Lesson-4

Refrigeration Cycles

Objectives:

- After studying this unit, you should be able to

- Describe the term ton of refrigeration and COP
- know what is refrigeration cycle,
- understand about the air refrigeration, vapour compression cycle and vapour absorption cycle,
- describe the air refrigeration, vapour compression cycle and vapour absorption cycle

Glossary of terms:

i. **Refrigeration:** Refrigeration is the science of producing and maintaining temperatures below that of the surrounding atmosphere.

ii. **Co-efficient of Performance (C.O.P.):** The performance of a refrigeration system is expressed by a term known as the "co-efficient of performance", which is defined as the ratio of heat absorbed by the refrigerant while passing through the evaporator to the work input required to compress the refrigerant in the compressor

iii. **Tons of refrigeration (TR):** Refrigerating effect produced by the melting of 1 tonne of ice from and at 0°C in 24 hours.

iv. **Refrigerating effect:** Amount of heat exteracted by Evaporator is called refrigerating effect.

v. **Work of Compression:** Power required to drive the compressor is called work of compression.

Introduction:

- Refrigeration is the science of producing and maintaining temperatures below that of the surrounding atmosphere. This means the removing of heat from a substance to be cooled. Heat always passes downhill, from a warm body to a cooler one, until both bodies are at the same temperature.

- Maintaining perishables at their required temperatures is done by refrigeration. Not only perishables but today many human work spaces in offices and factory buildings are air-conditioned and a refrigeration unit is the heart of the system.

- Before the advent of mechanical refrigeration water was kept cool by storing it in semi porous jugs so that the water could seep through and evaporate.

- The evaporation carried away heat and cooled the water. This system was used by the Egyptians and by Indians in the Southwest. Natural ice from lakes and rivers was often cut during winter and stored in caves, straw lined pits, and later in sawdust-insulated buildings to be used as required. The Romans carried pack trains of snow from Alps to Rome for cooling the Emperor’s drinks.

Introduction….

- Though these methods of cooling all make use of natural phenomena, they were used to maintain a lower temperature in a space or product and may properly be called refrigeration.
- In simple, refrigeration means the cooling of or removal of heat from a system. The equipment employed to maintain the system at a low temperature is termed as refrigerating system and the system which is kept at lower temperature is called refrigerated system.
- Refrigeration is generally produced in one of the following three ways: (i) By melting of a solid. (ii) By sublimation of a solid. (iii) By evaporation of a liquid. Most of the commercial refrigeration is produced by the evaporation of a liquid called refrigerant.
- Mechanical refrigeration depends upon the evaporation of liquid refrigerant and its circuit includes the equipments naming evaporator, compressor, condenser and expansion valve.
- It is used for preservation of food, manufacture of ice, solid carbon dioxide and control of air temperature and humidity in the air-conditioning system.

Important refrigeration applications:

1. Ice making

2. Transportation of foods above and below freezing

3. Industrial air-conditioning

4. Comfort air-conditioning

5. Chemical and related industries

6. Medical and surgical aids

7. Processing food products and beverages

8. Oil refining and synthetic rubber manufacturing

9. Manufacturing and treatment of metals

10. Freezing food products

11. Miscellaneous applications:

    (i) Extremely low temperatures (ii) Plumbing (iii) Building construction etc.

Principle of Refrigeration

- Refrigeration is defined as the production of temperature lower than those of the surrounding and maintain the lower temperature within the boundary of a given space.
- The effect has been accomplished by non cyclic processes such as the melting of ice or sublimation of solid carbon dioxide.
- However, refrigeration effect is usually produced by transferring heat from a low temperature source to a high temperature source by spending mechanical work.
- To produce this effect requires certain machinery, hence, the method is called mechanical refrigeration. The working media of such machines are called refrigerants.

Refrigeration Systems

- The various refrigeration systems may be enumerated as below:

  1. Ice refrigeration

  2. Air refrigeration system

  3. Vapour compression refrigeration system

  4. Vapour absorption refrigeration system

  5. Special refrigeration systems

     (i) Adsorption refrigeration system (ii) Cascade refrigeration system

     (iii) Mixed refrigeration system (iv) Vortex tube refrigeration system

     (v) Thermoelectric refrigeration (vi) Steam jet refrigeration system.

Methods of Refrigeration:

The refrigeration effect may be produced by bringing the substance to be cooled in direct or indirect contact with cooling medium such as ice. The common methods of refrigeration are as follows.

1. Ice refrigeration 2. Dry Ice refrigeration 3. Air expansion Refrigeration 4. Evaporative refrigeration 5. Gas throttling refrigeration 6. Steam jet refrigeration 7. Liquid gas refrigeration 8. Vapour compression refrigeration 9. Vapour absorption refrigeration.

Methods of Refrigeration….

Ice Refrigeration:

- The ice refrigeration systems consists of an insulated cabinet equipped with a tray or tank at the top, for holding blocks of ice pieces.
- Shelves for food are located below the ice compartment. Cold air flows downward from ice compartment and cools the food on the shelves below.
- Air returns from the bottom of the cabinet up, the sides and back of the cabinet which is warmer, flows over the ice, and again flows down over the shelves to be cooled.

Methods of Refrigeration….

Dry Ice Refrigeration:

- Dry ice is the solidified form of CO_2.
- It evaporates directly from solid to vapour without liquid phase.
- This phenomena is called sublimation. In this, the dry ice in the form of flakes or slabs Is placed on the cartons containing food stuffs.
- When dry ice sublimates, it will absorb heat from food stuff in the cartons and thus keeps them in a frozen condition.
- This is used for preservation of frozen foods and ice creams in storage and transportation. It has twice the heat absorbing capacity of ice refrigeration. However its cost is high.

Methods of Refrigeration….

Air Expansion Refrigeration:

- In this method, air is compressed to 5 bar and cooled down at constant pressure.
- It is then expanded adiabatically to a pressure of 1 bar. This gives the maximum temperature reduction.
- In a given pressure range, because work is done by expense of internal energy which depends on the temperature.
- The cold air thus obtained is circulated through the cold chamber to remove heat from the products stored in it.

Evaporative Refrigeration:

- In the evaporative refrigeration, water evaporates by absorbing latent heat from the surrounding air. Thus the air is cooled, and circulated to the cold chambers.

Methods of Refrigeration….

Gas Throttling Refrigeration:

- In the gas throttling refrigeration process, there is no change in enthalpy and also for a perfect gas, there is no change in temperature.
- However, for actual gases there is a substantial change, usually a decrease in temperature. This temperature drop depends upon the Joule- Thomas coefficient, the pressure drop, and the initial state of the gas.
- High pressure gas is throttled through porous plug into the space to be cooled and escapes outside after absorbing heat from the space.
- This produces the refrigeration effect in the space or the product kept in the space.

Methods of Refrigeration….

Steam – Jet Refrigeration:

- The steam – jet refrigeration is based on the principle that the boiling point of water is lowered as the pressure is reduced.

- In this, water is a refrigerant and a steam ejector is used to lower the pressure and to reduce the boiling point of water.

- Water to be chilled is filled in the flash chamber, steam generated in the boiler is expanded through a nozzle and ejected out at high velocity. Due to this, low pressure is produced in flash chamber and water evaporates rapidly.

- The steam ejector draws evaporated vapour from the chamber, and sends the fluid to condenser at a high velocity. The condensate is re circulated to the boiler.

- The heat needed for the evaporation is taken from the water in the chamber. Thus its temperature is reduced.

- The cold water is circulated through refrigerated space where it absorbs heat producing the refrigeration effect. Water as refrigerant is very safe and widely used in air conditioning system.

Methods of Refrigeration….

Liquid gas Refrigeration:

- In liquid gas refrigeration, liquid gas like nitrogen, which non-toxic is used for producing refrigeration effect.
- It is filled in a well insulated cylinder which is connected to a pipe with intermittent perforations.
- Required quantity of liquid nitrogen is passed through the pie and sprayed through the perforations into the space to be cooled.
- The quantity of nitrogen is regulated by means of valve. The temperature produced in the space may be -2 °C. Liquid gas vaporize after absorbing heat, and the gas is released to atmosphere.
- This method is used for cooling fluids, vegetables, meat, fish and other food stuffs place in the cold storage. This type of cooling is also used in transporting vehicles carrying food stuffs.

Methods of Refrigeration….

Vapour compression refrigeration:

- The Vapour compression refrigeration system consists of an evaporator, compressor, condenser and an expansion valve.
- The refrigeration effect is obtained in the cold region as heat is extracted by the vaporization of refrigerant in the evaporator.
- The refrigerant vapour from the evaporator is compressed in the compressor to a high pressure at which its saturation temperature is greater than the ambient or any other heat sink.
- Hence when the high pressure, high temperature refrigerant flows through the condenser, condensation of the vapour into liquid takes place by heat rejection to the heat sink.
- To complete the cycle, the high pressure liquid is made to flow through an expansion valve. In the expansion valve the pressure and temperature of the refrigerant decrease.
- This low pressure and low temperature refrigerant vapour evaporates in the evaporator taking heat from the cold region.
- It should be observed that the system operates on a closed cycle.
- The system requires input in the form of mechanical work. It extracts heat from a cold space and rejects heat to a high temperature heat sink.

Methods of Refrigeration….

Vapour absorption refrigeration:

- In the Vapour compression refrigeration Water is a strong absorbent of NH_3. If NH_3 is kept in a vessel that is exposed to another vessel containing water, the strong absorption potential of water will cause evaporation of NH_3 requiring no compressor to drive the vapours.

- A liquid pump is used to increase the pressure of strong solution. The strong solution is then heated in a generator and passed through a rectification column to separate the water from ammonia.

- The ammonia vapour is then condensed and recycled. The pump power is negligible hence; the system runs virtually on low- grade energy used for heating the strong solution to separate the water from ammonia.

- These systems were initially run on steam. Later on oil and natural gas based systems were introduced.

Units of Refrigeration and Coefficient of performance:

The unit of refrigeration is expressed in terms of 'tonnes of refrigeration' (TR). "A tonne– of refrigeration is defined as the amount of refrigeration effect produced by the uniform melting of one tonne (900 kg) of ice at 0°C in 24 hours." Since the latent heat of ice is 335 kJ/kg, therefore one tonne of refrigeration,

$$1 \text{ TR} = 900 \times 335 \text{ kj in 24 hours}$$

$$= \frac{900 \times 335}{24 \times 60} = 209.375\ kj/\min = 210\ kj/min \text{ or } 3.5\ kj/sec$$

Coefficient of Performance of a Refrigerator The coefficient of performance is the ratio of heat extracted in the refrigerator to the– work done.

Mathematically,

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

Where, Q = Amount of heat extracted in the refrigerator (or the amount of refrigeration produced, or the capacity of a refrigerator)

W = Amount of work done

Air Refrigeration System:

Introduction:

- Air cycle refrigeration is one of the earliest methods of cooling developed. It became obsolete for several years because of its low co-efficient of performance (C.O.P.) and high operating costs.

- It has, however, been applied to aircraft refrigeration systems, where with low equipment weight, it can utilise a portion of the cabin air according to the supercharger capacity.

- The main characteristic feature of air refrigeration system, is that throughout the cycle the refrigerant remains in gaseous state.

Air Refrigeration System..

The air refrigeration system can be divided in two systems:

- Closed system (ii) Open system.

- In closed (or dense air) system the air refrigerant is contained within the piping or components parts of the system at all times and refrigerator with usually pressures above atmospheric pressure.

- In the open system the refrigerator is replaced by the actual space to be cooled with the air expanded to atmospheric pressure, circulated through the cold room and then compressed to the cooler pressure.

- The pressure of operation in this system is inherently limited to operation at atmospheric pressure in the refrigerator.

Air Refrigeration System…

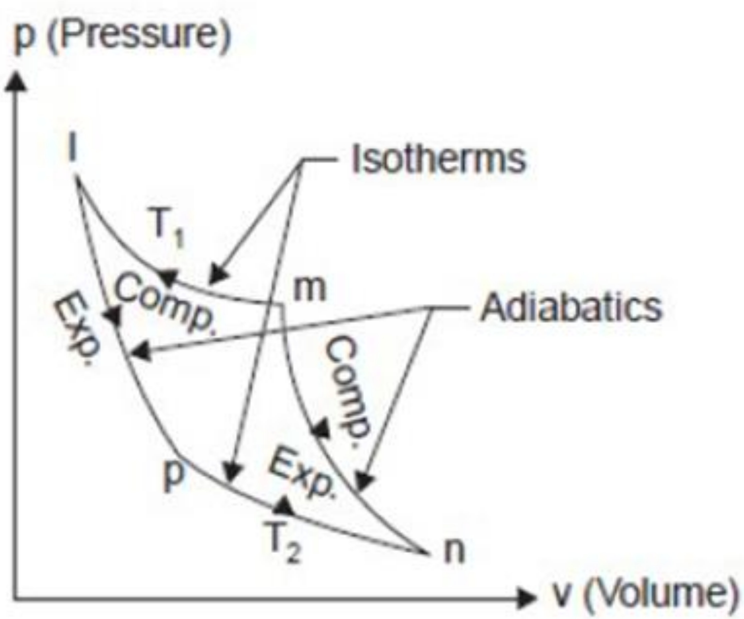
- A closed system claims the following advantages over open system: (i) In a closed system the suction to compressor may be at high pressure.

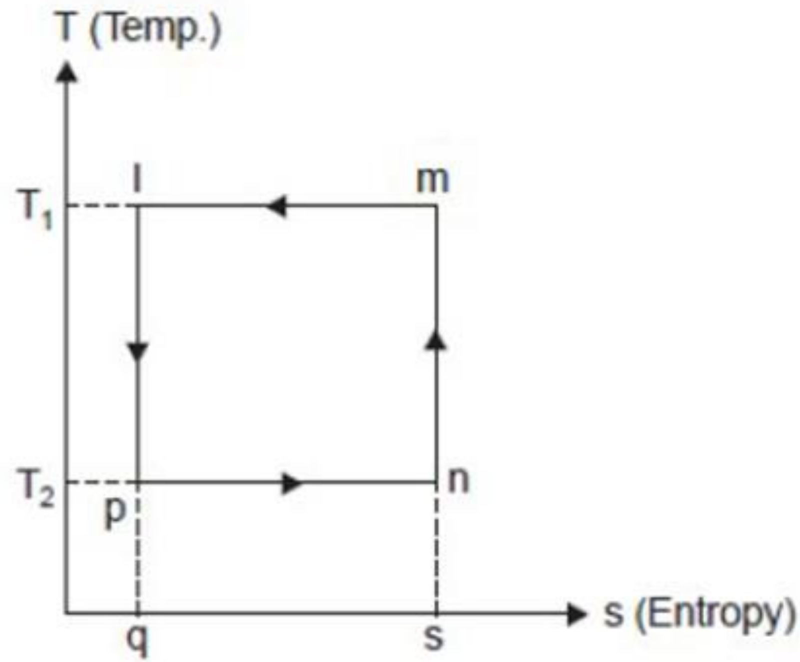
- The sizes of expander and compressor can be kept within reasonable limits by using dense air ; (ii) In open air system, the air picks up moisture from the products kept in the refrigerated chamber ; the moisture may freeze during expansion and is likely to choke the valves whereas it does not happen in closed system and (iii) In open system, the expansion of the refrigerant can be carried only up to atmospheric pressure prevailing in the cold chamber but for a closed system there is no such restriction.

Reversed Carnot Cycle

In refrigeration system, the Carnot cycle considered is reversed Carnot cycle. We know that a heat engine working on Carnot engine has the highest efficiency. Similarly, a refrigeration system working on the reversed cycle has the maximum coefficient of performance.

A reversed Carnot cycle, using air as the working medium is shown on P-V and T-S diagrams in Figures respectively. At point 1, let P_1, V_1, T_1 be the pressure, specific volume and temperature of air respectively. The four processes of the cycle are as follows:





Reversed Carnot Cycle….

Isentropic Compression Process

The air is compressed isentropically as shown by the curve 1-2 on P-V and T-S diagrams. During this process, the pressure of air increases from P_1 to P_2, specific volume decreases from $V_1$to V_2 and temperature increases from T_1 to T_2. We know that during isentropic compression, no heat is absorbed or rejected by the air.

Isothermal Compression Process

The air is now compressed isothermally (i.e. at constant temperature, $T_2 = T_3$) 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 compression per kg of air,

$$Q_{2\text{-}3} = \text{area under npqs}$$

$$= T_3 (S_2 - S_3)$$

$$= T_2 (S_2 - S_3)$$

Isentropic Expansion Process

The air is now expanded isentropically as shown by the curve 3-4 on P-V and T-S diagrams. The pressure of air decreases from P_3 to P_4, specific volume increases from $V_3$to V_4 and temperature decreases from T_3 to T_4. We know that during isentropic expansion, no heat is absorbed or rejected by the air.

Reversed Carnot Cycle….

Isothermal Expansion Process

The air is now expanded isothermally (i.e. at constant temperature, $T_4 = T_1$) as shown by the curve 4-1 on P-V and T-s diagrams. During this process, the pressure of air decreases from P_4 to P_1 and specific volume increases from V_4 to V_1. We know that the heat absorbed by the air during isothermal compression per kg of air,

$$Q_{4-1} = \text{area under lpnm}$$

$$= T_4 (S_1 - S_4)$$

$$= T_4 (S_2 - S_3)$$

$$= T_1 (S_2 - S_3)$$

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

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

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

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

Therefore, coefficient of performance of the refrigeration system working on reversed Carnot cycle,

Reversed Carnot Cycle….

$$COP = \frac{\text{Heat Absorbed}}{\text{Work Done}}$$

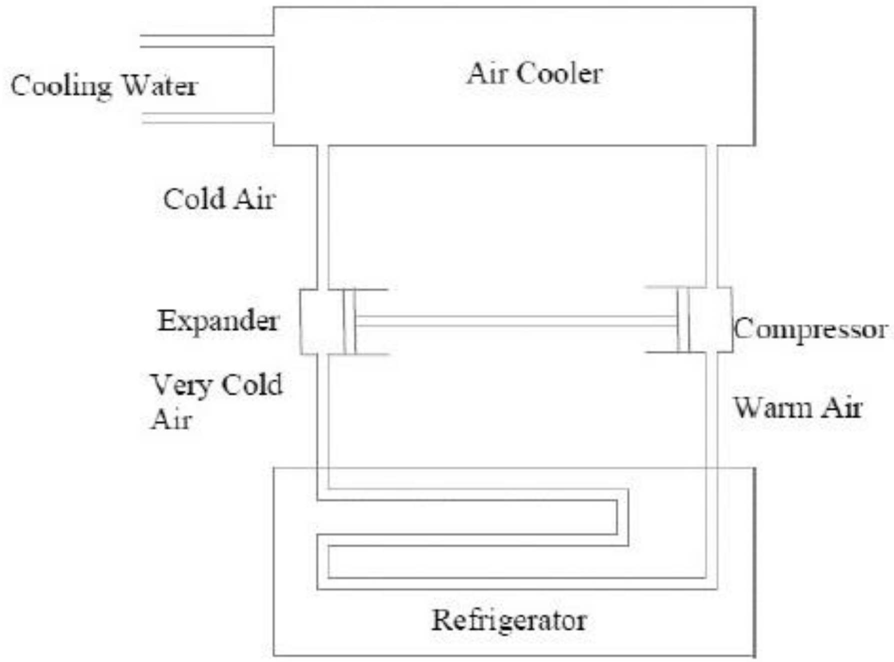
$$= \frac{T_1(S_2 - S_3)}{(T_2 - T_1)(S_2 - S_3)}$$

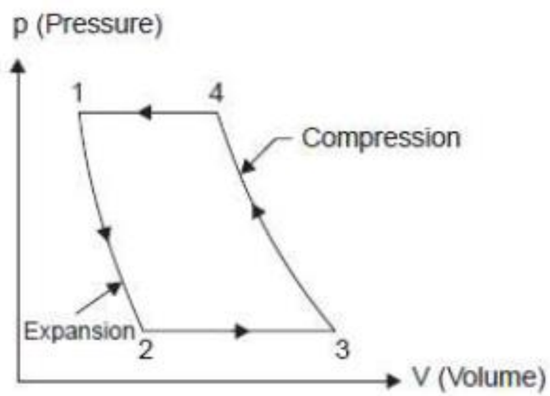
$$COP = \frac{T_1}{T_2 - T_1}$$

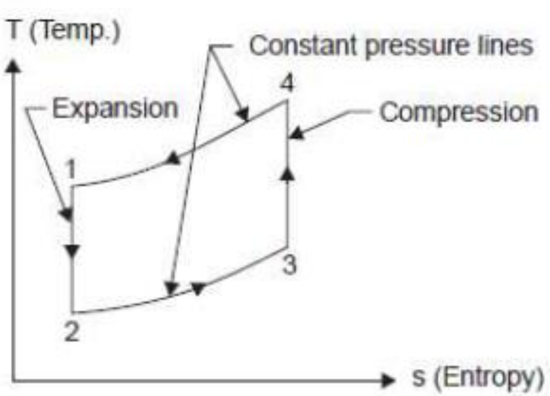
Reversed Brayton Cycle OR Bell Coleman cycle

Fig shows a schematic diagram of an air refrigeration system working on reversed Brayton cycle. Elements of this system are:

1. Compressor 2. Cooler (Heat exchanger) 3. Expander 4. Refrigerator.







Reversed Brayton Cycle OR Bell Coleman cycle…

In this system, work gained from expander is employed for compression of air, consequently less external work is needed for operation of the system. In practice it may or may not be done e.g.,in some aircraft refrigeration systems which employ air refrigeration cycle the expansion workmay be used for driving other devices.This system uses reversed Brayton cycle which is described below:

Figs. 2. shows P-V and T-Sdiagrams for a reversed Brayton cycle. Here it isassumed that (i) absorption and rejection of heat are constant pressure processes and (ii) Compressionand expansion are isentropic processes.

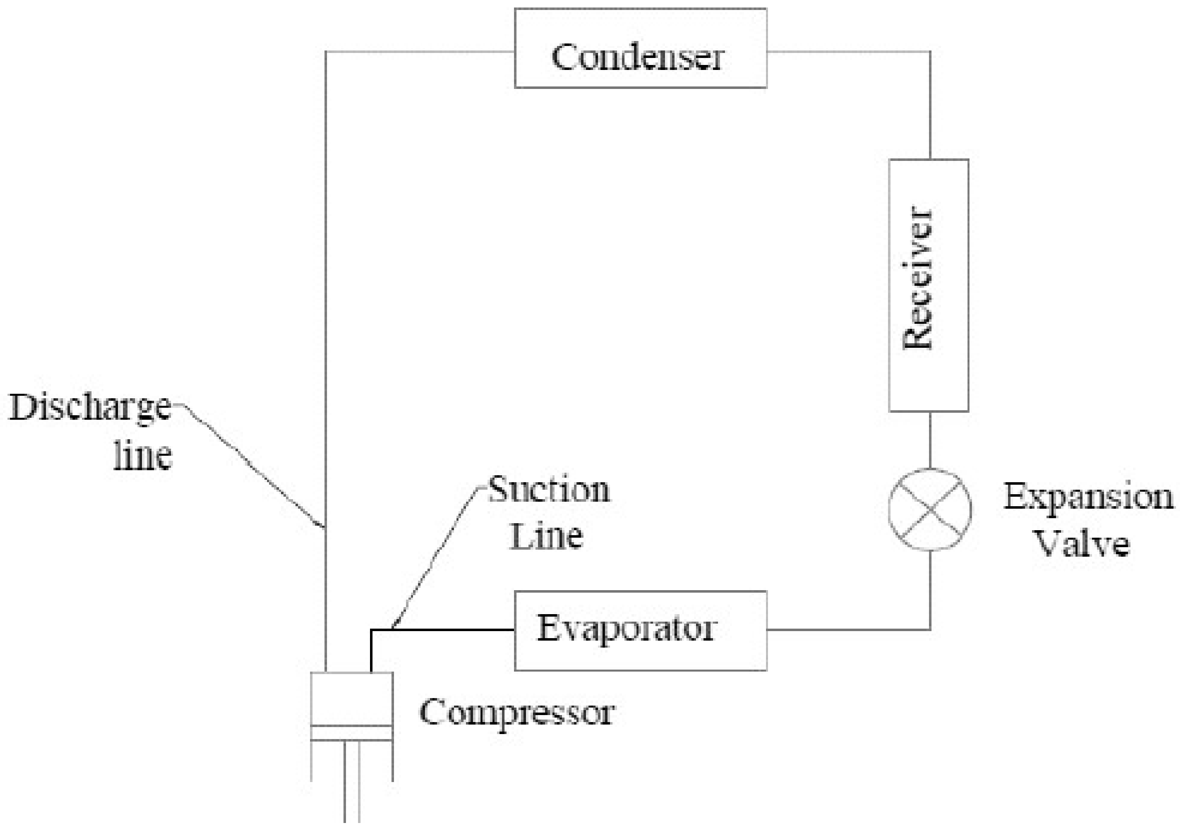
Vapour compression refrigeration:

Introduction:

- Out of all refrigeration systems, the vapour compression system is the most important system from the view point of commercial and domestic utility.
- It is the most practical form of refrigeration. In this system the working fluid is a vapour.
- It readily evaporates and condenses or changes alternately between the vapour and liquid phases without leaving the refrigerating plant.
- During evaporation, it absorbs heat from the cold body. This heat is used as its latent heat for converting it from the liquid to vapour.
- In condensing or cooling or liquefying, it rejects heat to external body, thus creating a cooling effect in the working fluid.

Vapour compression refrigeration..

Simple Vapour Compression Cycle:



In a simple vapour compression system fundamental processes are completed in one cycle.

These are: 1. Compression 2. Condensation 3. Expansion 4. Vaporization.

The flow diagram of such a cycle is shown in Fig.

Vapour compression refrigeration..

The vapour at low temperature and pressure enters the "compressor" where it iscompressed isentropically and subsequently its temperature and pressure increase considerably. This vapour after leaving the compressor enters the ''condenser" where it is condensedinto high pressure liquid and is collected in a "receiver tank". From receiver tank itpasses through the "expansion valve", here it is throttled down to a lower pressure and has a lowtemperature. After finding its way through expansion "valve" it finally passes on to"evaporator" where it extracts heat from the surroundings or circulating fluid being refrigeratedand vaporizes to low pressure vapour.

Functions of Parts of a Simple Vapour Compression System

Here follows the brief description of various parts of a simple vapour compression systemshown in Fig.

1. Compressor. The function of a compressor is to remove the vapour from the evaporator,and to raise its temperature and pressure to a point such that it (vapour) can be condensed withavailable condensing media.

2. Discharge line (or **hot gas line**). A hot gas or discharge line delivers the high-pressure,high-temperature vapour from the discharge of the compressor to the condenser.

3. Condenser. The function of a condenser is to provide a heat transfer surface throughwhich heat passes from the hot refrigerant vapour to the condensing medium.

Vapour compression refrigeration..

4. Receiver tank. A receiver tank is used to provide storage for a condensed liquid so thata constant supply of liquid is available to the evaporator as required.

5. Liquid line. A liquid line carries the liquid refrigerant from the receiver tank to therefrigerant flow control.

6. Expansion valve (refrigerant flow control). Its function is to meter the proper amountof refrigerant to the evaporator and to reduce the pressure of liquid entering the evaporator sothat liquid will vaporize in the evaporator at the desired low temperature and take out sufficientamount of heat.

7. Evaporator. An evaporator provides a heat transfer surface through which heat canpass from the refrigerated space into the vaporizing refrigerant.

8. Suction line. The suction line conveys the low pressure vapour from the evaporator tothe suction inlet of the compressor.

Pressure-Enthalpy (p-h) Chart:

The diagrams commonly used in the analysis of the refrigeration cycle are:

(i) Pressure-enthalpy (p-h) chart

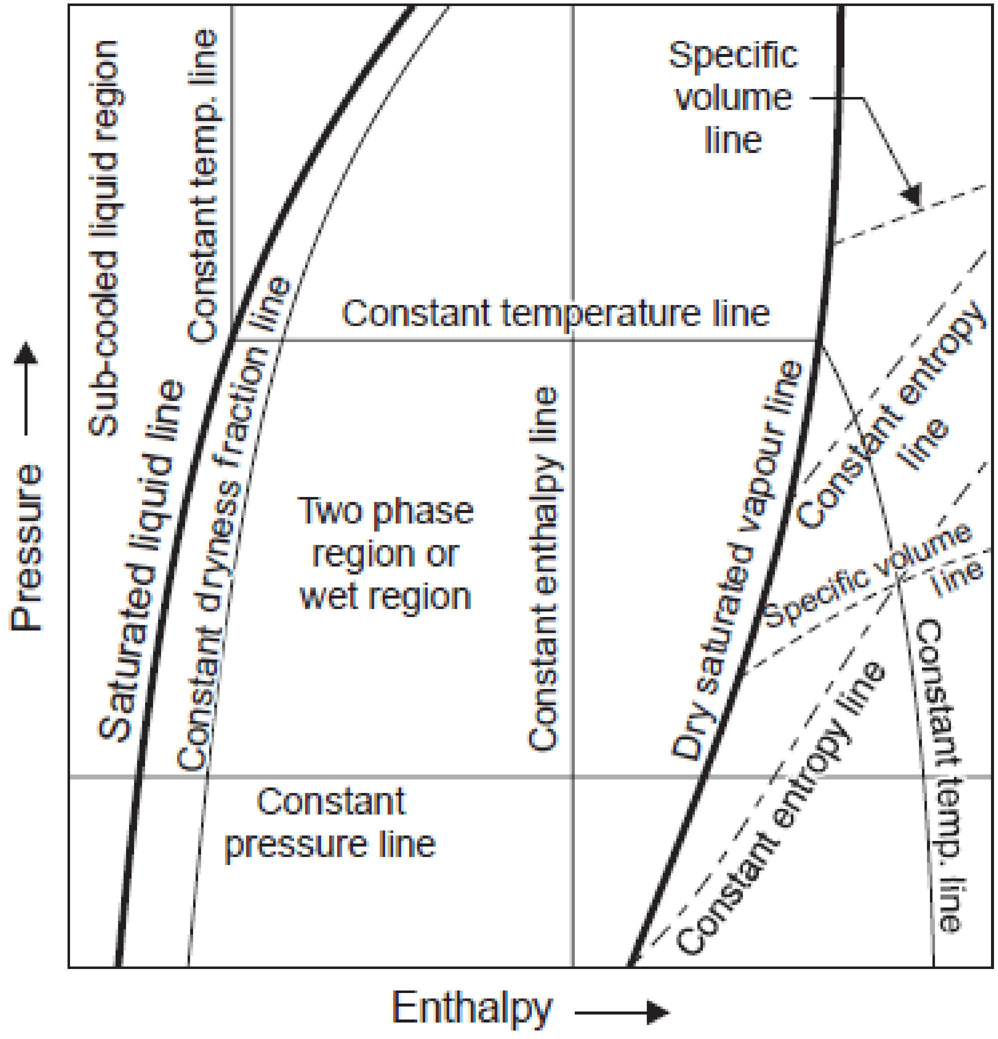
(ii) Temperature-entropy (T-s) chart.

- The condition of the refrigerant in any thermodynamic state can be represented as a point on the p-h chart.
- The point on the p-h chart that represents the condition of the refrigerant in anyone particular thermodynamic state may be located if any two properties of the refrigerant for that state are known, the other properties of the refrigerant for that state can be determined directly from the chart for studying the performance of the machines.
- Refer Fig. The chart is dividing into three areas that are separated from each other by the saturated liquid and saturated vapour lines. The region on the chart to the left of the saturated liquid line is called the sub-cooled region.

Pressure-Enthalpy (p-h) Chart..

- At any point in the sub-cooled region the refrigerant is in the liquid phase and its temperature is below the saturation temperature corresponding to its pressure.
- The area to the right of the saturated vapour line is superheated region and the refrigerant is in the form of a superheated vapour.
- The section of the chart between the saturated liquid and saturated vapour lines is the two phase region and represents the change in phase of the refrigerant between liquid and vapour phases.
- At any point between two saturation lines the refrigerant is in the form of a liquid vapour mixture.
- The distance between the two lines along any constant pressure line, as read on the enthalpy scale at the bottom of the chart, is the latent heat of vaporization of the refrigerant at that pressure.

Pressure-Enthalpy (p-h) Chart..



Pressure-Enthalpy (p-h) Chart..

- The horizontal lines extending across the chart are lines of ‘constant pressure’ and the vertical lines are lines of constant enthalpy.
- The lines of ‘constant temperature’ in the sub-cooled region are almost vertical on the chart and parallel to the lines of constant enthalpy. In the centre section, since the refrigerant changes state at a constant temperature and pressure, the lines of constant temperature are parallel to and coincide with the lines of constant pressure.
- At the saturated vapour line the lines of constant temperature change direction again and, in the superheated vapour region, fall of sharply toward the bottom of the chart. The straight lines which extend diagonally and almost vertically across the superheated vapour region are lines of constant entropy.
- The curved, nearly horizontal lines crossing the superheated vapour region are lines of constant volume. P-h chart gives directly the changes in enthalpy and pressure during a process for thermodynamic analysis.

Types of vapour compression cycles with p-h and T-s diagram

Following are the important from the subject point of view.

1. Cycle with dry saturated vapour after compression,
2. Cycle with wet vapour after compression,
3. Cycle with superheated vapour after compression,
4. Cycle with superheated vapour before compression, and
5. Cycle with undercooling or subcooling of refrigerant.

Types of vapour compression cycles with p-h and T-s diagram...

Theoretical vapour Compression Cycle with Dry Saturated Vapour after Compression

A vapour compression cycle with dry saturated vapour after compression is shown on T-s and p-h diagrams in Fig. 5. At point 1 let T_1, p_1 and s_1, be the temperature, pressureand entropy of the vapour refrigerant respectively. The four processes of the cycle are asfollows:

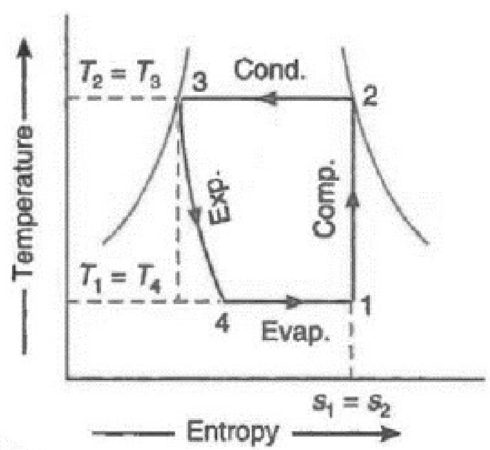
Compression process: The vapour refrigerant at at low pressure p1, and temperatureT_1 is compressed isentropically to dry saturated vapour as shown by the vertical line 1-2and p-h diagram. The pressure and temperature rises from p_1 to p_2 and T_1 to T_2respectively.

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

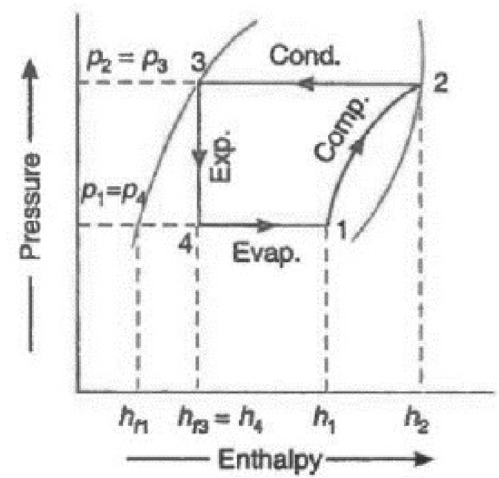
$$w = h_2 - h_1$$

Where h_1 = Enthalpy of vapour refrigerant at temperature T_1, at suction of the compressor, and

h_2= Enthalpy of vapour refrigerant at temperature T_2, at discharge of thecompressor



(a) T-s diagram.



(b) p-h diagram.

Types of vapour compression cycles with p-h and T-s diagram...

Condensing process: The high pressure and temperature vapour refrigerant from thecompressor is passed through the condenser where it is completely condensed at constanttemperature at constant pressure as shown by the horizontal line 2-3 on T-s and p-hdiagrams. The vapour refrigerant is changed into liquid refrigerant. The refrigerant, whilepassing through the condenser gives its latent heat to the surrounding condensing medium.

Expansion process: The liquid refrigerant at pressure $p_3 = p_2$ and temperature $T_3 = T_2$, isexpanded by throttling process through the expansion valve to a low pressure $p_4 = p_1$ andtemperature $T_4 = T_1$ as shown by the curve 3-4 on T-s diagram and p-h diagram. Duringthrottling some of the liquid refrigerant evaporates as it passes through the expansion valve,but the greater portion is vaporised in the evaporator and no heat is absorbed by the liquidrefrigerant.

Vaporisation: The liquid-vapour mixture of the refrigerant at pressure $p_4 = p_1$ andtemperature $T_4 = T_1$ is evaporated and changed into vapour refrigerant at constant pressureand temperature, as shown by the 4-1 on T-s and p-h diagrams. During evaporation, theliquid-vapour refrigerant absorbs its latent heat of vaporisation from the medium (air, wateror brine) which is to be cooled. This heat which is absorbed by the refrigerant is calledrefrigerating effect. The process of vaporisation continues up to point 1 which is the startingpoint and thus the cycle is completed.

Types of vapour compression cycles with p-h and T-s diagram...

Now the refrigerating effect or the heat absorbed or extracted by the liquid-vapourrefrigerant during evaporation per kg of refrigerant is given by,

$$R.E = h_1 - h_4 = h_1 - h_{f3}$$

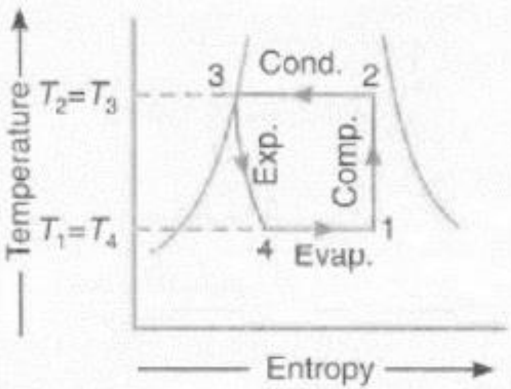
Now the coefficient of performance may be found out as usual from the relation,

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

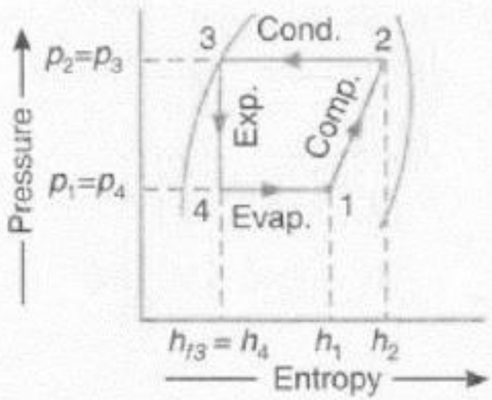
Types of vapour compression cycles with p-h and T-s diagram...

Theoretical Vapour Compression Cycle with Wet Vapour afterCompression

A vapour compression cycle with wet vapour after compression is shown on T-s and p-h diagrams in Fig. 6. In this cycle, the enthalpy at point 2 is found out with the help ofdryness fraction at this point. The dryness fraction at points 1 and 2 may be obtained byequating entropies at points 1 and 2.



(a) T-s diagram.



(b) p-h diagram.

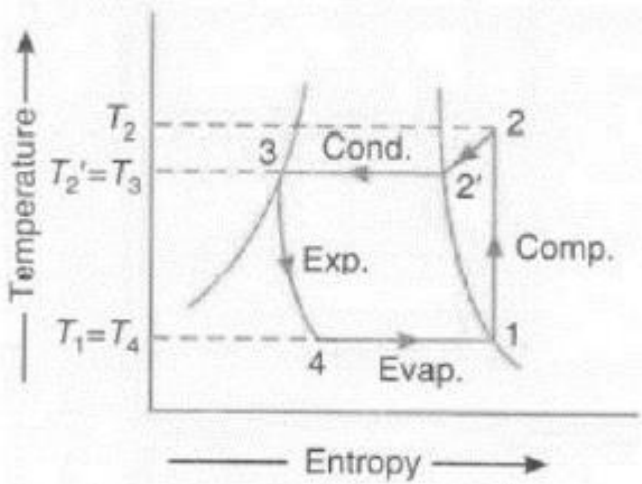
$$\text{C.O.P}= \frac{Refrigerating\ effect}{Work\ done} = \frac{h_1-h_4}{h_2-h_1} = \frac{h_1-h_{f3}}{h_2-h_1}$$

Types of vapour compression cycles with p-h and T-s diagram...

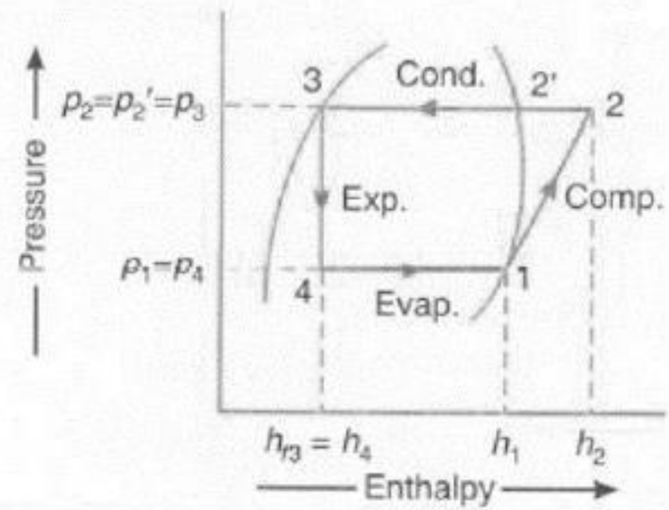
Theoretical Vapour Compression Cycle with Superheated Vapour after Compression:

A vapour compression cycle with superheated vapour after compression is shown on T-sand p-h diagrams in Fig. 7. In this cycle, the enthalpy at point 2 is found out with the help of degree of superheat. The degree of superheat may be found out by equating theentropies at points 1 and 2. Now the coefficient of performance may be found out as usual from the relation,

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



(a) T-s diagram.



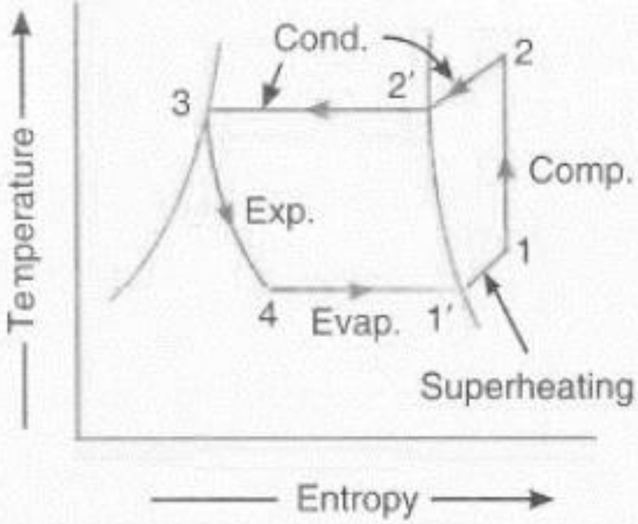
(b) p-h diagram.

Types of vapour compression cycles with p-h and T-s diagram...

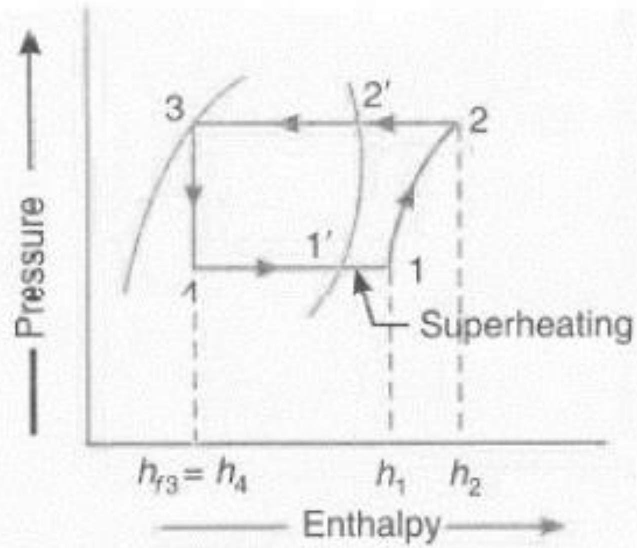
As shown in Fig. the superheating increases the refrigerating effect and the amount of work done in the compressor. Since the increase in refrigerating effect is less ascompared to the increase in work done, therefore, the net effect of superheating is tohave low coefficient of performance. In this cycle, the cooling of superheated vapour will take place in two stages. Firstly, itwill be condensed to dry saturated stage at constant pressure (shown by graph 2-2') andsecondly, it will be condensed at constant temperature (shown by graph 2'-3). Theremaining cycle is same as discussed in the last article.

Types of vapour compression cycles with p-h and T-s diagram...

Theoretical Vapour Compression Cycle with Superheated Vapour before Compression



(a) T-s diagram.



(b) p-h diagram.

A vapour compression cycle with superheated vapour before compression is shown onT-s and p-h diagrams in Fig. 8. In this cycle, the evaporation starts at point 4 andcontinues up to point 1', when it is dry saturated. The vapour is now superheated beforeentering the compressor up to the point 1.

Types of vapour compression cycles with p-h and T-s diagram...

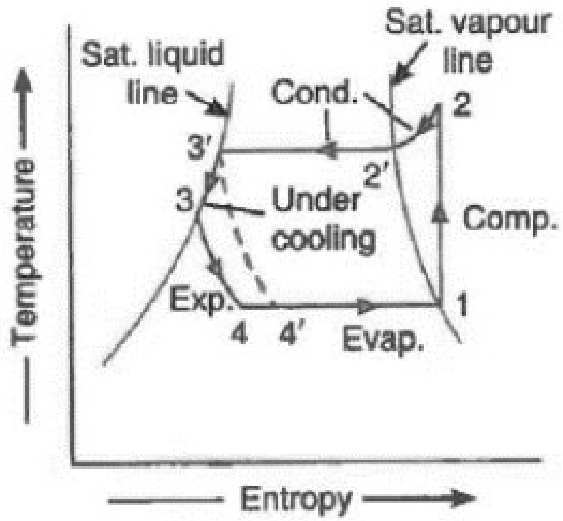
The coefficient of performance may be found out as usual from the relation. Now thecoefficient of performance may be found out as usual from the relation,

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

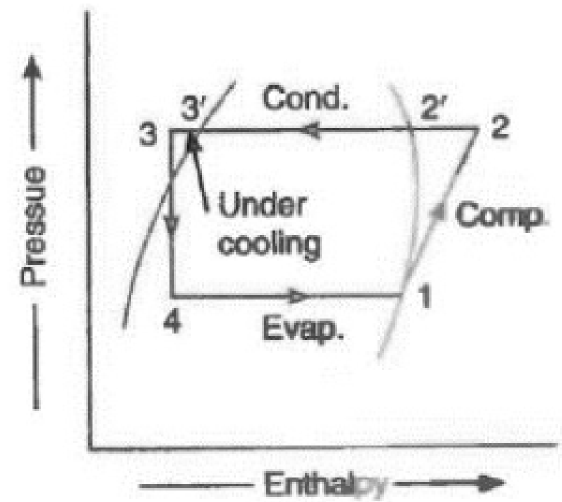
In this cycle, the heat is absorbed (or extracted) in two stages. Firstly from point 4 topoint 1'and secondly from point 1' to point 1. The remaining cycle is same as discussedin the previous article.

Types of vapour compression cycles with p-h and T-s diagram...

Theoretical Vapour Compression Cycle with Undercooling or Subcooling of Refrigerant



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



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

Sometimes, the refrigerant, after condensation process 2'-3', is cooled below thesaturation temperature ($T_{3'}$) before expansion by throttling. Such a process is calledundercooling of the refrigerant and is generally done along the liquid line as shown inFig. 9.The ultimate effect of the undercooling is to increase the value of coefficient of performance under the same set of conditions.

Types of vapour compression cycles with p-h and T-s diagram...

The process of undercooling is generality brought about by circulating more quantity ofcooling water through the condenser or by using water colder than the main circulatingwater. Sometimes, this process is also brought about by employing a heat exchanger. Inactual practice, the refrigerant is superheated after compression and undercooledbefore throttling, as shown in Fig. 9 the refrigerating effect is increased by adoptingboth the superheating and undercooling process as compared to a cycle without them,which is shown by dotted line.

Now the coefficient of performance may be found out as usual from the relation,

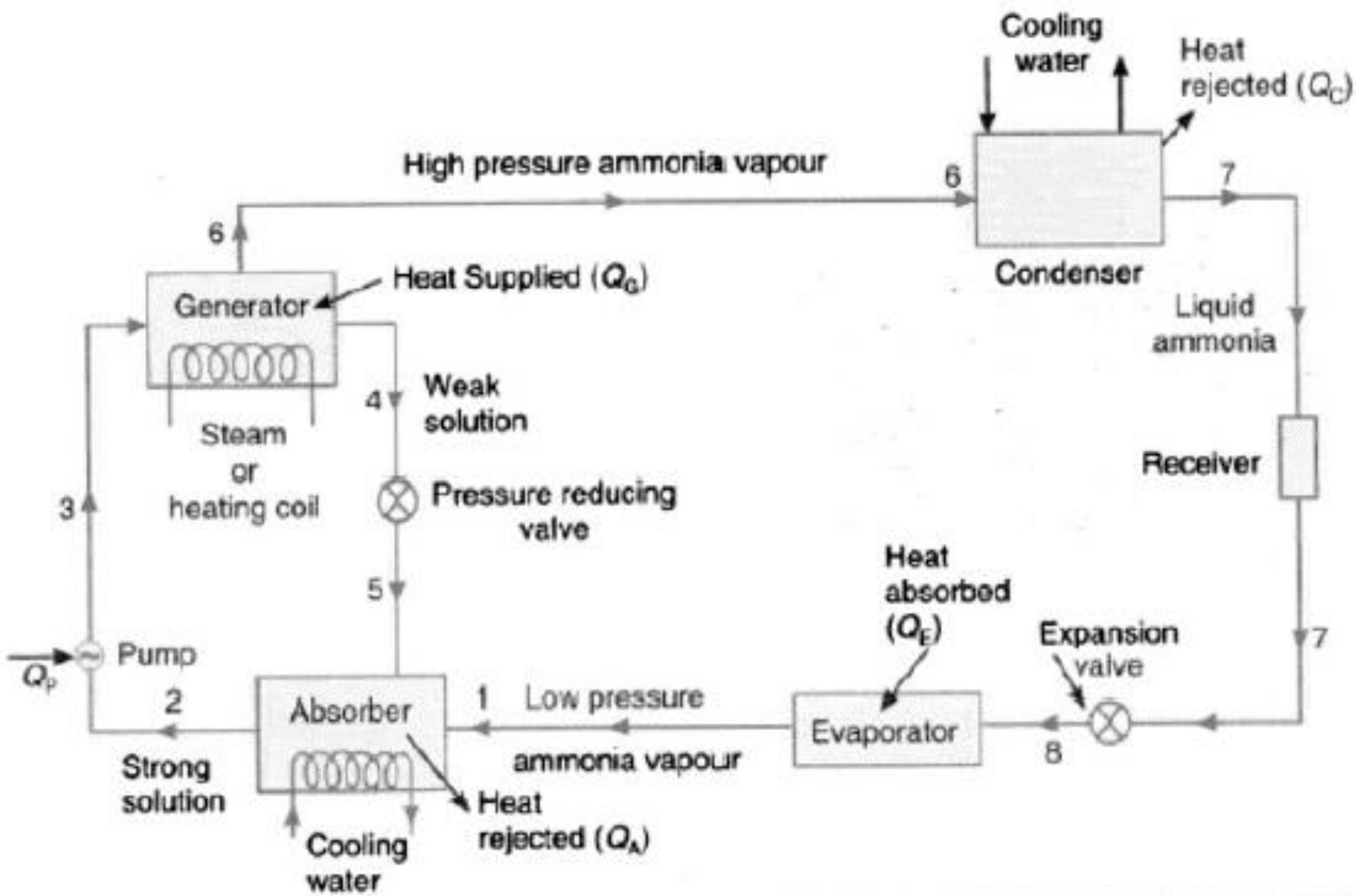
$$C.O.P = \frac{Refrigerating\ effect}{Work\ done} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{h_1 - h_{f3}}{h_2 - h_1}$$

Vapour Absorption refrigeration system:

- **Introduction**
- In vapour absorption system the refrigerant is absorbed on leaving the evaporator, the absorbing medium being a solid or liquid.
- In order that the sequence of events should be continuous it is necessary for the refrigerant to be separated from the absorbent and subsequently condensed before being returned to the evaporator.
- The separation is accomplished by the application of direct heat in a ‘generator’. The solubility of the refrigerant and absorbent must be suitable and the plant which uses ammonia as the refrigerant and water as absorbent will be described.

Vapour Absorption refrigeration system..

Simple Vapour Absorption System



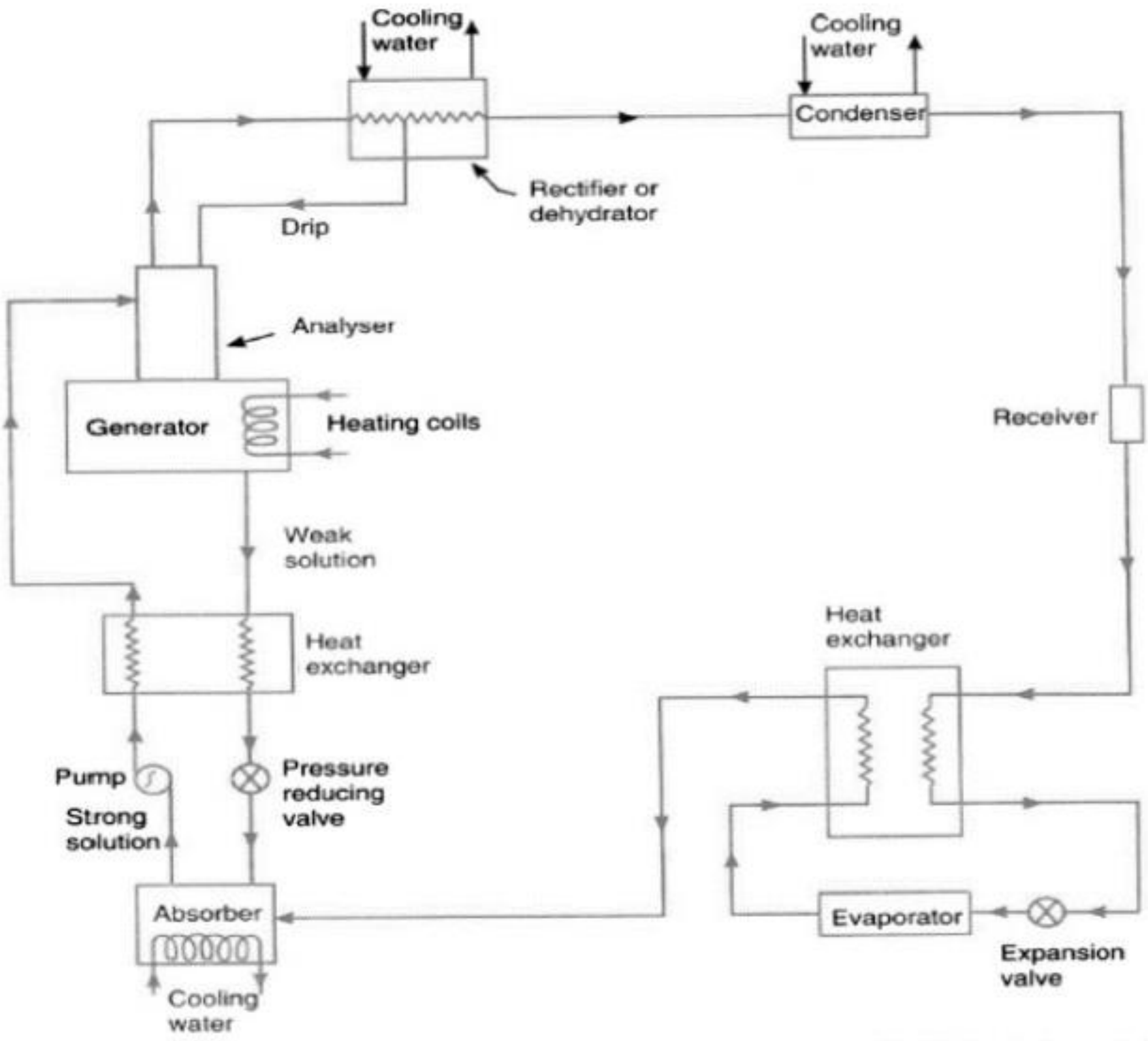
Vapour Absorption refrigeration system..

Refer Fig. for a simple absorption system. The solubility of ammonia in water at lowtemperatures and pressures is higher than it is at higher temperatures and pressures. The ammoniavapour leaving the evaporator at point 2 is readily absorbed in the low temperature hot solutionin the absorber. This process is accompanied by the rejection of heat. The ammonia in watersolution is pumped to the higher pressure and is heated in the generator. Due to reduced solubilityof ammonia in water at the higher pressure and temperature, the vapour is removed from thesolution. The vapour then passes to the condenser and the weakened ammonia in water solution isreturned to the absorber.

In this system the work done on compression is less than in vapour compression cycle (since pumping a liquid requires much less work than compressing a vapour between the samepressures) but a heat input to the generator is required. The heat may be supplied by any convenientform e.g. steam or gas heating.

Vapour Absorption refrigeration system..

Practical Vapour Absorption System



Vapour Absorption refrigeration system..

Refer Fig.   although a simple vapour absorption system can provide refrigeration yetits operating efficiency is low. The following accessories are fitted to make the system more practicaland improve the performance and working of the plant.

1. Heat exchanger. 2. Analyser. 3. Rectifier.

1. Heat exchanger:

A heat exchanger is located between the generator and the absorber.The strong solution which is pumped from the absorber to the generator must be heated; and theweak solution from the generator to the absorber must be cooled. This is accomplished by a heatexchanger and consequently cost of heating the generator and cost of cooling the absorber arereduced.

2. Analyser:

An analyser consists of a series of trays mounted above the generator. Itsmain function is to remove partly some of the unwanted water particles associated with ammoniavapour going to condenser. If thesewater vapours are permitted to enter condenser they mayenter the expansion valve and freeze; as a result the pipe line may get choked.

3. Rectifier:

A rectifier is a water-cooled heat exchanger which condenses water vapourand some ammonia and sends back to the generator. Thus final reduction or elimination of thepercentage of water vapour takes place in a rectifier.

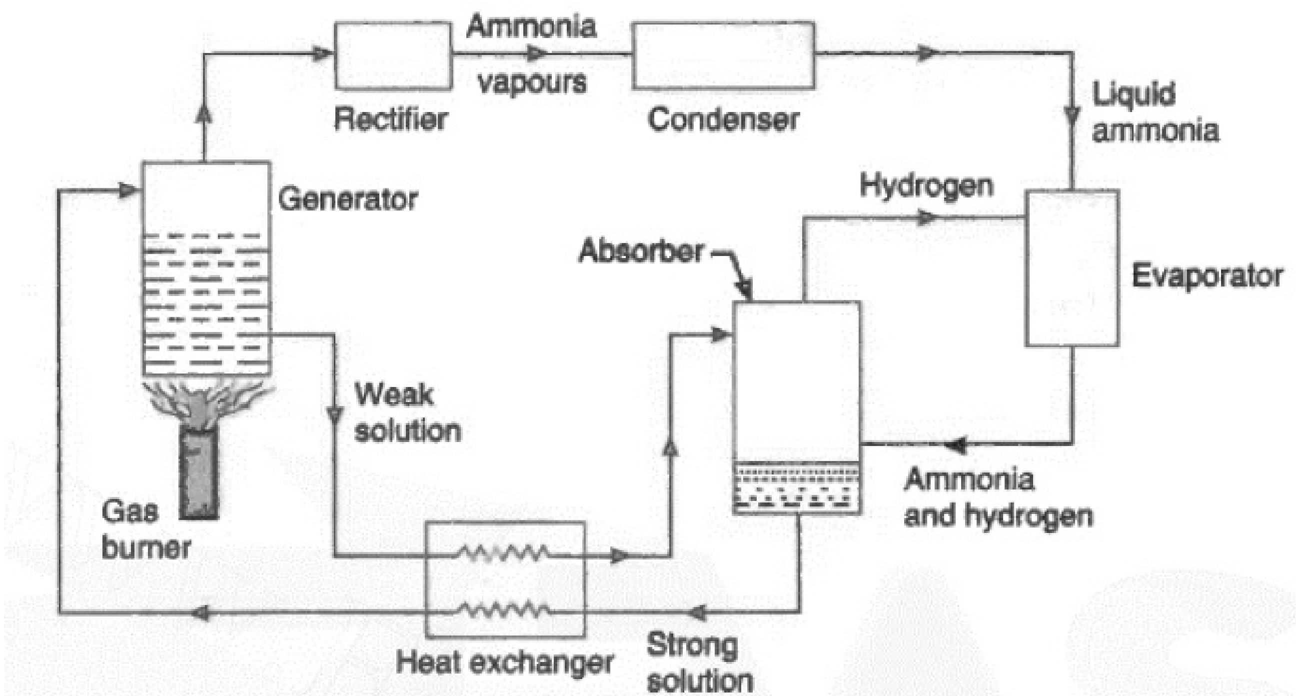
The co-efficient of performance (C.O.P.) of this system is given by,

$$\text{C.O.P.} = \frac{\text{Heat Extracted from Evaporator}}{\text{Heat supplied in the generator} + \text{Work done by liquid pump}}$$

Vapour Absorption refrigeration system..

Domestic Refrigerator (NH2-H2) Refrigerator:

This type of refrigerator is also called three-fluid absorption system. The main purposeof this system is to eliminate the pump so that in the absence of moving parts, themachine becomes noiseless. The three fluids used in this system are ammonia, hydrogenand water. The ammonia is used as a refrigerant because it possesses most of thedesirable properties. It is toxic, but due to absence of moving parts, there is very littlechance for the leakage and the total amount of refrigerant used is small. The hydrogen,being the lightest gas, is used to increase the rate of evaporation of the liquid ammoniapassing through the evaporator. The hydrogen is also non-corrosive and insoluble inwater. This is used in the low-pressure side of the system. The water is



Vapour Absorption refrigeration system..

used as a solvent because it has the ability to absorb ammonia readily. The principle of operation of adomestic Electrolux type refrigerator, as shown in Fig. is discussed below:

The strong ammonia solution from the absorber through heat exchanger is heated in thegenerator by applying heat from an external source, usually a gas burner. During thisheating process, ammonia vapour are removed from the solution and passed to thecondenser. A rectifier or a water separator fitted before the condenser removes watervapour carried with the ammonia vapour, so that dry ammonia vapour are supplied tothe condenser. This water vapour, if not removed, will enter into the evaporator causingfreezing and choking of the machine. The hot weak solution left behind in the generatorflows to the absorber through the heat exchanger. This hot weak solution while passingthrough the exchanger is cooled. The heat removed by the weak solution is utilised inraising the temperature of strong solution passing through the heat exchanger. In thisway, the absorption is accelerated and the improvement in the performance of a plant isachieved.

The ammonia vapour in the condenser are condensed by using external cooling source.The liquid refrigerant leaving the condenser flows under gravity to the evaporator whereit meets the hydrogen gas. The hydrogen gas which is being fed to the evaporatorpermits the liquid ammonia

Vapour Absorption refrigeration system..

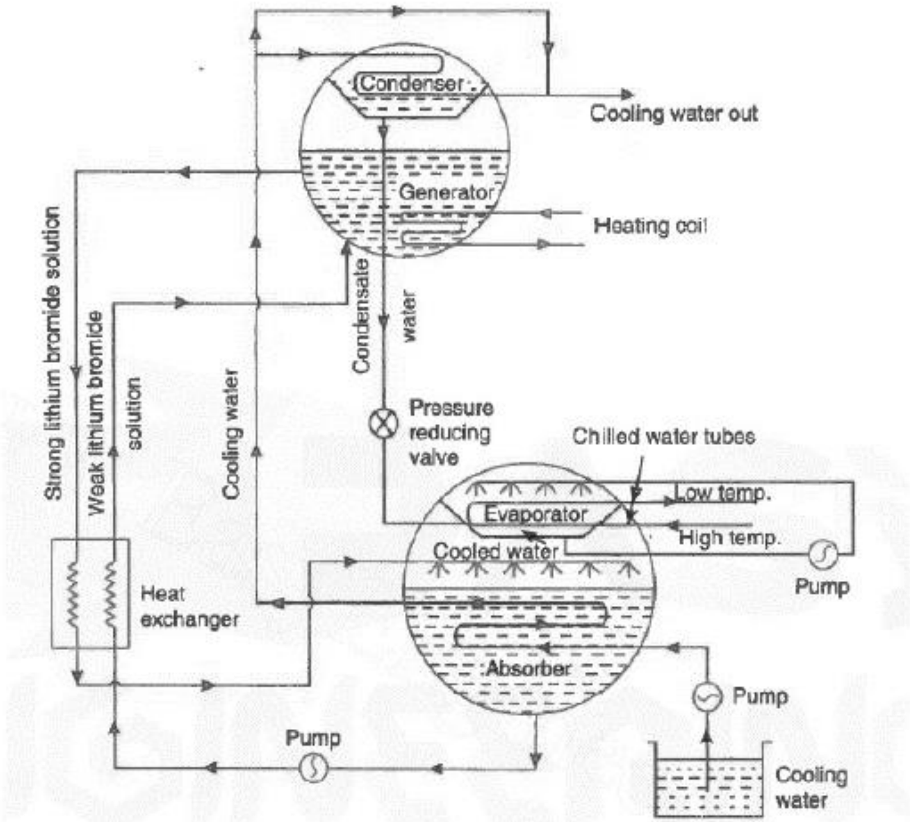
to evaporate at a low pressure and temperature accordingto Dalton's principle. During the process of evaporation, the ammonia absorbs latentheat from the refrigerated space and thus produces cooling effect. The mixture of ammonia vapour and hydrogen is passed to the absorber where ammonia is absorbed inwater while the hydrogen rises to the top and flows back to the evaporator. Thiscompletes the cycle. The coefficient of performance of this refrigerator is given by:

$$C.O.P. = \frac{\text{Heat Extracted from Evaporator}}{\text{Heat supplied in the generator}}$$

Vapour Absorption refrigeration system..

Lithium Bromide Absorption Refrigeration System:

The lithium bromide absorption refrigeration system uses a solution of lithium bromidein water. In this system, the water is being used as a refrigerant whereas lithiumbromide, which is a highly hydroscopic salt, as an absorbent. The lithium bromidesolution has a strong affinity for water vapour because of its very low vapour pressure.Since lithium bromide solution is corrosive, therefore, inhibitors should be added inorder to protect the metal parts of the system against corrosion. Lithium chromate isoften used as a corrosion inhibitor. This system is very popular for air-conditioning inwhich low refrigeration temperatures (not below 0°C) are required.



Vapour Absorption refrigeration system..

Fig. . shows a lithium bromide vapour absorption system. In this system, the absorberand the evaporator are placed in one shell which operates at the same low pressure ofthe system. The generator and condenser are placed in another shell which operates atthe same high pressure of the system. The principle of operation of this system isdiscussed below:

The water for air-conditioning coils or process requirements is chilled as it is pumpedthrough the chilled water tubes in the evaporator by giving up heat to the refrigerantwater sprayed over the tubes. Since the pressure inside the evaporator is maintainedvery low, therefore, the refrigerant water evaporates. The water vapour thus formedwill be absorbed by the strong lithium bromide solution which is sprayed in the absorber. In absorbing the water vapour, the lithium bromide solution helps inmaintaining very low pressure (high vacuum) needed in the evaporator, and the solution

Vapour Absorption refrigeration system..

The water for air-conditioning coils or process requirements is chilled as it is pumpedthrough the chilled water tubes in the evaporator by giving up heat to the refrigerantwater sprayed over the tubes. Since the pressure inside the evaporator is maintainedvery low, therefore, the refrigerant water evaporates. The water vapour thus formedwill be absorbed by the strong lithium bromide solution which is sprayed in theabsorber. In absorbing the water vapour, the lithium bromide solution helps inmaintaining very low pressure (high vacuum) needed in the evaporator, and the solutionbecomes weak. This weak solution is pumped by a pump to the generator where it isheated up by using steam or hot water in the heating coils. A portion of water isevaporated by the heat and the solution now becomes more strong. This strong solutionis passed through the heat exchanger and then sprayed in the absorber as discussedabove. The weak solution of lithium bromide from the absorber to the generator is alsopassed through the heat exchanger. This weak solution gets heat from the strongsolution in the heat exchanger, thus reducing the quantity of steam required to heat theweak solution in the generator.

The refrigerant water vapour formed in the generator due to heating of solution arepassed to the condenser where they are cooled and condensed by the cooling waterflowing through the condenser water tubes. The cooling water for condensing ispumped from the cooling water pond or tower. This cooling water first enters theabsorber where it takes away the heat of condensation and dilution. The condensatefrom the condenser is supplied to the evaporator to compensate the

Vapour Absorption refrigeration system..

water vapourformed in the evaporator. The pressure reducing valve reduces the pressure ofcondensate from the condenser pressure to the evaporator pressure. The cooled water

from the evaporator is pumped and sprayed in the evaporator in order to cool the waterfor air-conditioning flowing through the chilled tubes. This completes the cycle.

Vapour Absorption refrigeration system..

Advantages of Vapour Absorption Refrigeration System over Vapour Compression Refrigeration System:

Following are the advantages of vapour absorption system over vapour compressionsystem:

1. In the vapour absorption system, the only moving part of the entire system is apump which has a small motor. Thus, the operation of this system is essentially quietand is subjected to little wear. The vapour compression system of the same capacityhas more wear, tear and noise due to moving parts of the compressor.

2. The vapour absorption system uses heat energy to change the condition of therefrigerant from the evaporator. The vapour compression system uses mechanicalenergy to change the condition of the refrigerant from the evaporator.

3. The vapour absorption systems are usually designed to use steam, either at highpressure or low pressure. The exhaust steam from furnaces and solar energy mayalso be used. Thus this system can be used where the electric power is difficult toobtain or is very expensive.

4. The vapour absorption systems can operate at reduced evaporator pressure andtemperature by increasing the steam pressure to the generator, with little decreasein capacity. But the capacity of vapour compression system drops rapidly withlowered evaporator pressure.

Vapour Absorption refrigeration system..

5. The load variations do not affect the performance of a vapour absorption system.The load variations are met by controlling the quantity of aqua circulated and thequantity of steam supplied to the generator. The performance of a vapourcompression system at partial loads is poor.

6. In the vapour absorption system, the liquid refrigerant leaving the evaporator has nobad effect on the system except that of reducing the refrigerating effect. In thevapour compression system, it is essential to superheat the vapour refrigerantleaving the evaporator so that no liquid may enter the compressor.

7. The vapour absorption systems can be built in capacities well above 1000 tonnes ofrefrigeration each, which is the largest size for single compressor units.

8. The space requirements and automatic control requirements favour the absorptionsystem more and more as the desired evaporator temperature drops.

References:

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2) Engineering Thermodynamics by R. K. Rajput, Laxmi Publications.