SWAMI VIVEKANANDA SCHOOL OF

ENGINEERING & TECHNOLOGY

SUBJECT NOTE – REFRIGERATION & AIR CONDITIONING

SEMESTER – 5TH

LECTURER NAME – ER. KUNAL PRADHAN

① **Definition**: The term refrigeration may be defined as the process of removing heat from a substance under controlled conditions. It is also includes the process of reducing and maintaining the temp of a body below the general temp of its surroundings. In other words, the refrigeration means a continued extraction of heat from a body whose temp is already below the temp of its surroundings.

The Practical unit of refrigeration is expressed in terms of 'tonne of refrigeration' (TR). A tonne of refrigeration is defined as the amount of refrigera -tion effect produced by the uniform melting of one tonne (1000 kg) of ice from and at 0°C in 24 hours.

Since the latent heat of ice is 335 kJ/kg,

$\therefore$ 1 TR = 1000 × 335 kJ in 24 hours $= \frac{1000 \times 335}{24 \times 60} = 232.6$ kJ/min

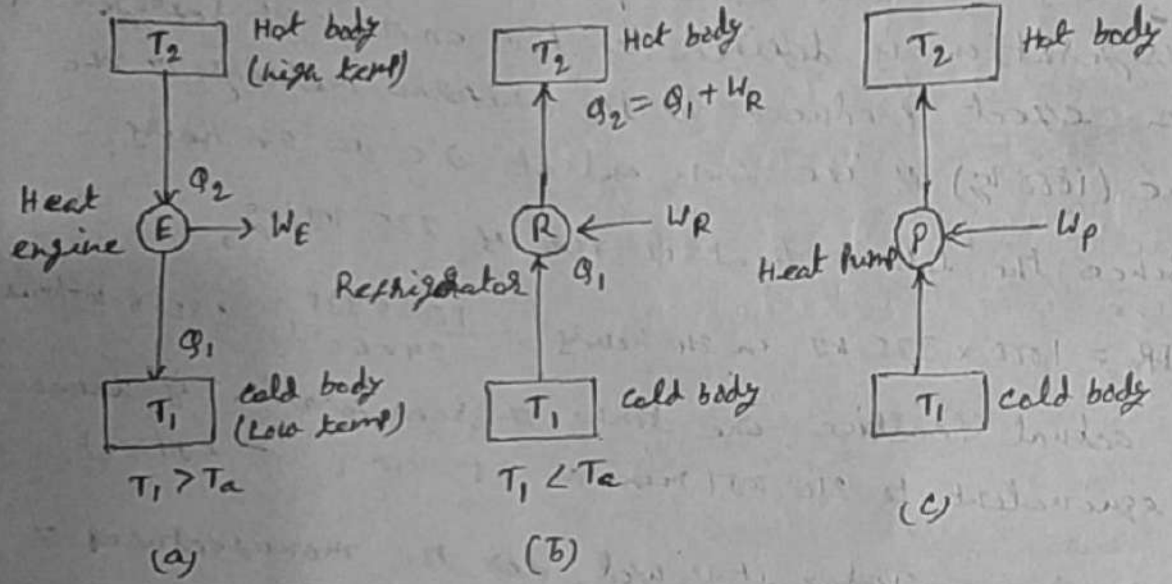
In actual practice, one tonne of refrigeration is taken as equivalent to 210 kJ/min or 3.5 kW (3.5 kJ/sec).

① **Application**: Today it is used for the manufacture of ice and similar product. It is also widely used for the cooling of storage chambers in which perishable foods, drinks and medicines are stored. The refrign has also wide application in submarine ships, air crafts and rockets.

① **Air conditioning**: The air conditioning is that branch of engineering science which deals with the study of conditioning of air i.e, supplying and maintaining desirable internal atmospheric conditions for the man comfort, irrespective of external conditions. The following are the four important factors for comfort air conditioning: (1) Temperature of air, (2) Humidity of air (3) Purity of air and (4) Motion of air.

⑩ <u>Application</u> : It deals with the conditioning of air for industrial purposes, food processing, storage of food and other materials.

⑪ <u>Heat engine</u> : In a heat engine as shown in figure (a) the heat supplied to the engine is converted into useful work. If Q_2 is the heat supplied to the engine and Q_1 is the heat rejected from the engine then the net work done by the engine is given by - $W_E = Q_2 - Q_1$



The performance of a heat engine is expressed by its efficiency. We know that the efficiency or coefficient of performance of an engine.

$$\eta_E \text{ or } (C.O.P)_E = \frac{\text{Work done}}{\text{Heat supplied}} = \frac{W_E}{Q_2} = \frac{Q_2 - Q_1}{Q_2}$$

$$\left[\text{or } \eta_E = \frac{\text{Work done}}{\text{heat absorbed}} = \frac{T_1 - T_2}{T_1}\right]$$

A refrigerator as shown in figure (b) is a reversed heat engine which either cool or maintain the temp of a body (T_1) lower than the atmospheric temp (T_a). This is done by extracting the heat (Q_1) from a cold body and delivering heat to a hot body (Q_2). In doing so work W_R is required to be done on the system. According to first law of thermodynamics, $W_R = Q_2 - Q_1$

The performance of a refrigerator is expressed by the ratio of amount of heat taken from a cold body (Q_1) to the amount of work required to be done on the system (W_R). This ratio is called coefficient of performance. mathematically, COP of a refrigerator,

$$(C.O.P)_R = \frac{Q_1}{W_R} = \frac{Q_1}{Q_2 - Q_1} \quad \left[(COP)_R = \frac{T_2}{T_1 - T_2}\right]$$

Any refrigeration system is a heat pump as shown in figure (c), which extracts heat (Q_1) from a cold body and delivers it to a hot body. Thus there is no difference between the cycle of operations of a heat pump and a refrigerator. The main difference between the two is in their operating temperatures. A ref works between the cold body temp (T_1) and the atm temp (T_a) and the whereas the heat pump operates between the hot body temp (T_2) and the atmp temp (T_a). A refrigerator used for cooling in summer can be used as a heat pump for heating in winter.

In the similar way, as discussed for refrigerator, we have, $W_P = Q_2 - Q_1$

The performance of a heat pump is expressed by the ratio of the amount of heat delivered to the hot body (Q_2) to the amount of work required to be done on the system (W_P). This ratio is called C.O.P or energy performance ratio (E.P.R) of a heat pump,

$$(C.O.P)_P \text{ or } E.P.R = \frac{Q_2}{W_P} = \frac{Q_2}{Q_2 - Q_1} \quad \left[\eta = \frac{T_2}{T_1 - T_2}\right]$$

$$= \frac{Q_1}{Q_2 - Q_1} + 1$$

From above we see that c.o.p may be less than one or greater than one or greater than one depending on the type of refrigeration system used. But the c.o.p of heat pump is always greater than 1.

(II) Coefficient of performance of a Refrigerator:

The c.o.p is the ratio of heat extracted in the refrigerator to the work done, on the refrigerant. It is also known as theoritical c.o.p. Mathematically

$$\text{Theoritical c.o.p} = \frac{Q}{W}$$

where, Q = Amount of refrigeration produced, or the capacity of the refrigerator.

W = Amount of work done.

(1) The c.o.p is the reciprocal of the efficiency $(1/\eta)$ of a heat engine. It is thus obvious, the value of c.o.p is always greater than unity.

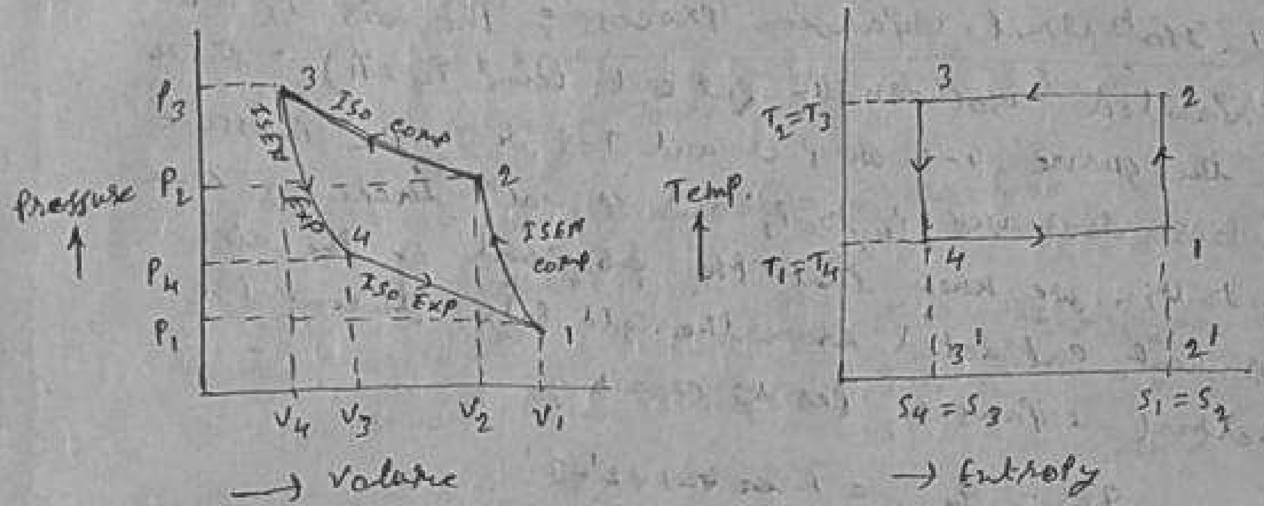
(2) The ratio of actual c.o.p the theoritical c.o.p is known as Relative c.o.p.

(III) Air Refrigeration working on reversed carnot cycle:

In refrigerating system, the carnot cycle considered is the reversed carnot cycle, We know that the heat engine working on carnot cycle is the highest possible efficiency. Similarly a refrigeration system working on the reversed carnot cycle, will having the maximum possible coefficient of performance. We also know that it is not possible to make an engine working on the carnot cycle.

Similarly it is not possible to make a refrigerating machine working on reversed carnot cycle. However, it is used as the ultimate standard of comparison.

A reversed carnot cycle using air as working medium (or refrigerant) is shown on P-v and T-S diag. in fig (a) and (b) respectively.



(a) P-v diag (b) T-s diag

The four processes of the cycle are as follows:

(1) Isentropic compression process: This process is represented by 1-2 on P-v and T-S diagrams. During this process, the pressure of air increases from P_1 to P_2, sp. volume decreases from v_1 to v_2 and temp increases from T_1 to T_2. We know that during isentropic compression, no heat is absorbed or rejected by the air.

(2) Isothermal compression process: The air is now compressed isothermally (i.e, at const temp $T_2 = T_3$) as shown by the curve 2-3 on P-v and T-S diagrams. During this process, the pressure of air increases from P_2 to P_3 and specific volume decreases from v_2 to v_3. We know that the heat rejected by the air during isothermal comp per kg of air,

$$q_R = q_{2-3} = \text{Area } 2\text{-}3\text{-}3'\text{-}2' = T_3 (S_2 - S_3) = T_2 (S_2 - S_3)$$

(3) Isentropic expansion process: The air is now expanded isentropically as shown by the curve 3-4 on P-v and T-s diag. The pressure of air decreases from P_3 to P_4, sp. volm increases from v_3 to v_4 and temp. decreases from T_3 to T_4. We know that during isentropic expansion no heat is absorbed or rejected by the air.

(4) Isothermal expansion process: The air is now expanded isothermally (at const. temp $T_4 = T_1$) as shown by the curve 4-1 on P-v and T-s diag. The pressure of air decreases P_4 to P_1 and sp. volm increases from v_4 to v_1. We know that the absorbed by the air (or heat extracted from the cold body) during iso-thermal expansion per kg of air,

$$q_A = q_{4-1} = \text{Area } 4-1-2'-3'$$

$$= T_4 (S_1 - S_4) = T_1 (S_2 - S_3)$$

We know that the work done during the cycle per kg of air,

$$W_R = \text{Heat rejected} - \text{Heat absorbed}$$

$$= q_{2-3} - q_{4-1}$$

$$= T_2 (S_2 - S_3) - T_1 (S_2 - S_3) = (S_2 - S_3)(T_2 - T_1)$$

∴ C.O.P of the Refrigeration system working on reversed carnot cycle

$$(C.O.P)_R = \frac{\text{Heat absorbed}}{\text{Work done}} = \frac{q_{4-1}}{q_{2-3} - q_{4-1}}$$

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

The C.O.P of the reversed carnot cycle may be improved by -

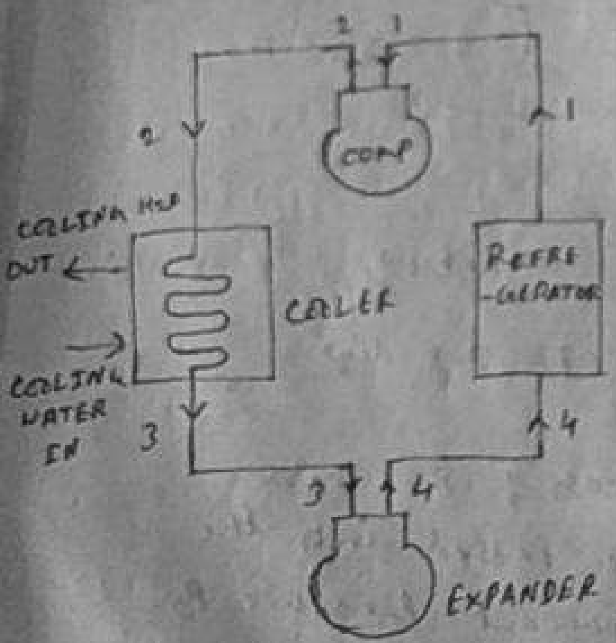
(a) decreasing the higher temp (temp of hot body, T_2)

(b) increasing the lower temp (temp of cold body, T_1).

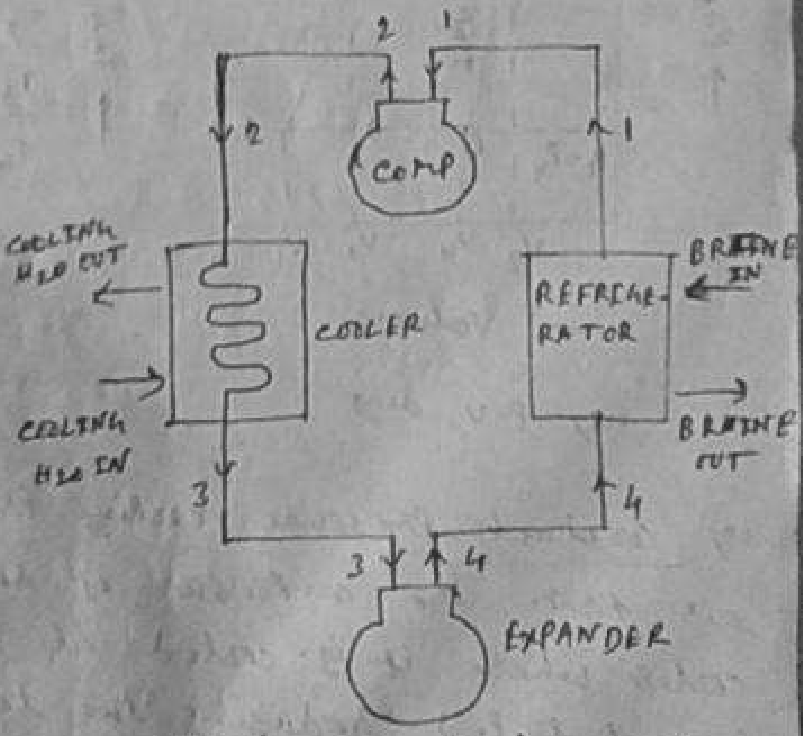
① The C.O.P of domestic refrigerator is less than C.O.P of a domestic air conditioner.

① Air refrigerator working on a Bell coleman cycle (or reversed Brayton or Joule cycle):

A Bell-coleman air refrigeration machine was developed by Bell-coleman and Light Foot by reversing the Joule air cycle. It was one of the earliest types of refrigerators used in ships carrying frozen meat. Fig shows the schematic diag of such a machine which consists of a compressor, a cooler, an expander and a refrigerator.



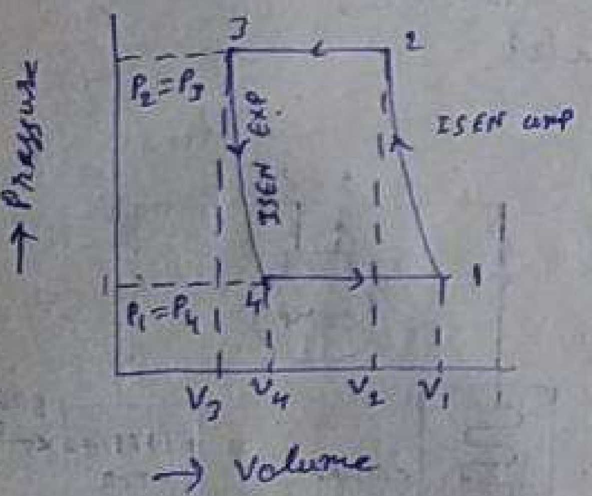
Open cycle Bell-coleman Refrigerator



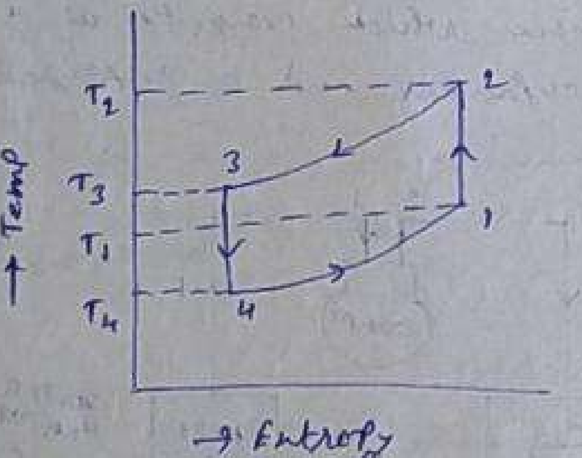
Closed cycle or dance air Bell-coleman Ref.

The Bell-coleman cycle is a modification of reversed carnot cycle. The cycle is shown on P-v and T-S diag in fig (a) and (b). At point 1, let P_1, v_1, T_1 be the pressure, vol^n and Temp of air respectively. The four processes of the cycle are as follows:

(1) Isentropic compression process: The cold air from the refrigerator is drawn into the compressor cylinder where is compressed isentropically in the comp as shown by the curve 1-2 on P-v and T-S diag. During the comp^n stroke, both the pressure and temp increases and the sp. volume of air at delivery from compressor reduces from v_1 to v_2. We know that during isentropic comp^n process, no heat is absorbed or rejected by the air.



(a) P-v diag



(b) T-S diag

(2) Constant pressure cooling process: The warm air from the compressor is now passed into the cooler where it is cooled at constant pressure P_3 (equal to P_2), reducing the temp from T_2 to T_3 (The temp of cooling water) as shown by the curve 2-3 on P-v and T-S diag. The sp. vol^m also reduces from v_2 to v_3. We know that heat rejected by the

air during constant pressure per kg of air,

$$q_R = Q_{2-3} = c_p (T_2 - T_3)$$

(3) Isentropic expansion process : The air from the cooler is now drawn into the expander cylinder where it is expanded isentropically from pressure P_3 to the refrigerator pr P_4 (The temp much below the cooling water, T_3). The expansion process is shown by the curve 3-4 on the P-v and T-s diagrams. The sp. vol^n of air at entry to the refrigerator increases from v_3 to v_4. We know that during isentropic expansion of air, no heat is absorbed or rejected by air.

(4) Constant pressure expansion process : The cold air from the expander is now passed into the refrigerator where it is expanded at const pressure P_4 (equal to P_1). The temp of the air increases from T_4 to T_1. This process is shown by the curve 4-1 on the P-v and T-s diag. Due to the heat from the refrigerator the sp. vol^n of the air changes from v_4 to v_1. We know that the heat absorbed by the air (heat extracted from the refrigerator & the refrigerating effect) during cons. pressure expansion per kg of air is –

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

∴ coefficient of performance,

$$C.O.P = \frac{\text{Heat absorbed}}{\text{Work done}} = \frac{q_A}{q_R - q_A}$$

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

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

We know that isentropic compression process 1-2,

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

Similarly, for isentropic expansion process 3-4,

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

Since, $P_2 = P_3$ and $P_1 = P_4$, therefore from equation (ii) and (iii) –

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

Now substituting this values in equ^n (i), we get,

$$c.o.p = \frac{T_4}{T_3 - T_4} = \frac{1}{\frac{T_3}{T_4} - 1}$$

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

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

Where, r_p = compression or expansion ratio

$$= \frac{P_2}{P_4} = \frac{P_3}{P_4}.$$

Problem:

(1) Find the c.o.p of a refrigeration system if the work input is 80 KJ/kg and refrigeration effect produced is 160 KJ/kg of refrigerant flowing.

Solution: Given, $W = 80$ KJ/kg, $q = 160$ KJ/kg

We know that c.o.p of a refrigeration system

$$= \frac{q}{W} = \frac{160}{80} = 2 \text{ Ans.}$$

$$= \frac{R.E}{\text{Work done}}$$

(2) A machine working on a carnot cycle operates betwⁿ 305 K and 260 K. Determine the c.o.p when it is operated as: 1. a refrigerating machine, (2) heat pump, (3) and a heat engine.

Solution: Given, $T_2 = 305$ K, $T_1 = 260$ K

(1) c.o.p of a refrigerating machine,

$$(C.O.P)_R = \frac{T_1}{T_2 - T_1} = \frac{260}{305 - 260} = 5.78 \text{ Ans:}$$

(2) c.o.p of a heat pump,

$$(C.O.P)_P = \frac{T_2}{T_2 - T_1} = \frac{305}{305 - 260} = 6.78 \text{ Ans:}$$

(3) c.o.p of a heat engine,

$$(C.O.P)_E = \frac{T_2 - T_1}{T_2} = \frac{305 - 260}{305} = 0.147 \text{ Ans:}$$

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

(a) calculate the coefficient of performance of this refrigeration cycle.

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

(c) If the carnot heat pump operates between the same temperatures as the above refrigeration cycle, what is coefficient of performance?

(d) How many kJ/min will the heat pump deliver at 300 K if it absorbs 1130 kJ/min at 270 K.

Ans: (a) coefficient of performance of carnot refrigeration cycle -

$$(C.O.P)_R = \frac{T_1}{T_2 - T_1} = \frac{270}{300 - 270} = 9 \text{ Ans:}$$

(b) Work required per second,

Let, W_R = work required per second,

Heat absorbed at 270 K (i.e, T_1),

$$Q_1 = 1130 \text{ kJ/min} = 18.83 \text{ kJ/sec}$$

We know that, $(C.O.P)_R = \frac{Q_1}{W_R}$

or, $9 = \frac{18.83}{W_R}$

or, $W_R = 2.1$ kJ/sec Ans:

(c) Coefficient of performance of carnot heat pump,

$$(C.O.P)_P = \frac{T_2}{T_2 - T_1} = \frac{300}{300-270} = 10 \text{ Ans:}$$

(d) Heat delivered by heat pump at 300 K

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

Heat absorbed at 270 K (i.e, T_1)

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

We know that, $(C.O.P)_P = \frac{Q_2}{Q_2 - Q_1}$

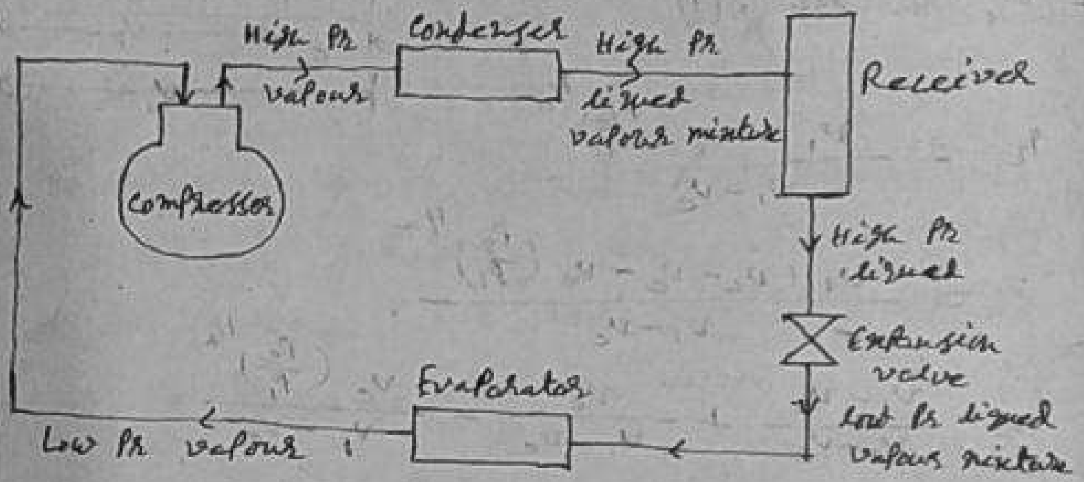
or, $10 = \frac{Q_2}{Q_2 - 1130}$

or, $10 Q_2 - 11300 = Q_2$

or, $Q_2 = 1256$ kJ/min Ans:

⑩ Vapour compression refrigeration system:

A schematic diagram of a simple vapour compression refrigeration system is shown in figure. In this system, a suitable working ~~system~~ substance (known as refrigerant) such as ammonia, carbon dioxide, sulpher dioxide or freon 12 is used. It consists of the following five essential parts:



(1) Compressor: The low pressure and temp vapour refrigerant from evaporator is drawn into the compressor through the inlet or suction valve A, where it is compressed to a high pressure and temp. This high pressure and temp vapour refrigerant is discharged into the condenser through the delivery or discharge valve B.

(2) Condenser: The condenser or cooler consists of coils of pipe in which the high pressure and temp vapour refrigerant is cooled and condensed.

(3) Receiver: The condensed liquid refrigerant from the condenser is stored in a vessel known as receiver from where it is supplied to the evaporator through the expansion valve or refrigerant control valve.

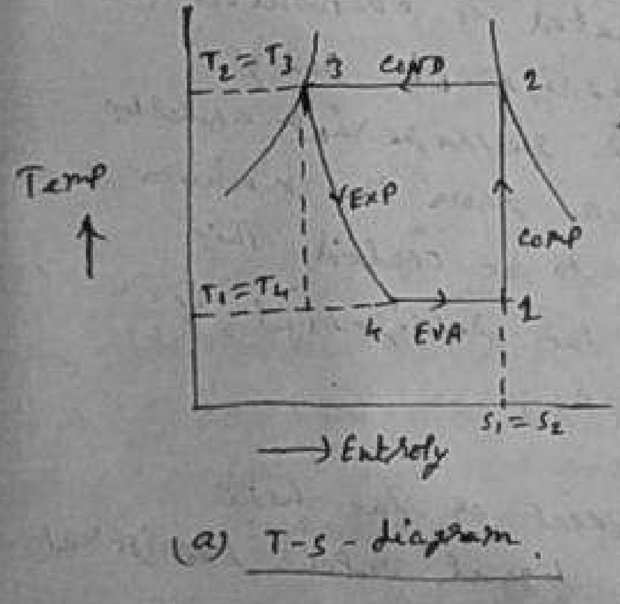
(4) Expansion valve: The expansion valve allows the liquid refrigerant under high pressure and temp to pass at a controlled rate after reducing the pressure and temp.

(5) Evaporator: An evaporator consists of coils of pipe in which the liquid vapour refrigerant at low pressure and temperature is evaporated and changed into vapour refrigerant at low pressure and temp.

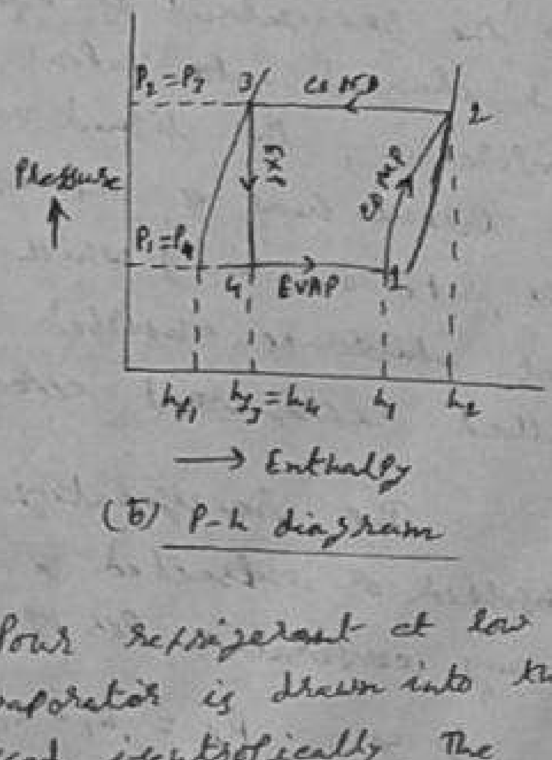
Note:

(1) Vapour compression cycle (theoritical):

A vapour compression cycle with dry saturated vapour after compression is shown on T-s and P-h diagrams in figure (a) and (b). It essentially consists of compression, condensation, expansion or throttling and evaporation as discussed below:



(a) T-s-diagram.



(b) P-h diagram

(1) Compression process: The vapour refrigerant at low pressure and temp from the evaporator is drawn into the compressor where it is compressed isentropically. The pressure and temp rises from P_1 to P_2 and T_1 to T_2 respectively. The workdone during isentropic compression per kg of refrigerant is given by - $w = h_2 - h_1$

where, h_1 = Enthalpy of vapour refrigerant at temp T_1, i.e at suction of the compressor, and

h_2 = Enthalpy of vapour refrigerant at temp T_2 i.e, at discharge of the compressor.

(2) <u>Condensing Process</u>: The high pressure and temp vapour refrigerant from the compressor is passed through the compressor condenser where it is completely condensed at constant pressure and temp. The vapour refrigerant is changed into liquid refrigerant

(3) <u>Expansion Process</u>: The liquid refrigerant at high pressure and temp is expanded by throttling process through the expansion valve to a low pressure and temp. Some of the liquid refrigerant evaporates as it is passes through the expansion valve but the greater portion is vaporised in evaporator.

(4) <u>Vaporising Process</u>: The liquid vapour mixture of the refrigerant is evaporated is evaporated and changed into vapour refrigerant. During evaporation, the liquid vapour refrigerant absorbs its latent heat of vaporisation from the medium (air, water or brine) which is to be cooled. This heat which is absorbed by the refrigerant is called refrigerant effect (RE).

The refrigerating effect or the heat absorbed or extracted by the liquid vapour refrigerant during evaporation per kg of refrigerant is given by —

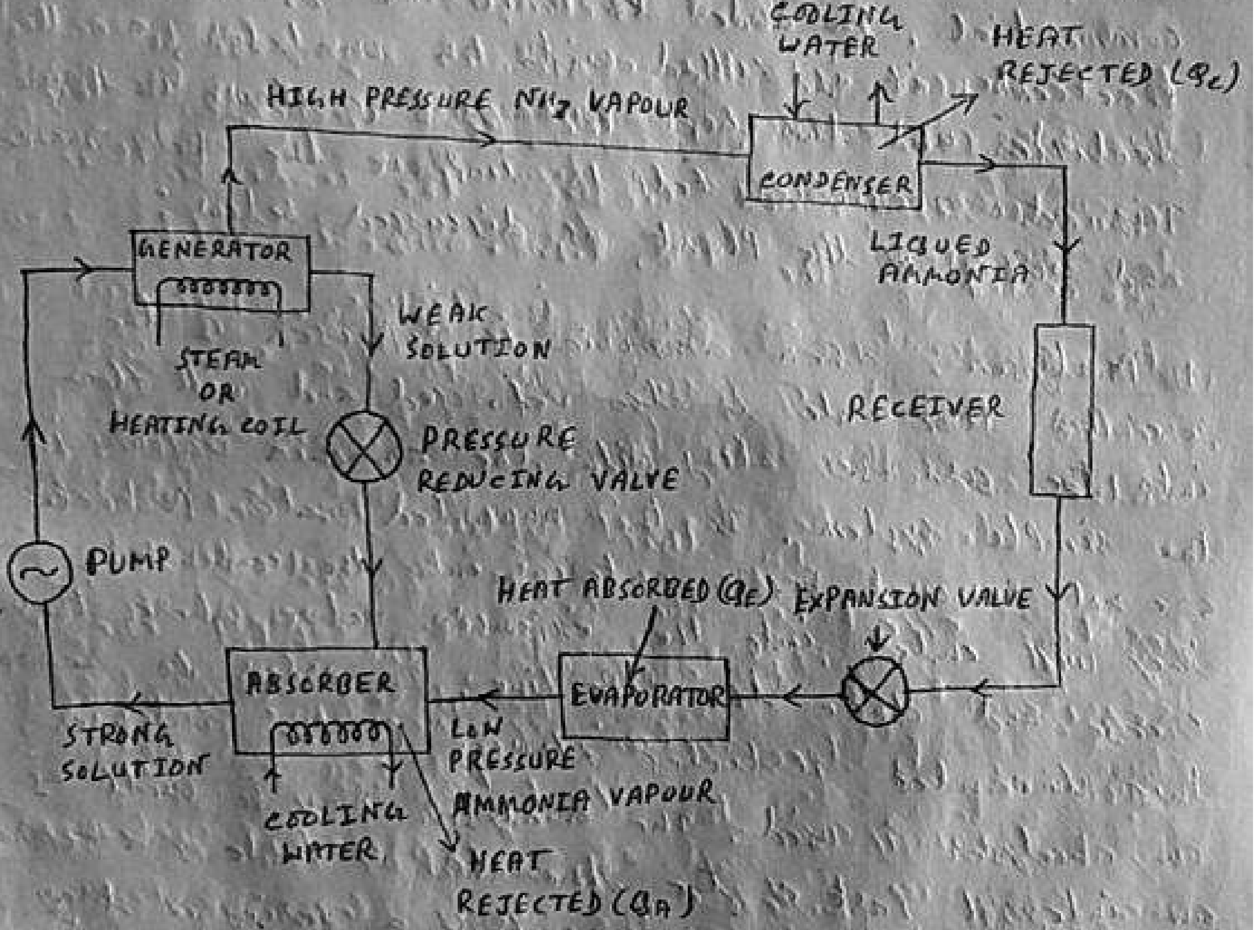
$$R_E = h_1 - h_4 = h_1 - h_{f3}$$

where, h_{f3} = Enthalpy of liquid refrigerant leaving the condenser

$$C.O.P = \frac{\text{Refrigerant effect}}{\text{work done}} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{h_1 - h_{f3}}{h_2 - h_1}$$

(1) Simple vapour absorption refrigeration system :

It is one of the oldest method of producing refrigerating effect. This system may be used in both the domestic and large industrial refrigerating plants. The refrigerant commonly used in this system is ammonia. The vapour absorption system uses heat energy, insted of mechanical energy as in vapour compression systems, in order to change the conditions of the refrigerant required for the operation of the refrigeration cycle.



The vapour absorption system as shown in figure consists of an absorber, a pump, a generator, and a pressure reducing valve.

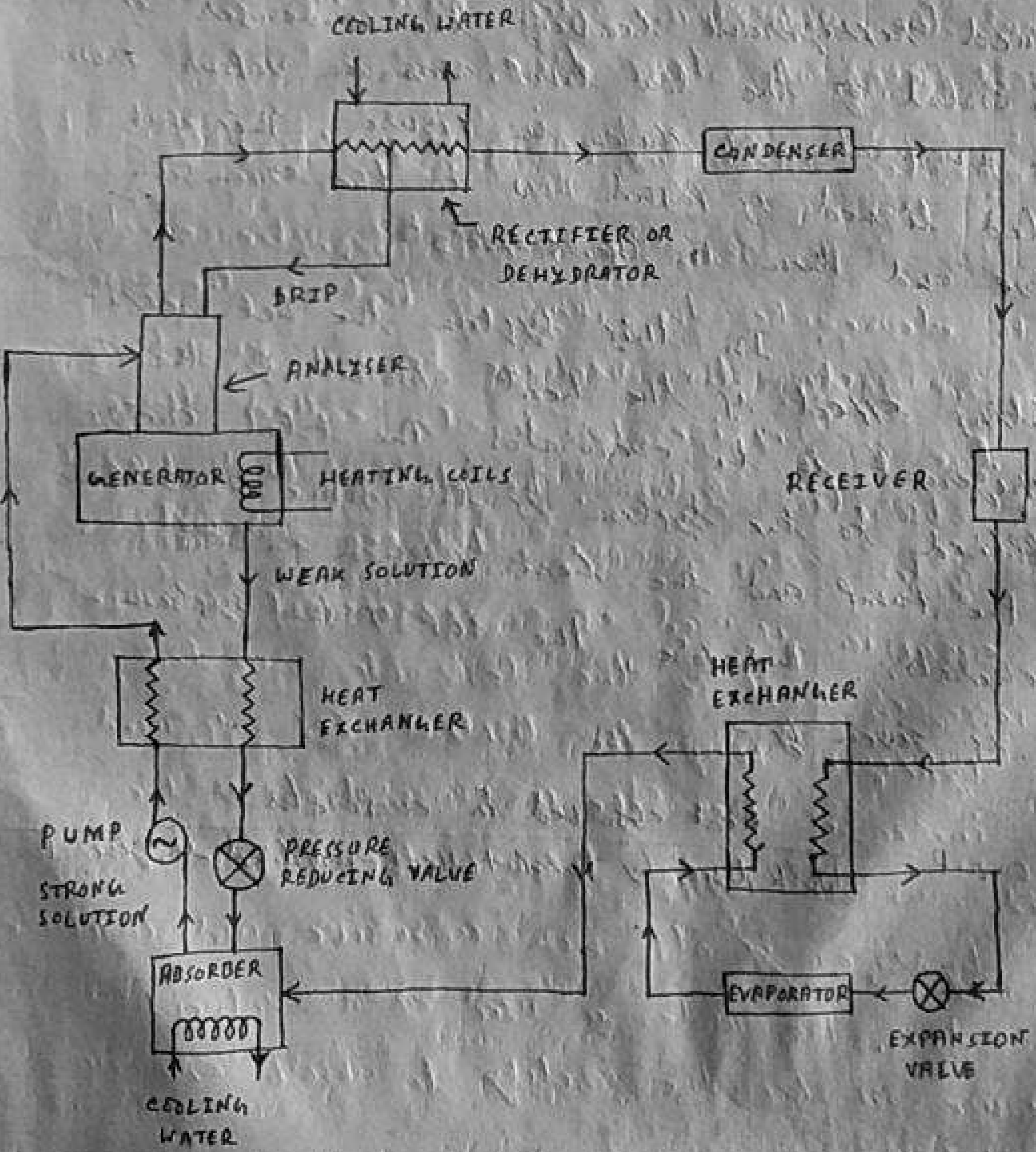
These components perform the same function as that of a compressor in vapour compression system. In the vapour absorption system, the vapour refrigerant from the evaporator is drawn into an absorber where it is absorbed by weak solution of the refrigerant forming a strong solution. This strong solution is pumped to the generator where it is heated by some external source. During the heating process, the vapour refrigerant is driven off by the solution and enters into the condenser where it is liquified. The liquid refrigerant then flows into the evaporator and thus the cycle is completed.

(II) Practical vapour absorption system:

The simple vapour absorption system as discussed in the previous article is not very commercial. In order to make the system more practical, it is fitted with an analyser, a rectifier and two heat exchangers as shown in figure. This accessories help to improve the performance and working of the plant, as discussed below:

(1) Analyser: When ammonia is vaporised in the generator, some water is also vaporised and will flow into the condenser along with the ammonia vapours in the simple system. If this unwanted water particles are not removed before entering into the condenser, they will enter into the expansion valve where they freeze and choke the pipe line. In order to remove this unwanted particles flowing to the condenser, an analyser is used. The analyser may be built as an integral part of the generator or made as a separate piece of equipment. It consists of a series of tray mounted above the generator. The strong solution from the absorber and the aqua from the rectifier are introduced at the top of the analyser and flow downward over the trays and into the generator. The vapour is cooled and most of the water vapour condenses, so that mainly ammonia vapour (Approx 99%) leaves the top of the analyser. Since the aqua is heated by the vapour, less external heat is required in the generator.

(2) **Rectifier:** In case of the water vapours are not completely removed in the analyser a closed type vapour cooler called rectifier (also known as dehydrator) is used. It is generally water cooled and may be of the double pipe, shell and coil or shell and tube type. Its function is to cool further the ammonia vapours leaving the ~~water~~ analyser so that the remaining water vapours are condensed. Thus only dry or anhydrous ammonia vapours flow to the condenser. The condensate from the rectifier is returned to the top of the analyser by a drip return line.



(3) Heat exchangers: The heat exchanger provided between pump and the generator is used to cool the weak hot solution returning from the generator to the absorber. The heat removed from the weak solution rises the temp of the strong solution leaving the pump and going to analyser and generator. This operation reduces the heat ~~absorbed~~ supplied to the generator and the amount of cooling required for the absorber. Thus the economy of the plant increases.

The heat exchanger provided between the condenser and the evaporator may also be called liquid sub-cooler. In this heat exchanger, the liquid refrigerant leaving the condenser is sub cooled by the low temp ammonia vapour from the evaporator as shown in figure. This sub cooled liquid is passed now to the expansion valve and then to the evaporator.

In this system the net refrigerating effect is the heat absorbed by the refrigerant in the evaporator. The total energy supplied to the system is the sum of workdone by the pump and the heat supplied in the generator. Therefore, the COP of the system is given by –

$$C.O.P = \frac{\text{Heat absorbed in evaporator}}{\text{Work done by pump + Heat supplied in generator}}$$

(2) According to the number of working strokes

(a) single acting compressors and

(b) double acting compressors

(3) According to the number of stages:

(a) single stage (or single cylinder) compressors

(b) and multi stage (or multi cylinder) compressors

(4) According to the method of drive employed:

(a) Direct drive compressors and

(b) belt drive compressors.

(5) According to the location of the prime mover:

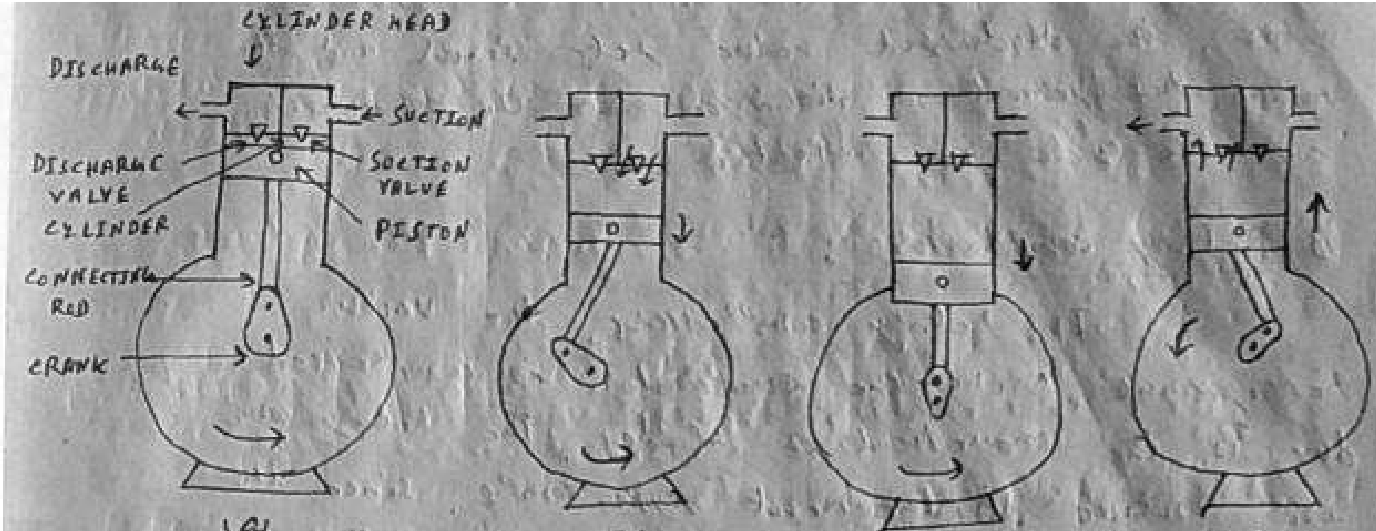
(a) semi-hermetic compressors (direct drive, motor and compressor in separate housings) and

(b) hermetic compressors (" in same housing)

(1) Reciprocating compressors:

These compressors are used for refrigerants which have comparatively low volume per kg and a large differential pressure, such as ammonia (R-717), R-12, R-22, and methyl chloride (R-40). The reciprocating compressors are available in sizes as small as 1/12 kW which are used in small domestic refrigerators and up to about 150 kW for large capacity installations.

The two types of reciprocating compressors in general use are single acting vertical compressors and double acting horizontal compressors. The single acting compressors have their cylinders arranged vertically, radially or in a V or W form. The double acting comp. usually have their cylinders arranged horizontally.



(a) (B) (c) (d)

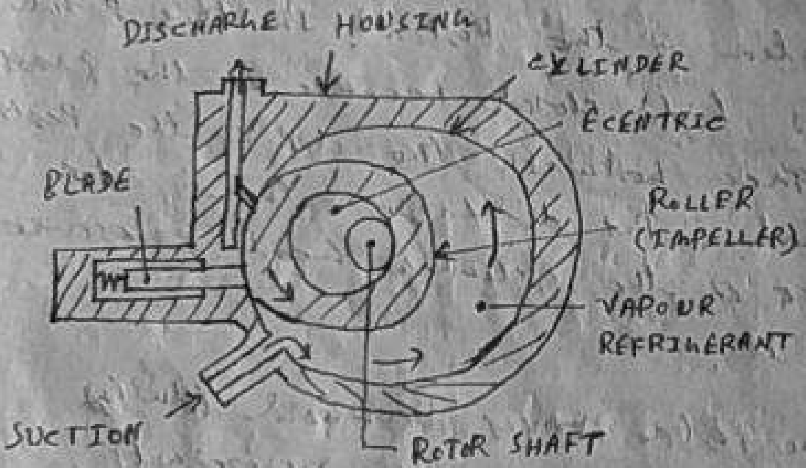
PRINCIPLE OF OPERAN OF A SINGLE STAGE, SINGLE ACTING RECI COMP

Let us consider the piston is at the top of its stroke as shown in figure (a). This is called top dead centre position of the piston. In this position, the suction valve is held closed because of the pressure in the clearance space between the top of the piston and the cylinder head. The discharge valve is also held closed because of the cylinder head pressure acting on the top of it.

When the piston moves downward (during suction stroke) as shown in fig (b), the refrigerant left in the clearance space expands. Thus the volume of the cylinder (above the piston) increases and the pressure inside the cylinder decreases. When the pressure becomes slightly less than the suction pressure or atm pressure, the suction valve gets opened and the vapour refrigerant flows into the cylinder. This flow continues until the piston reaches the bottom of its stroke (bottom dead centre). At the bottom of the stroke as shown in fig (c), the suction valve closes because of spring action. Now the piston moves upward (during compn stroke) the volm of cylinder decreases and the pr inside the cylinder increases. When the pr inside the cylinder becomes greater than that on the top of the discharge valve, the discharged valve gets opened and the vapour refrigerant is discharged into the condenser and the cycle is repeated.

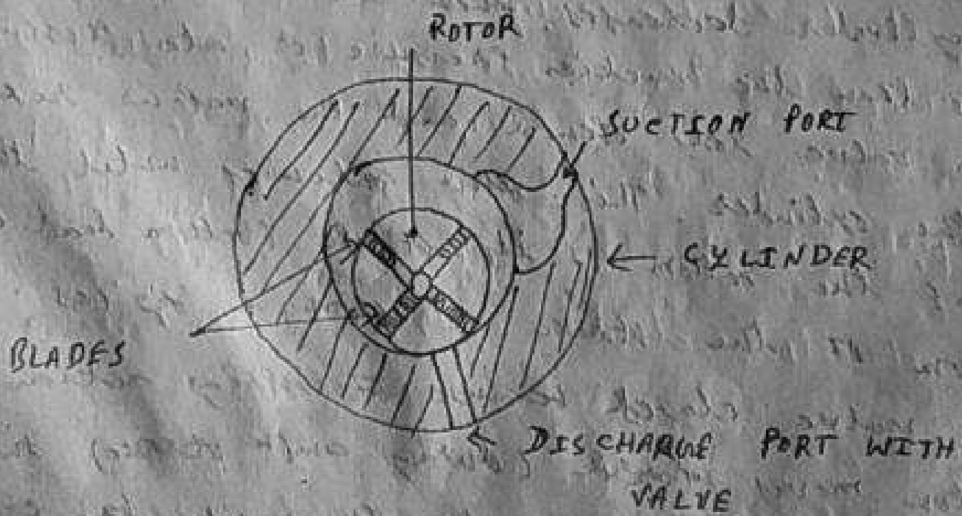
⑦ Rotary compressors :

In rotary compressors, the vapour refrigerant from the evaporator is compressed due to the movement of blades. The rotary comp are positive displacement type comps. Since the clearance in rotary comp is negligible, therefore they have high volumetric efficiency. These compressors may be used with refrigerants R-12, R-22, R-114 and ammonia.



(a) COMPLETION OF INTAKE STROKE AND BEGINNING COMP

STATIONARY SINGLE BLADE ROTARY COMP

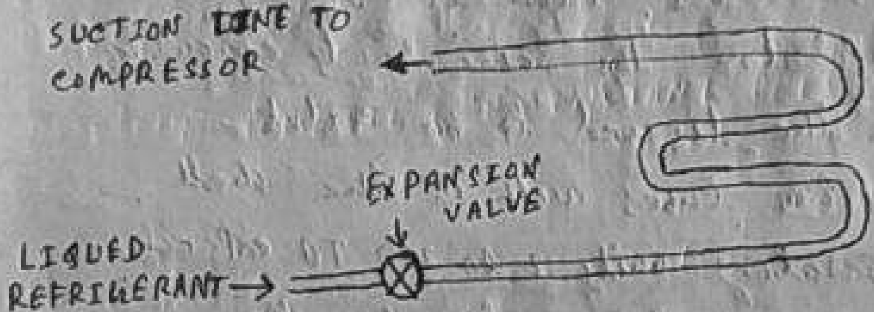


ROTATING BLADE TYPE ROTARY COMP

coil and the medium being

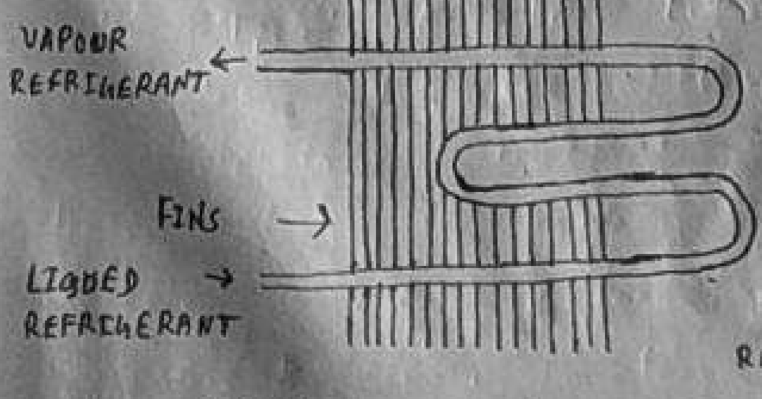
① Bare tube coil evaporators:

The bare tube coil evaporators are also known as prime-surface evaporators because of its simple construction, the bare tube coil is easy to clean and defrost. A little consideration will show that this type of evaporator offers relatively little surface area contact area as compared to other types of coils.



② Finned evaporators:

The finned evaporator as shown in figure, consists of bare tubes or coils over which the metal plates or fins are fastened. The metal fins are constructed of thin sheets of metal having good thermal conductivity. The shape, size or spacing of the fins can be adopted to provide best rate of heat transfer for a given application. Since the fins greatly increase the contact surfaces for heat transfer.



FINNED EVAPORATOR

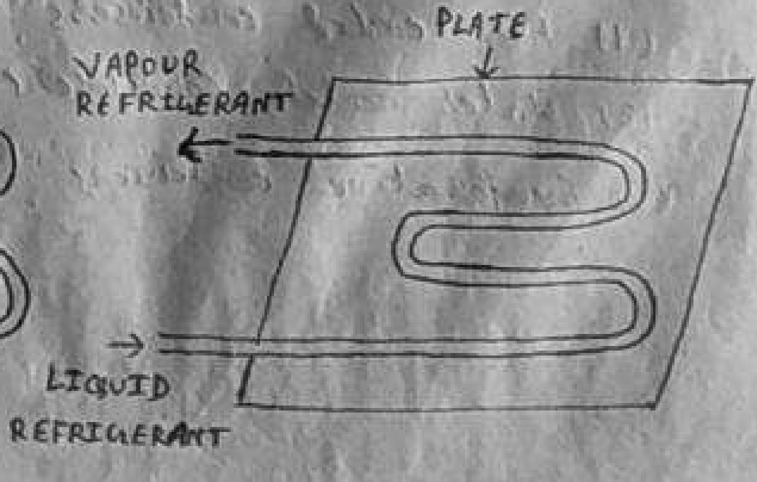


PLATE EVAPORATOR

① Plate evaporators :

In this type evaporator, the coils are either welded on one side of a plate or between the two plates which are welled together at the edges. The plate evaporator are generally used in household refrigerators, home freezers, beverage coolers, ice cream cabinates, locker plants etc.

② Shell and tube evaporators :

These evaporator are generally used to chill water or brine solutions. When it is operated as dry expansion evaporator, the refrigerants circulates through the tubes and the liquid to be cooled fills the space around the tubes with in the shell. These are used for refrigerating units 2 to 250 TR capacity when it is operated as a flooded evaporator, the water or brine flows through the tubes and the refrigerants circulates around the tubes. These are used for refrigerating units of 10 to 5000 TR capacity

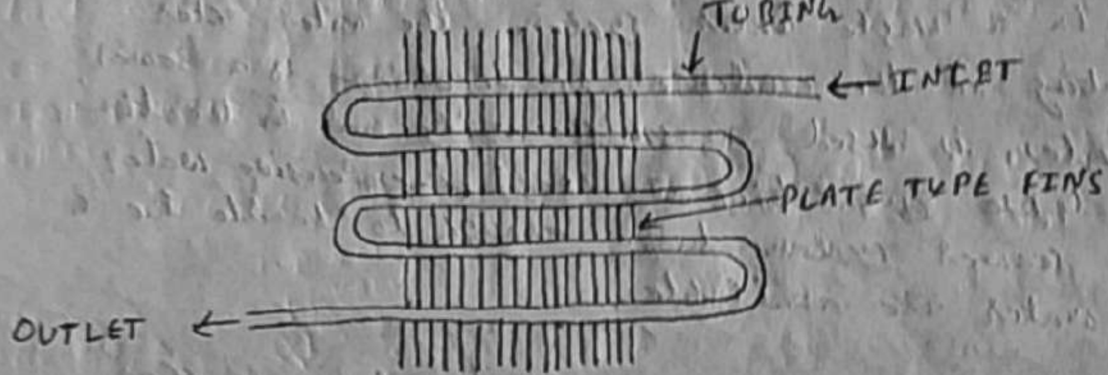
③ classification of condensers :

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

(1) Air - cooled condensers,
(2) water - cooled condensers,
(3) Evaporative condensers.

(i) Air cooled condensers:

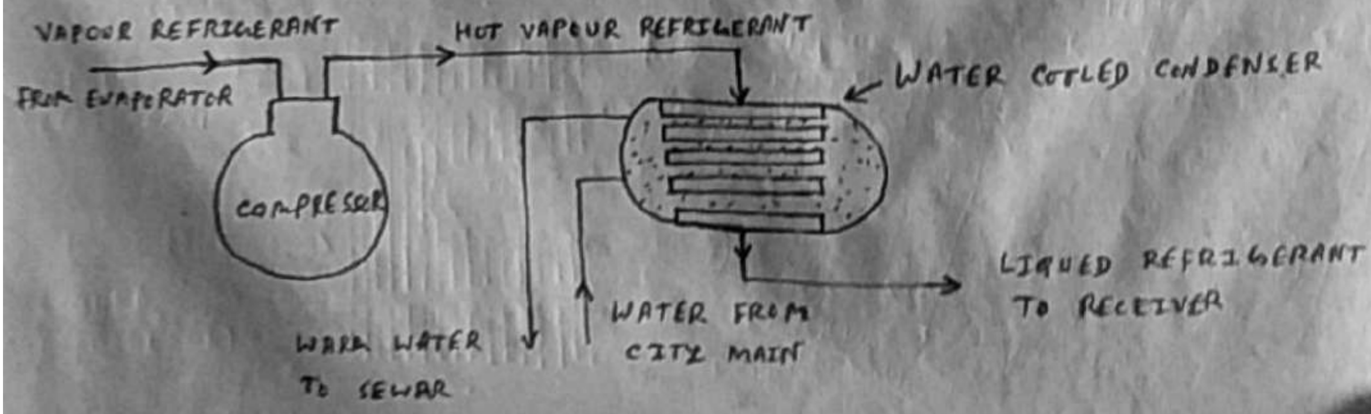
An air cooled condenser is one in which the removal of heat is done by air. It contains of steel or copper tubing through which the refrigerant flows. The size of tubes ranges from 6 mm to 18 mm outside diameter, depending upon the size of condenser. The tubes are usually provided with plate type fins to increase the surface area for heat transfer as shown in figure. The fins are usually made from aluminium because of its light weight, the fins spacing is quite wide to reduce dust clogging.



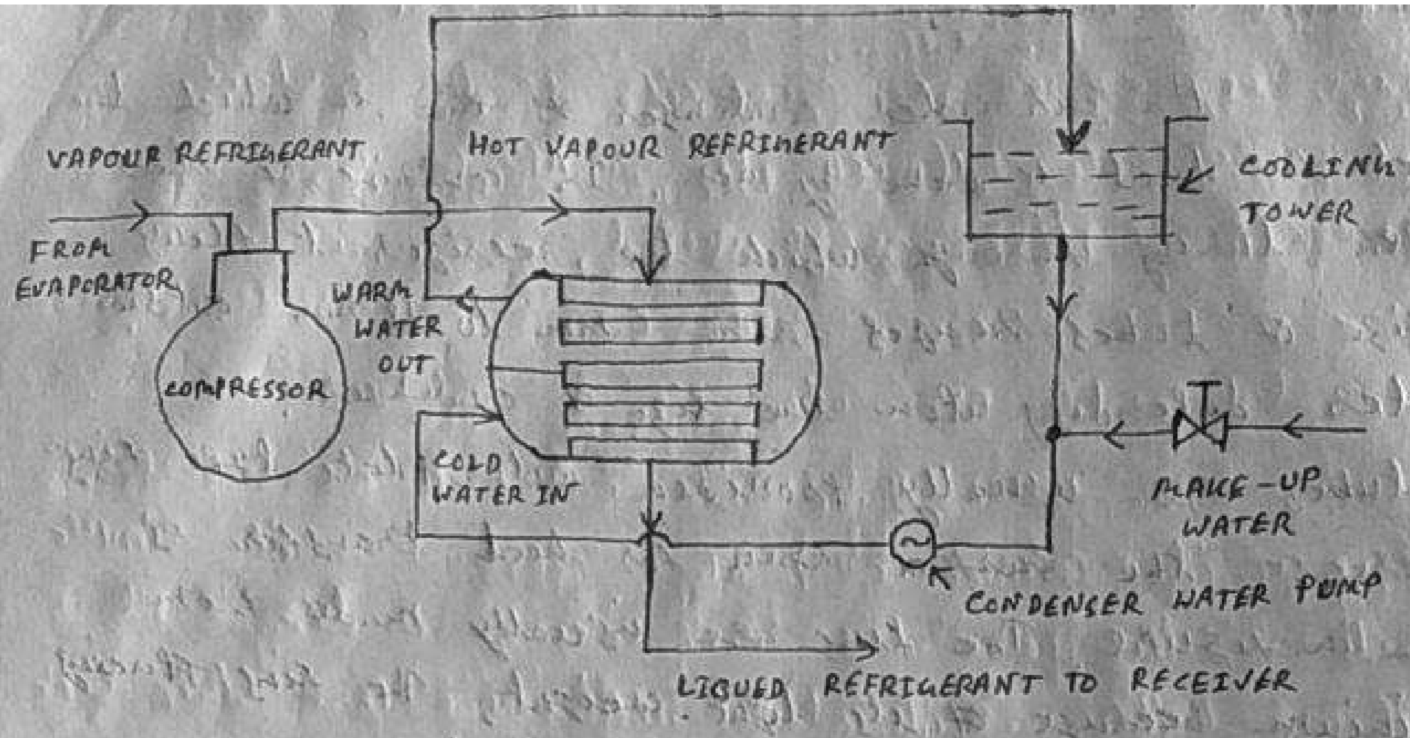
(ii) Water cooled condenser:

A water cooled condenser is one in which water is used as the condensing medium. These condensers are commonly used in commercial and industrial refrigerating units. This use either of the following two water system:

(1) Waste water system
(2) Recirculated water system.



WATER COOLED CONDENSER USING WASTE WATER SYSTEM



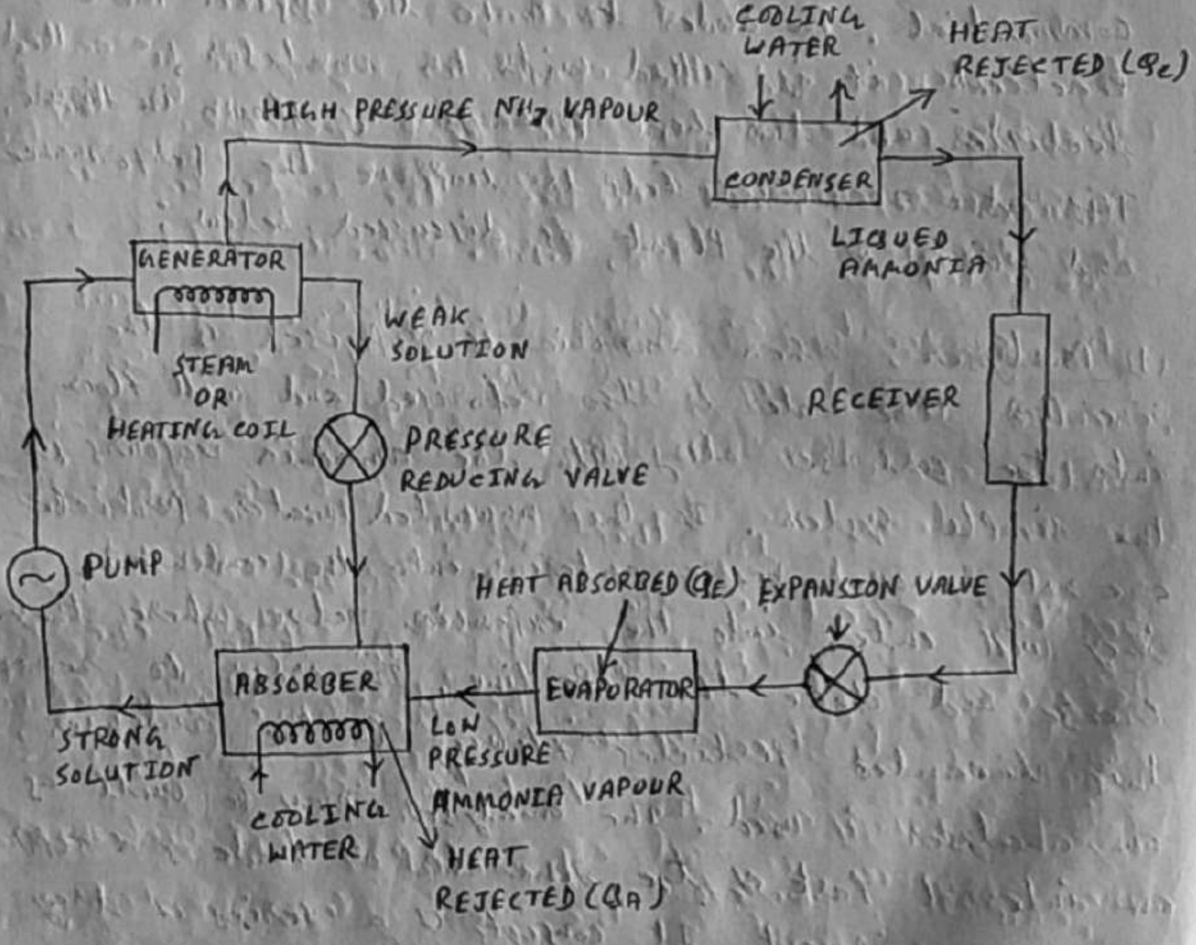
WATER COOLED CONDENSER WITH RECIRCULATING WATER SYSTEM

In a waste water system, the water after circulating in the condenser is discharge to a sewer. This system is used on small units and in locations where large quantities of fresh inexpensive water and a seawer system large enough to handle the waste water are available.

In a recirculated water system, as shown in figure, the same water circulating in the condenser is cooled and used again an again. The cooling water towers and spray ponds are most common cooling devices used in a recirculated water system.

(1) Simple vapour absorption refrigeration system :

It is one of the oldest method of producing refrigerating effect. This system may be used in both the domestic and large industrial refrigerating plants. The refrigerant commonly used in this system is ammonia. The vapour absorption system uses heat energy, insted of mechanical energy as in vapour compression systems, in order to change the conditions of the refrigerant required for the operation of the refrigeration cycle.



The vapour absorption system as shown in figure consists of an absorber, a pump, a generator, and a pressure reducing valve.

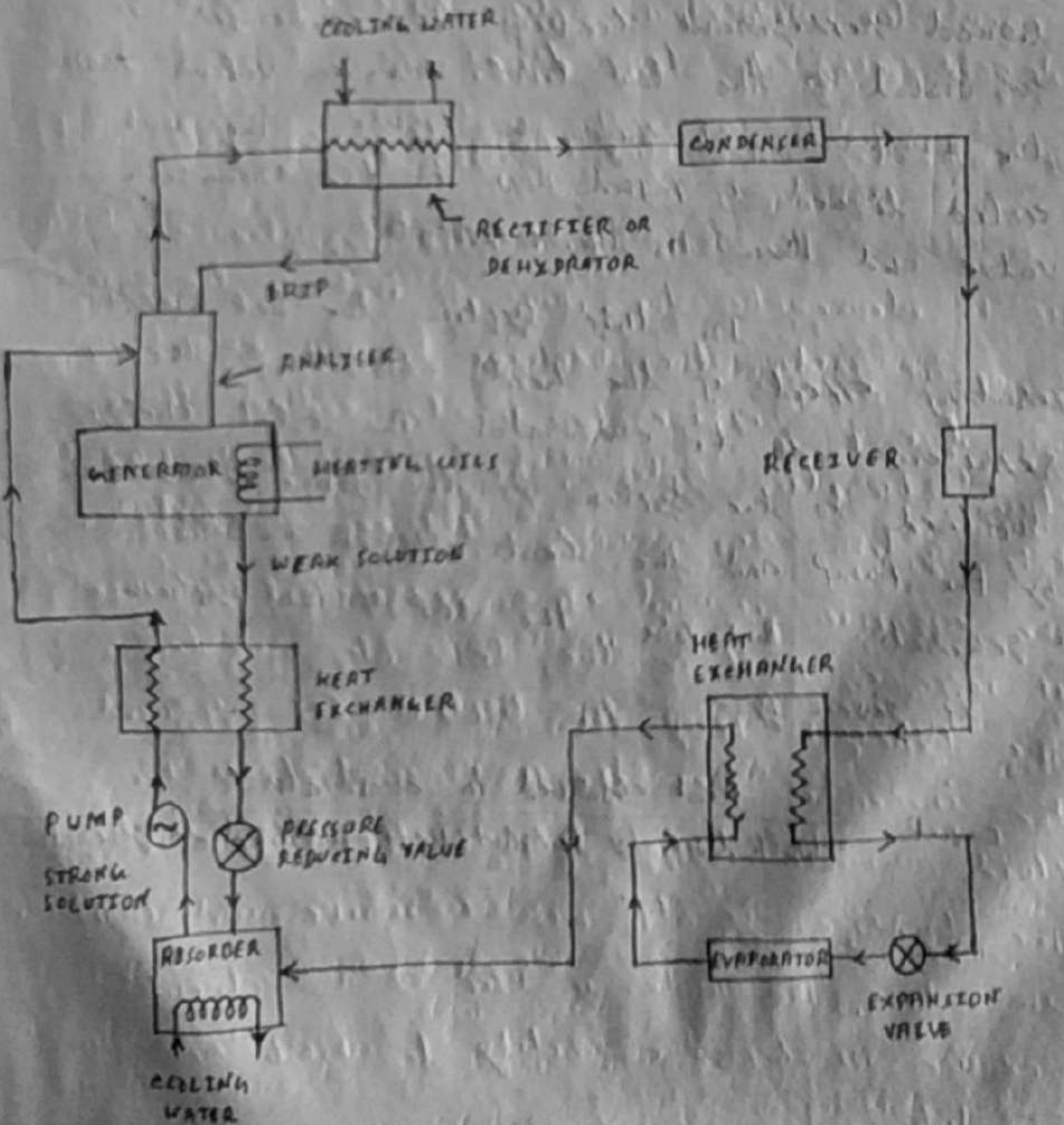
These components perform the same function as that of a compressor in vapour compression system. In the vapour absorption system, the vapour refrigerant from the evaporator is drawn into an absorber where it is absorbed by weak solution of the refrigerant forming a strong solution. This strong solution is pumped to the generator where it is heated by some external source. During the heating process, the vapour refrigerant is driven off by the solution and enters into the condenser where it is liquified. The liquid refrigerant then flows into the evaporator and thus the cycle is completed.

(II) Practical vapour absorption system:

The simple vapour absorption system as discussed in the previous article is not very commertial. In order to make the system more practical, it is fitted with an analyser, a rectifier and two heat exchangers as shown in figure. This accessories help to improve the performance and working of the plant, as discussed below:

(1) Analyser: When ammonia is vaporised in the generator, some water is also vaporised and will flow into the condenser along with the ammonia vapours in the simple system. If this unwanted water particles are not removed before entering into the condenser, they will enter into the expansion valve where they freeze and choke the pipe line. In order to remove this unwanted particles flowing to the condenser, an analyser is used. The analyser may be built as an integral part of the generator or made as a separate piece of equipment. It consists of a series of tray mounted above the generator. The strong solution from the absorber and the aqua from the rectifier are introduced at the top of the analyser and flow downward over the trays and into the generator. The vapour is cooled and most of the water vapours condenses, so that mainly ammonia vapour (Approx 99%) leaves the top of the analyser. Since the aqua is heated by the vapour, less external heat is required in the generator.

(3) <u>Rectifier</u>: In case of the water vapours are not completely removed in the analyser, a closed type vapour cooler called rectifier (also known as dehydrator) is used. It is generally water cooled and may be of the double tube, shell and coil or shell and tube type. Its function is to cool further the ammonia vapours leaving the ~~analyser~~ analyser so that the remaining water vapours are condensed. Thus only dry or anhydrous ammonia vapours flow to the condenser. The condensate from the rectifier is returned to the top of the analyser by a drip return line.



(3) Heat exchangers: The heat exchanger provided between pump and the generator is used to cool the weak hot solution returning from the generator to the absorber. The heat removed from the weak solution rises the temp of the strong solution leaving the pump and going to analyser and generator. This operation reduces the heat ~~absorbed~~ supplied to the generator and the amount of cooling required for the absorber and thus the economy of the plant increases.

The heat exchanger provided between the condenser and the evaporator may also be called liquid sub-cooler. In this heat exchanger, the liquid refrigerant leaving the condenser is sub cooled by the low temp ammonia vapour from the evaporator as shown in figure. This sub cooled liquid is passed now to the expansion valve and then to the evaporator.

In this system the net refrigerating effect is the heat absorbed by the refrigerant in the evaporator. The total energy supplied to the system is the some of workdone by the pump and the heat supplied in the generator. Therefore, the COP of the system is given by -

$$C.O.P = \frac{\text{Heat absorbed in evaporator}}{\text{Work done by pump + Heat supplied in generator}}$$

Psychrometry:

The Psychrometry is that branch of engineering science which deals with the study of moist air i.e. dry air mixed with water vapour or humidity. It also includes the study of behaviour of dry air and water vapour mixture under various sets of conditions.

Dry bulb temperature:

It is the temp of air recorded by a thermometer, when it is not effected by the moisture present in the air. (DBT → t_d or t_{db})

Wet bulb temperature:

It is the temp of air recorded by a thermometer, when its bulb is surrounded by a wet cloth exposed to the air, such a thermometer is called wet bulb thermometer. (WBT)

Thermodynamic wet bulb temperature:

Thermodynamic wet bulb temp or adiabatic saturation temp. It is the temp at which the air can be brought to saturation state, adiabatically, by the evaporation of water into the flowing air.

Dew point temperature:

It is the temperature of air recorded by a thermometer, when the moisture (water vapour) present in it begins to condense. In other words dew point temp is the saturation temp corresponding to the partial pressure of water vapour.

Humidity ratio:

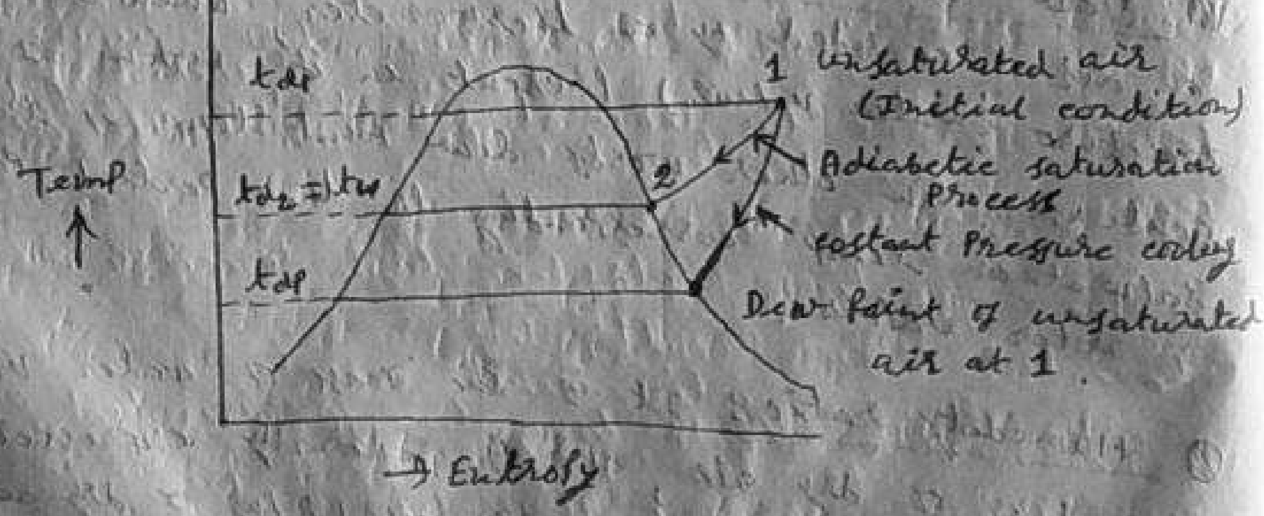
It is the mass of water vapour in 1 kg of dry air, and is generally expressed in terms of gram per kg of dry air (g/kg of dry air). It is also called specific humidity.

(ii) <u>Relative humidity</u>: It is the ratio of actual mass of water vapour in a given volume of moist air to the mass of water vapour in the same volume of saturated air at the same temperature and pressure.

(iii) <u>Degree of saturation</u>: It is the ratio of actual mass of water vapour in a unit mass of dry air to the mass of water vapour in the same mass of dry air when it is saturated at the same temp and pressure. In other words, it may be defined as the ratio of actual specific humidity to the specific ~~hu~~ humidity of saturated air at the same dry bulb temp.

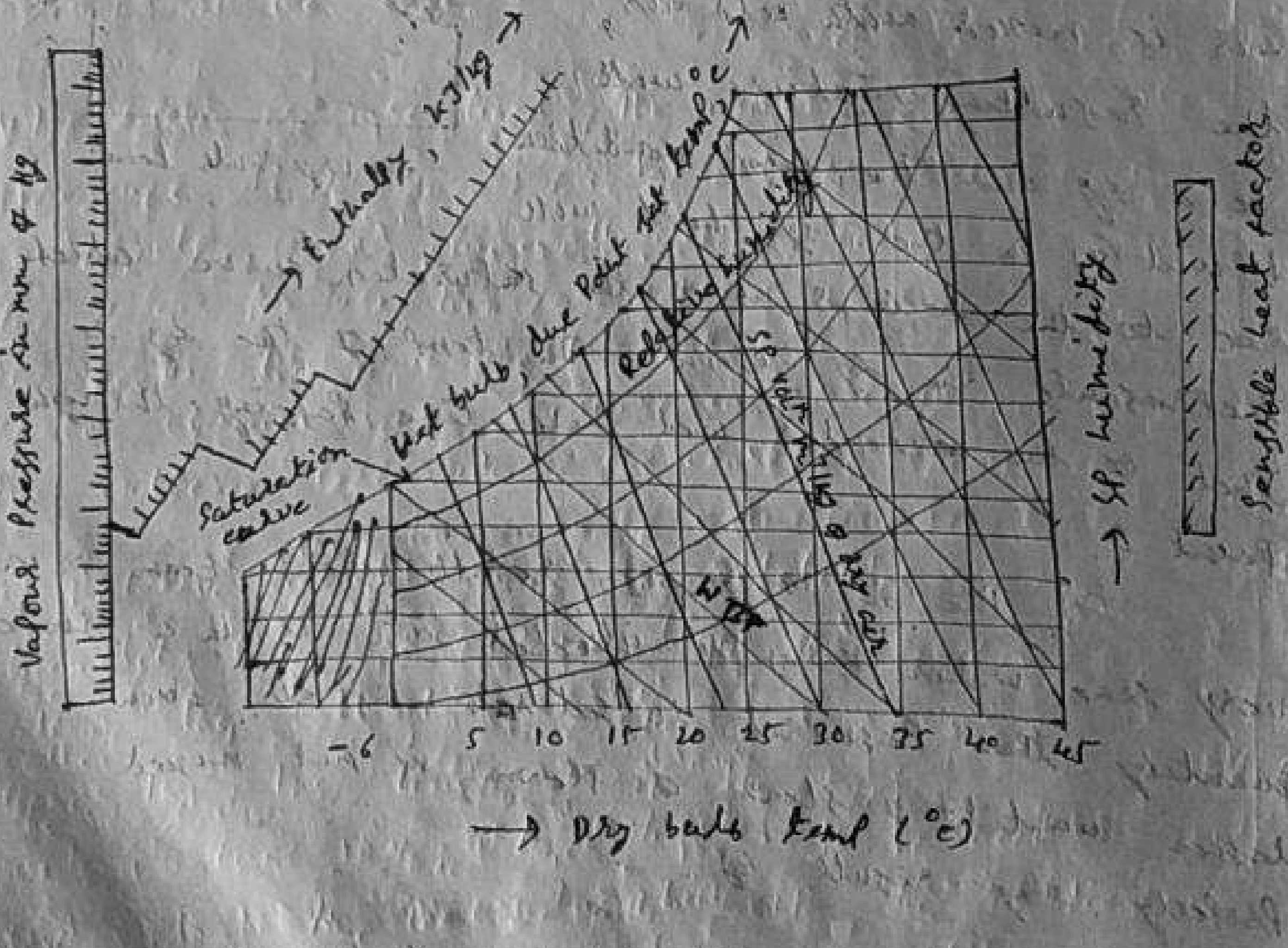
(iv) <u>Enthalpy (Total heat) of moist air</u>: The enthalpy of moist air is numerically equal to the enthalpy of dry air plus the enthalpy of water vapour associated with dry air. Let us consider 1 kg of dry air.

(v) <u>The aidabetic saturion Process can be represented on T-S diagram as shown by the curve 1-2</u>:



⑦ Psychrometric chart :

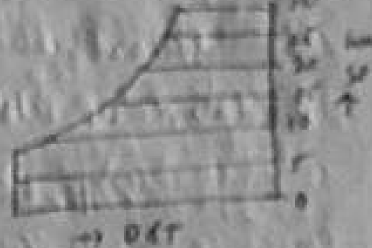
It is a graphical representation of the various thermodynamic properties of moist air. The psychrometric chart is very usefull for finding out the properties of air (which are required in the field of air conditioning) and eleminate lot of calculations. There is slight variation in the charts prepared by different air-conditioning manufactures but basically they are all like. The Psy. chart is normally drawn for standard atm. pressure of 760 mm of Hg (or 1.01325 bar)



(1) Dry bulb temp line: These are vertical, i.e. parallel to the ordinate and uniformly spaced as shown in figure. Generally the temp range of these line on psy chart is from -6°C to 45°C

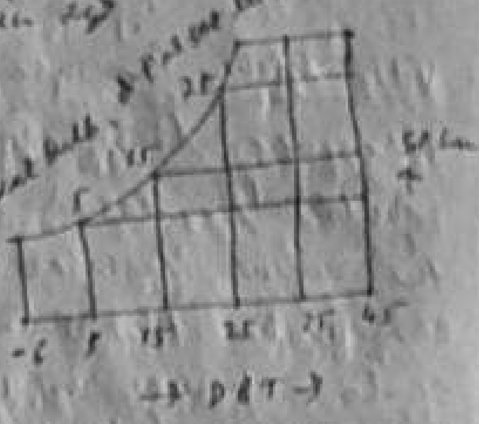
(2) Specific humidity or moisture content line

These lines are horizontal parallel to the abscissa and are also uniformly spaced as shown in fig. Generally moisture content range of these lines on psy chart is from 0 to 30 g/kg of dry air.



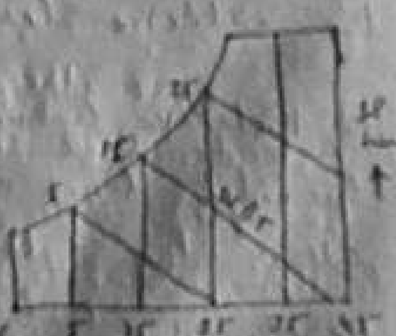
(3) Dew point temp lines:

The dew point temp lines are horizontal i.e. parallel to the abscissa and non uniformly spaced as shown in fig. At any point on saturation curve the dry bulb and dew point temp are equal.



(4) Wet bulb temp lines

These lines are inclined straight lines and non uniformly spaced as shown in fig. At any point on the saturation curve, the DBT and WBT are equal.



The values of wet bulb temp are generally given along the saturation curve of the chart as shown in figure.

(5) Enthalpy (total heat) lines: The enthalpy (or total heat) lines are inclined straight lines and uniformly spaced as shown in

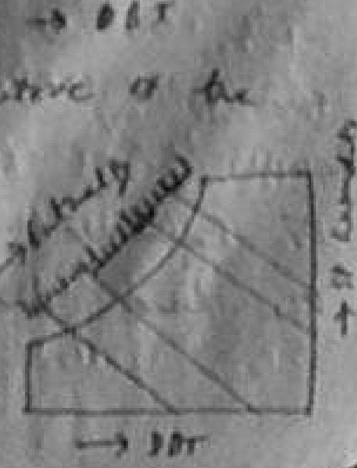
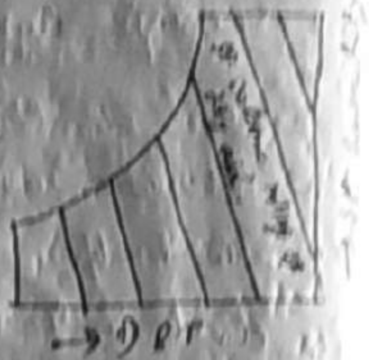


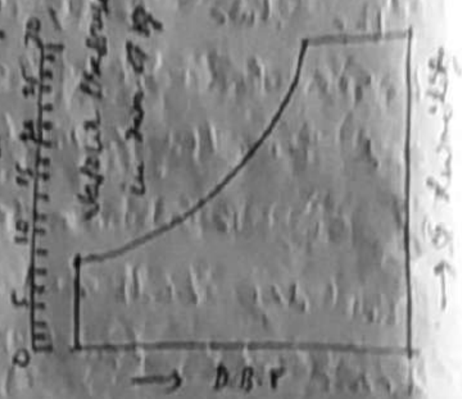
Figure. The lines are parallel to the wet bulb temp lines, and are drawn upto saturation curve. Some of the lines coincide with the wet bulb temp lines also.

The ~~total~~ values of total enthalpy are given on a scale above the saturation curve as shown in the figure.

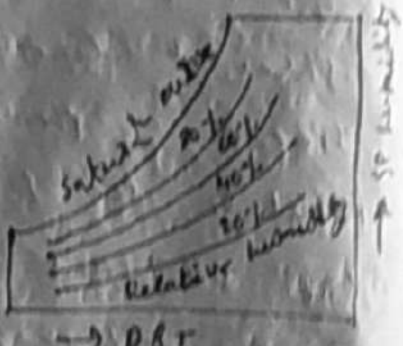


(6) <u>Specific volume lines</u>: The specific volume lines are obliquely inclined straight lines and uniformly spaced as shown in fig. These lines are drawn up to the saturation curve.

The values of volume lines are generally given at the base of the chart.



(7) <u>Vapour Pressure lines</u>: The vapour pressure lines are horizontal and uniformly spaced. Generally, the vapour pressure lines are not drawn in the main chart. But scale showing vapour pressure in mm of Hg is given on the extreme left side of the chart as shown in figure.



(8) <u>Relative humidity lines</u>: The relative humidity lines are curved lines and follow the saturation curve. Generally, this lines are drawn with values 10 %, 20 %, 30 % etc. and upto 100 %. The saturation curve represents 100 % relative humidity. The values of relative humidity lines are generally given along the lines themselves as shown in figure.

(1) Air conditioning system :

The air conditioning is that branch of engineering which deals with the study of conditioning of air i.e, supplying and maintaining desirable internal atmospheric conditions for human comfort, irrespective of external conditions. It also deals with conditioning of air for industrial purposes, food processing, storage of food and other materials.

(2) Factors affecting comfort air conditioning :

(1) Temperature of air : It may be noted that a human being feels comfortable when the air is at 21°C with 56% relative humidity.

(2) Humidity of air : In general for summer air conditioning, the relative humidity should not be less than 60% whereas for winter air conditioning it should not be more than 40%.

(3) Purity of air : For the comfort of a human body, proper filtration, cleaning and purification of air is essential to keep it free from dust and other impurities.

(4) Motion of air : The motion or circulation of air is another important factor which should be controlled in order to keep constant temp. throughout the conditioned space.

(3) Equipments used in air conditioning system :

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

(2) Air conditioning unit : It is a unit which consists of cooling and dehumidifying process for summer air conditioning or heating and humidification process for winter air conditioning.

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

(4) Supply outlets: This are grills which distribute the conditioned air evenly in the room.

(5) Return outlets: This are the opening in a room surface which allow the room air to enter the return duct.

(6) Filters: The main function of the filters is to remove dust, dirt and other harmfull bacteria from the air.

(1) Classification of air conditioning systems:

(1) According to the Purpose:

(a) comfort air conditioning system.

(b) Industrial air conditioning system.

(2) According to season of the air:

(a) Winter air conditioning system.

(b) Summer air conditioning system.

(c) Year-round air conditioning system.

(3) According to the arrangement of equipment:

(a) Unitary air conditioning system,

(b) central air conditioning system.

(1) comfort air conditioning system:

In comfort air conditioning, the air is brought to the required dry bulb temp and relative humidity for the human helth, comfort and efficiency. If sufficient data of the required conditioned is not given, then it is assumed to be 21°C dry bulb temp and 50% relative humidity. The sensible heat factor is generally kept as following:

For residance of private office = 0.9

For restaurant or busy office = 0.8

Auditorium or cinema hall = 0.7

Ball room dance hall, etc = 0.6

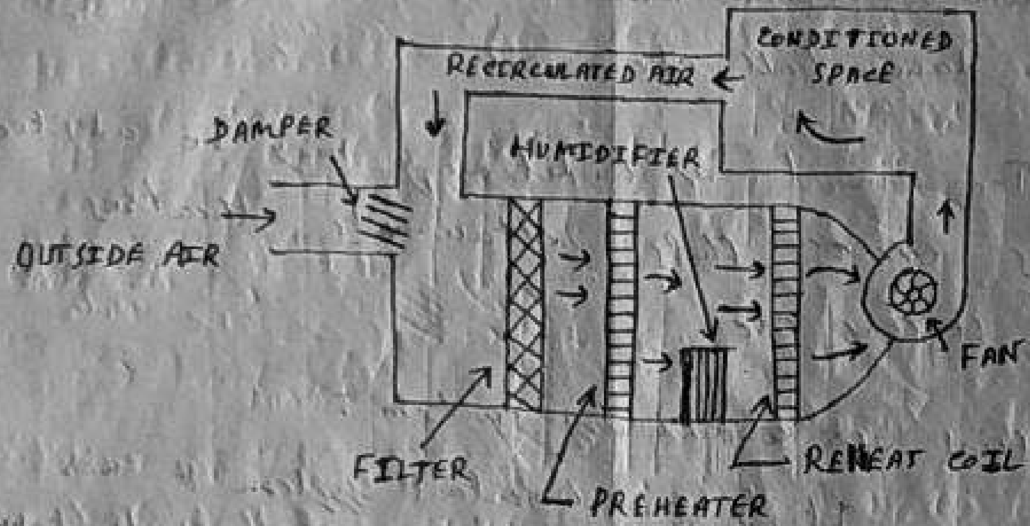
The comfort air conditioning may be adopted for homes, offices, shops, restaurants, theatres, hospitals, schools etc.

(ii) Industrial air conditioning system:

It is an important system of air conditioning this days in which inside dry bulb temp and relative humidity of the air is kept constant for the proper research and manufacturing processes. Some of the sophesticated electronic and other machines need a perticular dry bulb temp and relative humidity. Sometimes, these machines also require a perticular method of psychrometric processes. This type of air conditioning system is used in textiles mills, paper mills, machine-parts manufacturing plants, tool rooms, photo-processing plants etc.

Winter air conditioning system:

In winter air conditioning, the air is heated, which is generally accompanied by humidification. The schematic arrangement of the system is shown in figure.

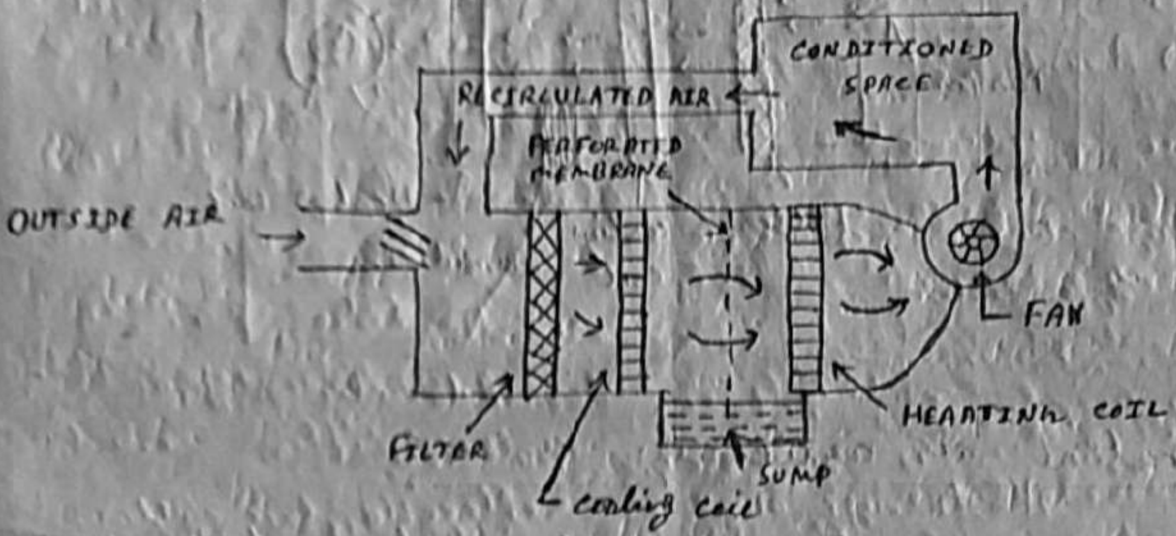


The outside air flows through a damper and mixes up with the recirculated air (which is obtained from the conditioned space) The mixed air passes through a filter to remove dirt, dust and other impurities. The air now passes through a preheat coil in order to prevent the possible freezing of water and the control the evaporation of water in the humidifier. After that the air is made to pass through a reheat coil to bring the air to the designed dry bulb temp. Now, the conditioned air is supplied to the conditioned space by a fan. From the conditioned space, a part of the used air is exhausted to the ~~exhausted to the~~ atmosphere by the exhaust fans or ventilators. The remaining part of the used air (known as recirculated air) is again conditioned as shown in figure.

The outside air is sucked and made to mix with recirculated air, in order to make up for the loss of conditioned (or used) air through exhaust fans or ventilation from the conditioned space.

① Summer air conditioning system:

It is most important type of air conditioning, in which the air is cooled and generally dehumidified. The schematic arrangement of a typical summer air conditioning system is shown in figure.

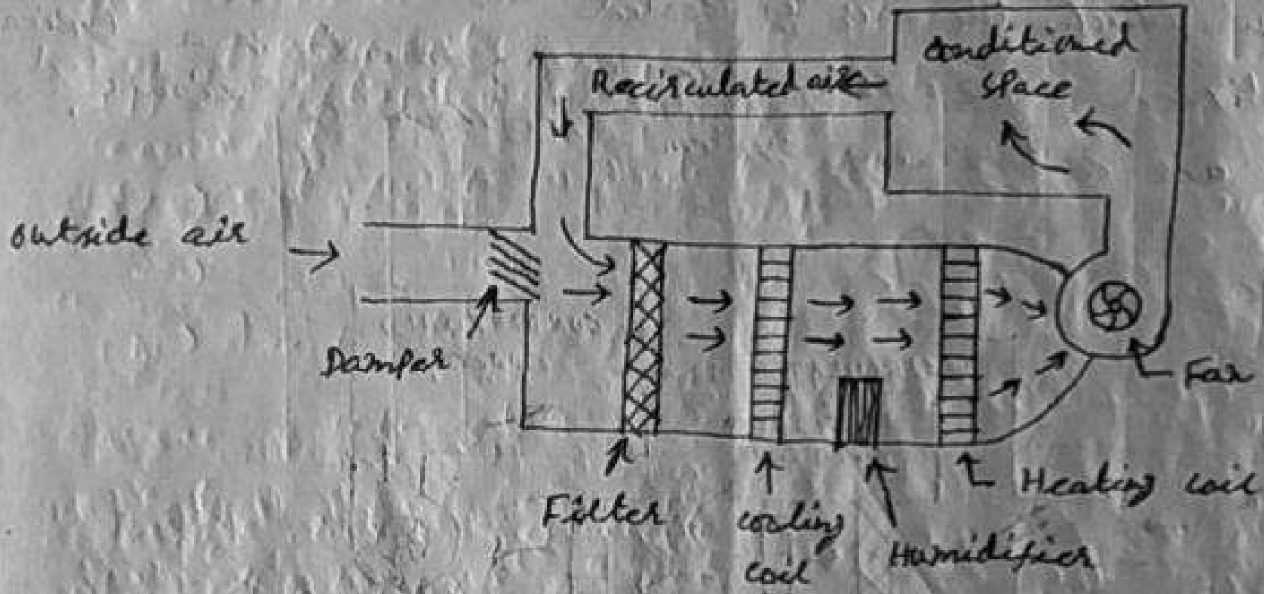


The outside air flows through the damper, and mixes up with recirculated air (which is obtained from the conditioned space). The mixed air passes through a filter to remove dirt, dust and other impurities. The air is now passes through a cooling coil. The coil has a temp much below the required dry bulb temp of the air in the conditioned space. The cooled air passes through a perforated membrane and loses its moisture in the condensed form which is collected in a sump. After that the air is ~~passed~~ made to pass through a heating coil which heats up the air slightly. This is done to bring the air to the designed dry bulb temp and relative humidity.

Now the conditioned air is supplied to the

(iii) Air round air conditioning system:

The year-round air conditioning system should be equipped for both the summer and winter air conditioning. The schematic arrangement of a modern summer year-round air conditioning system as shown in figure.



(iv) central air conditioning system:

This is most important type of air conditioning system, which is adopted when the cooling capacity required is 25 TR or more. The central air conditioning system is also adopted when the air flow is more than 300 m^3/min or different zones in a building are to be air conditioned.

(7) Air cooler and desert cooler :

With the heat waves piercing into your body and temp shooting up above 45°C and with the crossing of mercury level, it is time to relax within doors. The body gets sweating, forcing them to stick to their homes. The room cooler is the minimum requisite needed than a costly air conditioner. The water circulation along the pads by pump and rotation of the blades makes the heat keep a distance away.

Cooler body: The cooler body is made of G.I sheets. These sheets are galvanised to prevent it from rust. Air vents are provided in the cooler body for supply of fresh air. Fresh air is entered into the cooler for cooling purpose. Three covers are provided in the cooler body. These covers are parts of back and both sides of the cooler. It length and width is the same as tray size. The depth is so that the installed electric motor and blower could be driven easily. The covers are equipped with cooling pad.

Cooling kit : (motor & pump): cooling kit comprises of two main parts, motor and pump. This is the heart of the cooler.

Cooler motor: An electric motor is a machine which converts electrical energy into mechanical energy. Its action is based on the principle that when a current carrying conductor is placed in a magnetic field it experiences a mechanical force.

In desert air cooler particularly single phase motors are used. Such motors are designed to operate a single phase supply are manufactured in a large number of types to perform a wide variety of useful service in home. It has distributed stator winding and squirrel cage rotor. When feed from a single phase supply, its stator winding produces a flux which is only alternating. An alternating or pulsating flux acting on a stationary squirrel cage motor cannot produce rotation. That is why it is not self starting.

Pump: The pump used in case of 'Desert air cooler' is centrifugal pump. But in this centrifugal pump there is no suction pipe. Only it lifts the water from water tank to a centrifugal distributor. This has a impeller which when rotate a centrifugal force is developed.

This centrifugal force lift the water from lower level to central distributor. The pump is fitted at the bottom of the water capacity tank. From pump coupling rods are attached. When power is supplied to motor.