Theoretical C.O.P
2. Actual C.O.P
3. Amount of ice produced at $0°c$ from water at $15°c$ if 6.4 kg of ammonia is circulated per min.

Temp.	h_f (kJ/kg)	h_{fg} (kJ/kg)	S_f (kJ/kg-k)
$25°c$	298.8	1167.8	1.124
$-5°c$	158.2	1280.08	0.630



At point '4',

$h_4 = h_{f4} = 298.8$ kJ/k

$\because$ (4-1) throttling process,

$h_{f4} = h_{f1} = 298.8$ kJ/kg

$h_2 = h_{f2} + x_2 h_{fg2}$

$= 158.2 + 0.62 \times 1280.08$

$= 952.29$ kJ/kg

$h_3 = h_{f3} + x_3 h_{fg3}$

$= 298.8 + x_3 \times 1167.8$

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

$dQ = h_g - h_f = h_{fg}$

$ds = s_g - s_f = s_{fg}$

Since process 2-3 is isentropic,

$S_{f2} + x_2 \times S_{fg2} = S_{f3} + x_3 \cdot S_{fg3}$, $S_2 = S_3$

$$S_{f2} + x_2 \times \frac{h_{fg2}}{T_2} = S_{f3} + x_3 \cdot \frac{h_{fg3}}{T_3}$$

$$\Rightarrow 0.63 + 0.62 \times \frac{1280.08}{268} = 1.124 + x_3 \frac{1167.8}{298}$$

$\Rightarrow x_3 = 0.63$

$h_3 = h_{f3} + x_3 + h_{fg3}$

$= 298.8 + 0.63 \times 1167.8 = 1034.173$ kJ/kg.

$$(C.O.P)_{theoretica} = \frac{R_N}{W_d}$$

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

$$= \frac{952.29 - 298.8}{1034.173 - 952.29}$$

$$= \underline{\underline{7.98}}$$

Relative COP = $\frac{\text{actual COP}}{\text{theo. COP}}$

$\therefore$ COP_{act} = Re COP × COP_{theo}

$$(COP)_{Act} = \text{Rela. COP} \times (COP)_{theoretical}$$

$$= 0.55 \times 7.98 = \underline{\underline{4.39}}$$

$$\frac{R_N}{W_d} = 4.39$$

$$R_n = 4.39 \times (h_3 - h_2)$$

$$= 4.39 \times (1034.173 - 952.29)$$

Then, Total heat abstractracted by 6.4 kg per minute

$$6.4 \times 4.39 \times (1034.173 - 952.29)$$

$$= 2299.8 \text{ kJ/min}$$

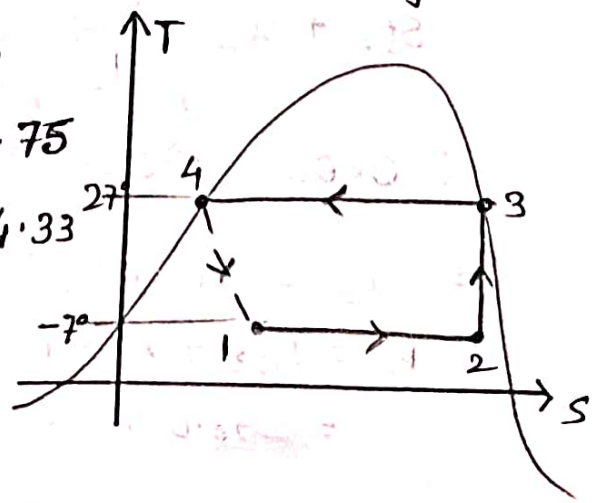
$\therefore$ mass of ice form $= \frac{2299.8}{398}$

$$= \underline{\underline{5.778 \text{ Kg/min}}}.$$

Qn. 2. A refrigerator works between temperature limit of −7°c and 27°c. The vapour is dry and saturated at the end of adiabatic compression. Determine

a) C.O.P b) Power required to remove 180 kJ/min.

Temp.	h_f	h_{fg}	S_f	S_g
27°c	115	1173	4.27	4.75
−7°c	−30	1298	−0.108	4.33



$h_4 = h_{f4} = 115$ kJ/kg

Since 4-1 throttling,

$\because h_4 = h_1 = 115$ kJ/kg

$h_2 = h_{f2} + x_2 h_{fg2}$

$h_3 = h_{g3} = h_{fg} + h_f = 1173 - 115$

$= 1088$ kJ/kg

$\because$ 2-3 is isentropic,

$S_2 = S_3$

$S_{f2} + x_2 S_{fg2} = S_{g3}$

$\Rightarrow S_{f2} + x_2 (S_{g2} - S_{f2}) = S_{g3}$

$= -0.108 + x_2 (4.33 + 0.108) = 4.75$

$\Rightarrow x_2 = \frac{4.858}{4.438} = 1.946$

$x_2 = 0.9094$

$h_2 = h_{f2} + x_2 h_{fg2}$

$= -30 + 0.9094 \times (1298)$

$= 1154.4$ kJ/kg

$C.O.P = \frac{R_n}{W_d} = \frac{h_2 - h_1}{h_3 - h_2} = \frac{1154.4 - 115}{1088 - 115.4} = 7.524$

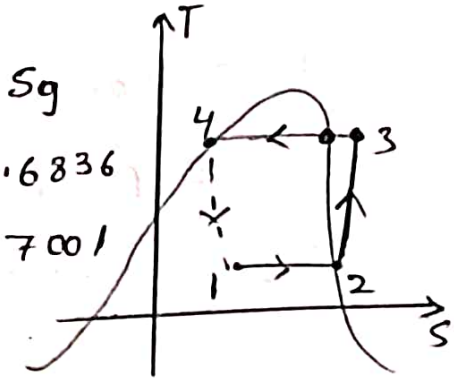
$COP = \frac{\text{Desired effect}}{\text{Work done}} \Rightarrow 7.524 = \frac{180}{W_d}$

$W_d = \frac{180}{7.524}$ kJ/min

$\text{Power} = \frac{180}{7.524 \times 60} = \frac{3}{7.524} = 0.3987$ kW

Qn. 3 A refrigeration machine using R-12 as a refrigerant operates between pressure limit of 2.5 bar and 9 bar the vapour is dry and saturated at the begining of compression Calculate the theoretical COP. & net cooling produce per hour for refrigerant flowing 5 kg/min if actual COP is 0.65 of theoretical COP. $C_{pv} = 0.678$.

Pressure	Sat. Temp.	h_f	h_g	S_g
9 bar	36 °C	70.55	201.8	0.6836
2.5 bar	−7 °C	29.62	184.5	0.7001



$h_4 = h_{f4} = 70.55$ kJ/kg

$h_1 = h_4 = 70.55$ kJ/kg (4-1 is throttling)

$h_2 = h_{g2} = 184.5$

h_3 = Super heated refrigerant

$= h_{sat} + C_{pv} \cdot \log_e \left[\frac{T_{sup}}{T_{sat}}\right]$

$= h_3 + C_{pv} \log \left[\frac{T_{sup}}{T_{sat}}\right]$

$\because$ 2-3 is isentropic

$\because S_2 = S_3$

$S_{g2} = S_{g3} + 2.3 \log \left[\frac{T_{sup}}{T_{sat}}\right]$

$S_{sup} = S_{sat} + C_{pv} \log_e \left(\frac{T_{sup}}{T_{sat}}\right)$

$S_{sup} = S_{sat} + 2.3 \log \left(\frac{T_{sup}}{T_{sat}}\right)$

$0.7001 = 0.6836 + 2.3 \times 0.678 \times \log \left(\frac{T_{sup}}{T_{sat}}\right)$

$0.7001 - 0.6836 = 2.3 \times 0.678 \times \log \left(\frac{T_{sup}}{309}\right)$

$\frac{0.7001 - 0.6836}{2.3 \times 0.678} = \log \left(\frac{T_{sup}}{309}\right)$

$\frac{T_{sup}}{309} = \text{antilog} \left(\frac{0.7001 - 0.6836}{2.3 \times 0.678}\right)$

$T_{sup} = 314.14$

$\because h_3 = h_3 + C_{pv} \left[\frac{T_{sup}}{T_{sat}}\right] = 201.8 + 0.678 [5.14]$

$= 205.84$ kJ/kg

$$COP_{theo} = \frac{h_2 - h_1}{h_3 - h_2} = \frac{184.5 - 70.55}{205.84 - 184.5} = 5.3397$$

$\because$ $COP_{act} = 0.65 \times 5.33$ = $\underline{\underline{3.46}}$

R_n = COP × wd

= $3.46 \times [h_3 - h_2]$

= 73.83 kJ/kg

then, heat abstracted by 5.3 kg refrigerant per minute

= 73.85 × 5.3 × 60

= $\underline{\underline{23484.3}}$ kJ/kg

Vapour Absorption Refrigeration System

If the amount of heat abstraction is very small then vapour compression refrigeration system is applicable but when the amount of heat abstraction is very large then if for this we use vapour compression system it will require more work to increase the pressure of refrigerant from suction pressure to discharge pressure.

To archieve this we require large compressor or com-pressure with high pressure ratio, which is not desirable as it will increase operating cost, main-tenance cost by huge amount.

Therefore for large amount of heat abstracti

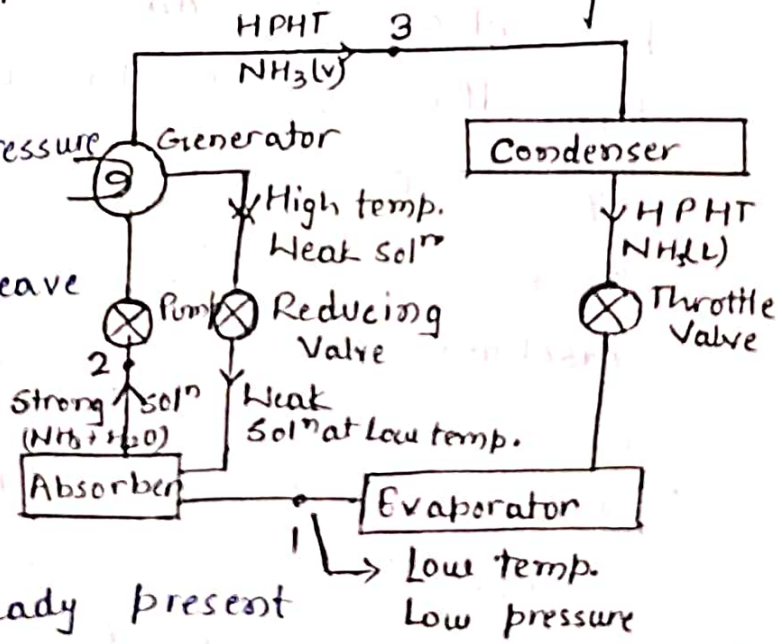
we replace vapour compression refrigeration system by a new system known as vapour absorption refrigeration system.

In this system we replace compressor by generator for increase the pressure and temp of refrigerant and in this we use compressible fluid as a refrigerant so that when temp rises its pressure increases. Ammonia is used as refrigerant.

But since amonia is very rarer fluid which cant flow in refrigeration circuit through itself hence it is absorbed in water and with the water it can be easily flow in circuit.

Since in this system ammonia is absorbed in water hence it is known as vapour absorption refrigeration system.

Working of Vapour ~~Compression~~ Absorption Refrigeration System :-

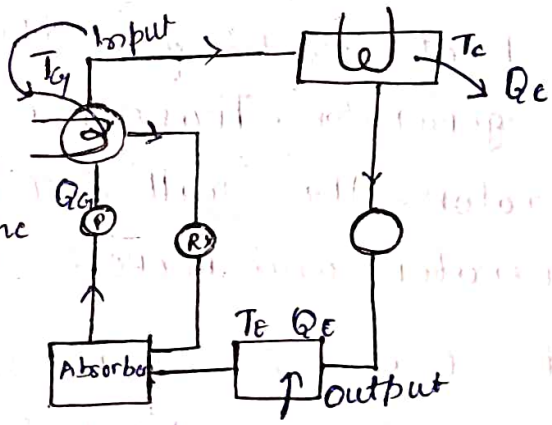


- At point (1) The low pressure ammonia vapour after abstracting the heat leave when the evaporator enters into absorber where ammonia vapour is absorved into water which is already present in absorber and very strong solution of ammonia and water form.
- At point(2) the strong solution is pumped into generator where heat is supplied from external source. Since boiling point of ammonia is less than water hence it vaporise and due to rise in temp. its pressure also rises and becomes equal to condensor pressure.

Since water has high boiling point hence it doesn't vaporise it gets returned back to absorber by reducing its pressure and temperature with reducing valve. This water may contain a very small amount of ammonia.

- At point (3) this high pressure high temperature ammonia vapour enters into condensor and reject heat into atmosphere after rejecting heat it gets condensed into liquid.
- At point (4) Ammonia liquid is throttled due to which its temperature and pressure falls now it enters into evaporator and abstract heat from body. After abstracting heat it become vapour.

COP of Vapour Absorption Refrigeration System



from, equation 1,

Heat supplied to system
= Heat rejected by the system

$$Q_s = (-Q_r) = 0$$

$$Q_s = Q_R$$

$$Q_G + Q_E = Q_c \quad -(1)$$

Entropy is conserved

$$\frac{Q_G}{T_G} + \frac{Q_E}{T_E} = \frac{Q_c}{T_c} \quad -(11)$$

$$\frac{Q_G}{T_G} + \frac{Q_E}{T_E} = \frac{Q_G + Q_E}{T_c}$$

$$\frac{Q_G}{T_G} - \frac{Q_G}{T_c} = \frac{Q_E}{T_c} - \frac{Q_E}{T_E}$$

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

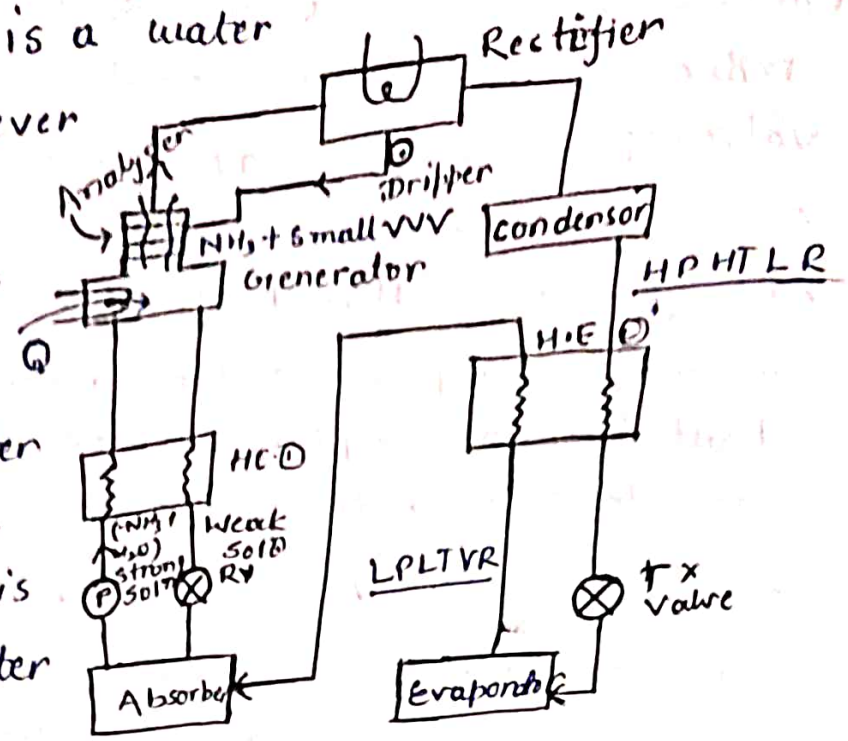
$$Q_G\left(\frac{T_c - T_G}{T_G T_c}\right) = Q_E\left(\frac{T_E - T_c}{T_c T_E}\right)$$

$$\therefore \frac{Q_E}{Q_G} = \frac{T_c - T_G}{T_G} \times \frac{T_E}{T_E - T_c}$$

$$\boxed{COP = \frac{Q_E}{Q_G} = \frac{(T_c - T_G)\,T_E}{(T_E - T_c)\,T_G}}$$

Practical Vapour Absorption System

Rectifier - Rectifier is a water cooled condenser however the NH_3 vapour after leaving the analyser may contains very little amount of Water vapour ~~present~~ with itself. In rectifier this little amount of water vapour present is condensed and flows to generator through dripper.



Heat exchange between Generator & Absorber :-

In heat exchanger the weak solution returning from generator. Transfer heat strong solution going to generator. This will decrease the heat input in generator and increase C.O.P.

Heat exchanger between condensor and evaporator :-

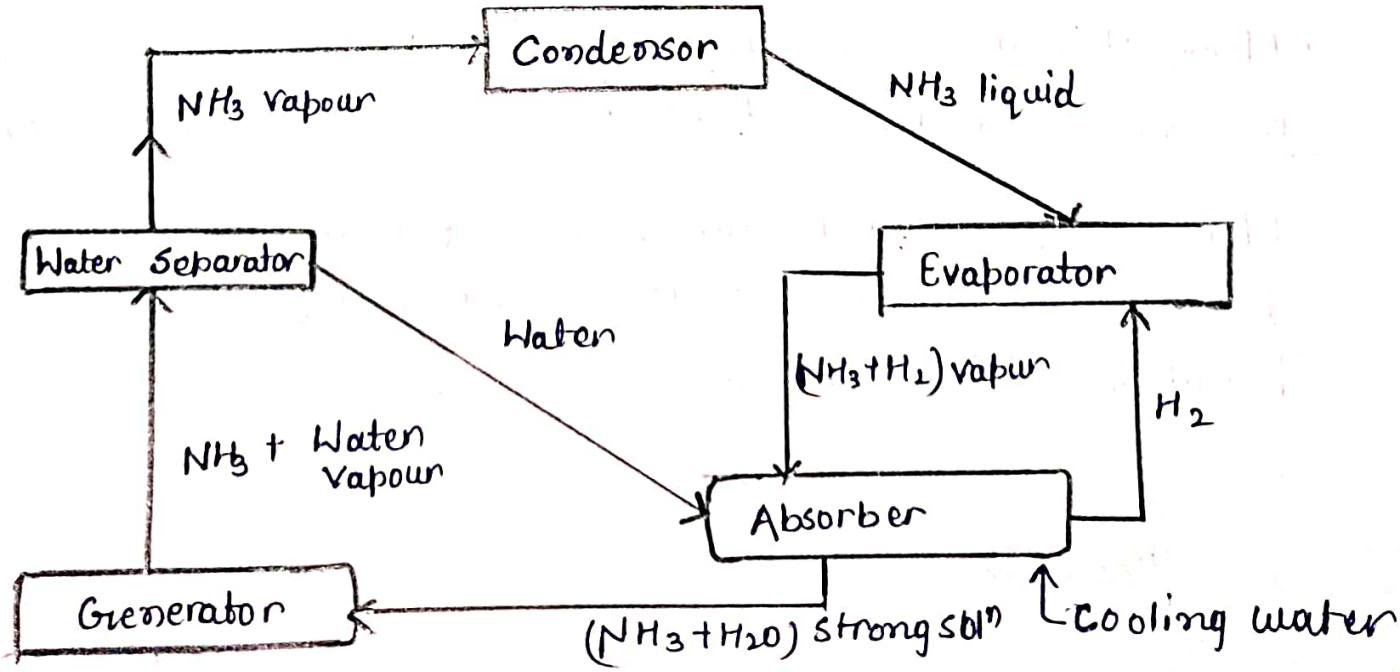
Heat exchanger heat from condensed ammonia, liquid gets transfered to ammonia vapour coming from evaporator. This causes the cooling of ammonia refrigerant after condensation which is a process of of subcooling which will increase C.O.P.

condensor , ----

Difference between Vapour Absorption and Vapour compression system :—

Vapour Absorption System	Vapour Compression System
• A uses heat energy which is a low grade energy.	• It uses electric energy which is high grade of energy.
• Moving parts only exist in pump which is a small element hence very quite in operation.	• Moving parts exist in compressor which runs very high r.p.m. Thus noisy in operation.
• The vapour leaving evaporator doesn't have any hazardous effect on the generator.	• The vapour leaving evaporater if is wet and enters into compressor may damage blade by causing cavitation.
• It is used in industrial purpose.	• It is used in domestic purpose.
• Its COP is low.	• Its COP is High.
• It utilize more space.	• It utilize less space.
• It is more costly.	• It is less costly

• ELECTROLUX - REFRIGERATION SYSTEM



Electrolux - Refrigeration System

Electrolux refrigeration system is a three fluid refrigeration system. In this ammonia, water and hydrogen are used.

In this system,

- The ammonia liquid leaving the condensor at high pressure and high temperature is mixed with hydrogen at the entry of evaporator. In presence of atmosphere of hydrogen, the pressure and temperature of ammonia (NH_3) liquid reduces. Now this low pressure, low temp. ammonia liquid abstract the heat from the body in evaporator. This is our desired effect.
- Now after abstracting heat the ammonia becomes vapour and leaves evaporator with hydrogen enters into absorber where ammonia is diffused in water and hydrogen gas liberated. The hydrogen gas enters into evaporator.
- The strong ($NH_3 + H_2O$) sol^n enters into generator where it is heated to raise its pressure and temperature. Due to heating ammonia gets transformed into vapour and also little ammount of water transformed into vapour. This water vapour is further separated into water separator.
- Now the ammonia vapour leaving water separator enters into condensor reject heat and get condensed into liquid.

Note :- If water is taken as refrigerant and lithium bromide as absorbent then such refrigeration system is called <u>lithium bromide absorption system</u>.

UNIT-3

Equipment Selection:

There are four basic component used in refrigeration sytem.

a) Compressor
b) Evaporator
c) Condensor
d) Expansion Valve

Compressor

Compressor is a device which is used to compress the vapour refrigerant to raise its pressure and temperature to a saturation point at which when the vapour refrigerant rejects its heat it starts condensing into liquid.

following types of compressors are used;

1). Open type reciprocating compressor
2). Hermettic or Closed type reciprocating compressor
3). Centrifugal compressor
4). Screw compressor
5). Scroll compressor.

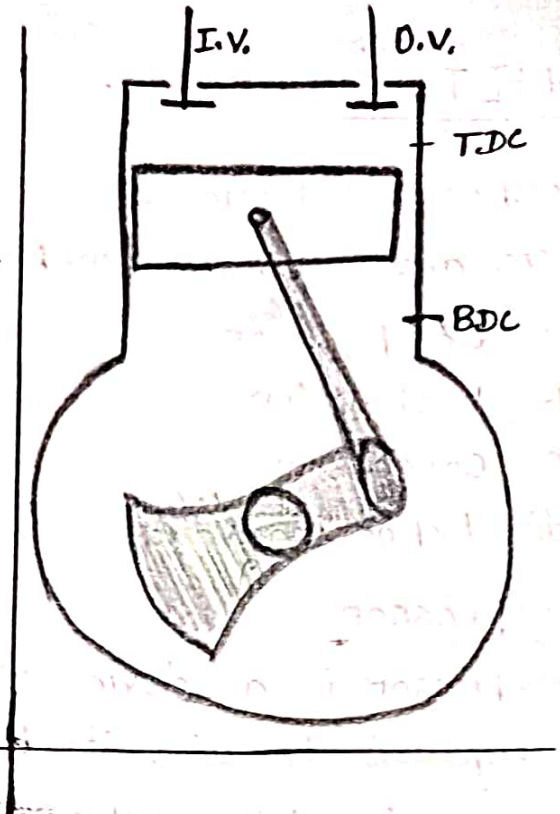
OPEN TYPE RECIPROCATING COMPRESSOR : The compressor in which vapour refrigerant is compressed by reciprocating motion of piston are called reciprocating compressor.

Working of reciprocating compressor consist of two strokes, (I) Suction Stroke and (II) Compression Stroke.

Suction Stroke :- When the piston are at TDC (top dead centre) both inner valve and outer valve are closed, when piston moves from TDC to BDC, inner valve opens to vapour refrigerant from evaporator rushes into compressor.

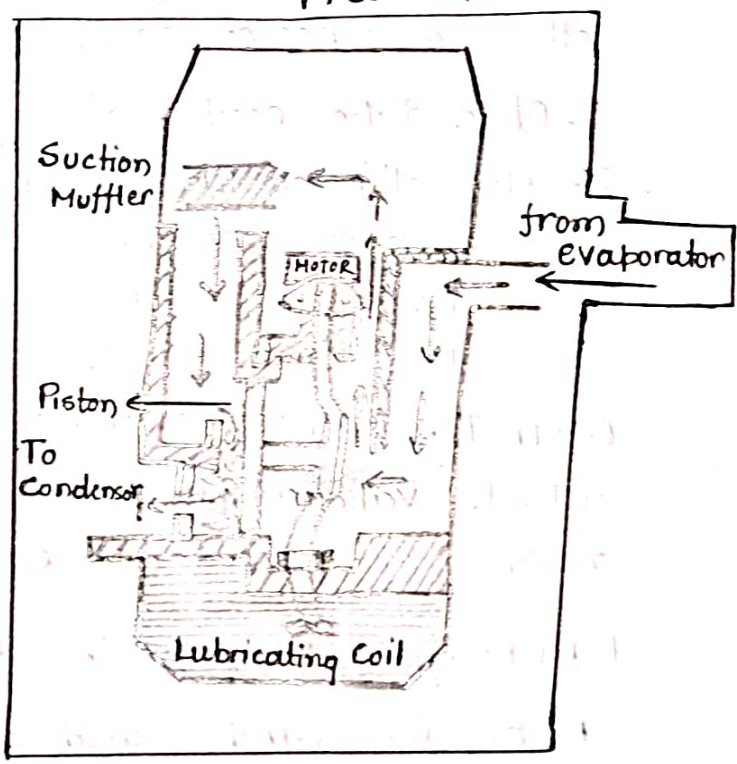
Compression Stroke :- When piston moves from BDC to TDC both inner and outer valve remains closed and vapour refrigerant gets compressed.

Due to which vapour refrigerant reaches to a state of saturation and then Outer valve opens and Saturated vapour refrigerant discharge to condensor.



Hermatic Sealed Reciprocating Compressor :—

When the motor chamber and piston chamber are enclosed in same casing such as compressor are known as hermatic sealed reciprocating ~~sealed~~ compressor.



- When the motor rotates it starts reciprocating the piston. This creates low pressure in pistor chamber.
- Thus the vapour refrigerant is sucked by the suction muffler and discharge to the piston chamber.
- In piston chamber, the gas vapour refrigerant compressed pressure rises at the end of stroke and is discharged to condenser at required pressure.
- This type of compressor eliminate the use of belt drive, crank shaft, chain drive out doesn't requires external cooling and lubricating system.

Advantages of Hermatic Sealed Reciprocating compressor:—

1. Since it is completely closed hence no problem of leakage.
2. It is less noisy in operation.
3. It is compact and requires less space.
4. Motor and piston gets lubricated continuously. which is service life.
5. Motor of compressor gets cool down continuosly.

Volumetric efficiency of reciprocating compressor

$$\text{Volumetric efficiency} = \frac{\text{Volume of air sucked}}{\text{Stroke volume}}$$

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

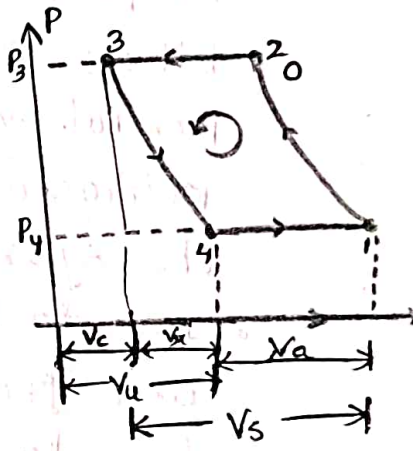
$$= \frac{V_s - V_x}{V_s}$$

$$= \frac{V_s - (V_4 - V_c)}{V_s}$$

$$= \frac{V_s - V_c\left[\frac{V_4}{V_c} - 1\right]}{V_s}$$

$$= 1 - \frac{V_c}{V_s}\left[\frac{V_4}{V_c} - 1\right]$$

$$= 1 - C\left[\frac{V_4}{V_3} - 1\right]$$



V_c - Clearance Volume

V_s - Stroke volume

V_a - Vol. of refrigerantly air actually sucked.

$\frac{V_c}{V_s}$ = Clearance Ratio.

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

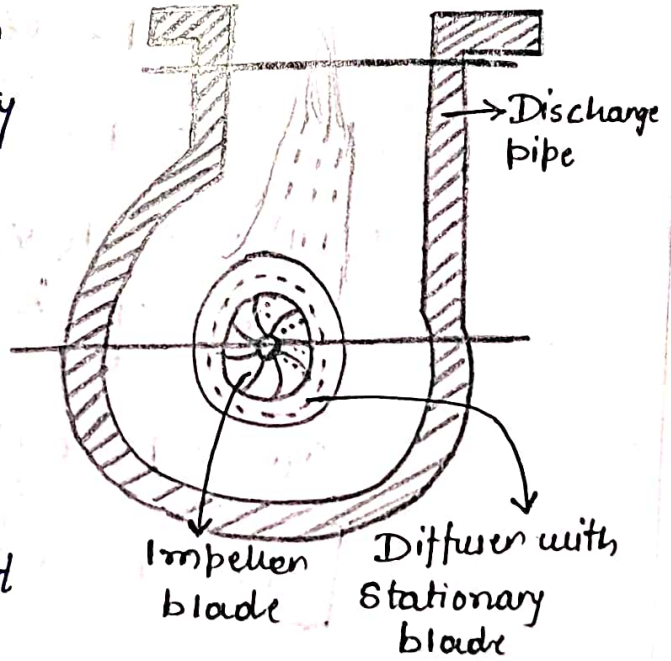
$$\frac{V_4}{V_3} = \left(\frac{P_3}{P_4}\right)^{1/n}$$

$$\eta_v = 1 - C\left[\left(\frac{P_3}{P_4}\right)^{1/n} - 1\right]$$

$$\boxed{\eta_v = 1 - C\left[(r_p)^{1/n} - 1\right]}$$

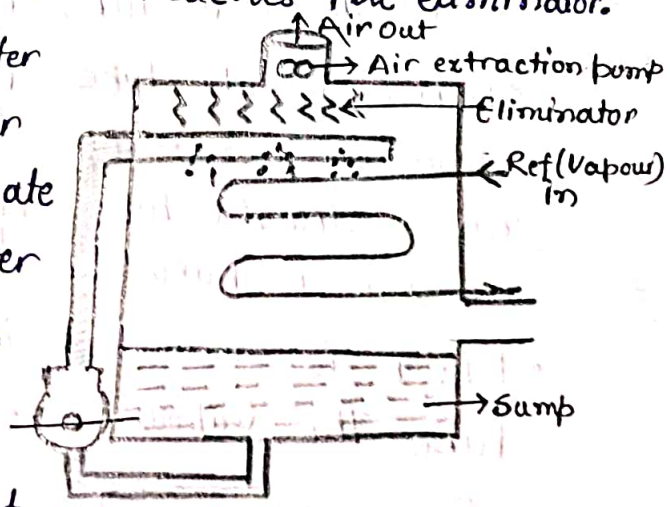
Centrifugal Compressor

- This compressor increases the pressure of low pressure vapour refrigerant from evaporator to high pressure through centrifugal action.
- It consist of an impeller to which no of curve blade are fitted symmetrically. The impeller is coupled with motor.
- When motor rotates impeller rotates this creates partial vaccum in the impeller due to this vapour refrigerant from evaporator enters impeller through its eye.
- Due to rotation of impeller the vapour refrigerant exit from blade of impeller with high velocity due to centrifugal force exerted by impeller on vapour refrigerant.
- The vapour refrigerant when leaves the impeller is at very high velocity and with high kinetic energy.
- In the diffuser the kinetic energy of vapour refrigerant is converted into pressure energy and vapour refrigerant pressure increases. The high pressure vapour refrigerant now gets discharged to condenser at this high pressure



Evaporative Condensor

- In this type of condensor, the water from the sump is circulated in chamber through spray nozzle in automised form.
- The atomised water particle when flows over the condensor coil, it abstract the heat of vapour refrigerant. Due to this vapour refrigerant gets condensed into liquid refrigerant.
- The atomised water particle after abstracting the heat becomes vapour and these vapour gets. Accumulates over the surface of condensor coil. This decreases the condenser efficiency.
- Therefore these vapour has to be eliminated for this eliminator is installed at the top of the chamber.
- Cold air comming from surrounding diffuses the vapour particles with itself and reaches the eliminator.
- Eliminator provides heat transfer surface area. The water vapour reject heat to air at eliminate and get condensed into water and get collected at sump.



Condensor

Condensor is basically a heat exchanger which is used to condense the vapour refrigerant comming from evaporator through compressor by rejecting the heat into surrounding atmosphere.

The condensor used in our refrigerating system are of three types;

a). Air cooled Condensor b). Water cooled condensor

c). Evaporative condensor

Air Cooled Condensor

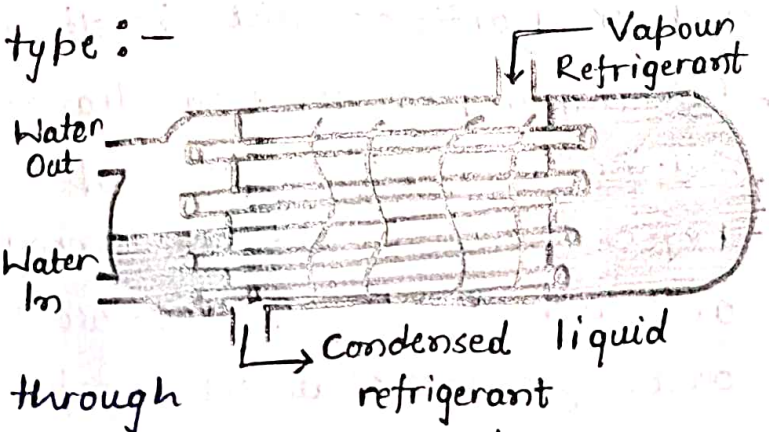
In this condensor in which the atmospheric air acts as condensing medium. The air abstract the heat from vapour refrigerant. Thus cools the vapour refrigerant due to which refrigerant get condensed.

They have tube fitted with fins which provide heat transfer surface area.

Water Cooled Condensor

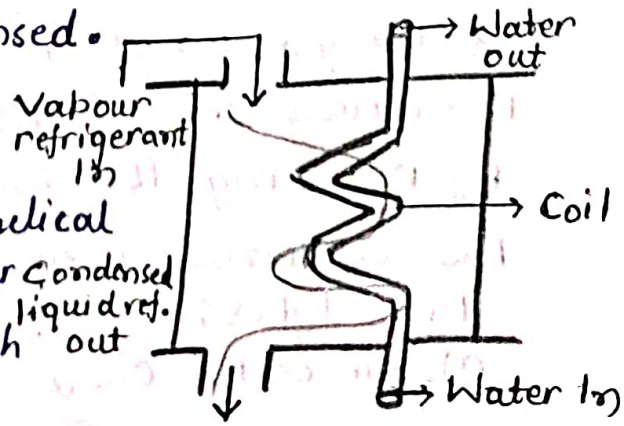
Those condensor in which the condensing medium is water which abstract the heat from vapour refrigerant due to which vapour refrigerant get condensed into liquid refrigerant. In water cooled condensor cooled water flow through the tubes and refrigerant flow over tube surface.

- Shell and Tube type :-



- Shell and tube type condensor consist of no of straight tube arrange in parallel.
- Water is circulated through tube. The vapour refrigerant flow over tube.
- The water in tube abstract the heat due to which refrigerant get condensed.

- Shell and coil type :-



In shell and coil condensor tube in which water flows is helical coil. Due to which flow of water in tube will be turbulant which increases heat transfer rate

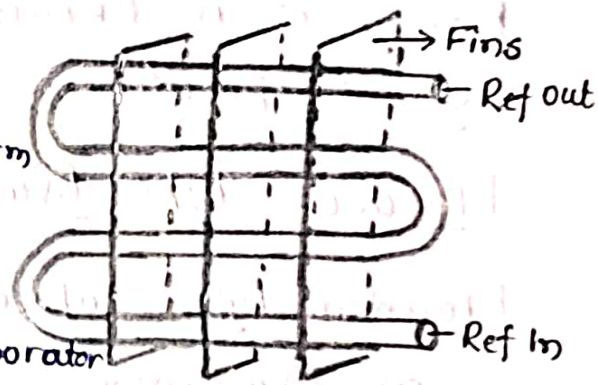
Evaporator

Evaporator is a device which is used to provide heat transfer surface area. Due to which heat from the body present in evaporator is transferred to the refrigerant flowing in evaporator.

On the basis of construction evaporator are of three types:-

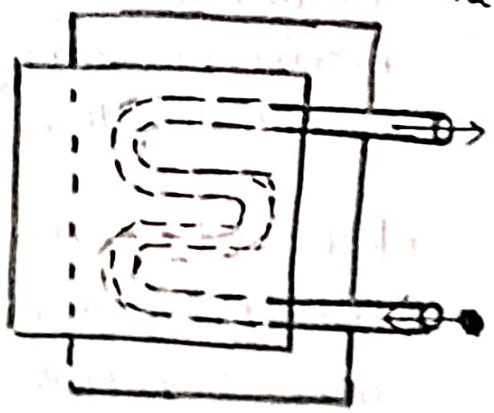
(i) Bare - tube type evaporator
(ii) Plate type evaporator
(iii) Finned type evaporator

- Bare - Tube Type Evaporator



- Bare tube evaporator is simplest form of evaporator made up of either steel tube or copper tube.
- Copper tube is used in small evaporator where from refrigerant is used.
- In large evaporator steel tube is used because ammonia is used as refrigerant.

- Plate Type Evaporator



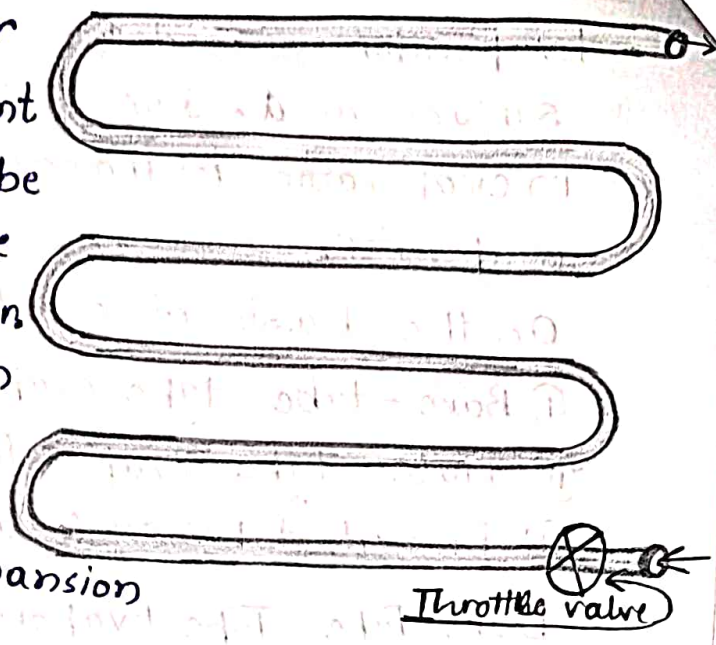
- Plate or surface type evaporator is generally used in domestic refrigerator.
- It consist of two flat sheet of metal generally aluminium which is light in weight and having high thermal conductivity.
- The evaporator coil is embosed between two plates.

- Finned Type Evaporator

Finned type evaporator are bare type evaporator in which fins are mounted over tube to increase the heat transfer rate.

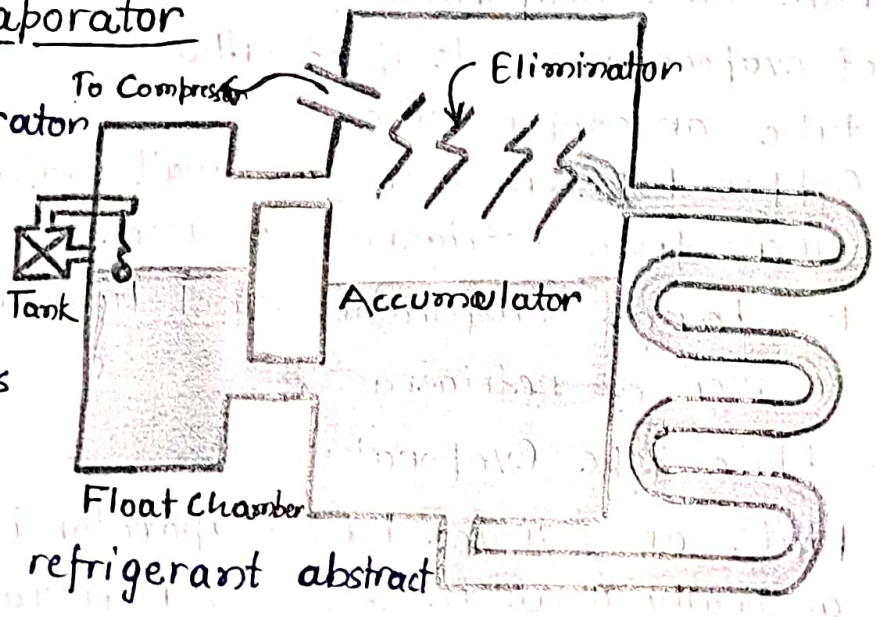
Dry Expansion Type Evaporator

In a dry expansion evaporator the amount of liquid refrigerant is limited to that which can be completely vaporise by the time it reaches the end of evaporator. Since the liquid refrigerant on reaching the evaporator is completely in vapour phase hence it is known as dry expansion type evaporator.



Flooded Type Evaporator

Flooded type evaporator is an evaporator which is completely filled with liquid refrigerant along its entire length.



- When the liquid refrigerant abstract the heat from the body to be cooled the refrigerant gets vaporise and amount of liquid refrigerant gets fall down.
- To increase the amount of liquid refrigerant, refrigerant is circulated from accumulator, now the float valve opens to admit the refrigerant in float chamber from tank.
- The refrigerant when leaves the evaporator is in vapour state with some liquid particles which is to be separated. This is done by eliminator.

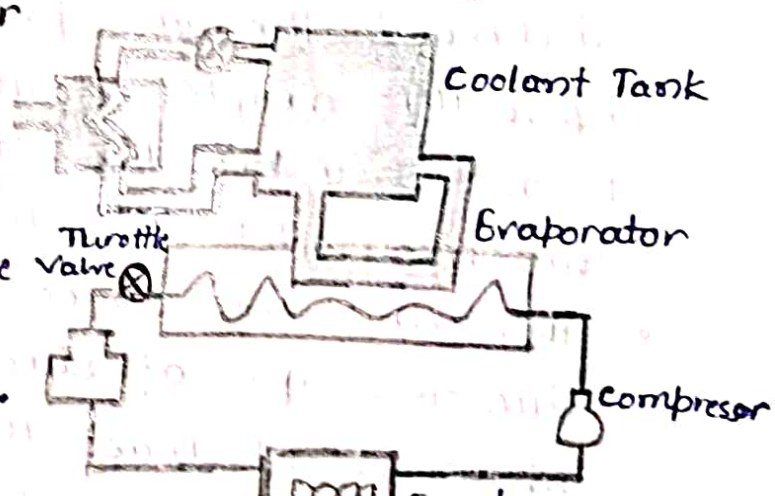
Chiller :— A chiller is a device which remove heat from ~~refri~~ liquid coolent by the help of either vapour compression refrigeration system or vapour absorption refrigeration system. This liquid coolant can be further circulated to a heat exchanger to cool equipment or another process steam (like Air/Water).

Classification of chiller

1. On the basis of refrigeration system.
   - Vapour compression refrigeration system chiller.
   - Vapour absorption refrigeration system chiller.
2. On the basis of evaporator used
   - Dry expansion type chiller
   - Flooded type chiller

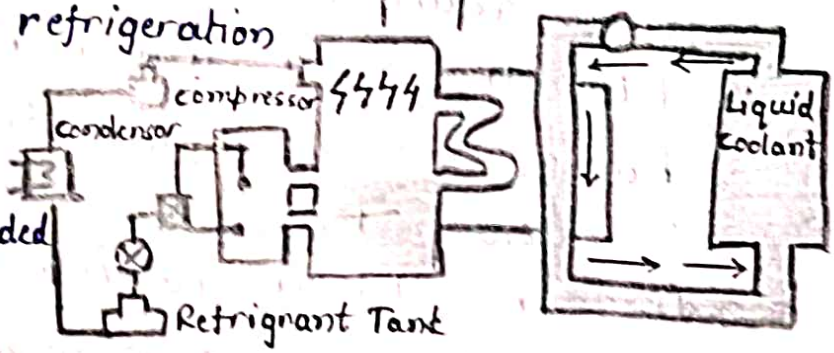
Dry Expansion Type Chiller

In this type of chiller refrigeration system may be either VCR or VAS but the evaporator will be dry expansion type evaporator.



Floaded Type Chiller

In this type of chiller refrigeration system may be either VCR or VAS but the evaporator will be floaded type evaporator.



Note :- If instead of liquid coolant water is to be chilled then it is called water chiller.

Cooling System

Cooling system is very important system required in large capacity air conditioning system, its main function is to cool down the heated water of water cooled condenser by means of cooling tower.

Cooling System is of two types:

Natural Draft Cooling System

- In this types of cooling system natural draft cooling tower is required.
- It consist of a water header which is basically a pipe line containing a series of a spray nozzle. Through the water header heated water enters & discharged through spray nozzle in form of droplets.
- Now this droplets flows through cooling fill which is a honey bee like structure here the speed of water droplets get slow down.
- The air enters to cooling tower from bottom & due to shape of chimney it flows to cooling fill where it abstract the heat of water droplet and make it to cool down.
- Now this cold water is collected in the cooling basin at the bottom from where it is circulated to condenser.
- The air after abstracting the heat from water droplets becomes hot and it may contains some moisture within itself.
- It flows in upward direction as becomes rarer.
- There is an eliminators installed just above water header to remove the moisture constant of heated air before escaping from chimney into atmosphere.

Forced Draught Cooling System

- A cooling system used to cool down heated water of water cooled condenser by help of a forced draught cooling tower is known as forced draught cooling system.
- Its main part is forced draught cooling tower.
- In this tower forced fan is located at the bottom of the cooling tower.
- This forced draught fan forces the air inside the cooling tower with high circulation rate.
- The hot water is supplied through condenser from top through series of nozzle.
- The heated water in form of droplets falls on the packing.
- The air blown by the fan rises up towards the packing.
- At the packing water in form of droplets is retained for few second, during this period of time the heated water droplet comes in contact with air.
- The air abstract the heat from water droplets and rises up while water looses its heat and gets cooled down.
- The heated air may contains some diffused water particle which is eliminated by eliminator before air gets discharged into atmosphere.
- The cold water is collected at the bottom from where it is supplied to condenser.

Refrigerant

- Refrigerant are those chemical substance which acts as cooling medium for refrigeration.
- Refrigerant has a very unique properties of changing phase readily during heat transfer.
- In the evaporator the liquid refrigerant abstract heat from the body and becomes vapour.
- In condenson the vapur refrigerant abstract heat ~~from the body and becomes to~~ in atmosphere and get condensed into liquid.
- Desirable properties of refrigerant are :-

1. Physical Properties:

a). Viscosity :— The refrigerant should have very low viscosity so that there must be very easy in circulation through pipe line.

b). Smell :— A refrigerant must have smelling properties in order to detect leakage.

c). Toxicity :— The refrigerant should not be toxic it may create hazardous problem.

d). Availability :— It should be available at low cost in large amount.

e). Corrosiveness :— The refrigerant should not be corrosive. It shouldn't promote the formation of oxide on the metal pipe lines.

2. Thermodynamic Properties :

a) Freezing Point :— The freezing point of the refrigerant must be as low as possible because if the freezing point is high then refrigerant after throttle or expansion process easily reaches to its freezing point and get freeze.

b). Boiling Point :- The boiling point of refrigerant must be as low as possible so that refrigerant after abstracting heat from body and becomes vapour. If boiling point is high evaporation process get prolonged which is not desirable.

c). Conductivity :- It should be as high as possible so that the heat transfer rate increases and move quickly will be the process of refrigeration.

d). Latent Heat :- High Latent heat of refrigerant is desirable because if latent heat will be more, more will be the refrigerating effect.

e). Specific Heat :- The total heat transfer from body to refrigerant is constant. The total heat is the sum of latent heat and sensible heat. To maximise the latent heat, sensible heat should be minimum and this would only be possible if specific heat minimum.

3. Chemical Properties :-

a). Stability :- The refrigerant should be chemically stable and inert. ie must be non reactive in nature.

b). Flammability :- It should be inflammable in nature.

For nomenclature of refrigerant it is devided into three groups :

a). Saturated Refrigerant
b). Unsaturated Refrigerant
c). Inorganic Refrigerant

Saturated Refrigerant

Those hydrocarbon refrigerant in which the carbon atoms are single bonded.

$$C_m H_n F_p Cl_q$$

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

for saturated refrigerant

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

Example; Dichloro Difluoro methane (CCl_2F_2)

Dichloro - tetra fluoro ethane.

Tri chloro monofluoro

Unsaturated Refrigerant :—

Those hydrocarbon/holocarbon refrigerant which contains either double bond or triple bond carbon atoms.

$C_m H_n F_p Cl_q$

m - no. of carbon atoms n - no. of hydrogen atoms

p - no of fluorine atoms q - no. of chlorine atoms

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

Designation

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

Ex; Ethene (C_2H_4)

Dichloro Ethene

Inorganic Refrigerant :—

Those refrigerant which doesn't contains carbon atom with itself.

Designation R(700 + mol. wt)

(i) Ammonia (NH_3)

(ii) Carbon Dioxide (CO_2)

(iii) Sulphur Dioxide (SO_2)

(iv) Water (H_2O)

Refrigerant are classified in two ways

a. Primary Refrigerant

b. Secondary Refrigerant

Primary Refrigerant :-

Those refrigerant which directly participate in process of refrigeration are called primary refrigerant. ~~which~~ It is further classified as;

a. Hydrocarbons :- Those primary refrigerant which contains hydrogen atom which carbon atom. Example, C_2H_6, C_4H_{10} etc.

b. Halocarbons :- Those primary refrigerant which contains halogen atoms with carbon and hydrogen atoms. Example Dichloro ethene.

c. Azeotropes :- It is refrigerant which is mixture of two refrigerants. Examples R12 & R152 combines t from R500.

d. Inorganic refrigerant :- Those refrigerant which doesn't have carbon atom. Examples - NH_3, SO_2, CO_2, H_2O.

Secondary Refrigerant :-

Those chemical substance which doesn't take part directly in process of refrigeration. It is 1st converted as refrigerant with help of primary refrigerant.

Example

1. Brine solution :- They are salt, they are 1st cooled by chilled water. Example :- $CaCl_2$, Nacl.

2. Glycol :- Ethylene glycol and propylene glycol when mixed with the chemical substance lowers the boiling point of chemical substance and convert it into refrigerant, thus refrigerant composed of glycol is secondary refrigerant.

Detection of leakage of Refrigerant

- Leakage of refrigerant from refrigeration system effects the performance of refrigeration system adversely.
- Due to leakage the running time of system increases continuosly this increases load on system equipments.
- Both suction pressure and discharge pressure decreases due to loss of refrigerant which reduces the C.O.P. of the system.
- There will be less liquid but more flash gas flow which effect the several component adversely.
- If the suction pressure falls below the atmospheric pressure there is also chance that the atmospheric air containing moisture enters into the system which effect several component adversely.

Method of leakage detection

Soap bubble test :-

- It is the oldest method of refrigerant leakage detection.
- Soap solution is applied at the suspected leak point.
- The escaping refrigerant causes bubble formation at the leakage point.
- However if leakage is very small and in windy condition this method of ineefective.

Halide torch test :-

- This test is more effective then soap bubble test.
- This test is based on the fact that the torch flame turns green when exposed to chlorine atom.
- However all refrigerant doesn't contains chlorine atom, hence it is not suitable for hydrocarbon refrigerant.

Electronic leakage detector method :-

- This method uses electronic sensor which is sensitive to halogenated gas.
- When there is leakage of refrigerant these sensor sense and generates either an audio or visual alarm signal.
- It is most correct, effective and hence widely used method

Ammonia leakage detection test :-

If the refrigerant containing ammonia its leakage can be detected by

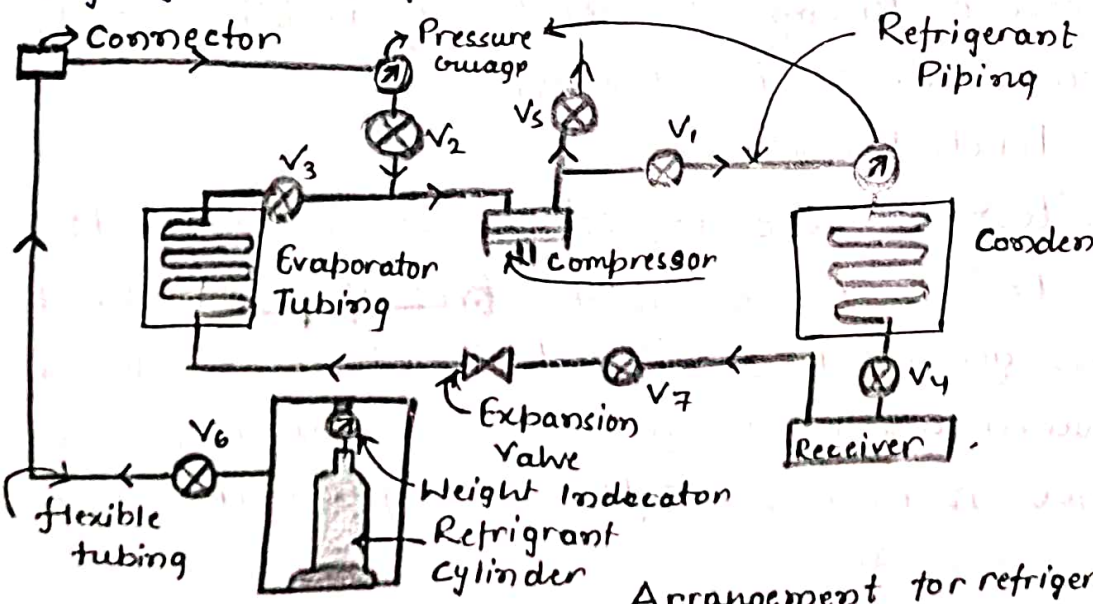
1. Use of phenolphthalein paper :-

When ammonia gas is encountered by this paper it turns pink thereby indecating ammonia leakage.

2. The another method is by the use of lighted sulfur candle which gives thick smoke when exposed with ammonia gas, thus indicated leakage.

Charging of Refrigerant

The process of filling the refrigerant in the suction line compressor - discharge line condenser is called as charging of refrigerant.



Arrangement for refrigerant charging.

Procedure :-

- Before charging of refrigerant air has to be removed from all equipments, for this following steps are to be followed:
  - Shut down the output of the compressor by closing the valve V_1.
  - Close the refrigerant inlet valve V_2.
  - Open the valve V_3 (output from evaporator tubing) & valve V_2 (input to receive).
  - Start the compressor.
  - The air from condenser, evaporator and receiver is forced out through valve V_5.
  - After removal vaccum is produced in system, if this vaccum persist of 30 min it indicates system is free from air.
  - After expulsion of air valve V_3 and V_4 are closed.
  - For charging of refrigerant following steps are done :-
    - Open the cylinder valve V_6 and compressor suction valve V_2.
    - Stop the compressor when sufficient amount of refrigerant has entered.
    - Close the valve V_2 and V_6.
    - The quantity of refrigerant charged is observed by noting the difference in the weight of the refrigerant cylinder.
    - The amount of refrigerant to be charged depends upon capacity of system.

Properties of (refrigerant) used in Lubricant :

- Good chemical stability :-

Lubricant oil should not react chemically with the refrigerant and material.

- Good thermal stability :-

Lubricant oil should not form hard carbon deposit or hotspot in compressor.

- Low viscosity :-

To maintain good lubrication properties at high temperature and good fluidity at low temperature.

- Low wax viscosity :-

At low temperature wax can form in form in lubricating oil. Hence Lubricating oil must have low wax content which block the filters and decrease the pressure of lubricant oil.

- Low pour point :-

The ability of oil to remain in fluid state at a point evaporating temperature.

- Low Floc Point :-

It is the most important property of lubricant oil in refrigeration system as it happens only in the presence of Lub oil.

- Moisture and antifoam characteristic.

Types of lubricating oil used in refrigerant

Mineral - A product of gasoline production. Naphthene-based mineral oils are suitable for refrigeration systems using CFC or HCFC refrigerants and have been the standard oils used for generations. Mineral oil worked well with refrigerants that contained chlorine, but it's not miscible with mordern HFC and HFO refrigerants.

Alkylbenzene - A synthetic oil suitable for refrigeration systems using CFC or HCFC refrigerants. It is compatible with mineral oil. It has improved refrigerant miscibility at low temperature conditions compared to mineral oil, so it was often used with HCFC refrigerants in commercial refrigeration.

Polylester - The most common oil utilized in refrigeration and air conditioning systems using HFC/HFO refrigerant. It is also suitable for systems using CFC or HCFC refrigerant.

Polyvinyl Ether - A synthetic oil used as an alternative to POE oil, it is very common in ductless and VRF systems. It is more hygroscopic than POE oil, but PVE oil doesn't undergo hydrolysis in the presence of water. While PVE will grab water more easily, it is capable of being dehydrated again unlike POE.

Polyalkylene Glycol - A synthetic oil primarily used in automotive air conditioning systems. It is more hygroscopic than either POE or PVE oils, but like PVE, it does not undergo hydrolysis in the presence of water.

UNIT - 4 Refrigerant flow controls

Expansion Device

Expansion device is a very important component of the V.C.R. system. It is located between condensor and evaporator of our system.

The expansion device used in our refrigerating system has two function;

1. Reduce pressure of refrigerant from condensor pressure to evaporator pressure by a process of throttling.
2. Controlling the mass flow rate per volume flow rate of refrigerant going into evaporator as per cooling load in evaporator.

Types of Expansion Device

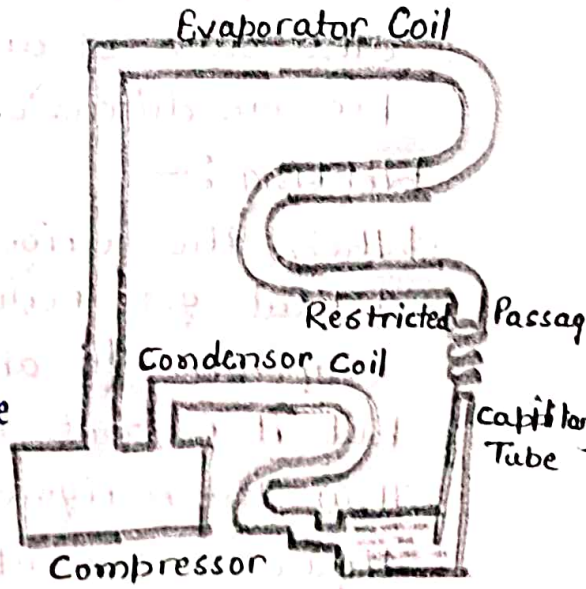
a). Capillary Tube b). Thermostatic Expansion Valve

c). Automatic Expansion Valve

Capillary Tube

The capillary tube used in refrigerating system are made up of copper with diameter 0.5 mm to 2.25 mm and length varies from 0.5 m to 5 m.

Due to frictional resistance offered by narrow diameter tube pressure drop takes place.

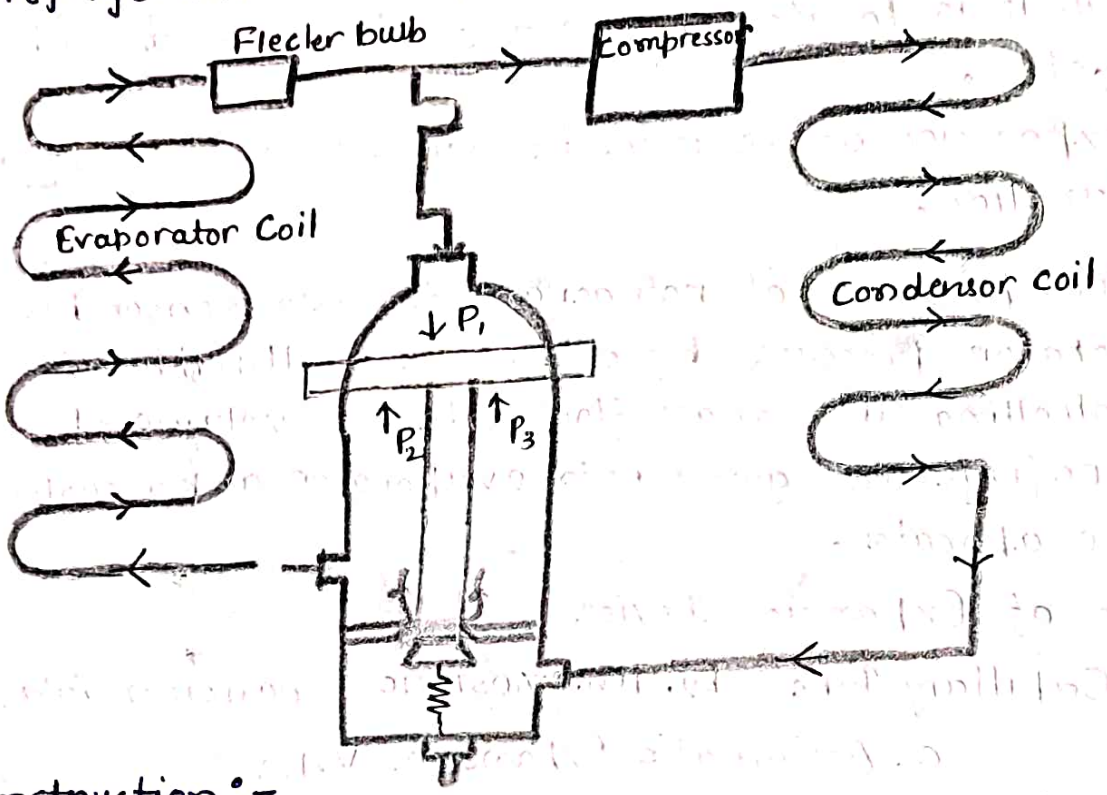


The frictional resistance offered is directly proportional to length of tube and inversely proportional to the diameter.

If longer in length and smaller in diameter greater will be pressure drop.

Thermostatic Expansion Valve

It reduces the pressure of liquid refrigerant from condensor pressure to evaporator pressure and controls the amount of refrigerant entering into evaporator.



Construction :-

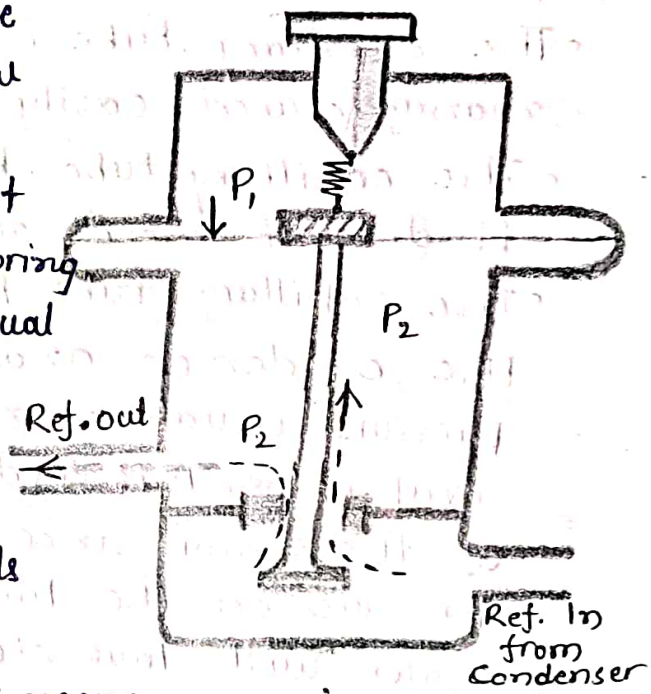
It consis of a spring with adjustable screw. Push rod with diaphragm and a feeler bulb filled with gases. On one side of diaphragm pressure P_2 and P_3. Act while on other side of diaphragm pressure P_1 acts. Due to pressure difference daphragm moves up and down.

Working :-

When the refrigerant abstract heat from evaporator. Amount of heat gets reduced. Now again if refrigerant enters into evaporator to abstract this reduced heat its temp rises but it is not sufficient to rise the temp till boiling. Thus the refrigerant entering into compressor will be in liquid state which cause corrosion. However this problem is eliminated by feeler bulb. If temp of refrigerant leaving evaporator is not sufficient than P_1 pressure gets reduce. Due to which diaphragm moves upward and reduces the passage Area. Due to this amount of refrigerant entering into evaporator gets control which abstract the reduce heat.

Automatic Expansion Valve

- Automatic expansion valve is a pressure reducing valve which is used to reduce the pressure of refrigerant from condensor pressure to evaporator by throttling process.
- Beside reducing the pressure this type of valve, also maintain constant pressure into evaporator. It consist of a diaphragm whose one side is attached to adjustable screw with help of spring.
- The screw is adjustable that it exert pressure through the spring on the diaphragm which is equal to evaporator pressure.
- On other side of diaphragm refrigerant comming after throttling exerts pressure equals to evaporator pressure.



- When the liquid refrigerant pressure comming after throttling process is less than evaporator pressure. Diaphragm moves downward and opens the passage thus amount of refrigerant going into evaporator increases this again maintain the constant evaporator pressure and vise-versa is also true.

Capillary Tube

- The capillary tube is one of the most commonly used expansion devices in refrigeration and air conditioning systems.
- The capillary tube is a copper tube with a very small diameter.
- It is of very long length and it is coiled to several turns so that it would occupy less space.
- When the refrigerant leaves from condensor and before entering into evaporator it has pass through a narrow opening of capillary tube. In the tube drop in pressure takes place due to friction resistance.

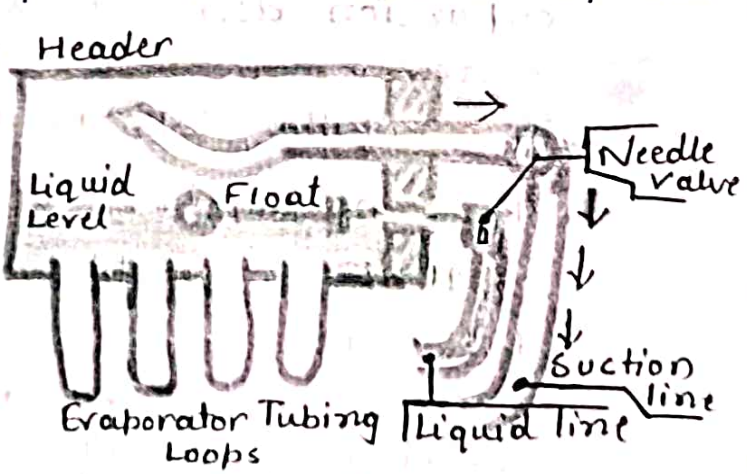
- This drop in pressure is directly proportional to the length of tube while inversely proportional to diameter of the tube.
- Flow of refrigerant is so adjusted that the drop in pressure is equals to the difference between condensor & evaporator pressure.

Advantages :-

- The capillary tube is a very simple device that can be manufactured easily and it is not very costly.
- The capillary tube has no moving parts. Therefore it doesn't need maintenance.
- The capillary tube provides an open connection between the condenser and evaporator hence during off-cycle, pressure equalization occurs between condensor and evaporator. This reduces the starting torque requirement of the motor since the motor starts with the same pressure on the two sides of the compressor. Hence, a motor with low starting torque (squirrel cage induction motor) can be used.
- It is compact in size.

LOW SIDE FLOAT VALVE

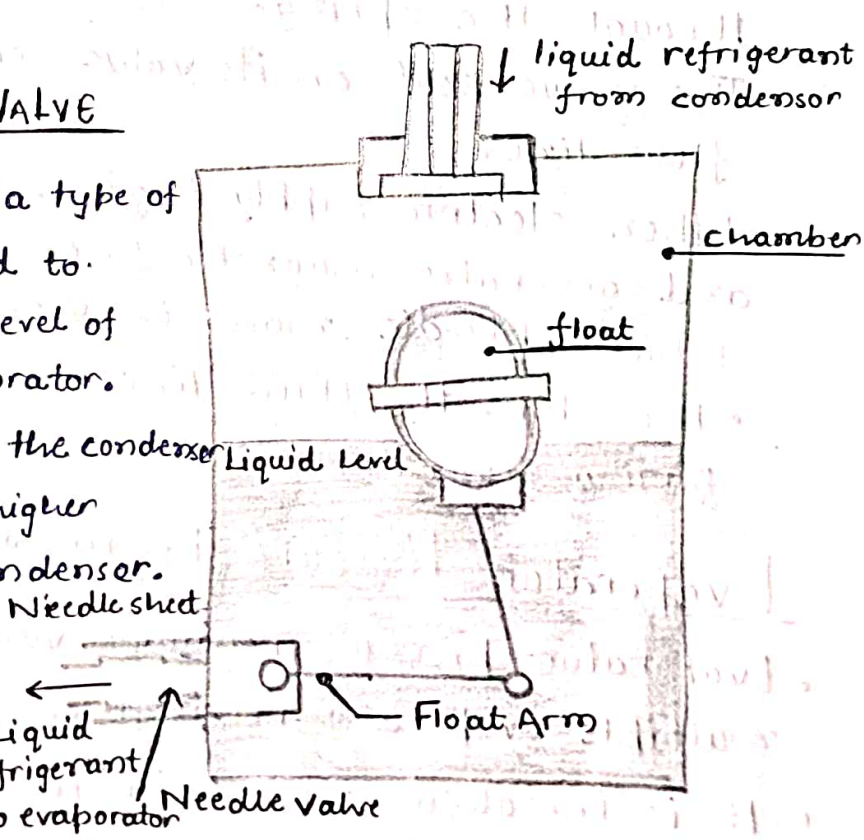
- Low side float valve is a type of float valve which is used to maintain a constant level of refrigerant in the evaporator.
- It is placed between compressor suction line & evaprator.
- It consist of a chamber having float containing liquid refrigerat at a certain level.



Low Side Float Valve

- There is a needle valve linked with float of float chamber. The needle valve is used to make and brake connection between float chamber and liquid line comming from condensor.
- The liquid refrigerant after gaining the heat becomes vapour and then enters to compressor through suction line.
- This cause the drop in level of refrigerant in float chamber.
- Due to this the float also falls and since float in linked with needle valve this create the needle valve to open.
- Due to this liquid refrigerant starts entering in the float chamber through liquid line.
- As the level of refrigerant rises and gets maintained float also rises and pushes the needle valve to close the liquid line.

HIGH SIDE FLOAT VALVE



- High side float valve is a type of float valve which is used to maintain a constant level of refrigerant in the evaporator.
- It is placed between the condenser and evaporator at the higher pressure side is near condenser.
- It consist of a float chamber at the inlet of which is connected with the condenser and outlet of which is connected to evaporator through the needle valve.
- Inside float chamber a float is present which attached to the needle valve.
- When the float is at its minimum level then liquid refrigerant from the condenser starts entering in the float chamber.

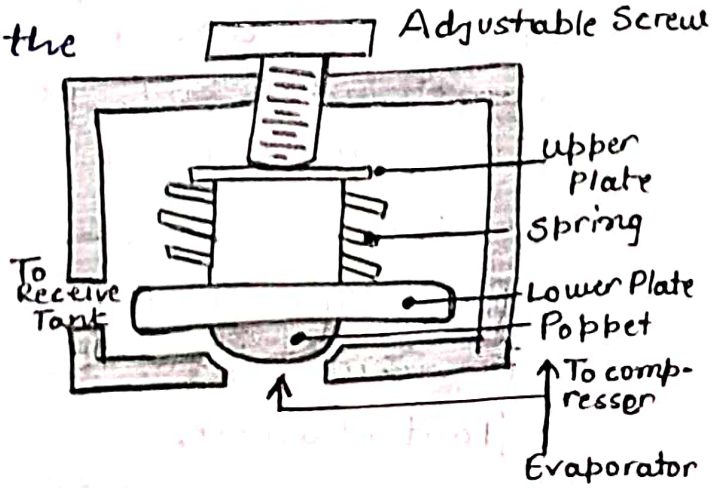
- This makes the float to rise and due to movement of float the needle valve opens and refrigerant enters to evaporator.

Solenoid Valve

- Solenoid valve are used to regulate the refrigerant flow from condenser to evaporator.
- It is placed between condenser and evaporator.
- It is consist of a pair of electromagnet having coil of wire through its entire surface known as solenoid.
- There is a spindle with valve at bottom is placed at the center of the electromagnet and is held vertically through the spring.
- The valve seats on its valve seat thus closing the fluid flow line.
- When electric supply is given to solenoid it gets energized and generates magnetic force on the spindle due to which spindle moves in verticle direction lift the valve.
- This opens the fluid line and thus refrigerant starts flowing from the condenser to evaporator.

Evaporator Pressure Regulator Valve

- Evaporator pressure regulator valve is mainly used nowdays multiple evaporator refrigeration system.
- It is installed just after the evaporator.
- It is installed to discharge the vapour refrigerant to compressor at a particular pressure.



Construction :-

- It consist of an adjustable screw with two supporting plates mounted on the either side of spring.
- By the help of screw, plate, screw a pressure is set on the spring which is equal to the required suction pressure for compressor.
- It has a conical poppet which is opperated by spring pressure and is responsible for opening and closing of valve.

Working :-

- If the refrigerant leaving the evaporator is at higher pressure then required suction pressure then the conical poppet moves upward causing some refrigerant to flow the receiver tank.
- This reduces the pressure of refrigerant to suction pressure as required.
- As the pressure drops to suction pressure the poppet valve falls down and closes the valve.

Freezing :

- Freezing is the removal of heat from packaged or whole foods resulting in the temperatures between slightly below the freezing point of food to -18°c.
- Frozen foods last many months without spoiling however, some loss may occur.
- Different types of freezing systems are available for foods. No single freezing system can satisfy all freezing needs, because of the wide variety of food product and process characteristics.
- The selection criteria of a freezing system will depend on the the type of the product, reliable and economic operation.

Advantages of freezing

- It increase shelf life of food.
- It increase the food supply.
- It decrease wastage of food.
- It adds varieties to the food.

Freezing Systems

Freezing system based on time required to freeze foods can be classified into two types:

a. Slow Freezing b. Quick freezing

Slow Freezing

- In the slow freezing method, the food products are placed in a low temperature room (sharp freezer) and allowed to freeze slowly is still air by natural convection.
- The temperature maintained in sharp freezers ranges from -17°C to 40°C.
- Since the circulation of air in the stored room is by natural convection, therefore the time required for freezing for freezing the food is considerably large.
- It may be from three hours to three days depending upon the bulk of product and the conditions in the sharp freezer.
- This method is commonly used for beef and boran, boxed poultry, fish, fruit in barrels and other large containers and eggs in cans.

Quick Freezing

- In the quick freezing method for freezing the food products in storage, the forced circulation of cold air is necessary.
- The difference between quick and slow freezing is only in size of ice crystals formed within the food during freezing.

Cold Storage

- Many food products may be stored at some temperature above the freezing point.
- The storage may be short-term storage or long-term storage.
- The storages which are used for short-term storage purposes are known as cold storages.
- The period for short-term storage ranges from one to two days or to a week or more in some cases, but not more than fifteen days under any circumstances.
- The following points should be kept in mind while storing the foods in cold storages:
  a. Storage temperature
  b. Relative humidity and air motion
  c. Mixed storage
  d. Condition of product at the time of storage
  e. Product chilling

Frozen Storage

- When the food products are to be preserved in its original fresh state for longer period, then they are usually frozen and stored approximately at -15°c or below. Such storages are known as frozen storages.
- They differ from the cold storages in their size and the temperature range.
- The size of the frozen storages is considerably smaller than cold storages and the temperatures used for preserving the foods are also low as compared with the temperatures used for cold storages.
- The food products which are commonly preserved in frozen storages include fruits, vegetables, meat, pourltry, breads, pastries, ice cream and a wide variety of pre-cooked foods.

Diary Refrigeration

- Refrigeration is a basic requirement for the processing and storage of milk and milk products.
- A refrigeration system is an imprtant and integral part of diary industry.
- Milk is collected from local farms by the diary for processing.
- Milk tankers use stainless steel bodies that enhance insulation.

Water Cooler

Working principle of the Water cooler :-

- The working principle of the water cooler is based upon the vapour comparession refrigeration cycle. The refrigerant is compressed by the compressor and is delivered to the condenser which is cooled by a fan. The high pressure liquid after being cooled by a condenser is collected in a receiver from where it goes to the expansion valve. The expansion valve takes the required quantity of the refrigerant depending upon the load on the evaporator.
- As the refrigerant passed through the expansion valve, its temp falls down considerably (up to -10°c). Its pressure also falls down. Then this liquid refrigerant passes through the evaporator coils, which surround the water tank (water may be stored in it). The liquid refrigerant in the coils absorbs its latent heat from the water, which cools down the water in the tank.
- The liquid refrigerant as it flows through the evaporator coils is converted into vapour and by the time it leaves the coils, it is almost converted into dry vapour. This vapour is again compressed through the compressor. This ~~vapour~~ way this cycle is repeated again & again. The cooled water may be drained out & the fresh water may be added to the tank for cooling.

UNIT-5 Air Conditioning

Psychrometry :

Psychrometry is a subject of engineering which deals with the Study of properties of moist air, so that they can be controlled to produce an environment for human confort.

Air is of three types;

1. Dry Air

It is a mixture of gas in which percentage of volume Nitrogent is 78% oxygen is 21% and remaining 1% is other gases.

- Water vapour is not present in dry air.

2. Moist Air

Those air in which water vapour is presented in diffused form is called moist air.

- $\boxed{\text{Dry air + Water vapour = Moist Air}}$

3. Saturated Air

It is a condition of moist air at which the water vapour present in moist air is maximum.

- That moist air for which relative humidity is 100%.

Properties of Moist Air

1. Dry-bulb Temperature :— It is the temp. of moist air measured by psyling thermometer, whose bulb is completely dry. Represented by "t_{Db}".
2. Wet-bulb Temperature :— It is the temp. of moist measured by a psyling thermometer whose bulb is coverd by wetted cotton & air is flowing at some velocity. Represented by "t_{WB}".

3. Wet - bulb depression :- It is the different between dry bulb temperature and wet bulb temperature.

- $\boxed{W_{BD} = t_{Db} - t_{Wb}}$

4. DEW point temp :- It is the temperature of moist air at which water vapour present in moist air starts condensing and transform into water droplets known as DEW. Represented by "t_{DP}".

5. Dew point Depression : It is the difference between dry bulb temperature and dew point temp.

- $\boxed{DPD = t_{Db} - t_{DP}}$

6. Specific Humidity :- Specific humidity is defined as mass of water vapour present in per unit mass of dry air. It is represented by "ω".

In a close room, at temp. T and volume of V,

Moist air $= M_1 P_T$

Dry air $= m_a P_a$

Water vapour $= m_v P_v$

according to Dalton's Theory,

$$\boxed{P_T = p_a + p_v}$$

$\because PV = mRT$

$\therefore M_v = \dfrac{p_v V}{R_v T}$

$M_a = \dfrac{p_a V}{R_a T}$

$R_v = \dfrac{R_o}{M_v} = \dfrac{8.314}{18} = 0.462$

$R_a = \dfrac{R_o}{M_a} = \dfrac{8.314}{29} = 0.287$

$\omega = \dfrac{M_v}{M_a} = \dfrac{P_v V}{R_v T} \times \dfrac{R_a T}{P_a V}$

$\omega = \dfrac{P_v R_a}{R_v P_a} = \dfrac{P_v}{P_a} \times 0.622$

and, $P_a = P_T - P_v$

$\therefore \boxed{\omega = 0.622 \times \dfrac{P_v}{P_T - P_v}}$

7. Relative Humidity :- Relative humidity is defined as the ratio of amount of water vapour present in unsaturated air to the amount of water vapour present in saturated air at same volume and temperature. Represented by "ϕ".

In a room system which is unsaturated, at temp. T & ~~pressure~~ volume V.

Moist air = M, P_T

Dry air = m_a, p_a

Water vapour = m_v p_v

In another system which is in saturated condition at same condition,

Moist air = M, P_T

Dry air = m_{as}, p_{as}

Water vapour = m_{vs}, p_{vs}

$$\because \phi = \frac{m_v}{m_{vs}}$$

$p_v \times V = m_v R_v T$ and $p_{vs} \times V = m_{vs} R_{vs} \times T$

$$m_v = \frac{P_v V}{R_v T} \qquad m_{vs} = \frac{p_{vs} \times V}{R_{vs} \times T} \qquad \cdot R_v = R_{vs}$$

$$\phi = \frac{P_v \cancel{V}}{\cancel{R_v T}} \times \frac{\cancel{R_{vs} \times T}}{p_{vs} \cancel{\times V}} = \frac{P_v}{P_{vs}}$$

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

8. Enthalpy of Moist air :-

h = enthalpy of unit mass of moist air (kJ/kg)

h_a = enthalpy of unit mass of ~~of~~ dry air (kJ/kg)

h_v = enthalpy of unit mass of water vapour (kJ/kg)

$$m = m_a + m_v$$

$$m = m_a \quad , \quad m_v <<< m_a.$$

Total enthalpy of moist air = Total enthalpy of dry air + Total enthalpy of water vapour

$$m \times h = m_a \times h_a + m_v \times h_v \quad -①$$

for dry air,

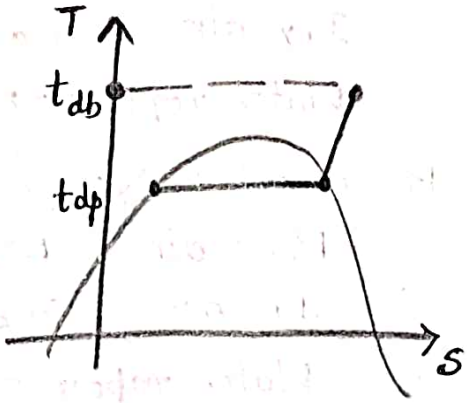
enthalpy of unit mass of dry air,

$h_a = 1.005 \times t_{db}$.

$\because$ Total enthalpy of dry air $= m_a \times 1.005 \times t_{db}$

for water vapur,

(unsaturated moist air water vapour is super heated),



$h_{sup} = h_{sat} + C_{pv}(T_{sup} - T_{sat})$

$h_v = 2500 + 1.88(t_{db} - t_{dp})$

$\because$ Total enthalpy of water vapour

$m_v[2500 + 1.88(t_{db} - t_{dp})]$

$\because \quad m \times h = m_a h_a + m_v h_v$

$h = \frac{m_a}{m} 1.005 t_{db} + \frac{m_v}{m}[2500 + 1.88(t_{db} - t_{dp})]$

$\because \boxed{h = 1.005\, t_{db} + W[2500 + 1.88(t_{db} - t_{dp})]}$

Numerical

Q. 1. Atmospheric condition are 20°C and $\omega = 0.0095$ kg/kg of dry air. Calculate,

1. Partial pressure of vapour
2. Relative Humidity
3. Dew point temperture.

$t_{db} = 20°$ and $\omega = 0.0095$ kg/kg

from steam table,

$t_{db} \rightarrow p_{vs} = 0.023$ bar

$\because W = \frac{0.622\, p_v}{P_t - p_v} \Rightarrow 0.0095 = \frac{0.622 p_v}{1.0132 - p_v}$

$0.622\, p_v = 0.0095 \times 1.0132 - p_v\, 0.0095$

$p_v(0.6315) = 0.0095 \times 1.0132$

$p_v = \frac{0.0095 \times 1.0132}{0.6315} = 0.01524$

Relative humidity,

$$\phi = \frac{P_v}{P_{vs}} = \frac{0.01524}{0.0234} = 0.6539$$

and $t_{dp} = 13.21°c$

Steam table (P based)

P_{min}	0.0150	13.04
P_c	0.01529	T_c
P_{max}	0.020	17.51

Interpolation,

$$T_{cal} = T_{min} + \frac{T_{max} - T_{min}}{P_{max} - P_{min}} \times (P_{cal} - P_{min})$$

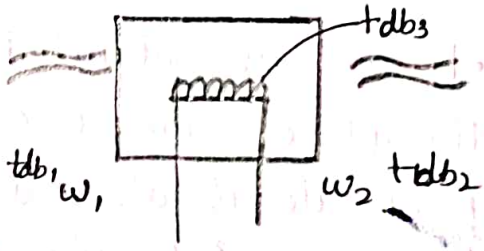
$$= 13.04 + \frac{17.51 - 13.04}{0.020 - 0.015} \times (0.0002)$$

$$= 13.21$$

Sensible Heating

The process in which when the moist air is passed through heating coil whose temperature is greater than the temperature of moist air entered and the surface of heating coil is completely dry. This causes increment in DBT of moist air while its surface humidity remains constant.

Thus such process in which DBT of moist air increases while specific humidity remains constant is called sensible heating.



$t_{db3} > t_{db2} > t_{db1}$

$W_1 = W_2$

It is the ratio of out temperature difference with coil tempeperature to input temperature difference with coil temperature.

$$\boxed{\text{Bypass factor} = \frac{t_{db3} - t_{db2}}{t_{db3} - t_{db1}}}$$

- In sensible heating relative humidity decreases.
- DPT is also constant

Objectives,

DBT ↑

W = C

DPT = C

WBT = ↑

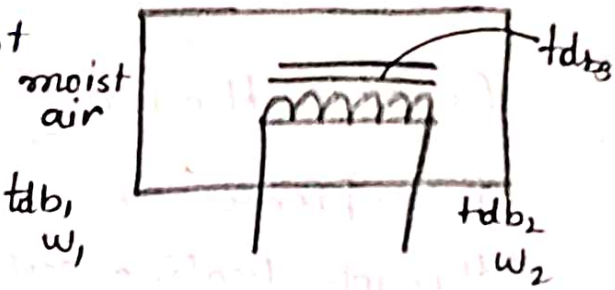
ϕ = ↓

h = ↑

Sensible Cooling

When ever the air is passed through the surface of cooling coil which is dry and whose temperature is less than the DBT of air but greater than the dew point temperature of air while the specific humidity remains constant.

If the surface temperature of coil is less than DPT of air then there is a possibility that the air when gets cooled its temp. reaches to its DPT and then specific humidity will not remains contant.

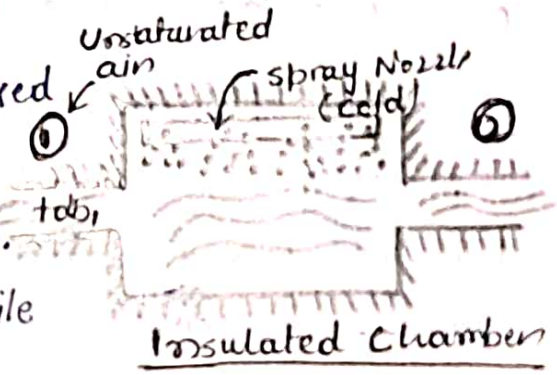


$$B.F = \frac{t_{db_2} - t_{db_3}}{t_{db_1} - t_{db_3}}$$

$t_{db_1} < t_{db_3} < t_{db_2}$

DBT = ↓ , DPT - C , W - C , ϕ - ↑ , h ↓

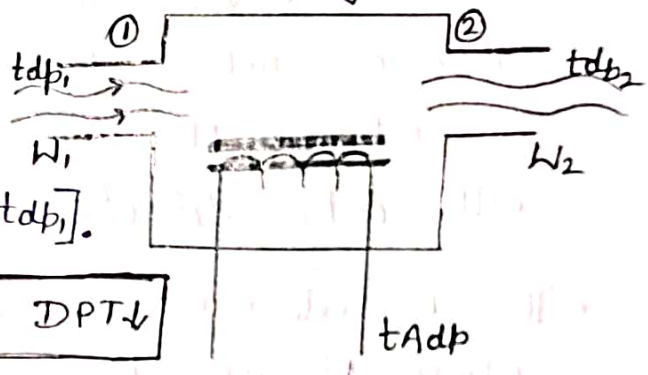
Cooling and Humidification



- If an unsaturated air is passed through a spray of continuous recirculated atomised water particle. Its specified humidity increases while its DBT decreases.
- When the unsaturated air comes in contact with the atomised water particle it reject its heat as form of sensible heat to water particle due to which its DBT increases.
- The rejected heat is utilized by water particle as latent heat & water particle get converted into water vapour & get diffused into unsaturated air due to which specific humidity increases.
- A process in which DBT of air decrease and specific humidity increases is called cooling & humidification.
- In this enthalpy of moist air remains constant hence it is called adiabatic humidification.

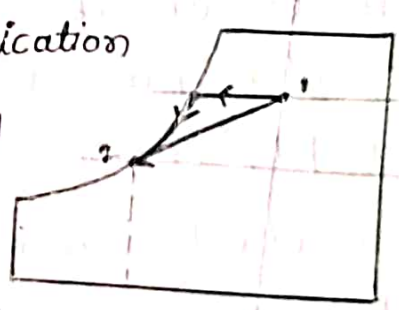
Cooling and Dehumidification

- Whenever the air is passed over a surface whose temperature is less than the dew point temperature of moist air, then condensation of water vapour present in moist air takes simultaneously with sensible cooling.
- When air is passed through the surface which is at a temperature lower than the dewpoint of air, the surface will cool down the moist air till it reaches it dew point. Due to this water vapour present in moist air gets condensed and gets separated with moist air. Thus cooling with dehumidification takes place.
- The temperature of our cooling surface is known as apparatus dew point temperature [$t_{Adp} < t_{db_1}$].

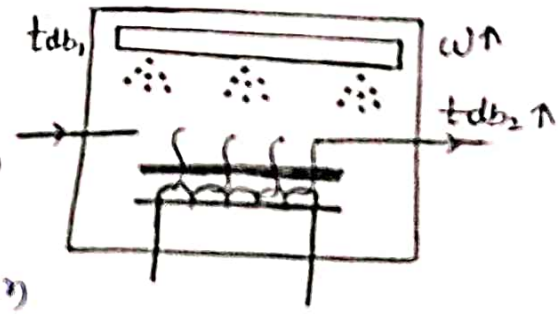


$\omega \downarrow$	DBT $\downarrow$	$h \downarrow$	$\phi \uparrow$	WBT $\downarrow$	DPT $\downarrow$

Heating humidification and dehumidification

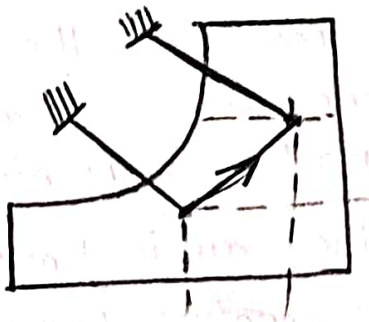


- If the air is passed through the coil which has temp. greater than the temperature of moist air in a cabin where spray of water is circulated through nozzle continuosly.
- The atomized water particle when comes in contact with heated coil surface it abstrat the heat and become vapour.
- Thus vapour gets diffused in the incomming moist air. Due to which its specific humidity increases and humidity increases and humidification will takes place.



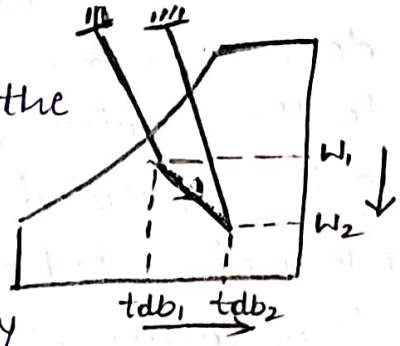
$t_c > t_{db_1}$

- The air in the chamber where flows over the surface of heating coil its DBT increases, ie heating with humidification takes place.



$\boxed{\omega\uparrow \quad DPT\uparrow \quad WBT\uparrow \quad h\uparrow \quad \phi\downarrow \quad DBT\uparrow}$

- If the air is passed over a surface whose temperature is greater than the temperature of moist air and the surface is covered with a chemical absorvent which has the property to absorb the water vapour present in air. Then heating with dehumidification takes place.



- The heated surface rises the DBT of moist air and the chemical absorbent like silica gel removes the moisture ie water present in air. Thus heating and dehumidification takes place.
- It is also known as "Chemical dehumidification."

$\boxed{\omega\downarrow \quad DBT\uparrow \quad WBT\uparrow \quad DPT\uparrow \quad \phi\downarrow \quad h\uparrow}$

Human Comfort

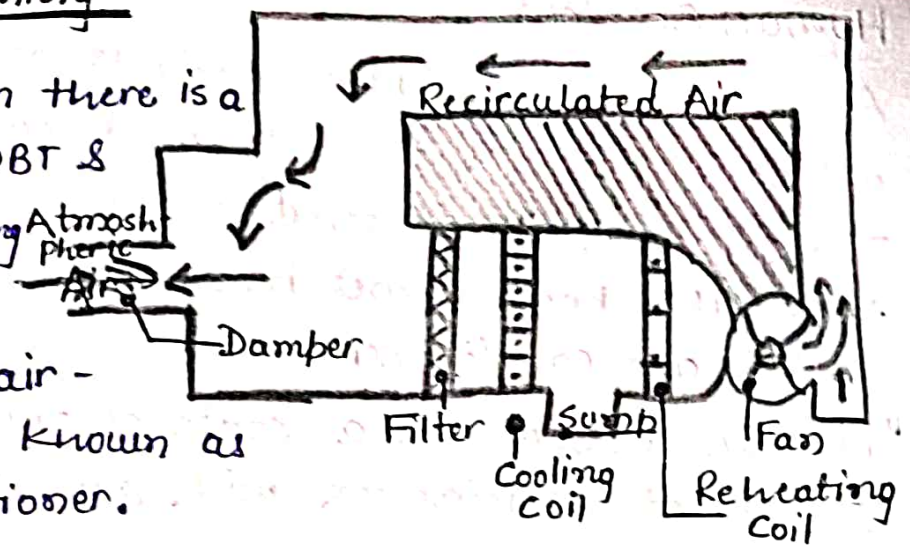
As we know that when body is in discomfort zone then it will not perform properly as because it will be not efficient. Therefore we conditioned our surrounding environment so that the body comes in a comfertable zone by a device called air conditioner.

"Human comfort is a state of mind which express the feeling of satisfaction with surrounding environment."

Factor affecting Human Comfort

1. Air Stratification :- When the temperature of air is high then it become rarer and moves upward towards terrace and creates lack of air at the floor space which creates lack of oxygen and cause human discomfort.
2. DBT of Air :— In summer season DBT of air increases due to which heat transfer rate from body decrease and human body feels very hot cause human discomfort. While in winter season DBT of air decreases due to which heat transfer rate from body increase and human body feels very cold cause human discomfort.
3. Air Humidity :— Relative humidity increases or decreases it would create discomfort. In winter season relative humidity is 30-40 %. In summer season relative humidity is 80-90%.
4. Air Velocity :- Air velocity is required to transfer heat from body. The air viscosity required 5 m/s, if air velocity is more than 5 m/s it would create discomfort.
5. Air Purity :— Air must not contains dust or dirt particle otherwise it would create discomfort.

Summer Air Conditioning

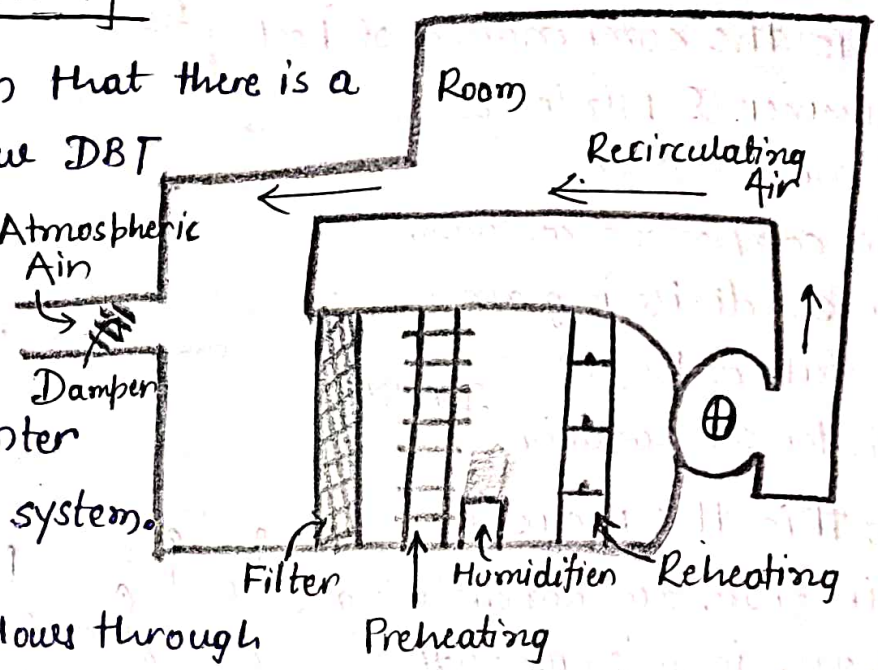


- During summer season there is a problem of increase DBT & humidity of air-entering in room
- This is done by an air-conditioning system known as summer air conditioner.
- The working process is summer-air conditioning system is cooling with dehumidification and simultaneosly heating the air at required temperature.
- In this system cooling coil is maintained at a temp less than the dew point temperature of air entered.
- The outside air flows through the damper and mixes with recirculated air from air conditioned space to maintain required quantity of air.
- The mixed air is now passed through cooling coil which is maintained at a temperature lower than DPT of the air entered, so that when air passes through it, gets cool down and reaches to its DPT. Dew to this water vapour present in it gets condensed and removed from air.
- This dehumidification air is very cold, therefore it is passed through heating coil where its DBT is increased as per requirement.
- This conditioned air is now forced to required space through fan.

Winter Air Conditioning

During winter season that there is a problem of very low DBT & very low humidity which creates uncomfortable.

∴ We require a winter air conditioning system.



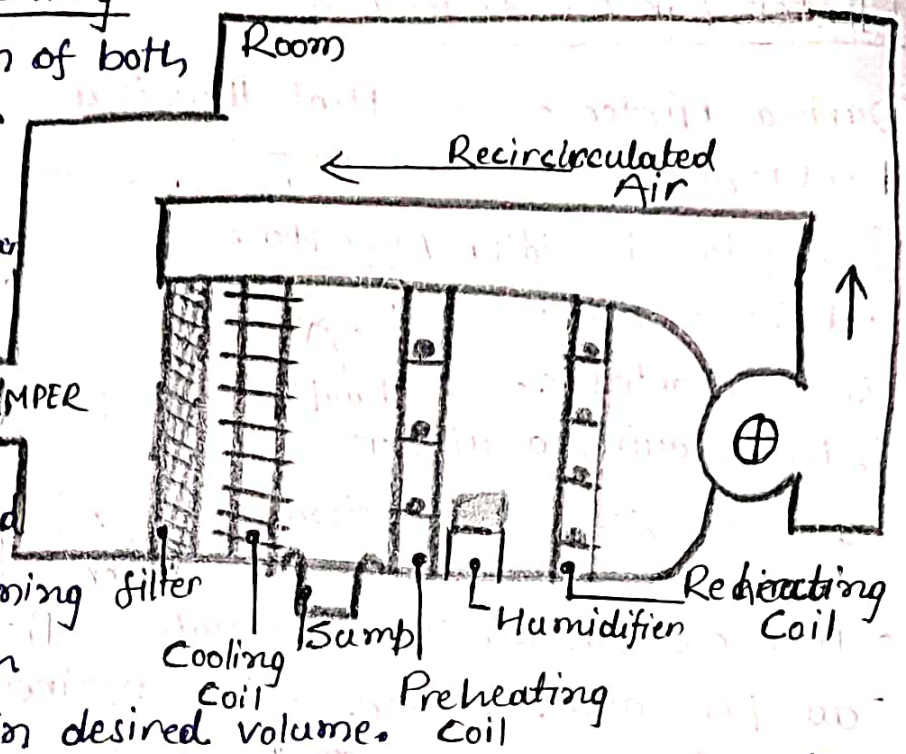
- The outside air flows through damper and mixed with recirculated air to maintain desired volume air. This air is now passed through filter which removes dust and dirt particles.
- The air is now passed through humidifier where atomized water particle takes the heat from preheated air and gets converted into vapour.
- ~~Now this air is passed~~
- This ~~air~~ Water Vapour diffused into air & thus humidification takes place. Now this air is passed through reheating coil to obtain desired DBT.

Difference between Summer & Winter air conditioning system.

Summer Air conditioning	Winter Air Conditioning
• It is used in summer season	• It is used in winter season.
• In this cooling & dehumidification takes place.	• In this heating & humidification is done.
• One heating coil is used to control the temp of air to human comfort.	• Two heating coil is used one is preheating & other is reheating.
• In this system refrigerant is circulated through cooling coil.	• In this water is circulated through humidifier.
• Operating cost is low.	• Operating cost is high.

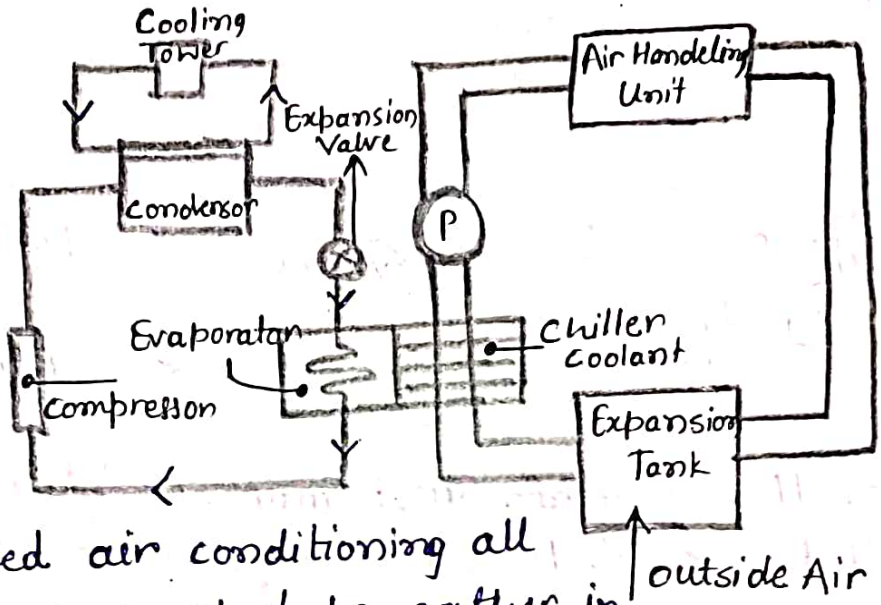
Allaround Air Conditioning

- It is the combination of both summer & winter air conditioning.
- The component of summer air conditioning are installed before winter air condition.
- In this the recirculated air from air conditioning space is mixed with outside air to obtain desired volume.



- The air is then passed through filter where purification is done.
- The air is then passed through a cooling coil which is at a temp lower than DPT of air which causes cooling & dehumidification.
- Now the air is passed through preheating coil which increases DBT of air as required and now forced in room operation of further component is stopped ~~and~~ ain summer.
- Now in winter season operation of cooling coil is stopped and air from filter passes first through preheating coil and then to humidifier which causes humidification & then passes for reheating coil to increase DBT. The air become conditioned air and is forced by fan into room.

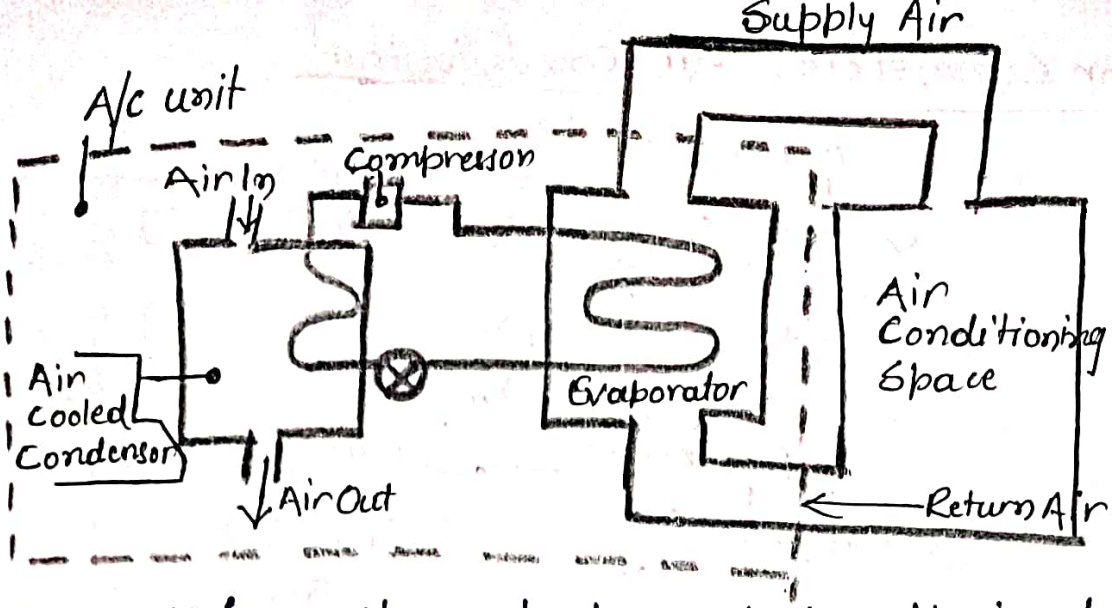
Central or Commercial Air Conditioning



- In centralized air conditioning all component are grouped to gather in a central room. The conditioned air are disturbed to different room by duct work.
- This system has a generally used for load above 25 T.R. and handle 2500 m^3 of air per minute.
- In this the outside air enters from expansion tank and goes to chiller where the chilled coolant makes this expanded air as very-very cold air.
- Now this very-very cold air is pumped to air handling unit from where the air is distributed to different room by duct work.
- It can be located away from air conditioning space which is very useful.
- Noise and vibration trouble are very less to people living in air conditioning space.

Unitary Air Conditioning

- In unitary air conditioning all the components of air conditioning are installment in a single unit.
- This single unit is installed within the air conditioning space. Example Window air conditioning.
- Unitary air conditioning meet requirement of single room.



- Since this ~~unitary~~ duct work is eliminated hence installation and labour charge minimize.
- Failure of Unitary air conditioning stop conditioning of one room but failure of central air conditioning stop conditioning of multiple room.

Tools used in AC installation

1. Multimeter :— Every HVAC professional needs a multimeter in their kit. This handy device will help us to see live currents in a wire, power switch or outlet. This prevents us from getting electrocuted (Injury) while working.
2. Thermometer :— Technicians need to check the temp on HVAC units. Use a thermometer to get an accurate reeding. If the reading is too high, add refrigerant to the HVAC unit.
3. Vaccum Pump :— Vaccum pumps are a must for HVAC technicians. Use this tool to remove moisture from any system that we are working on. Before filling of refrigerant it is very much necessary that the refrigeration system, component is free from moisture.

4. Hand Seamers (Tongs) :-

Use a hand seamer to create clean and accurate bends in our HVAC systems. Though these tools look like a pair of pliers, they are used for bending sheet metal & evaporator and condenser coil.

5. Refrigerant Gauges :- These are basically pressure gauges are used to measure the pressure of refrigerant in the evaporator and condenser.

6. Crimpers :— As an HVAC technician, we come in contact with a lot of open pipes. Use a crimper to close the open end of a rounded pipe. The teeth on the crimper are what allow for the open end to be closed.

7. Cordless Drill :— When we are running new wires, we need to drill tiny holes for them. Have a cordless drill so we can do this easily and effectively. We specifically recommend a cordless drill instead of a cordless drill instead of a corded drill because we won't have a cord to limit our movement. Just get a cordless drill and some batteries, and we are good to go any where.

8. Tubing Cutter :- It is designed to cut the tube of copper very efficiently.

Ac Installation Procedure

1. Select an unobstructed location on our interior wall to mount the indoor unit. We will need to cut a hole through the wall to feed the ~~supply~~ pipes from the indoor unit to the outdoor unit, so make sure the location we choose will allow us to do so. Choose a spot away from direct sun light and heat sources for the best results. Mount 7 feet off the floor and ensure there at least 6-12 inches of open space on every side of the unit to allow for proper airflow.

2. Secure the mounting plate to the interior wall. Hold the mounting plate against the wall where we want to install the indoor unit. Use a level to make it both horizontally and vertically level. Use the pencil to mark the locations of the screw holes, remove the plate, then drill a hole into the wall wher each screw will go.

3. Drill a (7.6cm) hole through the wall so we can feed the pipes outside. Make a mark in the centre of the hole in the mounting plate. Use a keyhole saw or a drill with a hole cutting attachment to create a circular (7.6 cm) opening through wall that slopes slightly downward toward the ground to ensure adequate drainage.

4. Check the electrical connection on the unit. Lift the air conditioning unit's front pannel and remove the cover. Make sure the cable wires are connected to the screw terminals and that the wiring matches the diagram that come with the unit.

5. Run the pipes and cables through the hole in the wall then connect them to unit.
6. Secure the indoor unit to the mounting plate. To attach the air conditioner to the wall, simply align the female connections on the back of unit with the male connections on the mounting plate and press firmly to secure the unit in place.
7. Position the outdoor unit away from any heavily trafficked, dusty, or hot areas. Find the hole we drilled through the mounting plate for the interior unit and position the exterior unit within 50 feet (15 m) so the piping and cable can easily be attached. Fix the outer unit on the wall or on the concrete pad by the help of bracket and screw.
8. Connect the piping and cable to the outdoor unit. Use flare nut to secure the 2 copper pipes from the indoor unit to the outdoor unit as per the instruction manual. Connect the power cable that runs from the indoor unit to the outdoor unit as well.

Faults In Air-Conditioning

There are various types of faults that occur in air-conditioning system which are as follows :-

Over-Charged :- Over charging means filling the system with excess amount of refrigerant that desired limit.

- This would create increase in both suction and discharge pressure which will effect the C.O.P. of the system.
- It will also decrease the superheating due to which the refrigerant entering into compressor is wet at

will cause cavitation.

- The electrical consumption also increases.

Under charged :- Under charging means filling the system with less refrigerant.

- This would decrease both the discharge and suction pressure and thus effect of C.O.P. of the system.
- Increase the superheating due to which compressor gets overheated and less will be electric consumption.

Capillarity Particle Block :- When there is moisture present in the system or impurities it will partially block the capillary tube.

- This would decrease suction & discharge pressure.
- As less amount of refrigerant entering into evaporator hence superheating increases and less amount of refrigerant entering into compressor hence less electricity is required.

Dirty Condensor :- When there is a accumulation of dirt and dust over the condensor coil then the amount of heat to be rejected in the atmosphere decreases this will reduce the refrigerating effect.

- This would increase the discharge pressure as refrigerant in condensor is at high temp. and the refrigerant entering into evaporator is in vapour state hence temp is high therefore suction pressure also increases.
- This would increase the super heating.

Low Cool Air Flow In Room :- This is due to blocked filter low level of refrigerant due to leakage.