BALASORE SCHOOL OF ENGINEERING

PREVIOUS YEAR SOLVED QUESTIONS & ANSWERS

BRANCH : MECHANICAL ENGG.

SEMESTER : 5TH

THEORY : 05

SUBJECT : REFRIGERATION AND AIR CONDITIONING

SUBMITTED BY

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CHAPTER-1

AIR REFRIGERATION CYCLE

Define refrigeration ?

The term **refrigeration** means cooling a space, substance or system to lower and/or maintain its temperature below the ambient one (while the removed heat is rejected at a higher temperature).[1][2] In other words, refrigeration is artificial (human-made) cooling.[3][4] Energy in the form of heat is removed from a low-temperature reservoir and transferred to a high-temperature reservoir.

Define unit of refrigeration ?

The **unit of refrigeration** is expressed in terms of ton of **refrigeration** (TR). ... One ton of **refrigeration** is defined as the amount of **refrigeration** effect (heat transfer rate) produced during uniform melting of one ton (100kg) of ice at 0°C to the water at the 0°C in 24 hours.

Define cop ?

The **coefficient of performance** or COP (sometimes CP or CoP) of a heat pump, refrigerator or air conditioning system is a ratio of useful heating or cooling provided to work required. Higher COPs equate to lower operating costs.

Define refrigerating effect ?

Refrigeration effect is the amount of heat that each pound of refrigerant retains from the refrigerated space to deliver helpful cooling. In the gas cycle, the refrigeration effect is equivalent to the result of the particular warmth of the gas and the ascent in temperature of the gas in the low temperature side.

Define open and closed air refrigeration system ?

Open air refrigeration cycle: When cooled air from the turbine enters the cabin and comes in physical contact with the occupants. It is not much in use because of moisture added to air in the cabin.

Closed air refrigeration cycle OR dense cycle: When cooled air from the turbine passes through the coil and a fan circulates and recirculates cabin air over it. The pressure of cooled air in such systems is much higher than in the open system. Because of high pressure, volume is less and hence density of air is high. It is therefore also called a dense system. It reduces compression ratio and hence COP is high. There is no moisture problem too.

Derive the cop of bellcoleman cycle ?

2.9 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's air cycle. It was one of the earliest types of refrigerators used in ships carrying frozen meat. Fig. 2.5 shows a schematic diagram of such a machine which consists of a compressor, a cooler, an expander and a refrigerator.

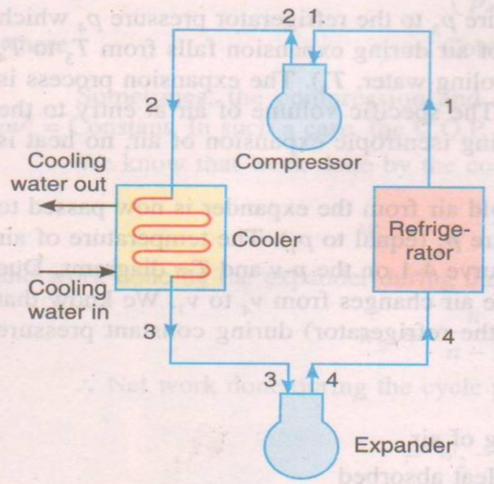


Fig. 2.5. Open cycle air Bell-Coleman Refrigerator.

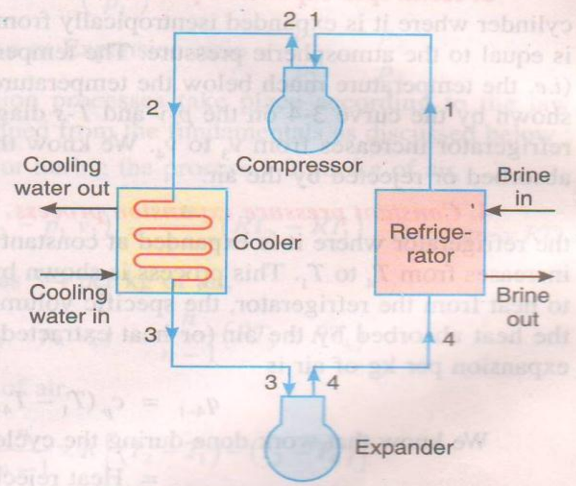
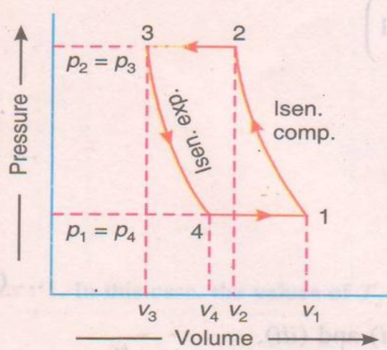


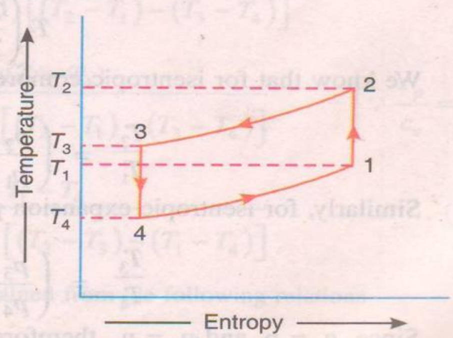
Fig. 2.6. Closed cycle or dense air Bell-Coleman Refrigerator.

The Bell-Coleman cycle (also known as reversed Brayton or Joule cycle) is a modification of reversed Carnot cycle. The cycle is shown on *p-v* and *T-s* diagrams in Fig. 2.7 (*a*) and (*b*). At point 1, let p_1, v_1 and T_1 be the pressure, volume and temperature 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 it is compressed isentropically in the compressor as shown by the curve 1–2 on *p-v* and *T-s* diagrams. During the compression stroke, both the pressure and temperature increases and the specific volume of air at delivery from compressor reduces from v_1 to v_2. We know that during isentropic compression process, no heat is absorbed or rejected by the air.



(*a*) *p-v* diagram.



(*b*) *T-s* diagram.

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 temperature from T_2 to T_3 (the temperature of cooling water) as shown by the curve 2-3 on p-v and T-s diagrams. The specific volume also reduces from v_2 to v_3. We know that heat rejected by the air during constant pressure per kg of air,

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

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 pressure p_4 which is equal to the atmospheric pressure. The temperature of air during expansion falls from T_3 to T_4 (i.e. the temperature much below the temperature of cooling water, T_3). The expansion process is shown by the curve 3-4 on the p-v and T-s diagrams. The specific volume 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 the air.

4. Constant pressure expansion process. The cold air from the expander is now passed to the refrigerator where it is expanded at constant pressure p_4 (equal to p_1). The temperature of air increases from T_4 to T_1. This process is shown by the curve 4-1 on the p-v and T-s diagrams. Due to heat from the refrigerator, the specific volume of the air changes from v_4 to v_1. We know that the heat absorbed by the air (or heat extracted from the refrigerator) during constant pressure expansion per kg of air is

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

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

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

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

$\therefore$ Coefficient of performance,

$$\text{C.O.P.} = \frac{\text{Heat absorbed}}{\text{Work done}} = \frac{c_p (T_1 - T_4)}{c_p (T_2 - T_3) - c_p (T_1 - T_4)}$$

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

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

We know that for isentropic compression process 1-2,

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma - 1}{\gamma}} \quad \ldots (ii)$$

Similarly, for isentropic expansion process 3-4,

$$\frac{T_3}{T_4} = \left(\frac{p_3}{p_4}\right)^{\frac{\gamma - 1}{\gamma}} \quad \ldots (iii)$$

Since, $p_2 = p_3$ and $p_1 = p_4$, therefore from equations (*ii*) and (*iii*),

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} \quad \text{or} \quad \frac{T_2}{T_3} = \frac{T_1}{T_4} \quad \ldots (iv)$$

Now substituting these values in equation (i), we get

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

$$= \frac{1}{\left(\frac{p_3}{p_4}\right)^{\frac{\gamma-1}{\gamma}} - 1} = \frac{1}{\left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1} = \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}} - 1} \quad \ldots (v)$$

where r_p = Compression or Expansion ratio $= \frac{p_2}{p_1} = \frac{p_3}{p_4}$

Sometimes, the compression and expansion processes take place according to the law pv^n = Constant. In such a case, the C.O.P. is obtained from the fundamentals as discussed below :

We know that work done by the compressor during the process 1-2 per kg of air,

$$w_1 = \frac{n}{n-1}(p_2 v_2 - p_1 v_1) = \frac{n}{n-1}(RT_2 - RT_1) \quad \ldots (\because pv = RT)$$

and work done by the expander during the process 3-4 per kg of air,

$$w_2 = \frac{n}{n-1}(p_3 v_3 - p_4 v_4) = \frac{n}{n-1}(RT_3 - RT_4)$$

$\therefore$ Net work done during the cycle per kg of air,

$$= w_2 - w_1 = \frac{n}{n-1} \times R\left[(T_2 - T_1) - (T_3 - T_4)\right]$$

We also know that heat absorbed during constant pressure process 4-1,

$$= c_p(T_1 - T_4)$$

$$\therefore \quad \text{C.O.P.} = \frac{\text{Heat absorbed}}{\text{Work done}} = \frac{c_p(T_1 - T_4)}{\frac{n}{n-1} \times R\left[(T_2 - T_1) - (T_3 - T_4)\right]} \quad \ldots (vi)$$

We know that $R = c_p - c_v = c_v(\gamma - 1)$

Substituting the value of R in equation (vi),

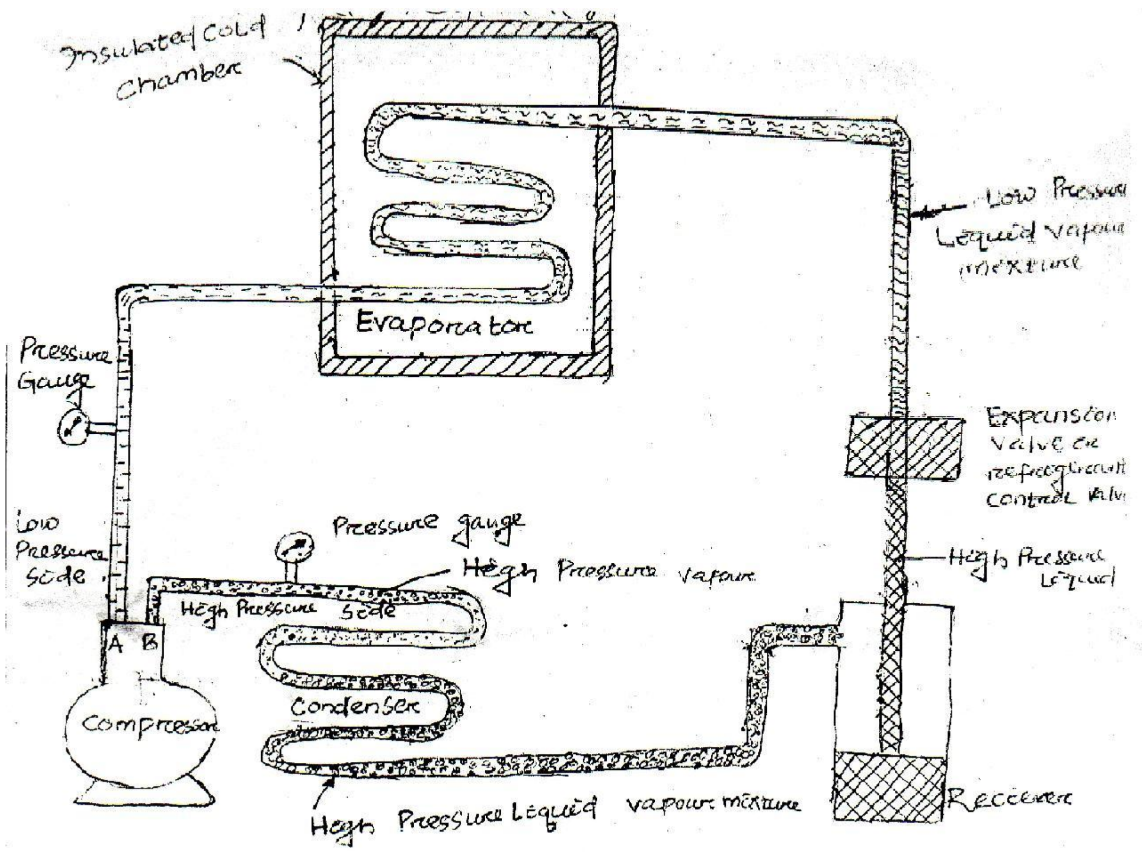
$$\text{C.O.P.} = \frac{c_p(T_1 - T_4)}{\frac{n}{n-1} \times c_v(\gamma - 1)\left[(T_2 - T_1) - (T_3 - T_4)\right]}$$

$$= \frac{\gamma(T_1 - T_4)}{\frac{n}{n-1} \times (\gamma - 1)\left[(T_2 - T_1) - (T_3 - T_4)\right]} \quad \ldots \left[\because \frac{c_p}{c_v} = \gamma\right]$$

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

(b) **Describe the different component of a simple apour compn refrigeration system**

3 (b) 2015 (W)



(1) **Compressor :-**

The low pressure and tempreture vapour regfigerant from evaporation is drain into the compressor through the inlet valve "A". In the compressor it is compressed to high pressure and high temprature vapour refrigerant.

(2) **Condensor :-**

It is also called coolant consist of coils of pipe in which the high pressure and high temprature vapour refrigerant is cooled and condensed. The condensor gives it latent heat to the sorrounding which is normally are on water.

(3) Reciever :-

The Condensed Liquid refrigerant from the condenser is stored in a vessel known as Reciever.

(4) Expansion Value :-

It is also called throttle valve or refregerant on control valve. Its function is also allow the
Liquid refrigerant under high pressure and temprature to pass of at a control rate after reducing pressure at temp some of the liquid refrigerant evaporates as it is passes through the expansion valve.

(5) Evaporator :-

It consist of coil of pipe in which the liquid vapour refrigerant at low pressure and temprature is evaporated and change in to vapour regrigerant at low pressure and temp.

In any vapour compression system there are two different pressure condition one is called high pressure side and other is called the low pressure side.

The high pressure side include the discharge Line, Receiver and expansion valve.
The low pressure side include the evaporator piping from exapansion valve to compressor

Q. derive the COP of vapor compression cycle with dry saturated vapor after compression.

A vapour compression cycle with dry saturated vapour after compression is shown on *T-s* and *p-h* diagrams in Fig. 4.3 (*a*) and (*b*) respectively. At point 1, let T_1, p_1 and s_1, be the temperature, pressure and entropy of the vapour refrigerant respectively. The four processes of the cycle are as follows :

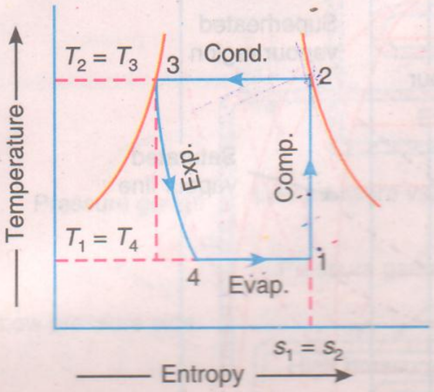
The vapour refrigerant at low pressure p_1 and temperature T_1 is compressed isentropically to dry saturated vapour as shown by the vertical line 1-2 on *T-s* diagram and by the curve 1-2 on *p-h* diagram. The pressure and temperature rises from p_1 to p_2 and T_1 to T_2 respectively.

The work done during isentropic compression per kg of refrigerant is given by

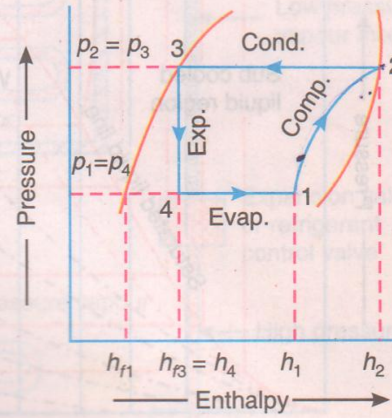
$$w = h_2 - h_1$$

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

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



(*a*) *T-s* diagram.



(*b*) *p-h* diagram.

Fig. 4.3. Theoretical vapour compression cycle with dry saturated vapour after compression.

2. *Condensing process.* The high pressure and temperature vapour refrigerant from the compressor is passed through the condenser where it is completely condensed at constant pressure p_2 and temperature T_2, as shown by the horizontal line 2-3 on *T-s* and *p-h* diagrams. The vapour refrigerant is changed into liquid refrigerant. The refrigerant, while passing through the condenser, gives its latent heat to the surrounding condensing medium.

3. *Expansion process.* The liquid refrigerant at pressure $p_3 = p_2$ and temperature $T_3 = T_2$ is expanded by *throttling process through the expansion valve to a low pressure $p_4 = p_1$ and temperature $T_4 = T_1$, as shown by the curve 3-4 on *T-s* diagram and by the vertical line 3-4 on *p-h* diagram. We have already discussed that some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporised in the evaporator. We know that during the throttling process, no heat is absorbed or rejected by the liquid refrigerant.

Notes: (*a*) In case an expansion cylinder is used in place of throttle or expansion valve to expand the liquid refrigerant, then the refrigerant will expand isentropically as shown by dotted vertical line on *T-s* diagram in Fig. 4.3 (*a*). The isentropic expansion reduces the external work being expanded in running the compressor and increases the refrigerating effect. Thus, the net result of using the expansion cylinder is to increase the coefficient of performance.

Since the expansion cylinder system of expanding the liquid refrigerant is quite complicated and involves greater initial cost, therefore its use is not justified for small gain in cooling capacity. Moreover, the flow rate of the refrigerant can be controlled with throttle valve which is not possible in case of expansion cylinder which has a fixed cylinder volume.

(*b*) In modern domestic refrigerators, a capillary (small bore tube) is used in place of an expansion valve.

4. *Vaporising process.* The liquid-vapour mixture of the refrigerant at pressure $p_4 = p_1$ and temperature $T_4 = T_1$ is evaporated and changed into vapour refrigerant at constant pressure and temperature, as shown by the horizontal line 4-1 on *T-s* and *p-h* diagrams. 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 *refrigerating effect* and it is briefly written as R_E. The process of vaporisation continues upto point 1 which is the starting point and thus the cycle is completed.

We know that the refrigerating effect or the heat absorbed or extracted by the liquid-vapour refrigerant during evaporation per kg of refrigerant is given by

$$R_E = h_1 - h_4 = h_1 - h_{f3} \qquad \ldots (\because\ h_{f3} = h_4)$$

where h_{f3} = Sensible heat at temperature T_3, *i.e.* enthalpy of liquid refrigerant leaving the condenser.

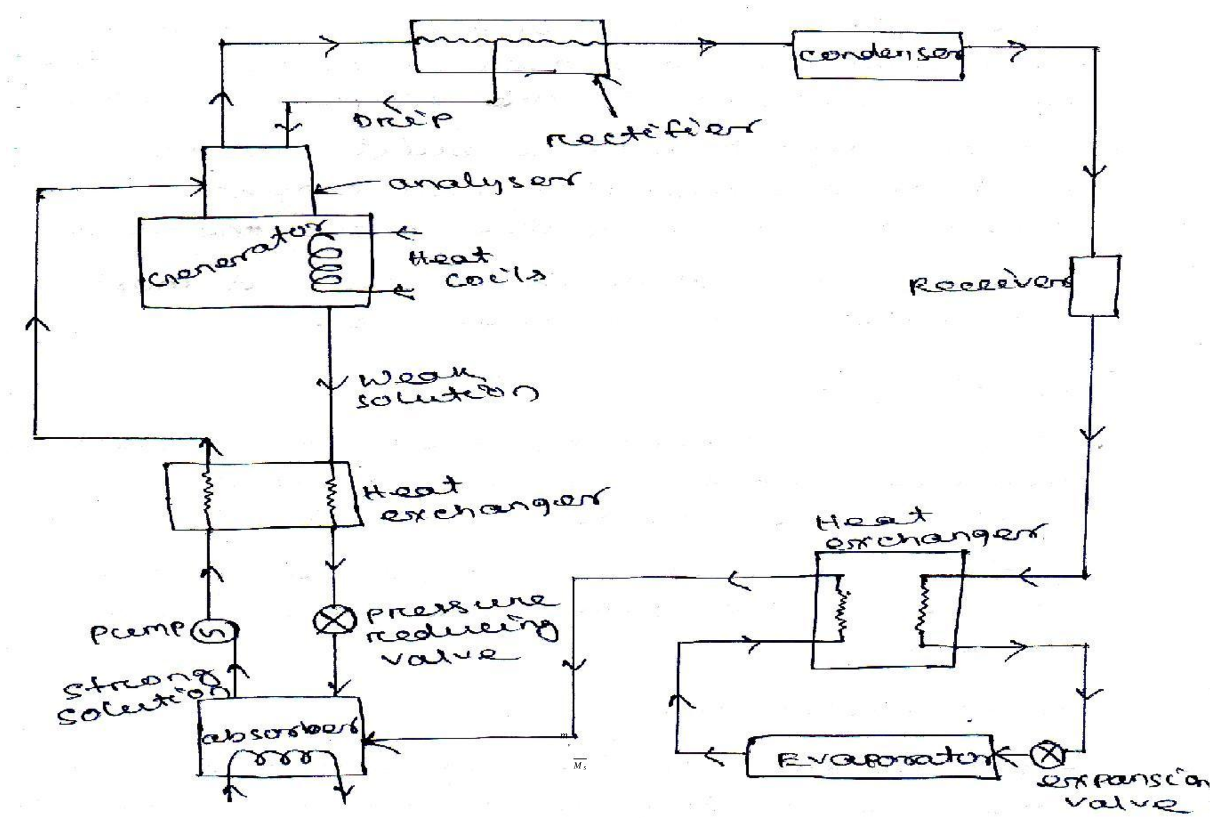
It may be noticed from the cycle that the liquid-vapour refrigerant has extracted heat during evaporation and the work will be done by the compressor for isentropic compression of the high pressure and temperature vapour refrigerant.

$\therefore$ Coefficient of performance,

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

Explain briefly with heat diagram working of a practical vapour absorption system. 2012-4(c), 2015- 4(c)

Ans : In order to make the simple absorption system more practical, it is fitted with an analyser a rectifier, and two heat exchangers. The accessories help to improve the performance and working of the plant.



(1) Analyser :-

\# When ammonia is vapourised in generated some water is also vapourised and will flow into the condenser along with the amonia vapours in the simple systems.

\# The analyser may be built as an integral part of the generator. It consists of Series of trays mounted above the generator .

Here the vapour is cooled and most of the water vapour condenses.

(2) Rectifier :-

In case of vapours are not completely removed in the analyser, a closed type vapour cooler called rectifier is used.

It is generally water cooled and may be of the double pipe, Shell and tube type.

(3) Heat exchanger :-

These are provide between the pump and the generator is used to cool the weak solution.

The heat exchanger provided between the condenser & the evaporator is called liquid sub-cooler.

Q. Give the Comparison between vapour absorption & vapour compression sys

Ans : <u>Vapour Absorption</u>

(i) The system is subjected to silence because it has no sliding part.

(ii) Heat energy is applied.

(iii) Energy input is more in this system.

(iv) Changing of refrigerant is difficult

(v) At reduced load it doesn't effect COP.

<u>Vapour Compression</u>

(i) The system is subjected to noise due to presence of compressor.
(ii) Mechanical energy is applied.

(iii) Energy input is low in this system.

(iv) Changing of refrigerant is easy.

(v) At reduced load the COP low.

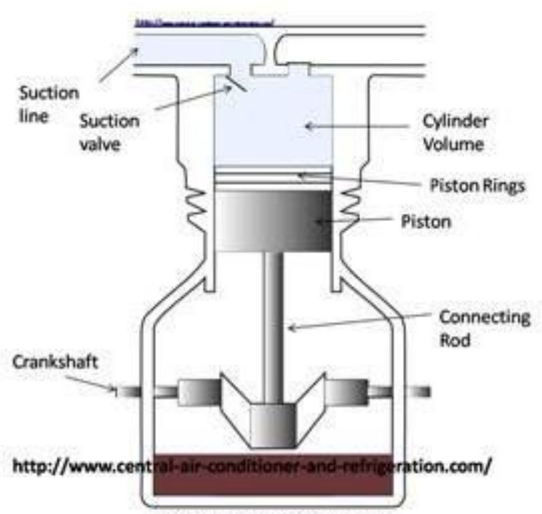
Reciprocating Compressors

Reciprocating Compressors are one of the most widely used types of compressors for refrigeration and air conditioning applications. The reciprocating compressors comprise of the piston and the cylinder arrangement similar to the automotive engine. While the engine generates power after consuming fuel, the reciprocating compressor consumes electricity to compress the refrigerant. Inside the cylinder the piston performs reciprocating motion which enables the compression of refrigerant inside it.

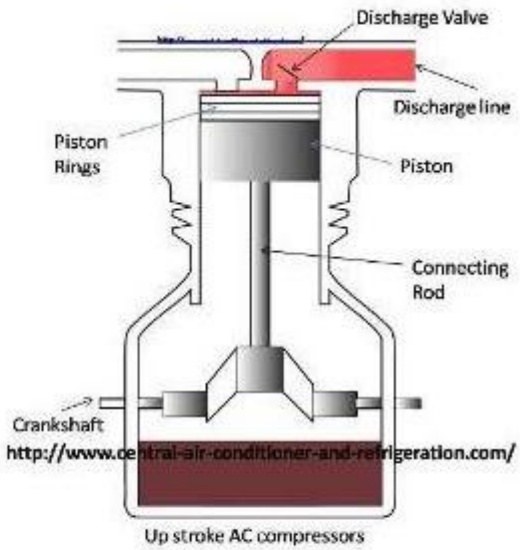
Principle of Working of the Reciprocating Compressors

Apart from the piston and the cylinder arrangement, the reciprocating compressor also comprises of the crankshaft, connecting rod and other small connecting elements. The crankshaft is connected to the electric motor directly by coupling or by belt and driven by the pulley arrangement. The rotary motion of the crankshaft is converted into the reciprocating motion of the piston inside the cylinder via the connecting rod. Let us see the various strokes of the piston inside the cylinder (refer the figures below):

Working of Reciprocating Compressor



Down stroke AC compressors



1. Piston at Top Dead Center (TDC) Position:

Let us suppose that initially the piston is at the top position inside the cylinder; this is called as the top dead center (TDC) position of the piston. At this position the refrigerant that has already been compressed is delivered from the discharge valve. From the top dead center position the piston starts moving towards the downward direction. At this instance the discharge valve is already closed, while the suction valve opens due to suction pressure of the refrigerant from the suction pipeline. The refrigerant from the suction pipeline is taken inside the cylinder of the compressor via the suction valve. As the piston moves downwards, the amount of the refrigerant taken inside the cylinder increases. When the piston reaches bottom most position it is said to be in bottom dead center position (BDC). At this position the maximum amount of the refrigerant is sucked by the cylinder or compressor.

2. Piston at Bottom Dead Center (BDC) Position:

At the BDC position the maximum amount of the refrigerant has been taken inside the cylinder from the suction line of the refrigeration or air conditioning system. The piston now starts moving in the upward direction due to which the volume of the refrigerant inside the cylinder starts reducing, that means the refrigerant starts getting compressed and its pressure starts increasing. Due to high pressure of the refrigerant inside the cylinder, its suction valve closes. Due to crankshaft motion the piston continues moving upwards and compressing the refrigerant. The pressure of refrigerant goes on increasing as it gets more and more compressed. At the end of the compression stroke the discharge valve opens and the refrigerant is delivered to the discharge pipeline or tubing of the refrigeration or the air conditioning system. Due to the rotary motion of the crankshaft the reciprocating motion of the piston continues inside the cylinder and it finally reaches the TDC position, where all the compressed refrigerant inside the cylinder is delivered to the discharge line and the discharge valve closes. From here on the piston starts moving again to the BDC position and the operation of the compressor continues.

When moving from BDC to the TDC position, the piston does not touch the cylinder at the top position, rather some volume is remains vacant between the top position of the piston and the cylinder, this volume is called as the clearance volume. Such clearance volume is also present at the bottom BDC position.

Thus there are two strokes of the piston inside the cylinder, the suction stroke and the compression stroke. For each revolution of the crankshaft one suction and one discharge stroke of the piston inside the cylinder is produced.