1st Chapter

Air Refrigeration Cycle

In an air refrigeration cycle, the air is used as a refrigerant. The basic elements of an air cycle refrigeration system are the compressor, the cooler or heat exchanger, the expander and the refrigerator.

Units of Refrigeration

The practical unit of refrigeration is One tonne (1000 kg)of ice from and 0^0 in 24 hours.

expressed in terms of "tonne of refrigeration' (briefly written as TR). A tonne of refrigeration is defined as the amount of refrigeration effect produced by the uniform melting of one tonne (1000kg) of ice from and at ^{O}C in 24 hour.

Since the latent heat of ice is 335 kJ/kg, therefore one one of refrigeration=

1 TR= 1000x335 kJ/ in 24 hours= (1000x335)/ (24x60) =232.6 kJ/min

In actual practice, one tonne of refrigeration is equivalent to 210 kJ/min or 3.5Kw (3.5 kJ/s)

Coefficient of performance

The coefficient of performance (C.O.P) is the is the ratio of heat extracted in the refrigerator to the work done on the refrigerant. It is also known as theoretical coefficient of performance. Mathematically,

Theoretical C.OP. = Q/W

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

W = Amount of work done.

* For per unit mass, C.O.P=q/w

Find the C.O.P. of a refrigeration system if the work input is 80kJ/kg and refrigeration effect produced is 160 kJ/kg of refrigerant flowing

Solution. Given: w = 80 kJ/kg : q = 160 kJ/kg

C.O.P. = q/w = 160/80= 2

Air cycle refrigeration is one of the earliest methods used for cooling. The key features of this method is that, the refrigerant air remain gaseous state throughout the refrigeration cycle. Based on the operation, the air refrigeration system can be classified into

1. Open air refrigeration cycle
2. Closed refrigeration cycle

Open air refrigeration cycle

In an open refrigeration system, the air is directly passed over the space is to be cooled, and allowed to circulate through the cooler. The pressure of open refrigeration cycle is limited to the atmospheric pressure. A simple diagram of the open-air Refrigeration system is given below.

Advantages and application

- It eliminates the need of a heat exchanger.
- It is used in aircraft because it helps to achieve cabin pressurization and air conditioning at once

Disadvantages

One of the disadvantages of this system is that its large size. The air supplied to the refrigeration system is at atmospheric pressure, so the volume of air handled by the system is large. Thus the size of compressor and expander also should be large. Another disadvantage of the open cycle system is that the moisture is regularly carried away by the circulating air, this leads to the formation of frost at the end of the expansion process and clogs the line, and hence a use of dryer is preferable to the open air refrigeration system.

Closed refrigeration system / Dense air refrigeration cycle

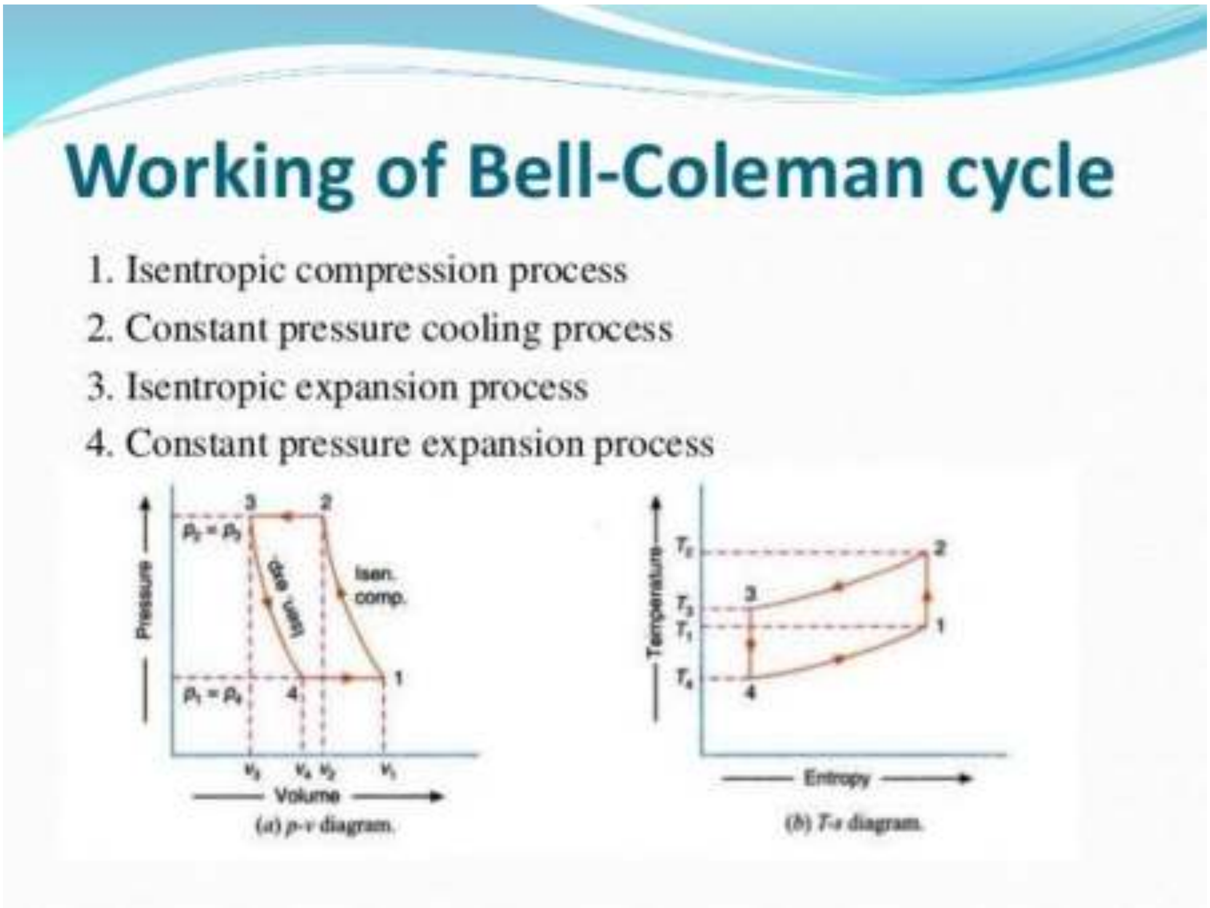
In closed or dense air refrigeration cycle, air refrigerant is contained within pipes and component part of the system at all time. The circulated air does not have to direct contact with the space to be cooled. The air is used to cool another fluid (brine), and this fluid is circulated into the space to be cooled. So the disadvantages listed in open air refrigeration can be eliminated. The advantages of closed air refrigeration system are

Advantages

- The suction to the compressor may be at high pressure, therefore the volume of air handled by the compressor and expander is low when compared to an open system. Hence the size of compressor and expander is small compared to the open air system.
- The chance of freezing of moister and choke the valve is eliminated.
- In this system, higher coefficient of performance can be achieved by reducing operating pressure ratio.

Bell Coleman Cycle

Bell Coleman Cycle also known as a Reversed Brayton Cycle or the Joule cycle. The **Bell Coleman Cycle** is a refrigeration **cycle** where the **working** fluid is air which is compressed and expanded but do not change state. ... In this **cycle**, the process of compression and expansion of gas is isentropic and heat absorption and rejection of heat takes place at constant pressure i.e isobaric process

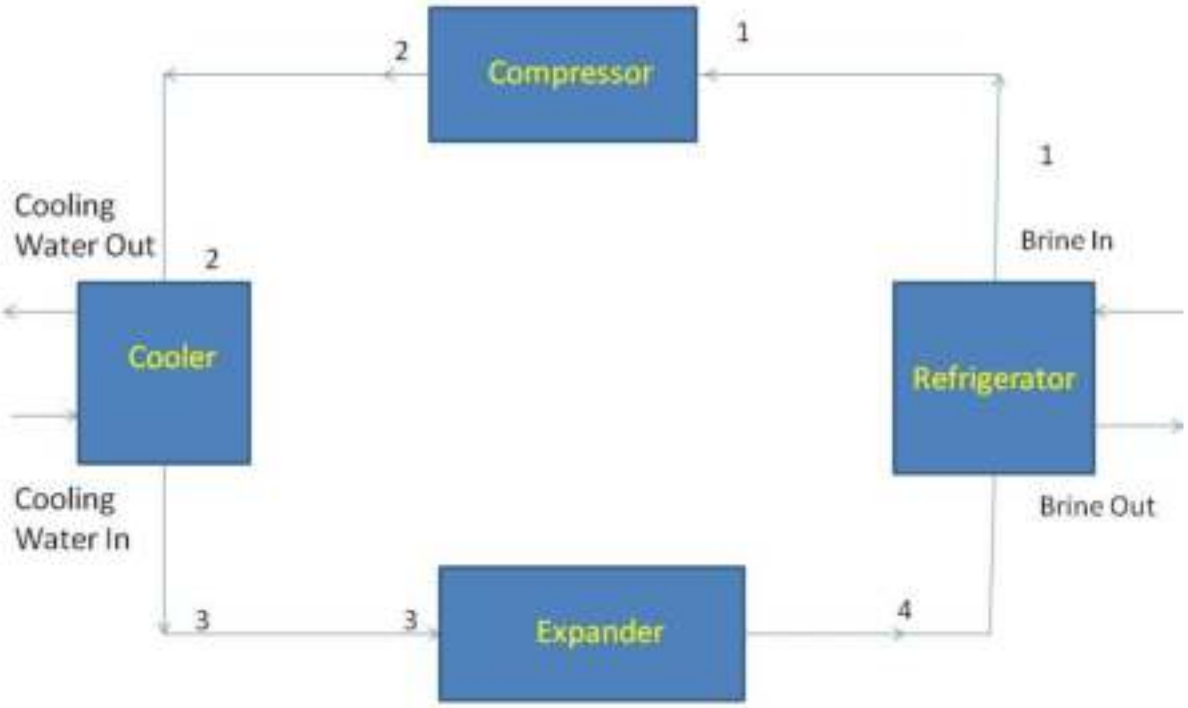


Working of Bell-Coleman cycle

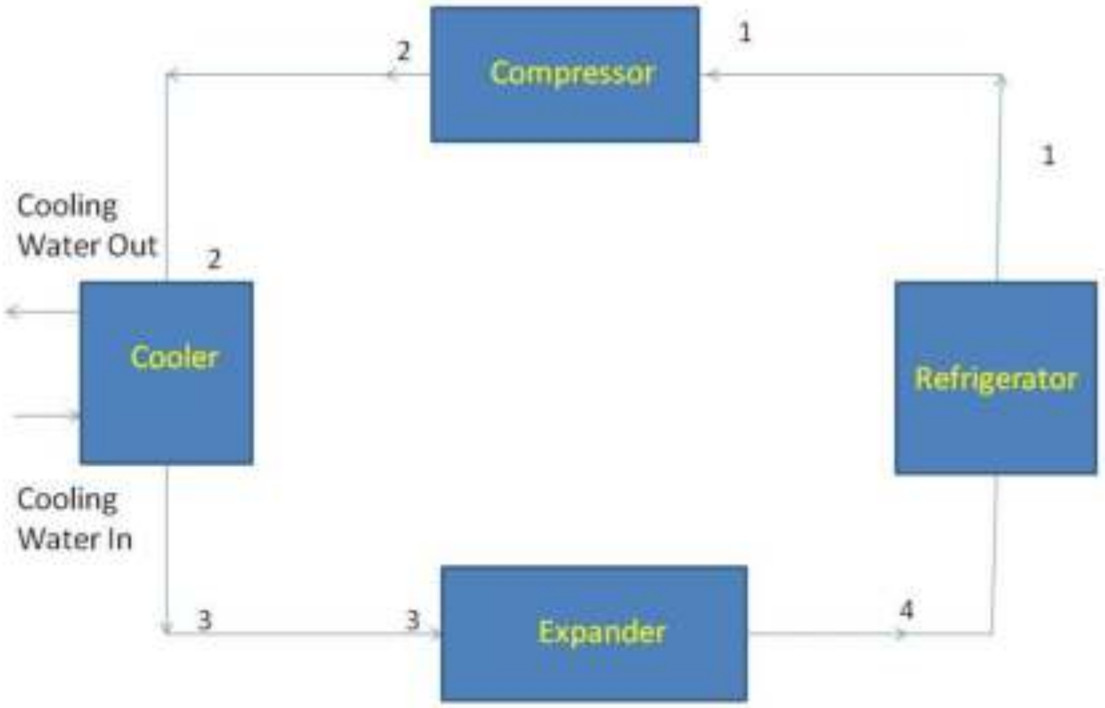
1. Isentropic compression process
2. Constant pressure cooling process
3. Isentropic expansion process
4. Constant pressure expansion process

(a) p-v diagram.

(b) T-s diagram.



Closed Bell Coleman Air Cycle



Open Bell Coleman Air Cycle

P-V and T-S diagram of bell coleman refrigerator. Here P_1, V_1, T_1, S_1 represents the pressure, volume, temperature, entropy of air respectively at point 1. And so on. It represents the corresponding condition of air when it passed through the component.

1-2 Isentropic Compression: The Cold air from the refrigerator is brought into the compressor and compressed isentropically. During this procedure, the pressure increments from P1 to P2. The specific volume decreases from v1 to v2 and the temperature increments from T1 to T2. During this procedure

Entropy ‘s’ stays steady (s1=s2). No heat is absorbed or rejected by the air.

2-3 Constant Pressure Cooling Process: The warm air from the compressor is then passed into the cooler where it is cooled at constant pressure, reducing the temperature from T3 to T2. The specific Volume reduces from v2 to v3.

Heat rejected by the air: $Q_r = C_p (T_2 - T_3)$

3-4 Isentropic Expansion: Air from the cooler is presently brought into the expander and is extended isentropically. The pressure of the air stays steady during this process. Specific volume changes from v3 to v4 and the temperature decreses from T3 to T4. No heat transfer takes place.

4-1 Constant Pressure expansion process: The cold air from the expander is then passed into the refrigerator and extended at a constant pressure. The temperature of the air increases from T4 to T1. The specific volume of the air changes from v4 to v1.
Heat absorbed by the air: $Q_a = C_p(T_1 - T_4)$

Work done during the cycle per kg of air = Heat rejected — Heat absorbed

= Cp(T2 — T3) — Cp(T1 — T4)

C.O.P during the cycle per kg of air = Heat absorbed / work done

= Cp(T1 — T4) / Cp(T2 — T3) — Cp(T1 — T4)

Equation of Coefficient of performance (COP) of Bell Coleman cycle:

Heat absorbed during cycle per kg of air $q_{4-1} = C_p(T_1 - T_4)$

Heat rejected during cycle per kg of air $q_{2-3} = C_p(T_2 - T_3)$

Then the work done per kg of air during the cycle is = Heat rejected – Heat absorbed = $C_p(T_2 - T_3) - C_p(T_1 - T_4)$

Coefficient of performance;

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

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

$$C.O.P. = \frac{T_4\left(\frac{T_1}{T_4} - 1\right)}{T_3\left(\frac{T_2}{T_3} - 1\right) - T_4\left(\frac{T_1}{T_4} - 1\right)} \tag{i}$$

For isentropic compression process 1-2

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

For isentropic expansion process 3-4

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

Since, P2 = P3 and P1 = P4, therefore from equation (ii) and (iii)
Substitute equation (iv) in (i)

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

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

$$C.O.P. = \frac{1}{\left(r_p\right)^{\frac{\gamma-1}{\gamma}} - 1}$$

$$r_p = Compression\ or Expansion\ ratio = \frac{P_2}{P_1} = \frac{P_3}{P_4}$$

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

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

$$C.O.P. = \frac{1}{\left(r_p\right)^{\frac{\gamma-1}{\gamma}} - 1}$$

$$r_p = Compression\ or Expansion\ ratio = \frac{P_2}{P_1} = \frac{P_3}{P_4}$$

2nd Chapter

Simple Vapour Compression Refrigeration System

A vapour compression refrigeration system is an improved type of air refrigeration system in which a suitable working substance, termed as refrigerant, is used. It condenses and evaporates at temperatures and pressures close to the atmospheric conditions. The refrigerants, usually, used for this purpose are ammonia (NH_3), carbon dioxide (CO_2) and sulphur dioxide (SO_2).

The refrigerant used, does. not leave the system, but is circulated throughout the system alternately condensing and evaporating. In evaporating, the refrigerant absorbs its latent heat from the brine (salt water) which is used for circulating it around the cold chamber. While condensing, it gives out its latent heat to the circulating water of the cooler. The vapour compression refrigeration system is, therefore a latent heat pump, as it pumps its latent heat from the brine and delivers it to the cooler.

The vapour compression refrigeration system is now-a-days used for all purpose refrigeration. It is generally used for all industrial purposes from a small domestic refrigerator to a big air conditioning plant.

Following are the advantages and disadvantages of the vapour compression refrigeration system over air refrigeration system:

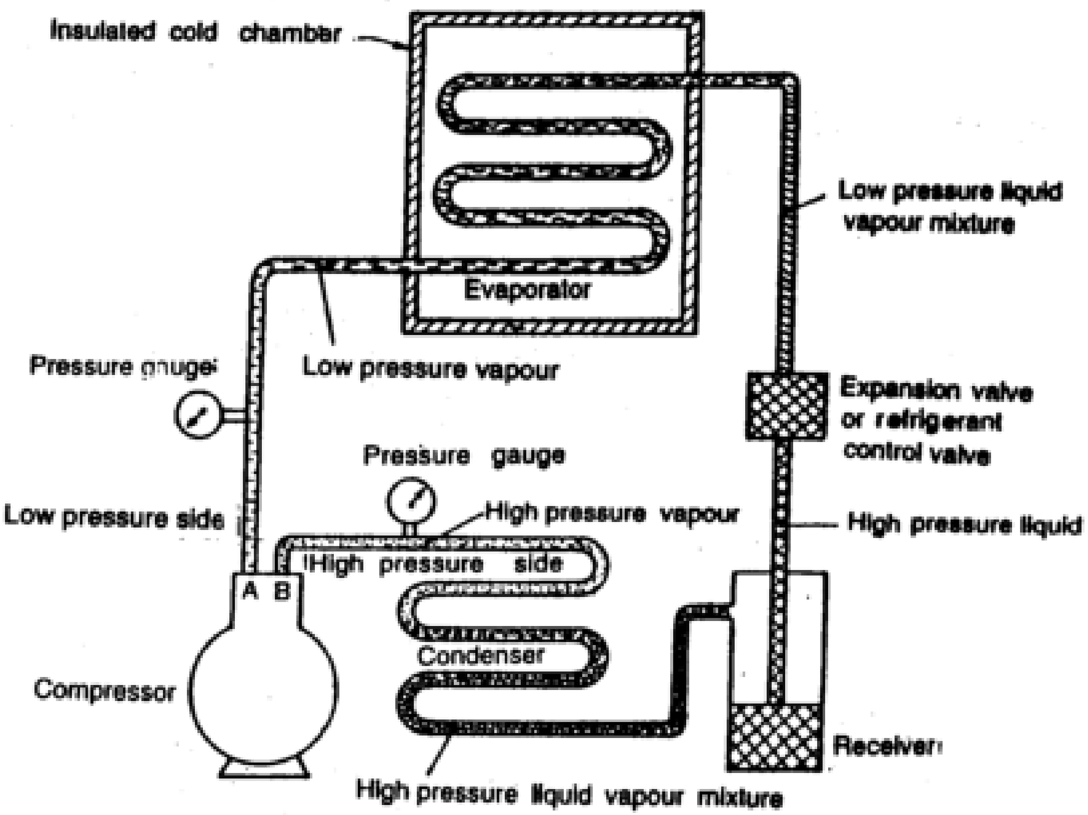
Advantages

1. It has smaller size for the given capacity of refrigeration.
2. It has less running cost.
3. It can be employed over a large range of temperatures.
4. The coefficient of performance is quite high.

Disadvantages

1. The initial cost is high.
2. The prevention of leakage of the refrigerant is the major problem in vapour compression system.

Mechanism of a Simple Vapour Compression Refrigeration System



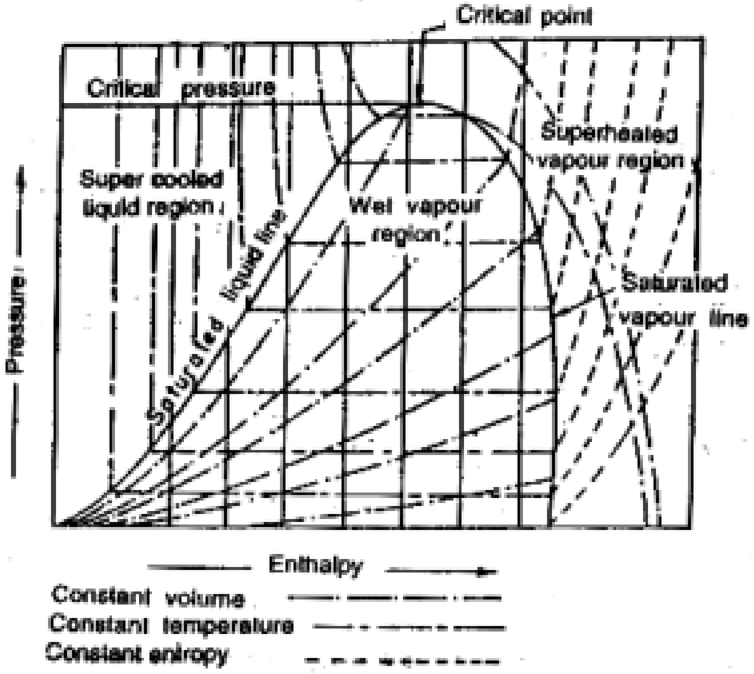
A simple vapour compression refrigeration system consists of the following five essential parts:

- **Compressor**: The low pressure and temperature 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 temperature. This high pressure and temperature vapour refrigerant is discharged into the condenser through the delivery valve B.
- **Condenser**: The condenser or cooler consists of coils of pipe in which the high pressure and temperature vapour refrigerant is cooled and condensed. the refrigerant, while, passing through the condenser, gives up its latent heat to the surrounding condensing medium which is normally air or water.
- **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.
- **Expansion valve**: It is also called throttle valve or refrigerant control valve. The function of the expansion valve is to allow the liquid refrigerant under high pressure and temperature to pass at a controlled rate after reducing its pressure and temperature. Some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporised in the evaporator at the low pressure and temperature.

- **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 temperature. In evaporating, the liquid vapour refrigerant absorbs its latent heat of vaporisation from the medium (air, water or brine) which is to be cooled.

In any compression, refrigeration system, there are two different pressure conditions. One is called the **high pressure side** and other is known as **low pressure side**. The high pressure side includes **the discharge line** (i.e. piping from delivery valve B to the condenser), condenser, receiver and expansion valve. The low pressure side includes **the evaporator**, piping from the expansion valve to the evaporator and the suction line (i.e. piping from the evaporator to the suction valve A).

Pressure-Enthalpy (p-h) Chart

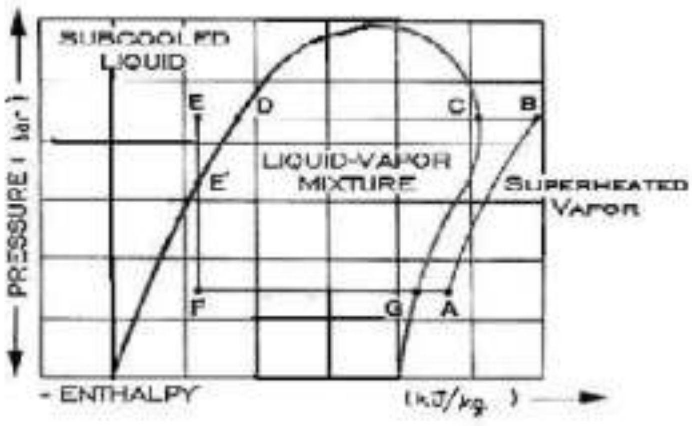


1. The most convenient chart for studying the behaviour of a refrigerant is the p-h chart, in which the vertical ordinates represent pressure and horizontal ordinates represent enthalpy (i.e. total heat).

2. A typical chart is shown above. in which a few important lines of the complete chart are drawn. The saturated liquid line and the saturated vapour line merge into one another at the critical point. A saturated liquid is one which has a temperature equal to the saturation temperature corresponding to its pressure.

3. The space to the left of the saturated liquid line will, therefore, be sub-cooled liquid region. The space between the liquid and the vapour lines is called wet vapour region and to the right of the saturated vapour line is a superheated vapour region.

Consider the chart below which is typical of the refrigerant R22, a common refrigerant in small refrigeration systems.



- A closer analysis of the chart shows that there are distinct regions separated by three “boundary lines”. The region on the left is sub cooled liquid. This is the refrigerant liquid at a temperature lower than the equivalent boiling point for the pressure noted.
- The region inside the “dome” is a liquid-vapor mixture. If the liquid is at the boiling point, but just hasn't begun to boil, it is defined as saturated liquid. Adding any heat to this liquid will vaporize a portion of it. Adding more heat to the liquid-vapor mixture eventually evaporates all of the liquid. At some precise point (G), the vapor is fully saturated. Adding any more heat to the vapor will cause it to rise in temperature further; this is referred to as superheated vapor which are above the corresponding saturated vapor point
- Similarly, sub cooled liquid can be generally warm. It just means that the liquid is cooler than the saturation line at that pressure.

Consider the refrigerant to be initially at point A. To reach this point after leaving the evaporator at G, the refrigerant is heated slightly and crosses the compressor suction valve to point A. The compressor elevates the refrigerant's pressure to a point at which it can push the discharge valve open and flow into the condenser. The refrigerant vapor leaves the compressor at point B, de-superheats to point C, and then begins to condense. After the vapor is completely condensed at point D, it is sub cooled a bit further (E), at which time it is still at a much higher pressure than the evaporator.

Controlling the flow to the evaporator and throttling to the pressure of the evaporator is performed by the expansion device, a capillary tube or a throttling valve in small refrigeration systems. This pressure reduction step vaporizes a portion of the liquid which cools (called flash gas) the remaining liquid going to point F. The "average" mixture of vapor and liquid crossing the valve doesn't change in energy content. It simply separates into liquid and vapor at the reduced temperature and pressure according to its precise thermodynamic properties. The liquid at point F is then ready to pick up heat in the evaporator and form vapor at point G where the cycle repeats itself.

Types of Vapour Compression Cycles

The vapour compression cycle essentially consists of compression, condensation, throttling and evaporation.

1. Cycle with dry saturated vapour after compression,

2. Cycle with wet vapour after compression,

3. Cycle with superheated vapour after compression,

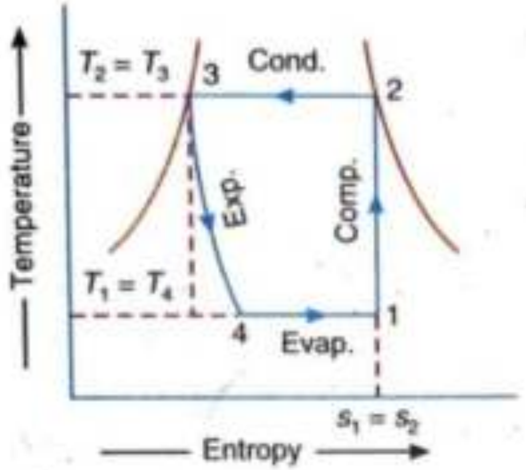
4. Cycle with superheated vapour before compression, and

5. Cycle with undercooling or subcooling of refrigerant.

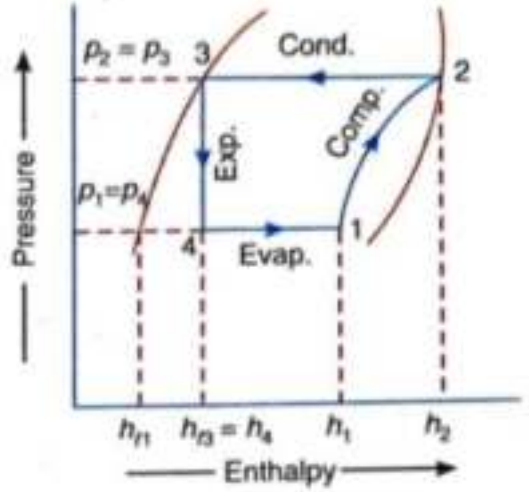
1. Theoretical Vapour Compression Cycle with Dry Saturated Vapour after Compression

A vapour compression cycle with dry saturated vapour after compression is shown on T-s and p-h diagrams in Fig. (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:

1. **Compression process**: The vapour refrigerant at low pressure p1, and temperature T1, 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.



(a) T-s diagram.



(b) p-h diagram.

The work done during isentropic compression per kg of refrigerant is given by W = = $h_2 - h_1$

Where h_1= Enthaply of vapour refrigerant at temperature at T_1 (at suction of the compressor)

h_2= Enthaply of vapour refrigerant at temperature at T_2 (at discharge of the compressor)

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 $p_4 = p_3$, 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 ph diagram. Some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporised in the evaporator. During the throttling process, no heat is absorbed or rejected by the liquid refrigerant.

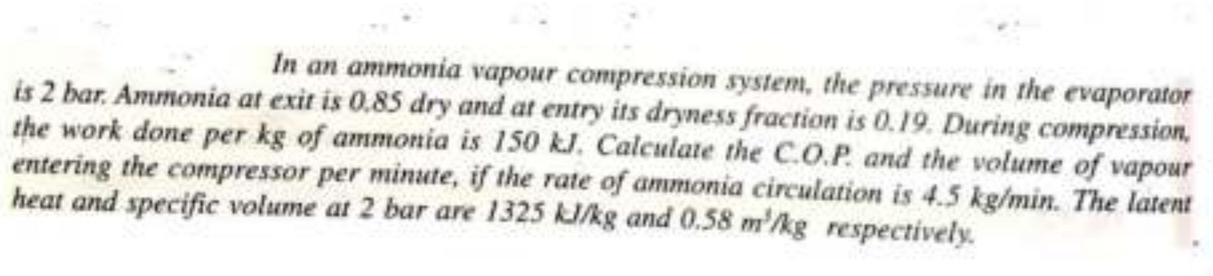
4. Vaparising process: The liquid-vapour mixture of the refrigerant at pressure $p_4 =p_1$, and temperature T_4, = T_1, is evaporated and changed into vapour refrigerant at constant pressure and temperature, as shown by the horizontal line 4-1 on T-s and p-h diagrams. During evaporation, the liquid-vapour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

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

Where h_{f3}= Sensible heat at temperature T_3

C.O.P= Refrigearting effect / Workdone = $(h_1-h_4)/ ((h_2-h_1)$

Problems:



In an ammonia vapour compression system, the pressure in the evaporator is 2 bar. Ammonia at exit is 0.85 dry and at entry its dryness fraction is 0.19. During compression, the work done per kg of ammonia is 150 kJ. Calculate the C.O.P. and the volume of vapour entering the compressor per minute, if the rate of ammonia circulation is 4.5 kg/min. The latent heat and specific volume at 2 bar are 1325 kJ/kg and 0.58 m³/kg respectively.

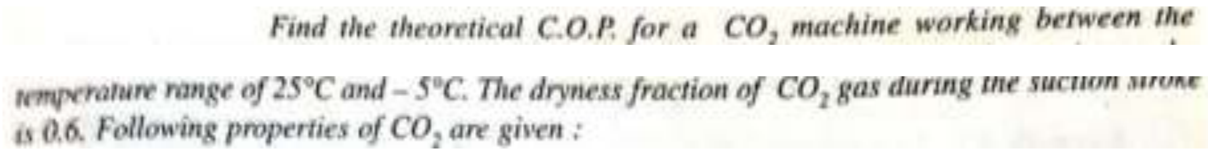
Theoretical Vapour Compression Cycle with Wet Vapour after Compression

(*a*) *T-s* diagram. (*b*) *p-h* diagram.

Theoretical vapour compression cycle with wet vapour after compression.

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

The coefficient of performance (C.O.P.)= Refrigearting effect / Workdone = (h_1-h_4)/ ((h_2-h_1)



Find the theoretical C.O.P. for a CO_2 machine working between the temperature range of 25°C and – 5°C. The dryness fraction of CO_2 gas during the suction stroke is 0.6. Following properties of CO_2 are given :

Temperature °C	*Liquid*		*Vapour*		*Latent heat* kJ/kg
	Enthalpy kJ/kg	*Entropy* kJ/kg K	*Enthalpy* kJ/kg	*Entropy* kJ/kg K	
25	164.77	0.5978	282.23	0.9918	117.46
–5	72.57	0.2862	321.33	1.2146	248.76

Solution. Given : $T_2 = T_3 = 25°\text{C} = 25 + 273 = 298$ K ; $T_1 = T_4 = -5°\text{C} = -5 + 273 = 268$ K ; $x_1 = 0.6$; $h_{f3} = h_{f2} = 164.77$ kJ/kg ; $h_{f1} = h_{f4} = 72.57$ kJ/kg ; $s_{f2} = 0.5978$ kJ/kg K; $s_{f1} = 0.2862$ kJ/kg K ; $h_{2'} = 282.23$ kJ/kg ; $h_{1'} = 321.33$ kJ/kg ; $^*s_{2'} = 0.9918$ kJ/kg K ; $^*s_{1'} = 1.2146$ kJ/kg K ; $h_{fg2} = 117.46$ kJ/kg ; $h_{fg1} = 248.76$ kJ/kg

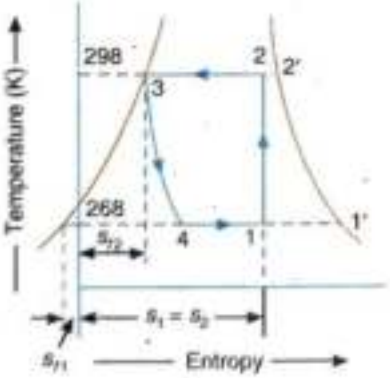
let us find the dryness fraction at point 2, *i.e.* x_2. We know that the entropy at point 1,

$$s_1 = s_{f1} + \frac{x_1\, h_{fg1}}{T_1} = 0.2862 + \frac{0.6 \times 248.76}{268} = 0.8431 \qquad \ldots (i)$$

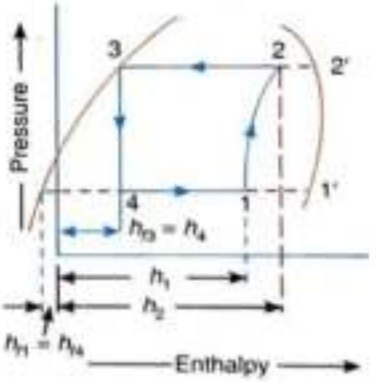
Similarly, entropy at point 2,

$$s_2 = s_{f2} + \frac{x_2\, h_{fg2}}{T_2} = 0.5978 + \frac{x_2 \times 117.46}{298}$$

$$= 0.5978 + 0.3941\, x_2 \qquad \ldots (ii)$$



T-s diagram.



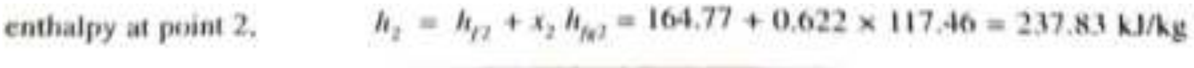
p-h diagram.

Since the entropy at point 1 (s_1) is equal to entropy at point 2 (s_2), therefore equating equations *(i)* and *(ii)*,

$$0.8431 = 0.5978 + 0.3941\, x_2 \qquad \text{or} \qquad x_2 = 0.622$$

enthalpy at point 1,

$$h_1 = h_{f1} + x_1\, h_{fg1} = 72.57 + 0.6 \times 248.76 = 221.83 \text{ kJ/kg}$$

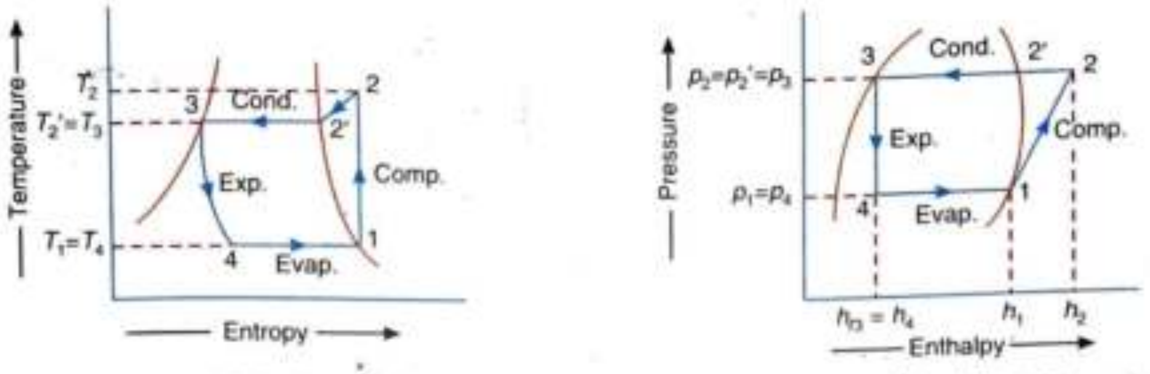


enthalpy at point 2. $h_2 = h_{f2} + x_2 h_{fg2} = 164.77 + 0.622 \times 117.46 = 237.83$ kJ/kg

Theoretical C.O.P. = Refrigerating effect / Workdone = $(h_1 - h_4) / ((h_2 - h_1) = (h_1 - h_{f3}) / ((h_2 - h_1)$

$= (221.83 - 164.77) / (237.83 - 221.83) = 3.57$

Theoretical Vapour Compression Cycle with Superheated Vapour after Compression



(a) T-s diagram. (b) p-h diagram.

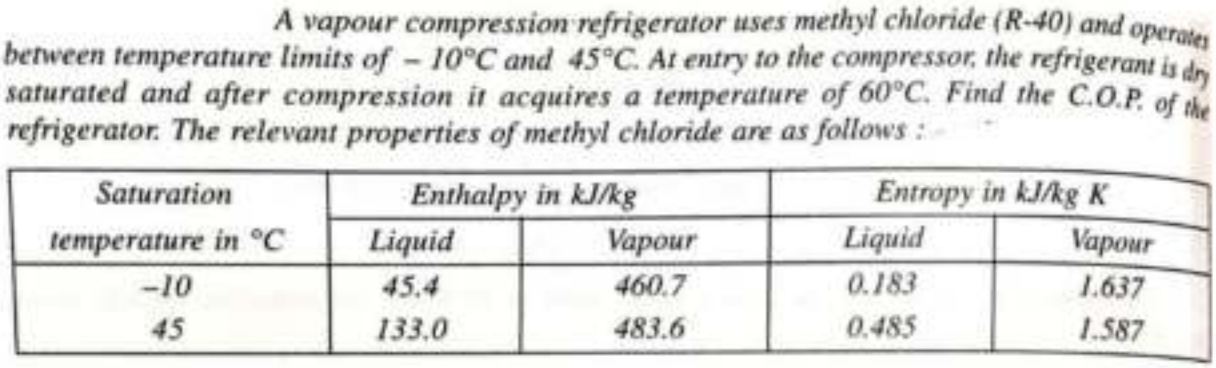
Theoretical vapour compression cycle with superheated vapour after compression.

A vapour compression cycle with superheated vapour after compression is shown on T-s and

p-h diagrams respectively. In this cycle, the enthalpy at point 2 is found out with the help of degree of superheat. The degree of superheat may is found out by equating the entropies at points 1 and 2.

The coefficient of performance(C.O.P.) = Refrigerating effect / Workdone = $(h_1 - h_4) / ((h_2 - h_1) = (h_1 - h_{f3}) / ((h_2 - h_1)$

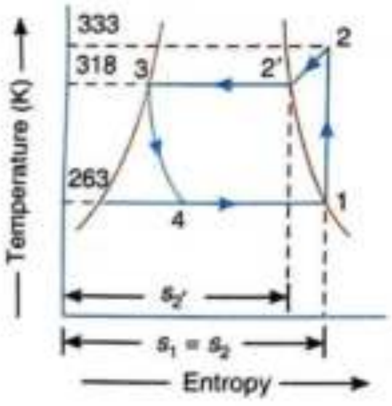
Problem:



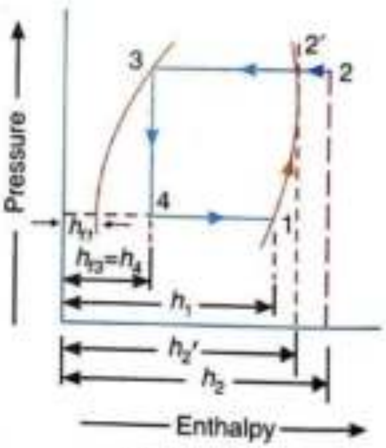
A vapour compression refrigerator uses methyl chloride (R-40) and operates between temperature limits of – 10°C and 45°C. At entry to the compressor, the refrigerant is dry saturated and after compression it acquires a temperature of 60°C. Find the C.O.P. of the refrigerator. The relevant properties of methyl chloride are as follows :

Saturation temperature in °C	*Enthalpy in kJ/kg*		*Entropy in kJ/kg K*	
	Liquid	*Vapour*	*Liquid*	*Vapour*
–10	*45.4*	*460.7*	*0.183*	*1.637*
45	*133.0*	*483.6*	*0.485*	*1.587*

Given : $T_1 = T_4 = -10°C = -10 + 273 = 263$ K ; $T_{2'} = T_3 = 45°C = 45 + 273 = 318$ K ; $T_2 = 60°C = 60 + 273 = 333$ K ; $^*h_{f1} = 45.4$ kJ/kg ; $h_{f3} = 133$ kJ/kg ; $h_1 = 460.7$ kJ/kg ; $h_{2'} = 483.6$ kJ/kg ; $^*s_{f1} = 0.183$ kJ/kg K ; $^*s_{f3} = 0.485$ kJ/kg K ; $s_1 = s_2 = 1.637$ kJ/kg K; $s_{2'} = 1.587$ kJ/kg K



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



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

Let c_p = Specific heat at constant pressure for superheated vapour.

We know that entropy at point 2,

$$s_2 = s_{2'} + 2.3\, c_p \log\left(\frac{T_2}{T_{2'}}\right)$$

$$1.637 = 1.587 + 2.3\, c_p \log\left(\frac{333}{318}\right)$$

$$= 1.587 + 2.3\, c_p \times 0.02 = 1.587 + 0.046\, c_p$$

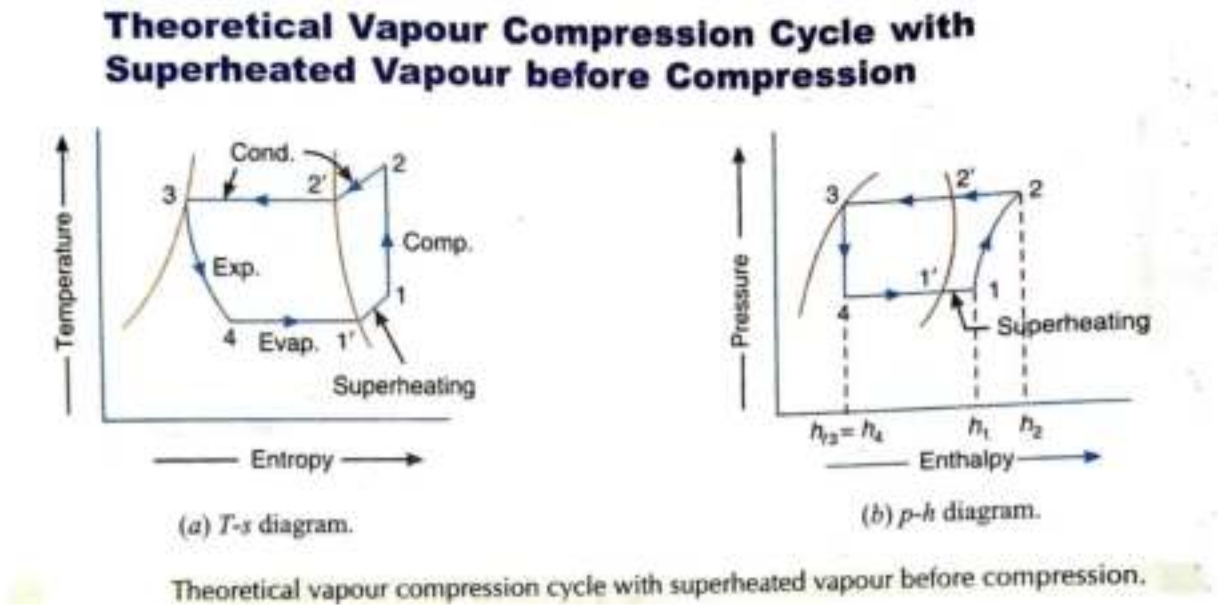
$$\therefore \quad c_p = 1.09$$

and enthalpy at point 2, $h_2 = h_{2'} + c_p \times$ Degree of superheat $= h_{2'} + c_p\,(T_2 - T_2')$

$$= 483.6 + 1.09\,(333 - 318) = 500 \text{ kJ/kg}$$

∴ C.O.P. of the refrigerator

$$= \frac{h_1 - h_{f3}}{h_2 - h_1} = \frac{460.7 - 133}{500 - 460.7} = 8.34$$



Theoretical Vapour Compression Cycle with Superheated Vapour before Compression

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

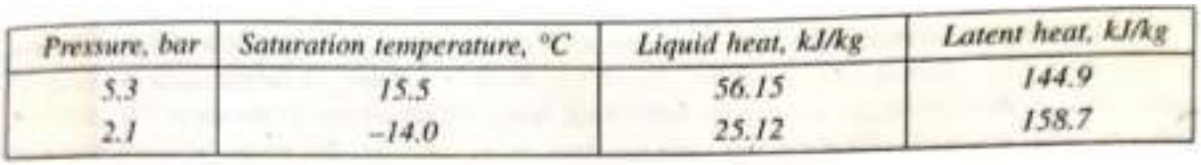
(*b*) *p-h* diagram.

Theoretical vapour compression cycle with superheated vapour before compression.

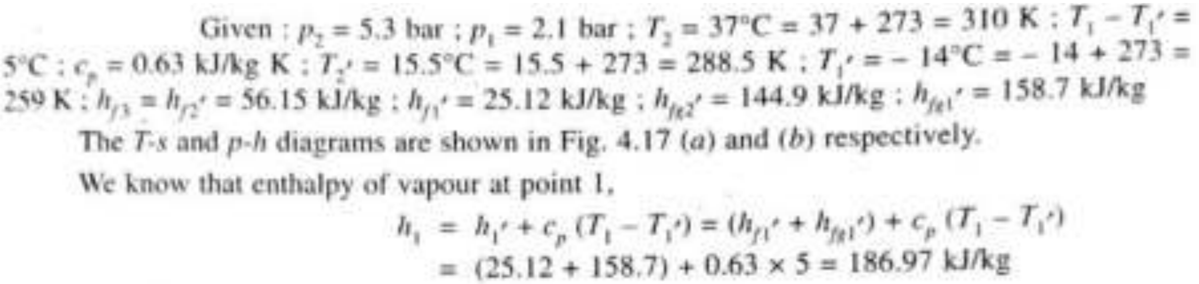
A vapour compression cycle with superheated vapour before compression is shown on T-s and p-h diagrams respectively. In this cycle, the evaporation starts at point 4 and continues upto point 1', when it is dry saturated. The vapour is now superheated before entering the compressor upto the point 1.

The coefficient of performance(C.O.P.) = Refrigerating effect / Workdone = $(h_1-h_4)/ ((h_2-h_1)= (h_1-h_{f3})/ ((h_2-h_1)$

Problems:



Pressure, bar	*Saturation temperature, °C*	*Liquid heat, kJ/kg*	*Latent heat, kJ/kg*
5.3	*15.5*	*56.15*	*144.9*
2.1	*–14.0*	*25.12*	*158.7*

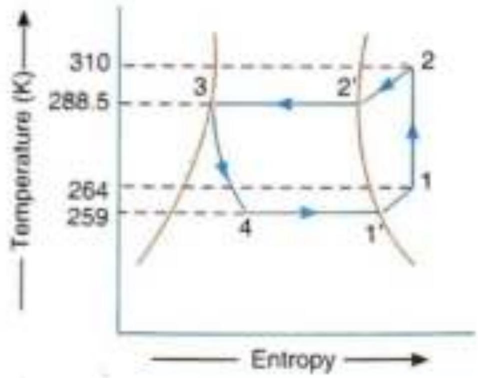


Given : $p_2 = 5.3$ bar ; $p_1 = 2.1$ bar ; $T_2 = 37°C = 37 + 273 = 310$ K ; $T_1 - T_{1'} = 5°C$; $c_p = 0.63$ kJ/kg K ; $T_{2'} = 15.5°C = 15.5 + 273 = 288.5$ K ; $T_{1'} = -14°C = -14 + 273 = 259$ K ; $h_{f3} = h_{f2'} = 56.15$ kJ/kg ; $h_{f1'} = 25.12$ kJ/kg ; $h_{fg2'} = 144.9$ kJ/kg ; $h_{fg1'} = 158.7$ kJ/kg

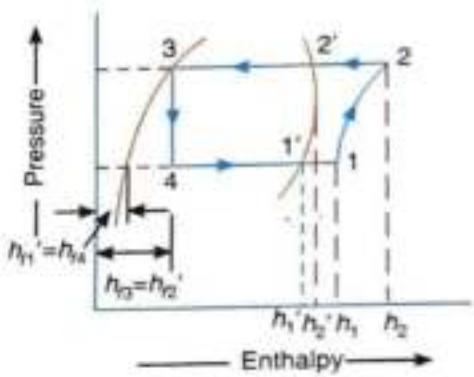
The *T-s* and *p-h* diagrams are shown in Fig. 4.17 (*a*) and (*b*) respectively.

We know that enthalpy of vapour at point 1,

$$h_1 = h_{1'} + c_p (T_1 - T_{1'}) = (h_{f1'} + h_{fg1'}) + c_p (T_1 - T_{1'})$$
$$= (25.12 + 158.7) + 0.63 \times 5 = 186.97 \text{ kJ/kg}$$



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



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

enthalpy of vapour at point 2,

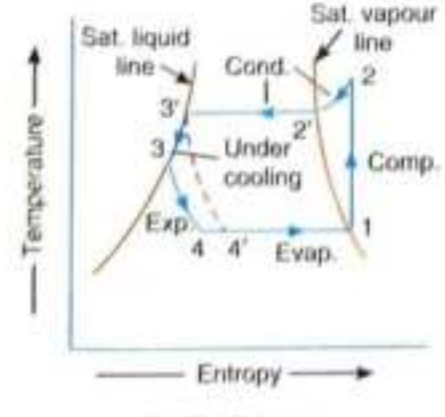
$$h_2 = h_{2'} + c_p (T_2 - T_{2'}) = (h_{f2'} + h_{fg2'}) + c_p (T_2 - T_{2'})$$

$$= (56.15 + 144.9) + 0.63\,(310 - 288.5) = 214.6 \text{ kJ/kg}$$

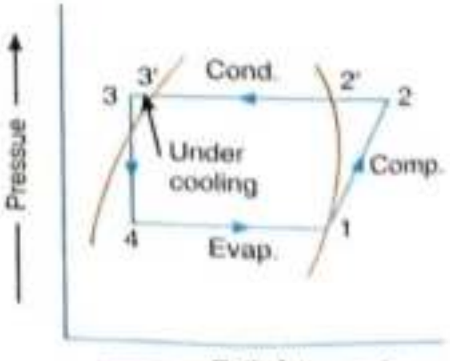
∴ Coefficient of performance of the plant,

$$\text{C.O.P.} = \frac{h_1 - h_{f3}}{h_2 - h_1} = \frac{186.97 - 56.15}{214.6 - 186.97} = \frac{130.82}{27.63} = 4.735$$

Theoretical Vapour Compression Cycle with Under-cooling or Subcooling of Refrigerant



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



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

The refrigerant, after condensation process 2'-3', is cooled below the saturation temperature (T_3',) before expansion by throttling this process is called undercooling or subcooling of the refrigerant and is generally done along the liquid line.The effect of the undercooling is to increase the value of coefficient of performance under the same set of conditions.

The process of undercooling is done by circulating more quantity of cooling water through the condenser or by using water colder than the main circulating water. The refrigerating effect is increased by adopting both the superheating and undercooling process which is shown by dotted lines in Fig (a).

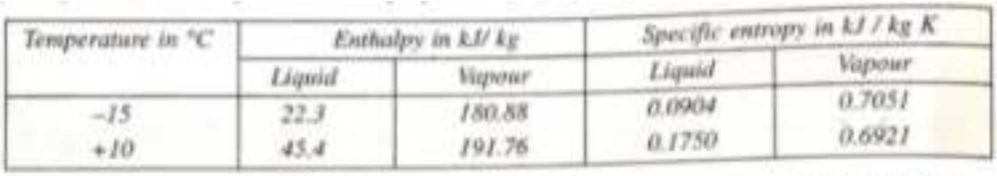
The coefficient of performance(C.O.P.) = Refrigerating effect / Workdone = $(h_1-h_4)/ ((h_2-h_1)= (h_1-h_{f3})/ ((h_2-h_1)$

The value of $hf_3 = hf_3$’xDegree of under cooling

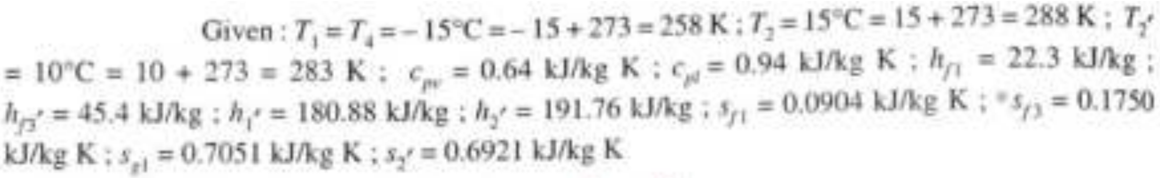
Problem:

A vapour compression refrigerator uses R-12 as refrigerant and the liquid evaporates in the evaporator at -15^{0}C. The temperature of this refrigerant at the delivery from the compressor is 15^{0}C when the vapour is condensed at 10^{0}C. Find the co-efficient of performance if (i) there is no undercooling and 9ii) the liquid is cooled by 5^{0}C before expansion by throttling.

Take specific heat at constant pressure for the superheated vapour as 0.64 kJ/kgK and that for liquid as 0.94 kJ/kgK. The other properties of refrigerant are as follows:

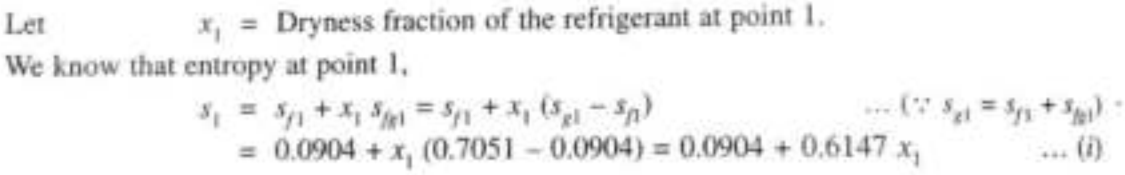


Temperature in °C	*Enthalpy in kJ/ kg*		*Specific entropy in kJ / kg K*	
	Liquid	*Vapour*	*Liquid*	*Vapour*
–15	*22.3*	*180.88*	*0.0904*	*0.7051*
+10	*45.4*	*191.76*	*0.1750*	*0.6921*



Given : $T_1 = T_4 = -15°C = -15 + 273 = 258$ K ; $T_2 = 15°C = 15 + 273 = 288$ K ; $T_{2'} = 10°C = 10 + 273 = 283$ K ; $c_{pv} = 0.64$ kJ/kg K ; $c_{pl} = 0.94$ kJ/kg K ; $h_{f1} = 22.3$ kJ/kg ; $h_{f3'} = 45.4$ kJ/kg ; $h_{1'} = 180.88$ kJ/kg ; $h_{2'} = 191.76$ kJ/kg ; $s_{f1} = 0.0904$ kJ/kg K ; $s_{f3} = 0.1750$ kJ/kg K ; $s_{g1} = 0.7051$ kJ/kg K ; $s_{2'} = 0.6921$ kJ/kg K

(i) Coefficient of performance if there is no undercooling



Let x_1 = Dryness fraction of the refrigerant at point 1.

We know that entropy at point 1,

$$s_1 = s_{f1} + x_1 s_{fg1} = s_{f1} + x_1 (s_{g1} - s_{f1}) \qquad \ldots (\because s_{g1} = s_{f1} + s_{fg1})$$

$$= 0.0904 + x_1 (0.7051 - 0.0904) = 0.0904 + 0.6147\, x_1 \qquad \ldots (i)$$

and entropy at point 2,

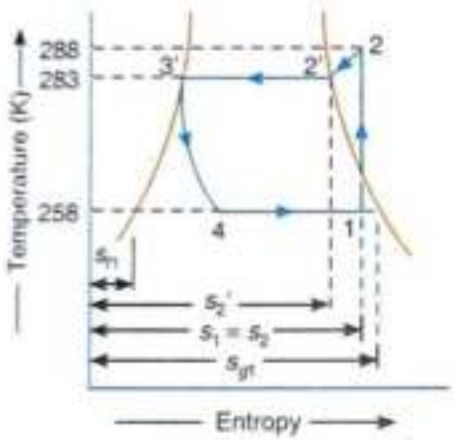
$$s_2 = s_{2'} + 2.3\, c_{pv} \log\left(\frac{T_2}{T_{2'}}\right)$$

$$= 0.6921 + 2.3 \times 0.64 \log\left(\frac{288}{283}\right)$$

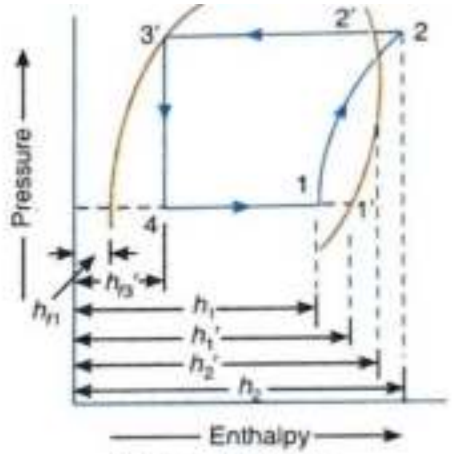
$$= 0.6921 + 2.3 \times 0.64 \times 0.0077 = 0.7034 \qquad \ldots (ii)$$

Since the entropy at point 1 is equal to entropy at point 2, therefore equating equations (*i*) and (*ii*),

$$0.0904 + 0.6147\, x_1 = 0.7034 \qquad \text{or} \qquad x_1 = 0.997$$



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



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

the enthalpy at point 1,

$$h_1 = h_{f1} + x_1\, h_{fg1} = h_{f1} + x_1\,(h_{g1} - h_{f1})$$

$$= 22.3 + 0.997\,(180.88 - 22.3) = 180.4 \text{ kJ/kg}$$

$$\ldots (\because h_{g1} = h_{1'})$$

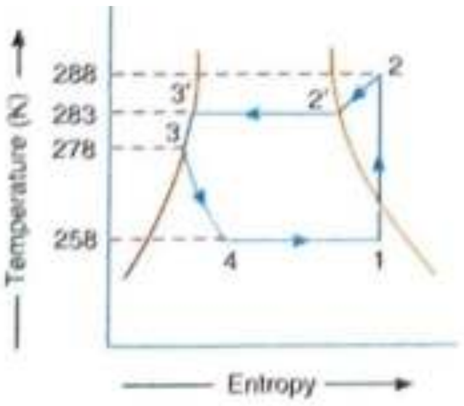
enthalpy at point 2,

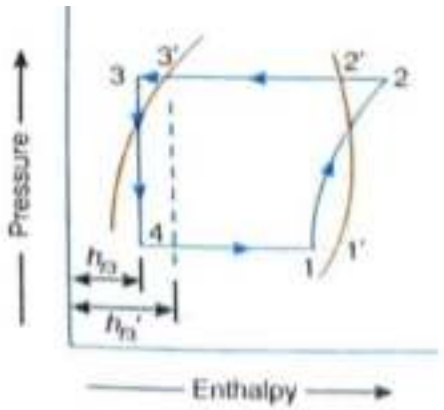
$$h_2 = h_{2'} + c_{pv}\,(T_2 - T_{2'})$$

$$= 191.76 + 0.64\,(288 - 283) = 194.96 \text{ kJ/kg}$$

$$\therefore \qquad \text{C.O.P.} = \frac{h_1 - h_{f3'}}{h_2 - h_1} = \frac{180.4 - 45.4}{194.96 - 180.4} = 9.27$$

(ii) Coefficient of performance when there is an undercooling of 5°C





enthalpy of liquid refrigerant at point 3,

$$h_{f3} = h_{f3}' - c_{pl} \times \text{Degree of undercooling}$$

$$= 45.4 - 0.94 \times 5 = 40.7 \text{ kJ/kg}$$

$$\therefore \quad \text{C.O.P.} = \frac{h_1 - h_{f3}}{h_2 - h_1} = \frac{180.4 - 40.7}{194.96 - 180.4} = 9.59$$

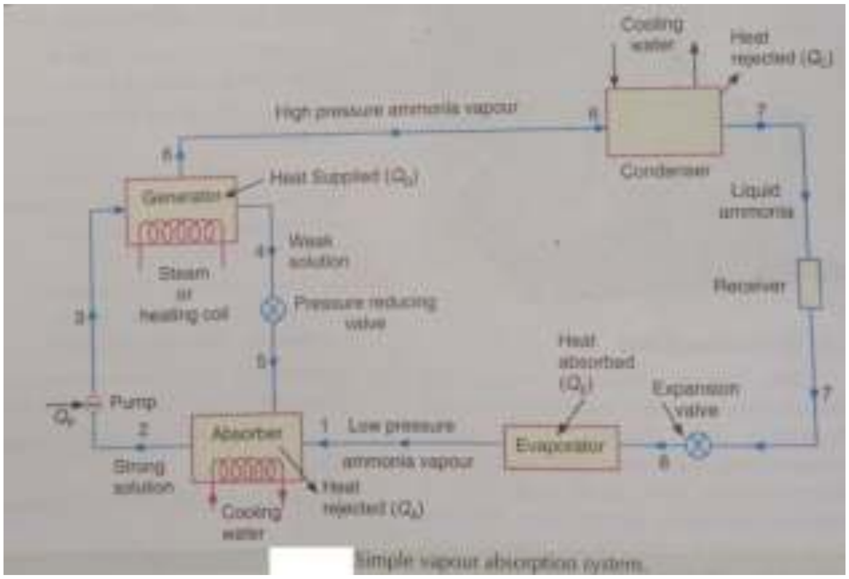
Vapour Absorption Refrigeration System

The vapour absorption refrigeration system is one of the oldest methods of producing refrigerating effect. This system uses heat energy instead of mechanical energy as in vapour compression system to change the conditions of the refrigerant required for the operation of the refrigeration cycle. It is used in both the domestic and large industrial refrigerating plants.

In the vapour absorption system, the compressor is replaced by an absorber, a pump, a generator, and a pressure reducing valve. The refrigerant used in a vapour absorption system is ammonia.

Simple Vapour Absorption System:

The simple vapour absorption system consists of an absorber, a pump a generator and a pressure reducing valve to replace the compressor of vapour compression system. The other components of the system are condenser, receiver, expansion valve and evaporator as in the vapour compression system.



Simple vapour absorption system.

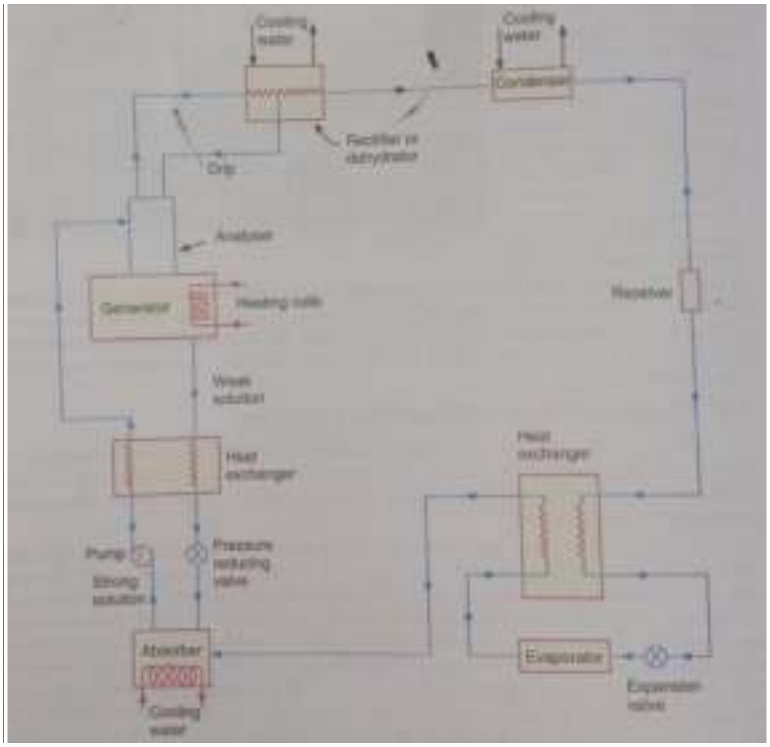
- In this system, the low pressure ammonia vapour leaving the evaporator enters the absorber where it is absorbed by the cold water in the absorber. The water has the ability to absorb large quantities of ammonia vapour and the solution, thus formed, is known as aqua-ammonia absorption of ammonia vapour in water lowers the pressure in the absorber which draws more ammonia vapour from the evaporator and thus raises the temperature of solution. Some form of water cooling arrangement is employed in the absorber to remove the heat of solution. This is necessary in order to increase the absorption capacity of water because at higher temperature water absorbs less ammonia vapour.

- The strong solution formed in the absorber is pumped to the generator by the liquid pump. The pump increases the pressure of the solution upto 10 bar. Then the strong solution of ammonia in the generator is heated by some external source.
- During the heating process, the ammonia vapour is driven off the solution at high pressure and leaves the hot weak solution which flows back to the absorber at low pressure after passing through pressure reducing valve.
- The high pressure ammonia vapour from the generator is condensed in the condenser to a high pressure liquid ammonia.
- This liquid ammonia is passed to the extension valve through the receiver and then to the evaporator.

This completes the simple vapour absorption cycle.

Practical Vapour Absorption System:

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



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 these unwanted water particles are not removed before entering into the condenser, they will enter ime the expansion valve where they freeze and choke the pipeline.

- In order to remove these unwanted particles flowing to the condenser, an analyser is used. The analyser may be built as an integral en of the generator or made as a separate piece of equipment. It consists of a series of trays 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.

2. Rectifier:

- In case 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 may be of the double pipe, shell and coil or shell and cube type .
- Its function is to cool further the ammonia vapours leaving the 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 to the top of the analyser by a drip return pipe

3. Heat exchangers:

- The heat exchanger provided between the 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 raises the temperature of the strong solution leaving the pump and going to analyser and generator.
- This operation reduces the heat 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 is also called liquid sub-cooler. In this heat exchanger, the liquid refrigerant leaving the condenser is sub-cooled by the low temperature ammonia vapour from the evaporator .
- This sub-cooled liquid is passed 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 work done by the pump and the heat supplied in the generator. Therefore, the

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

Coefficient of Performance of an Ideal Vapour Absorption Refrigeration System

An ideal vapour absorption refrigeration system,

(a) the heat (Q_G) is given to the refrigerant in the generator,

(b) the heat (Q_C) is discharged to the atmosphere or cooling water from the condenser and absorber,

(c) the heat (Q_E) is absorbed by the refrigerant in the evaporator, and

d) the heat (Qp) is added to the refrigerant due to pumpwork.

Neglecting the heat due to pump work (Qp), according to First Law of Thermodynamics,

$Q_C = Q_G + Q_E$ ………………(i)

Let T_G = Temperature at which heat (Q_G) is given to the generator,

Tc = Temperature at which heat (Q_C) is discharged to atmosphere or cooling water from the condenser and absorber, and

T_E = Temperature at which heat (Q_E) is absorbed in the evaporator.

Since the vapour absorption system is considered as a perfectly reversible system, therefore the initial entropy of the system must be equal to the entropy of the system after the change in its condition.

$$Q_C = Q_G + Q_E \qquad \ldots (i)$$

Let

T_G = Temperature at which heat (Q_G) is given to the generator.

T_C = Temperature at which heat (Q_C) is discharged to atmosphere or cooling water from the condenser and absorber, and

T_E = Temperature at which heat (Q_E) is absorbed in the evaporator.

Since the vapour absorption system can be considered as a perfectly reversible system, therefore the initial entropy of the system must be equal to the entropy of the system after the change in its condition.

$$\therefore \quad \frac{Q_G}{T_G} + \frac{Q_E}{T_E} = \frac{Q_C}{T_C} \qquad \ldots (ii)$$

$$= \frac{Q_G + Q_E}{T_C} \qquad \ldots \text{[From equation } (i)\text{]}$$

or

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

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

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

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

$$= Q_E \left(\frac{T_C - T_E}{T_E} \right) \left(\frac{T_G}{T_G - T_C} \right) \qquad \ldots (iii)$$

Maximum coefficient of performance of the system is given by

$$(\text{C.O.P.})_{max} = \frac{Q_E}{Q_G} = \frac{Q_E}{Q_E \left(\frac{T_C - T_E}{T_E} \right) \left(\frac{T_G}{T_G - T_C} \right)}$$

$$= \left(\frac{T_E}{T_C - T_E} \right) \left(\frac{T_G - T_C}{T_G} \right) \qquad \ldots (iv)$$

Advantages of Vapour Absorption Refrigeration System over Vapour Compression Refrigeration System Following are the advantages of vapour absorption system over vapour compression systems

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

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

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

4. **The vapour absorption systems** can operate at reduced evaporator pressure and temperature by increasing the steam pressure to the generator, with little decrease in capacity But the capacity of **vapour compression system** drops rapidly with lowered evaporator pressure.

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 the quantity of steam supplied to the generator. The performance of a **vapour compression system** at partial loads is poor.

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

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

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

Problems-1

In an absorption type refrigerator, the heat is supplied to NH_3 generator by condensing steam at 2 bar and 90% dry. The temperature in the refrigerator is to be maintained at -5° C. Find the maximum C.O.P. possible.

If the refrigeration load is 20 tonnes and actual C.O.P. is 70% of the maximum C.O.P., find the mass of steam required per hour. Take temperature of the atmosphere as 30° C.

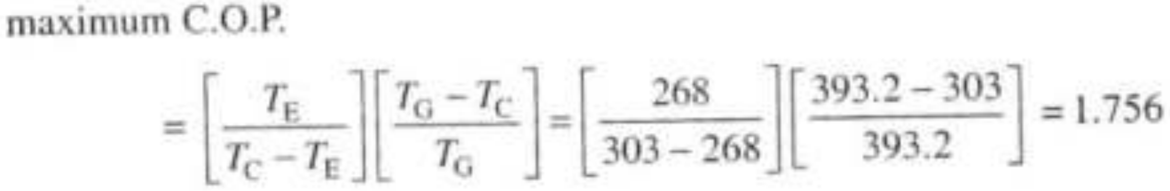
Solution.

Given : p = 2 bar ; x = 90% = 0.9 ; T = -5° C = - 5 + 273 = 268 K : Q = 20 TR

Actual C.O.P. = 70% of maximum C.O.P. ; Tc = 30° C = 30 + 273 = 303 K

Maximum C.O.P.

From steam tables, the saturation temperature of steam at a pressure of 2 bar is T_G = 120.2° C = 120.2 + 273 = 393.2 K



maximum C.O.P.

$$= \left[\frac{T_E}{T_C - T_E}\right]\left[\frac{T_G - T_C}{T_G}\right] = \left[\frac{268}{303 - 268}\right]\left[\frac{393.2 - 303}{393.2}\right] = 1.756$$

Mass of steam requires per hour

= 70% of maximum C.O.P. = 0.7 x 1.756 = 1.229

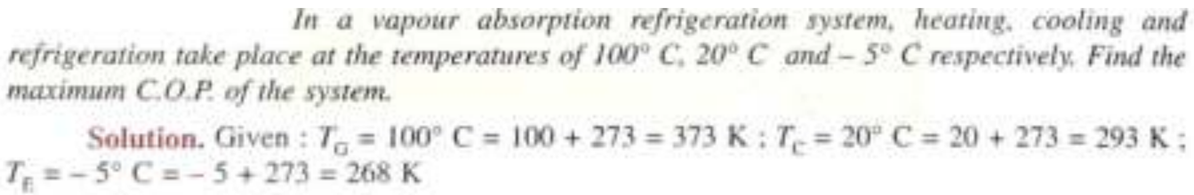
Actual heat supplied= Refrigeration load / Actual C.O.P.= (20x210)/1.229 =3417.4 kJ/min

From steam tables, the latent heat of steam at 2 bar is h_{fg} = 2201.6 kJ/kg .

Mass of steam required per hour= Actual heat supplied / h_{fg} =3417.4 / 2201.6 = 1.552 kg/min

=1.552 x 60 = 93.12 kg/h

Problems-2



In a vapour absorption refrigeration system, heating, cooling and refrigeration take place at the temperatures of 100° C, 20° C and – 5° C respectively. Find the maximum C.O.P. of the system.

Solution. Given : T_G = 100° C = 100 + 273 = 373 K ; T_C = 20° C = 20 + 273 = 293 K ; T_E = – 5° C = – 5 + 273 = 268 K maximum C.O.P. of the system

$$= \left(\frac{T_E}{T_C - T_E}\right)\left(\frac{T_G - T_C}{T_G}\right) = \left(\frac{268}{293 - 268}\right)\left(\frac{373 - 293}{373}\right) = 2.3$$

5th Chapter

REFRIGERANTS

The refrigerant is a heat carrying medium which during the cycle in the refrigeration system absorbs heat from a low temperature system and rejects the heat to a higher temperature system.

Refrigerant Classification

Refrigerants are working substances or heat- carrying medium in refrigeration system, during a refrigeration cycle heat is absorbed from a low temperature system and rejects the heat to a high temperature system.

Refrigerants can be classified as follows:

(I) On the basis of working principle:

(A) Primary refrigerants and (B) Secondary refrigerants

(A) Primary refrigerants

The refrigerant which directly participate in the refrigeration system and cools the products or substances are called Primary refrigerants. These refrigerants undergo change of phase during heat absorption or heat rejection in the evaporator and condenser.

(B) Secondary refrigerants

This refrigerant does not directly participate in the refrigeration cycle, but is used only as a medium for cooling. This refrigerant first cooled by primary refrigerants and then cools the substance which is to be maintained at lower temperatures.

Examples are H_2O, Brine and calcium chloride solutions.

Qualities of secondary refrigerants:

- Remain liquid state under all working conditions
- Non corrosive when in contact with metal
- High specific heat and
- Undergo no change when in contact with refrigerants or other gases.

(II) On the basis of nature of the refrigerants:

(A) Natural Refrigerants and (B) Artificial or synthetic refrigerants

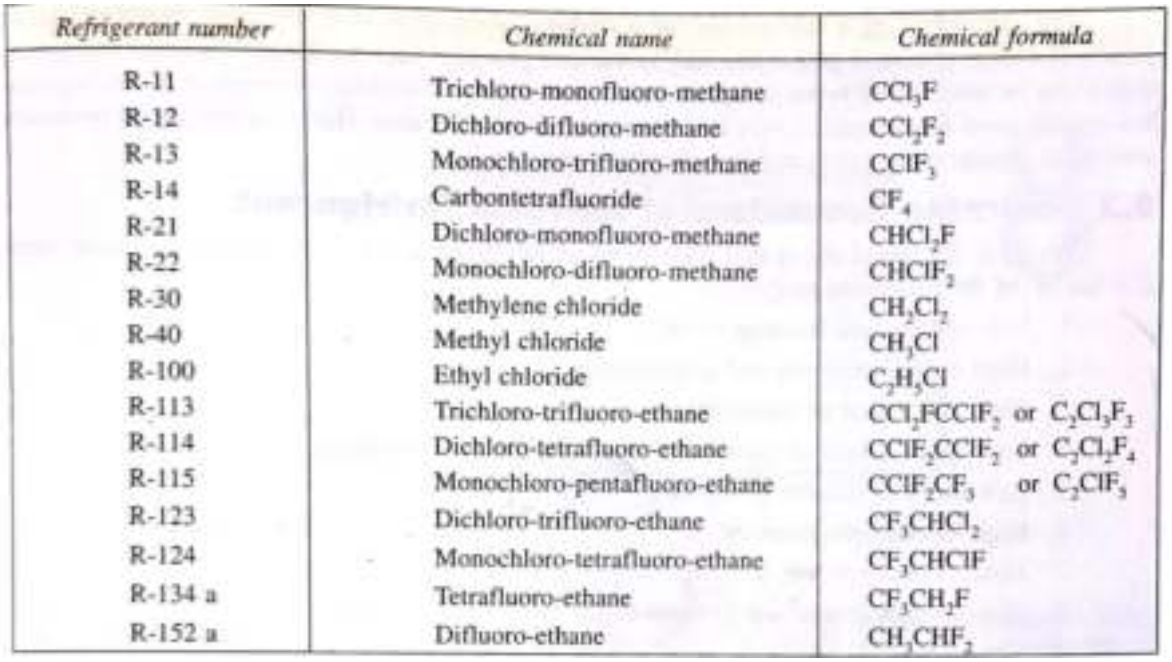
(III) On the basis of safety:

(A) Safety refrigerants and (B) Flammable refrigerants

(IV) On the basis of chemical composition

(A)Halocarbon refrigerants, (B) Hydrocarbon refrigerants,

(C)Inorganic refrigerants and (D) Azetropic refrigerants



Refrigerant number	*Chemical name*	*Chemical formula*
R-11	Trichloro-monofluoro-methane	CCl_3F
R-12	Dichloro-difluoro-methane	CCl_2F_2
R-13	Monochloro-trifluoro-methane	$CClF_3$
R-14	Carbontetrafluoride	CF_4
R-21	Dichloro-monofluoro-methane	$CHCl_2F$
R-22	Monochloro-difluoro-methane	$CHClF_2$
R-30	Methylene chloride	CH_2Cl_2
R-40	Methyl chloride	CH_3Cl
R-100	Ethyl chloride	C_2H_5Cl
R-113	Trichloro-trifluoro-ethane	CCl_2FCClF_2 or $C_2Cl_3F_3$
R-114	Dichloro-tetrafluoro-ethane	$CClF_2CClF_2$ or $C_2Cl_2F_4$
R-115	Monochloro-pentafluoro-ethane	$CClF_2CF_3$ or C_2ClF_5
R-123	Dichloro-trifluoro-ethane	CF_3CHCl_2
R-124	Monochloro-tetrafluoro-ethane	CF_3CHClF
R-134 a	Tetrafluoro-ethane	CF_3CH_2F
R-152 a	Difluoro-ethane	CH_3CHF_2

1. R-11, Trichloro-monofluoro-methane (CCl_3F) -The R-11 ia a synthetic chemical product which can be used as a refrigerant. It is stable, non-flammable and non-toxic. It is considered to be a low-pressure refrigerant. Due to its low operating pressure, this refrigerant is used in large centrifugal compressor system of 200 TR and above..

2. R-12, Dichloro-difluoro-methane (CCl_2F_2)- The R-12 is a colourless, odourless liquid with boiling point of - 29^0C at atmospheric pressure. It is non-toxic, non-corrosive, non-irritating and non-flammable. Itazze iw Dell 152 which is an advantage in small refrigerating mastices. The izoztu ziza will permit the use of less sensitive and more positive opening and naring teams operates at a low but positive head and back pressure and a winners BV refrigerant is used in many different types of industrial concer refrigerators, freezers, water coolers, room and windon osoite on rice is found in reciprocating and rotary compressors. but is use is a compresi commercial air-conditioning is increasing

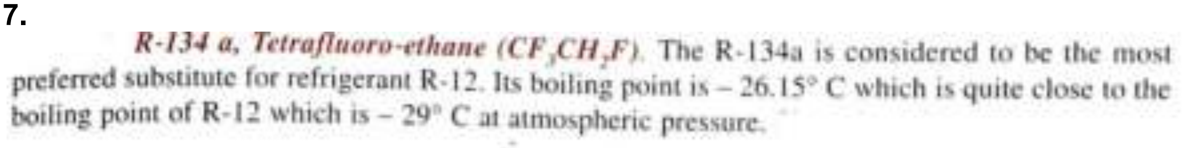
3. R-13, Monochloro-trifluoro-methane ($CClF_3$)- The R-13 has a boiling temperature of -81.4°C at atmospheric pressure and a critical temperature of + 28.8°C. This refrigerant is used for the low-temperature side of cascade systems. It is suitable with reciprocating compressors.

4. R-14, Carbontetrafluoride (CF_4) -The R-14 has a boiling temperature of - 128°C at atmospheric pressure and critical temperature of – 45.5°C. It serves as an ultra-low temperature refrigerant for use in cascade systems.

5. R-21, Dichloro-monofluoro-methane ($CHCl_2F$)- The R-21 has a boiling temperature of +9°C at atmospheric pressure. It is used in centrifugal compressor systems .

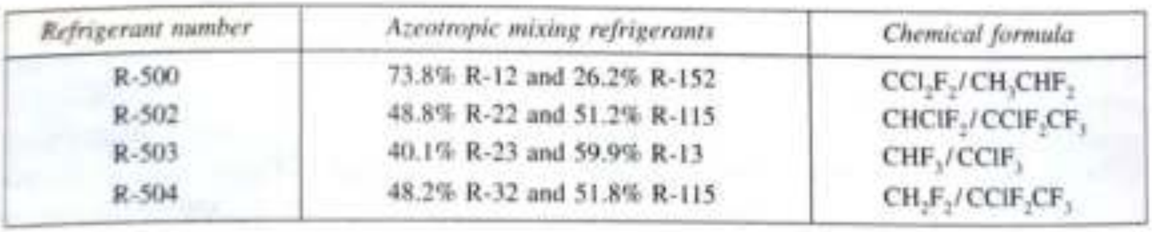
6. R-22, Monochloro-difluoro-methane ($CHClF_2$)- The R-22 is a man-made refrigerant developed for refrigeration installations that need a low evaporating temperature. It is used with reciprocating and centrifugal compressors.

7.



R-134 a, Tetrafluoro-ethane (CF_3CH_2F). The R-134a is considered to be the most preferred substitute for refrigerant R-12. Its boiling point is – 26.15° C which is quite close to the boiling point of R-12 which is – 29° C at atmospheric pressure.

Azeotrope Refrigerants



Refrigerant number	*Azeotropic mixing refrigerants*	*Chemical formula*
R-500	73.8% R-12 and 26.2% R-152	CCl_2F_2/CH_3CHF_2
R-502	48.8% R-22 and 51.2% R-115	$CHClF_2/CClF_2CF_3$
R-503	40.1% R-23 and 59.9% R-13	$CHF_3/CClF_3$
R-504	48.2% R-32 and 51.8% R-115	$CH_2F_2/CClF_2CF_3$

Methane Series:
CHFC ------------------R22 -------------------------------Monochlore difluoro methane
HFC ------------------R32 ------------------------------Difluoro methane
Ethane Series:
CHFC-------------------R123 (CHCL2 – CF3) -------------Dichloro trifluro ethane
HFC -------------------R125 (CHF2 –CF3) ----------------Pentafluoro ethane
HFC---------------------R134a (CH2F-CF3) ----------------Tetrafluoro ethane
HFC --------------------R143a (CH3 –CF3) ------------------Trifluro ehane
HFC---------------------R152a (CH3-CHF2) -----------------Difluro ethane

Propane Series:
HFC--------------------R245fa (C3H3F3) ------------------Pentafluoro propane
HC-------------------------R290 (C3H8) ------------------Propane

Butane Series:
HC --------------------------R600a---- (C4H10) --------------Isobutane
Zeotropic Blends:
HFC ------------------------R407A [R125/143a/134a (44/52/4)]
HFC ------------------------R407C [R32/125/134a (23/25/52)]
HFC -------------------------R410A [R32/125(50/50)]
Azeotropic Blends:
HFC ------------------------R507A [R125/143a (50/50)]

Inorganic refrigerants:
(NH3) -----------------------R717----------------------------Ammonia
(H2O) -----------------------R718----------------------------Water
(CO2) ---------------------- R744--------------------------- Carbon dioxide.

Properties of Refrigerants

An ideal refrigerant should give a good coefficient of performance and also safe to use while operating between the pressures. There is no ideal refrigerant which can be used under all operating conditions. The characteristics of some refrigerants make them suitable for use with reciprocating compressor and other refrigerants are best suited to centrifugal compressor or rotary compressor. Therefore in order to select a correct refrigerant, it is necessary that it should satisfy those properties which make it ideal to use for the particular application.
The properties of refrigerants are essential in determining its use for a particular application.

Desirable Properties of an Ideal Refrigerant

We have discussed above that there is no ideal refrigerant. A refrigerant is said to be ideal if it has all of the following properties :

1. Low boiling and freezing point,
2. High critical pressure and temperature,
3. High latent heat of vaporisation,
4. Low specific heat of liquid, and high specific heat of vapour,
5. Low specific volume of vapour,
6. High thermal conductivity,
7. Non-corrosive to metal,
8. Non-flammable and non-explosive,
9. Non-toxic,
10. Low cost,
11. Easily and regularly available,
12. Easy to liquify at moderate pressure and temperature,

There are three groups of properties,
(I). Thermodynamic properties of refrigerants,
(II). Chemical properties of refrigerants and
(III). Physical properties of refrigerants

(I) Thermodynamic properties of refrigerants:

1. Boiling point temperature:

- Low boiling temperature at atmospheric pressure is desirable. It increases the capacity of plant

2. Freezing point temperature:

- The freezing point should be low to prevent the refrigerant which will leads to choking of valves etc.

3. Evaporator and condenser pressures:

- The evaporative pressure and condenser pressure should be positive i.e., above the atmospheric pressure in order to avoid air leakage into the system.

4. Critical temperature and pressure:

- Critical temperature for a refrigerant should be high to prevent excessive power consumption
- Critical pressure should be low so as to give low pressure

5. Latent heat of vaporisation:

- Latent heat of vaporization should be large to minimize the quantity of refrigerant Used.

6. Coefficient of performance:

- High COP is desirable to reduce the running cost

7. Specific volume:

- Low specific volume reduces the size of the compressor

8. Power requirement:

- Power require should be low as possible
- Increases the system coefficient of performance.

(II) Chemical properties of refrigerants:

- Non flammable and non-explosive
- Non-poisonous, non-toxic and no effecting food stuffs
- Should not have any disagreeable odor
- Should not have any corrosion action on the parts of the system

(III) Physical properties of refrigerants:

1. Stability and inertness:

- An ideal refrigerant should not decompose at any temperature of refrigeration system.
- It should not form higher boiling point liquids or solid substance through polymerization

2. Corrosive property:

- An ideal refrigerant should not corrode with metals

3. Viscosity:

- Low viscosity is desirable for better heat transfer and low pumping Power

4. Leakage tendency:

- Leakage tendency of a refrigerant should be low to prevent loss of Refrigerant

5. Dielectric strength:

- Dielectric strength for a refrigerant is desirable to prevent electric motor directly exposed to the refrigerant

6. Thermal conductivity:

- High thermal conductivity of a refrigerant is desirable because it reduces the flow rate of refrigerant for a given capacity

7. Cost:

- The cost of the refrigerant should be low
- It vary depending upon the capacity of refrigerating system

The characteristics of some refrigerants make them suitable for use with reciprocating compressor and other refrigerants are best suited to rotary or centrifugal compressor. Therefore in order to select a correct refrigerant, it is necessary that it should satisfy those properties which

make it ideal to be used for the particular application. High flammable refrigerants have bigger risk, the refrigerant R-410A, Non-Flammable refrigerant and R-32.

Designation System for Refrigerants:

The refrigerants are internationally designated as 'R' followed by certain numbers such as R-11, R-12. R-114 etc. A refrigerant followed by a two-digit number indicates that a refrigerant is derived from methane base while three-digit number respresents ethane base. The first digit on the right is the number of fluorine (F) atoms in the refrigerant. The second digit from the right is one more than the number of hydrogen (H) atoms present. The third digit from the right is one less than the number of carbon (C) atoms, but when this digit is zero, it is omitted. The general chemical formula for the refrigerant, either for methane or ethane base, is given as $C_mH_nCl_pF_q$ in which $n+p+q= 2m + 2$

where

m = Number of carbon atoms.

n= Number of hydrogen atoms,

p= Number of chlorine atoms, and

q= Number of fluorine atoms.

the number of the refrigerant is given by R (m-1)(n+1) (q).

Let us consider the following refrigerants to find its chemical formula and the number.

1. Dichloro-difluoro-methane

In this refrigerant Number of chlorine atoms,

$p = 2$

Number of fluorine atoms, $q=2$

and number of hydrogen atoms.

$n=0$

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

$0+2+2 = 2m +2$

or

m=1
Number of carbon atoms =1 Thus the chemical formula for dichloro-difluoro-methane becomes CCl_2F_2, and the number of refrigerant becomes R (1-1) (0+1)(2) or R-012 i.e R-12

2. Dichloro-tetrafluoro-ethane

In this refrigerant

Number of chlorine atoms, p=2

Number of fluorine atoms, q=4

and number of hydrogen atoms, n=0

We know that n + p + q =2m+2

0+2+4=2m +2

or

m=2

Number of carbon atoms 2

Thus the chemical formula for dichloro-tetrafluoro ethane becomes C_2Cl_2,F_4, and the number

of refrigerant becomes R(2-1) (0+1) (4) or R-114.

3. Dichlore-trifluoro-ethane

In this refrigerant

Number of chlorine atoms, p=2

Number of fluorine atoms, q=3

and number of hydrogen atoms, n=1

We know that n + p + q =2m+2

1+2+3=2m +2

or

m=2

Number of carbon atoms 2

Thus the chemical formula for dichloro triflouro-ethane becomes $CHCl_2CF_3$, and the number of refrigerant becomes R(2-1)(1+1)(3) or R-123

Substitutes for Chloro-fluoro-Carbon (CFC) Refrigerants:

The most commonly used halo-carbon or organic refrigerants are the chloro-fluoro derivatives of methane (CH_4) and ethane(C_2H_6.). The fully halogenated refrigerants with **chlorine (Cl) atom** in their molecules are referred to as **chloro-fluoro-carbon (CFC)** refrigerants. The refrigerants such as **R-11, R-12, R-13, R-113, R-114 and R-115 are CFC refrigerants**

.The refrigerants which contain **hydrogen (H) atoms** in their molecule along with chlorine (Cl) and fluorine (F) atoms are referred to as **hydro-chloro-fluoro-carbon (HCFC) refrigerants**. The refrigerants such as **R-22, R-123 are HCFC refrigerants.**

The refrigerants which **contain no chlorine** atom in their molecules are referred to as **hydro fluoro carbon (HFC) refrigerants**. The refrigerants such as **R-134a, R-152a are HFC refrigerants**. The refrigerants which contain **no chlorine and fluorine atoms** in their molecule are referred to as **hydrocarbon (HC) refrigerants**. The refrigerants such as **R-290, R-600a are HC refrigerants**.

The fluorine (F) atom in the molecule of the refrigerants makes them physiologically more favourable. The chlorine (Cl) atom in the molecule of the refrigerants is considered to be responsible for the depletion of ozone layer in the upper atmosphere which allows harmful ultra-violet rays from the sun to penetrate through the atmosphere and reach the earth's surface causing skin cancer.

At present, the following substitutes are available
1. The HCFC refrigerant R-123a (CF_3CHCl_2) in place of R-11 (CCl_3F)
2. The HFC refrigerant R-134a (CF_3CH_2F) and R-152a (CH_3CHF_2) in place of R12

3 The HFC refrigerant R-143a (CH_3CF_3) and R-125 (CHF_2CF_3) in place of R-502 (a mixture of R-22 and R-115)

4 The HC refrigerants propane R--290 (C_3,H_8) and isobutene R-600a (C_4H_{10})
in place of R-12

Applications of refrigeration

cold storage: The storages which are used for short-term storage purposes are known as cold storages.

- The period of short term cold storages ranges from one to two days or to a week.
- The maximum period of long term cold storages ranges from seven to ten days for some sensitive products.
- Most of the foods for short-term storages are stored at a temperature slightly above the freezing point and the relative humidity and air motion should be controlled to prevent excessive loss of moisture from fruits and vegetables.
- When different types of food products are stored , then it is called mixed storage to minimise the chances of damaging the more sensitive products.
- The condition of the products at the time of entering the storage is one of the important factors for determining storage life of a refrigerated products.

dairy refrigeration: Pasteurization method is used on large scale to protect milk against bacterial infection.

- The milk used for the preparation of milk products like cheese, butter and ice cream is pasteurized.
- Refrigeration is the most important utility required for dairy plants for low temperature storage of different food and dairy products. It is also very essential for cold chain of handling of milk and other perishable food products.
- ammonia based vapour compression refrigeration systems are the most preferred mode for cooling in milk processing plants. Ammonia based systems are low pressure systems with very less sophistication. They have good heat transfer properties, low cost and high efficiency.

Ice plant:

- The function of an ice plant or ice factory is to make or form ice in large quantity and in large size **.** An ice plant which is a huge commercial factory, it uses separate ice making or ice freezing circuit. The cold is produced in one circuit and it is transferred to the water cans by another circuit.

- Ammonia: It is the primary refrigerant which takes heat from brine. This ammonia changes phase while moving in the circuit and Brine: It is the secondary refrigerant which takes heat from the water and produces ice.
- There are three main circuits of working medium in ice plant:

a. Refrigeration circuit: Ammonia as working medium which actually produces the cold by changes its phase at different location
b. Cooling water circuit: Cooling water as working medium to remove the heat of condenser
c. Brine circuit: Brine solution as working medium which transfers the cold from ammonia to water filled cans where ice is to be formed.

water cooler:

There are two types of Water Cooler as follows:
1. Storage type water cooler.
2. Instantaneous type water cooler.

1. Storage type water cooler: In this type of water cooler, the basic cycle is vapour compression cycle consisting of compressor, condenser, fan with motor, expansion device, filter or strainer, thermostatic switch and evaporator coil.

- Temperature is control by thermostatic switch as per our desired temperature.
- Compressor compresses the Refrigerant R12 vapour to high temperature high pressure vapour is then condensed in condenser by fan motor unit. High pressure high temperature vapour converted into High pressure high temperature liquid in condenser.
- Liquid refrigerant passes through strainer or filter which removes moisture and impurities
- The liquid refrigerant is throttled through expansion device (generally capillary tube). In throttling pressure and temperature of liquid drops down. This low-pressure low temperature refrigerant then extracts heat of water from the evaporator. By taking

heat from water refrigerant evaporates and this vapour refrigerant sucked by compressor and process continues.

2. Instantaneous type water cooler:

- This storage type cooler has evaporated coils solders on the wall of storage tank. The tank is either of stainless steel or galvanized steel.
- The Evaporator in instantaneous type consist of two separate coils made of either copper or stainless steel. Copper pipe carries R12 while stainless steel pipe carries water. The two pipe or coils are bound together by soldering.
- Thermostatic filler bulb is clamped on the water coil just at outlet end in case of instantaneous type, while in storage type it is emerged in the water in the tank.

Frost free refrigerator:

A **frost-free freezer** has three basic parts:

- A **timer**
- A **heating coil**
- A **temperature sensor**

- After every six hours or so, the timer turns on the heating coil. The heating coil is wrapped among the freezer coils. The heater melts the ice frosted on it and after a certain level of heat, the temperature sensor senses the rise in temperature above 32 degrees F (0 degrees C) and turns off the heater.
- Because of the frost-free refrigeration, it is much easier to see the food packaging and keeps the food fresh for up to 14 days with minimal effort and more comfort.
- the power consumption will not increase.

- Heating the coils every six hours takes energy, and it also cycles the food in the freezer through temperature changes. the food lasts longer and the freezer uses less power. Due to constant air circulation in frost-free refrigerators, the probability of experiencing bad odours in the fridge remains less.
- The frost-free freezer offers uniform cooling any time, delivers a more precise temperature control to help reduce internal fluctuations.

PSYCHROMETRY AND PROPERTIES

-> In this psychrometry chapter the properties of mixture of air and water vapour are studied.

Dry Air :- The dry air is considered as a mixture of nitrogen and oxygen neglecting the small percentages of other gases.

Moist Air :- It is a mixture of dry air and water vapour.

Water vapour :- The water vapour present in air is known as moisture.

Dry Bulb Temperature :- The temperature of air measured by ordinary thermometer is known as dry bulb temperature (DBT).

Wet Bulb Temperature :- The temperature measured by the thermometer when its bulb is covered with wet cloth and is exposed to a current of moving air is known as wet bulb temperature. The difference between DBT and WBT is known as WBD.

Dew point temperature :- The temperature of the air is reduced by continous cooling then the water vapour in the air will start condensing at a particular temperature. The temperature at which the condensing starts is known as dew point temperature. DPT is the steam table saturation temperature corresponding to the partial pressure of water vapour.

Specific humidity :- It is the mass of water vapour present per kg of dry air.

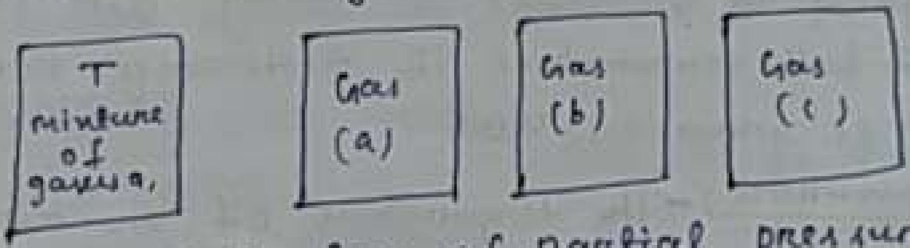
Absolute humidity :- The weight of water vapour present in unit volume of air is known as absolute humidity.

Degree of saturation :- The degree of saturation is defined as the ratio of mass of water vapour associated with unit mass of dry air to mass of water vapour associated with unit mass of dry ai saturated at the same temperature.

Relative Humidity :- The relative humidity is defined as the ratio of actual mass of water vapour in a given volume to the mass of water vapour if the air is saturated at the same tempera

* Dalton's Law of partial pressure -

It states that the total pressure of a mixtu of gases is equal to the sum of the partial pressures exerted by each gas.



As per Dalton's law of partial pressure

$$\boxed{P_t = P_a + P_b + P_c}$$

If this law is applied to the moist air which contains dry air and water vapour, then

$$\boxed{P_t = P_a + P_v}$$

P_t = Total pressure of moist air
P_a = partial pressure of dry air
P_v = partial pressure of water vapour.

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Specific Humidity :-

It is the mass of water vapour present per kg of dry air.

$$\omega = \frac{\text{mass of water vapour in mixture}}{\text{mass of dry air in mixture}}$$

$$\boxed{\omega = \frac{m_v}{m_a}}$$

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

$$\omega = \frac{\left(\frac{P_v V}{R_v T}\right)}{\left(\frac{P_a V}{R_a T}\right)} = \frac{P_v V}{R_v T} \times \frac{R_a T}{P_a V} = \left(\frac{R_a}{R_v}\right) \times \left(\frac{P_v}{P_a}\right)$$

$$R_a = \frac{K}{M_a} \quad , \quad R_v = \frac{K}{M_v}$$

$$\omega = \left(\frac{K/M_a}{K/M_v}\right) \times \frac{P_v}{P_a}$$

$$= \left(\frac{M_v}{M_a}\right) \times \left(\frac{P_v}{P_a}\right)$$

$$= \left(\frac{18}{29}\right) \times \left(\frac{P_v}{P_a}\right)$$

$$\boxed{\omega = 0.622 \times \left(\frac{P_v}{P_t - P_v}\right)}$$

Relative Humidity :(ϕ) :-

$$\phi = \frac{\text{mass of water vapour in a given volume}}{\text{mass of water vapour in same volume if saturate}}$$

$$= \left(\frac{m_v}{m_{vs}}\right) = \frac{\left(\frac{P_v V}{R_v T}\right)}{\left(\frac{P_{vs} V}{R_v T}\right)} = \left(\frac{P_v}{P_{vs}}\right).$$

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

Degree of Saturation :(μ):-

$$\mu = \frac{\text{mass of water vapour associated with unit mass of dry air}}{\text{mass of water vapour associated with saturated unit mass of dry air}}$$

$$\boxed{\mu = \frac{\omega}{\omega_s}}$$

$$\mu = \frac{\cancel{0.622}\left(\frac{P_v}{P_t - P_v}\right)}{\cancel{0.622}\left(\frac{P_{vs}}{P_t - P_{vs}}\right)}$$

$$\boxed{\mu = \frac{P_v\,(P_t - P_{vs})}{P_{vs}\,(P_t - P_v)}.}$$

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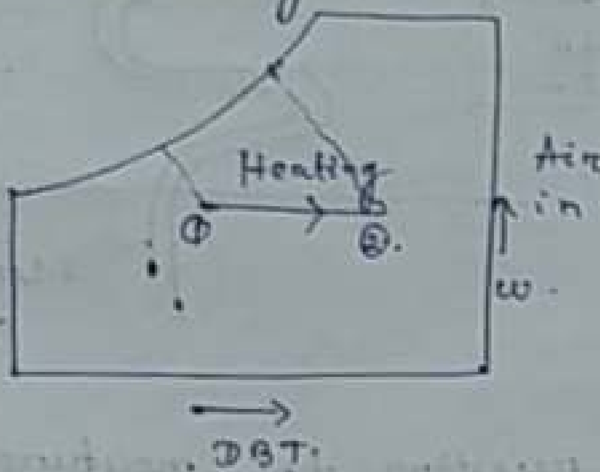
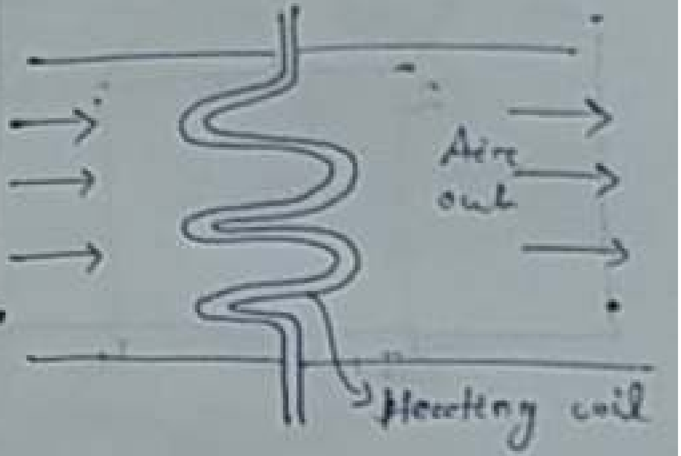
PSYCHROMETRIC PROCESS :-

① **Sensible Heating** :- Heating of air without addition of moisture is termed as sensible heating.

→ The heating can be achieved by passing the air over the heating coil.



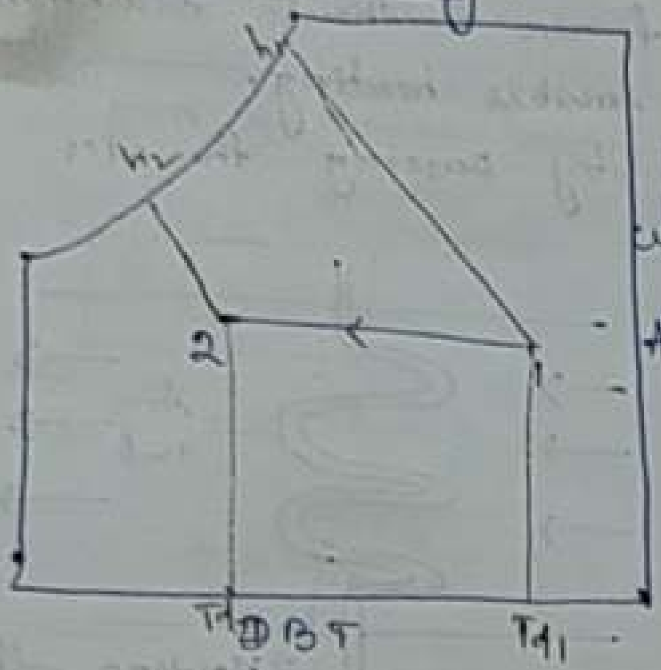


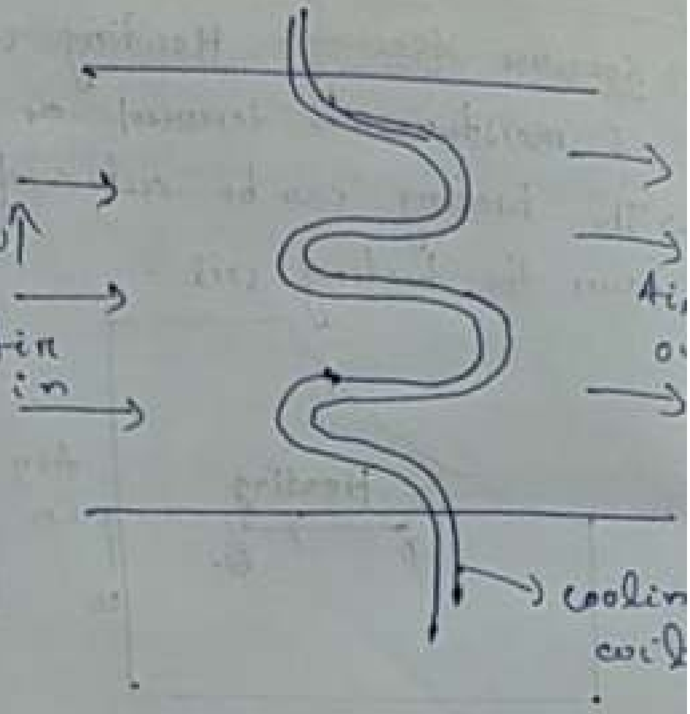
→ In this process the dry bulb Temperature (DBT) increases. specific humidity remains constant.

→ enthalpy value in this process increases and wet bulb temperature increases.

→ Relative humidity value decreases in this process.

Sensible cooling :-





→ Cooling of air without rejecting the moisture from the air is termed as sensible cooling.

→ This process is represented in the psychrometric chart by the line (1-2) from right to left.

→ The heat rejected by air during sensible cooling may be obtained from the psychrometric chart by the enthalpy difference $(h_1 - h_2)$.

→ In this sensible cooling process the specific humidity remains constant.

→ The dry bulb temperature reduces from t_{d_1} to td

→ The relative humidity value increases from ϕ_1 to ϕ_2.

→ heat rejected can be calculated by using the following formula.

$$\boxed{q = h_1 - h_2}$$

$$q = c_{pa}(T_{d1} - T_{d2}) + w c_{ps}(T_{d1} - T_{d2}).$$

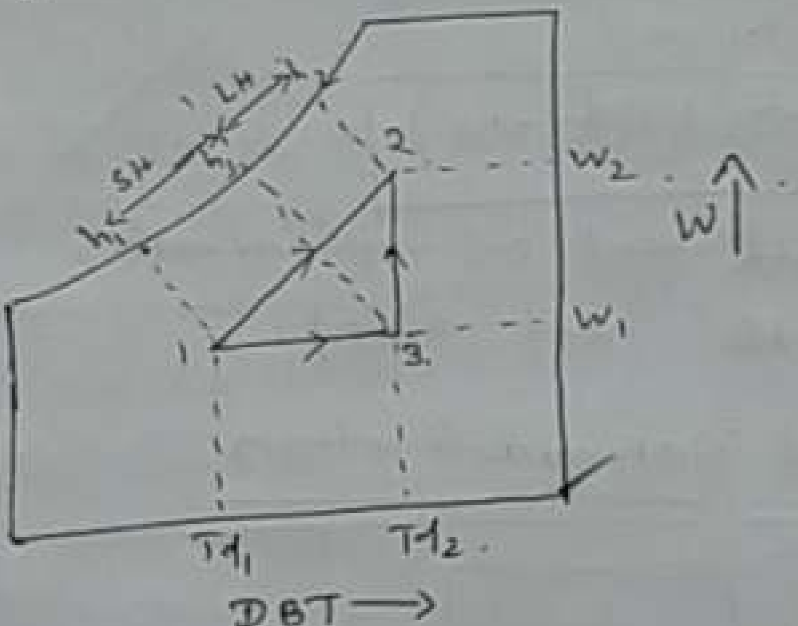
$$= (c_{pa} + w c_{ps})(T_{d1} - T_{d2})$$

$$\boxed{q = c_{pm}(T_{d1} - T_{d2})}$$

c_{pm} is called humid specific heat.

$$\boxed{C_{pm} = 1.022\ \text{KJ/kgK}}$$

Heating and Humidification :-



→ This process is generally used in winter air conditioning to warm and humidify the air.

→ when air is passed through a humidifier having spray water temperature higher than the dry bulb temperature of the entering air, the unsaturated air will reach the condition of saturation and thus the air becomes hot.

→ The process of heating and humidification is shown in (1-2).

- → Air enters at condition 1 and leaves at condition 2.
- → In this process both dry bulb temperature and specific humidity increases.
- → The final relative humidity of the air can be higher or lower than that of the entering air.

Total heat added

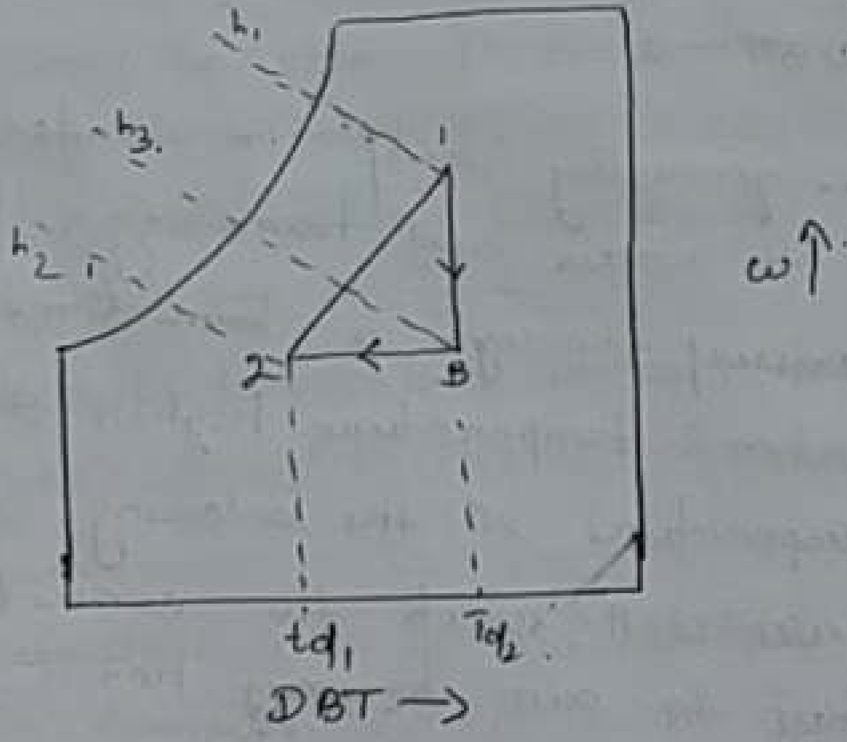
$q = h_2 - h_1$

$$\boxed{q = (h_2 - h_3) + (h_3 - h_1)}$$

$h_2 - h_3$ = Latent heat of vapourisation

$h_3 - h_1$ = sensible heat added.

Cooling and Dehumidification



→ This process is generally used in summer air conditioning to cool and dehumidify the

→ In this process the dry bulb temperature reduces and specific humidity decreases.

→ The final relative humidity of the air is generally higher than that of the . entering air.

→ The dehumidification is possible if the effectiv surface temperature of the cooling coil is less than that of the dew point temperature of the air entering the , coil.

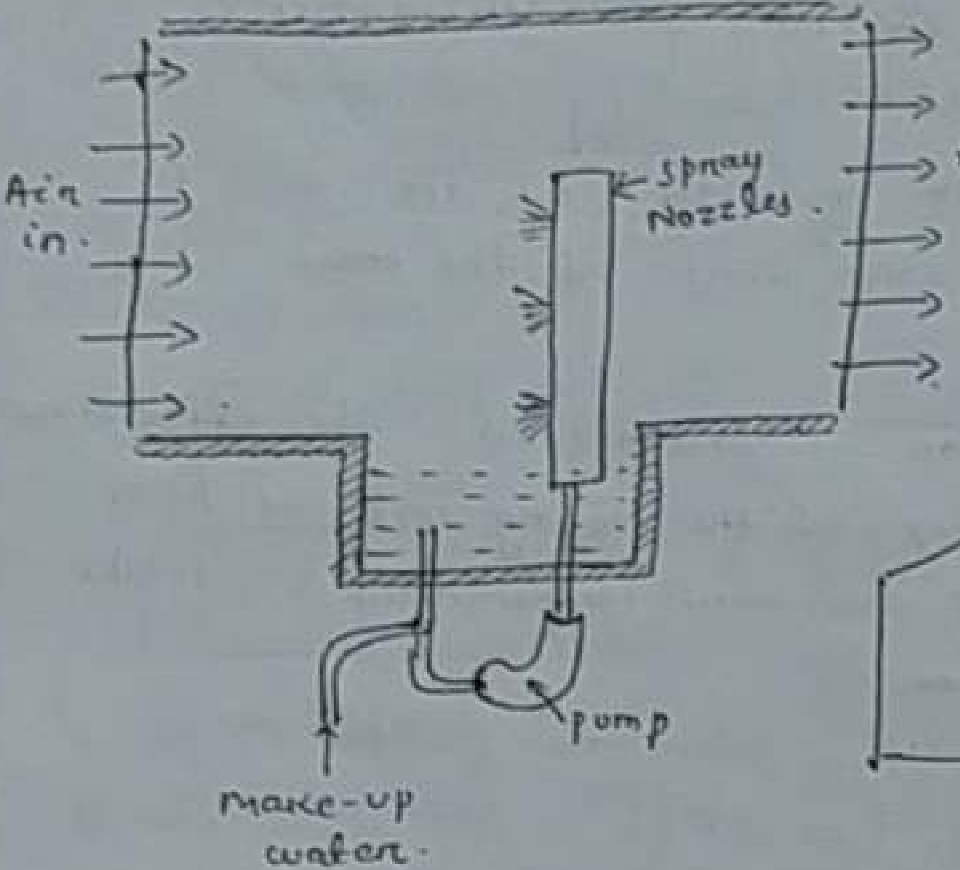
→ The cooling and dehumidification process is represented by the line (1-2).

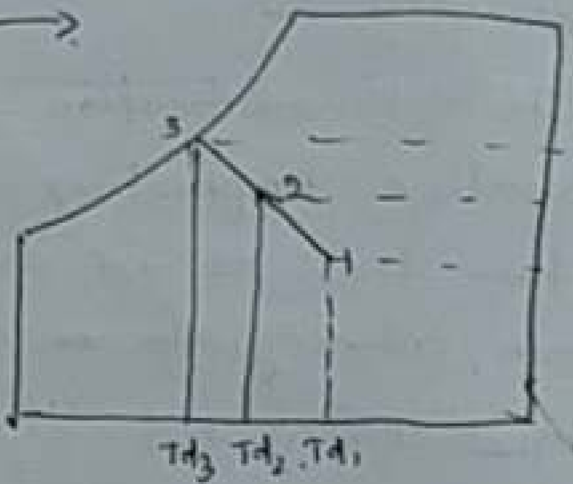
→ The total removed in the process is given by

$$q = (h_1 - h_2) = (h_1 - h_3) + (h_3 - h_2)$$

$$\boxed{q = (LH) + SH}$$

Cooling with Adiabatic Humidification :-





→ When the air is passed through an insulated chamber, having sprays of water maintained at a temperature (t_1) higher than the dew point temperature of the entering air (t_{dp_1}), but lower than its dry bulb temperature (t_{d_1}) of entering air.

→ The temperature of the spray water is equal to the wet bulb temperature (t_{wb}) of the entering air.

→ In this process air is getting cooled and humidified. Since no heat is supplied or rejected from the spray water, so the adiabatic saturation happens. In this process wet bulb temperature remains constant.

→ It is represented by the line (1-3) on the psychrometric chart. Though perfect cooling is not possible always, so the final condition of air is at point '2'.

→ effectiveness of the spray chamber is given by

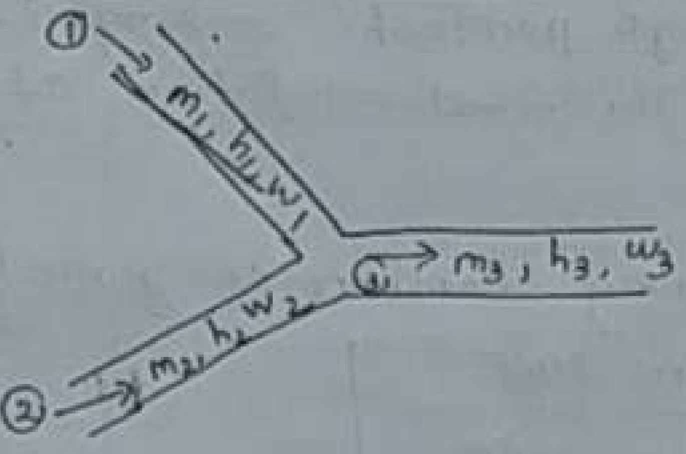
$$\boxed{\eta_H = \frac{\text{Actual drop in DBT}}{\text{~~A~~ ideal drop in DBT}}}$$

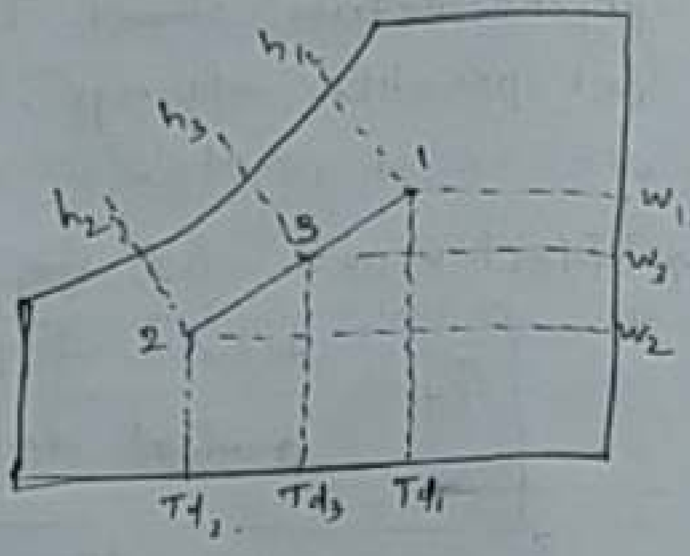
$$\Rightarrow \boxed{\eta_H = \frac{T_{d_1} - T_{d_2}}{T_{d_1} - T_{d_3}}}$$

also it can be represented by the differen between the specific humidity.

$$\boxed{\eta_H = \frac{\omega_1 - \omega_2}{\omega_1 - \omega_3}}$$

Adiabatic Mixing of two Air streams :-





Consider two air streams ① and ② mixing adiabatically as shown in the above figure.

m_1 = mass of air entering at ①

h_1 = enthalpy of air entering at ①

w_1 = specific humidity of air entering at ①.

m_2, h_2, W_2 = mass, enthalpy and specific humidity of air which are entering at point ②.

m_3, h_3, w_3 = mass, enthalpy and specific humidity of air at point ③.

→ For mass balance

$$\boxed{m_1 + m_2 = m_3} \quad \text{——} ①$$

→ For energy balance

$$\boxed{m_1h_1 + m_2h_2 = m_3h_3} \quad \text{——} ②.$$

For mass balance of water vapour

$$\boxed{m_1 W_1 + m_2 W_2 = m_3 W_3} \longrightarrow ③$$

Now substituting the value of m_3

$$m_1 h_1 + m_2 h_2 = m_3 h_3$$

$$\Rightarrow m_1 h_1 + m_2 h_2 = (m_1 + m_2) h_3$$

$$\Rightarrow m_1 h_1 + m_2 h_2 = m_1 h_3 + m_2 h_3$$

$$\Rightarrow m_1 (h_1 - h_3) = m_2 (h_3 - h_2)$$

$$\Rightarrow \boxed{\frac{m_1}{m_2} = \frac{h_3 - h_2}{h_1 - h_3}}$$

Now substituting the value of m_3 in eqn ③.

$$m_1 W_1 + m_2 W_2 = m_3 W_3$$

$$\Rightarrow m_1 W_1 + m_2 W_2 = (m_1 + m_2) W_3$$

$$\Rightarrow m_1 W_1 + m_2 W_2 = m_1 W_3 + m_2 W_3$$

$$\Rightarrow m_1 (W_1 - W_3) = m_2 (W_3 - W_2)$$

$$\Rightarrow \boxed{\frac{m_1}{m_2} = \frac{W_3 - W_2}{W_1 - W_3}.}$$

$$\text{So } \boxed{\frac{m_1}{m_2} = \frac{h_3 - h_2}{h_1 - h_3} = \frac{W_3 - W_2}{W_1 - W_3}}$$

Human Comfort -

It is that condition of mind, which expresses satisfaction with the enviornment (cold or hot).

The human body works best at a certain temp.

Effective temperature ←

The degree of warmth or cold (temperature) felt by human body depends mainly on the following three factors :

a. Dry bulb temp.
b. Relative humidity
3. Air velocity

→ Effective temperature is defined as that index which corelates the combined effects of dry bulb temp, relative humidity and air velocity on the human body.

→ The value of effective temp. is equal to the temperature of still saturated air (i.e 5 to 8 m/min air velocity)

→ The practical application of effective temp. is presented by Comfort Chart.

Factors affecting Optimum Effective temperature

① Climatic and seasonal difference:

→ The people living in colder climates feel comfortable at a lower temp. than those having in warmer region.

→ In winter season the optimum effective temp. is 19°c and in summer season the optimum effective temp. is 22°C.

② **Clothing :**

→ The person with light clothings need less optimum temperature than a person with heavy clothings.

③ **Age and Sex :**

→ The women of all ages require higher effective temp. (0.5°c) than men.

→ The children also need higher effective temperature than adults.

④ **Duration of stay -**

→ ~~If~~ the ~~stad~~ stay in a room (i.e in bank) is shorter, then effective temp. is required higher than for long stay (i.e in office)

⑤ **kind of activity -**

→ When the activity of person is heavy such as the people working in a factory, dancing hall, then low effective temp. is needed than for the people sitting in a cinema hall.

⑥ **Density of Occupants :**

→ The effect of body radiant heat from person to person in ~~adu~~ auditorium is large which require a slight lower effective temperature.

Comfort Chart :

→ A chart which relates effective temp, dry bulb temp, wet bulb temp. and air movement to human comfort

→ In this Chart, the dry bulb temp is taken as abscissa and the wet bulb temperature as ordinates.

→ The study of the chart reveals that the several combinations of wet and dry bulb temperatures with different relative humidities will produce the same effective temperature.

→ The comfort chart shows the range for both summer and winter condition ~~[illegible]~~ within which a condition of comfort exists for people.

→ For winter condition the comfort chart indicates an effective temp. of 20°C. ~~of~~ for 97.7% people and for Summer condition the comfort chart indicates an effective temp. of 21.6°C ~~of 98~~ for 98% people.

→ For comfort condition the women require 0.5°C higher effective temp. than men.

→ The greater the degree of activity, the lower the effective temp. necessary for comfort.

→ The effective temp. is 21°C for still air velocity i.e 6 m/min at 24°C dry bulb temp. and 16°C wet bulb temp. condition.

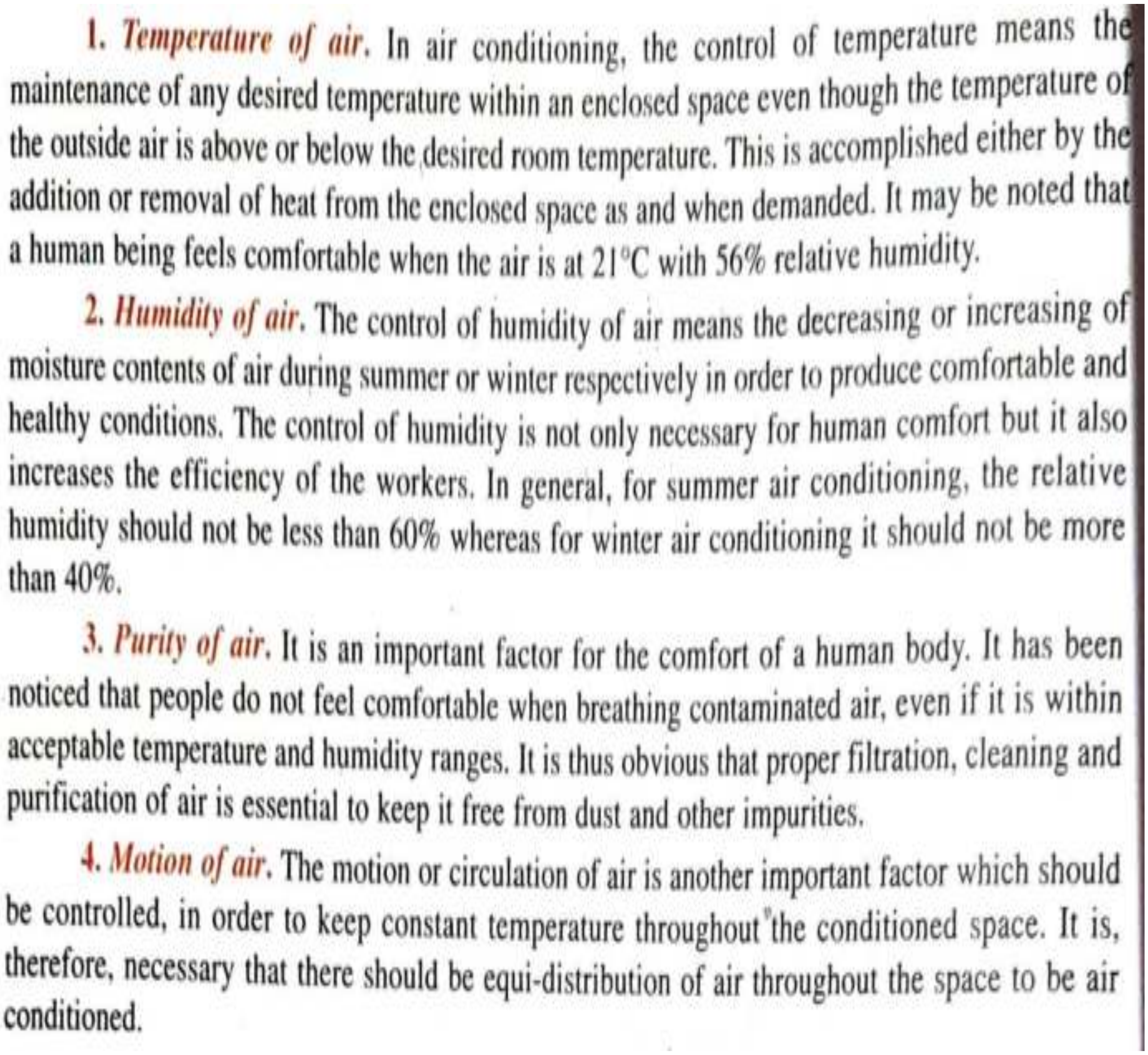
AIR CONDITIONING SYSTEMS

Air conditioning is the process of removing heat and moisture from the interior of an occupied space to improve the comfort of occupants. Air conditioning can be used in both domestic and commercial environments. This process is most commonly used to achieve a more comfortable interior environment, typically for humans

Factors affecting comfort air conditioning:

Following are the Factors affecting Comfort Air conditioning:

1. Temperature
2. Humidity
3. Purity of air
4. Motion of air.



1. *Temperature of air.* In air conditioning, the control of temperature means the maintenance of any desired temperature within an enclosed space even though the temperature of the outside air is above or below the desired room temperature. This is accomplished either by the addition or removal of heat from the enclosed space as and when demanded. 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.* The control of humidity of air means the decreasing or increasing of moisture contents of air during summer or winter respectively in order to produce comfortable and healthy conditions. The control of humidity is not only necessary for human comfort but it also increases the efficiency of the workers. 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.* It is an important factor for the comfort of a human body. It has been noticed that people do not feel comfortable when breathing contaminated air, even if it is within acceptable temperature and humidity ranges. It is thus obvious that 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 temperature throughout the conditioned space. It is, therefore, necessary that there should be equi-distribution of air throughout the space to be air conditioned.

Equipments Used in an Air Conditioning System

Following are the main equipments or parts used in an 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 processes for summer air conditioning or heating and humidification processes for winter air conditioning.

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

4. *Supply outlets*. These are grills which distribute the conditioned air evenly in the room.

5. *Return outlets*. These are the openings 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 harmful bacteria from the air.

Classification of Air Conditioning Systems

The air conditioning systems may be broadly classified as follows :

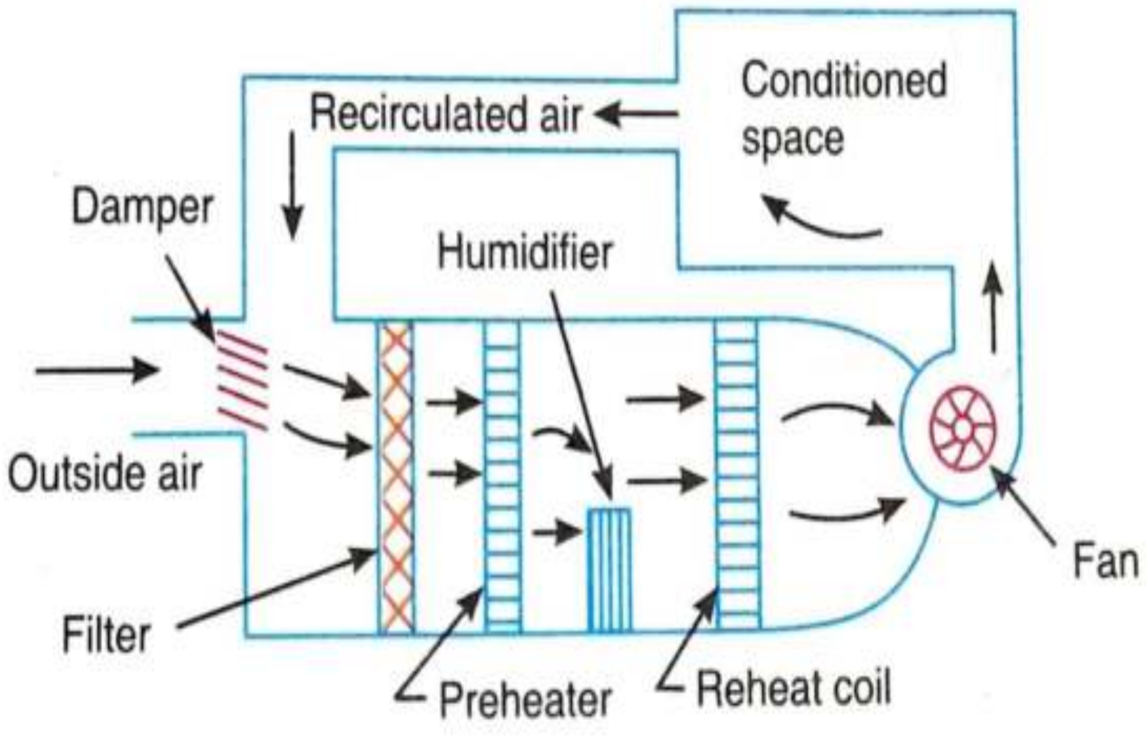
1. *According to the purpose*
   - (*a*) Comfort air conditioning system, and
   - (*b*) Industrial air conditioning system.
2. *According to season of the year*
   - (*a*) Winter air conditioning system,
   - (*b*) Summer air conditioning system, and
   - (*c*) Year-round air conditioning system.
3. *According to the arrangement of equipment*
   - (*a*) Unitary air conditioning system, and
   - (*b*) Central air conditioning system.

Winter Air Conditioning System:

In winter AC System, the inlet is heated by the heater, and in winter season due to less present in the air, we also need to add the moisture particle to the air, generally, a humidification system is added to maintain the moisture quantity.

Working of Winter Air Conditioning System:

In winter air conditioning, the air is heated and is accompanied by humidification.



Winter air conditioning system

1. The outside air flows through a damper and mixes up with the recirculated air which is obtained from the conditioned space.

2. The mixture here passes through a filter to remove dirt, dust, and other impurities.

3. The air now passes through a preheat coil to prevent possible freezing of water due to which dry bulb temperature increases to a very high value and the relative humidity drops to a low value.

4. This air is being pumped into the humidifier.

So, humidification of air (addition of moisture) is done and then the air is made to pass through a reheat coil to bring the air to the designed dry bulb temperature.

5. Now the conditioned air is supplied to the conditioned space by mea fan. From the conditioned space, a part of the used air is exhausted to the atmosphere by the exhaust fans or ventilators.

The remaining part of the air known as recirculated air is again conditioned

6. Initially, the relative humidity is 60% in the winter season, so to reduce it, a process of reheating is done where it is reduced to 20%.

So it is again humidified due to which it reaches a point of 80% or 100% RH where the DBT is very low.

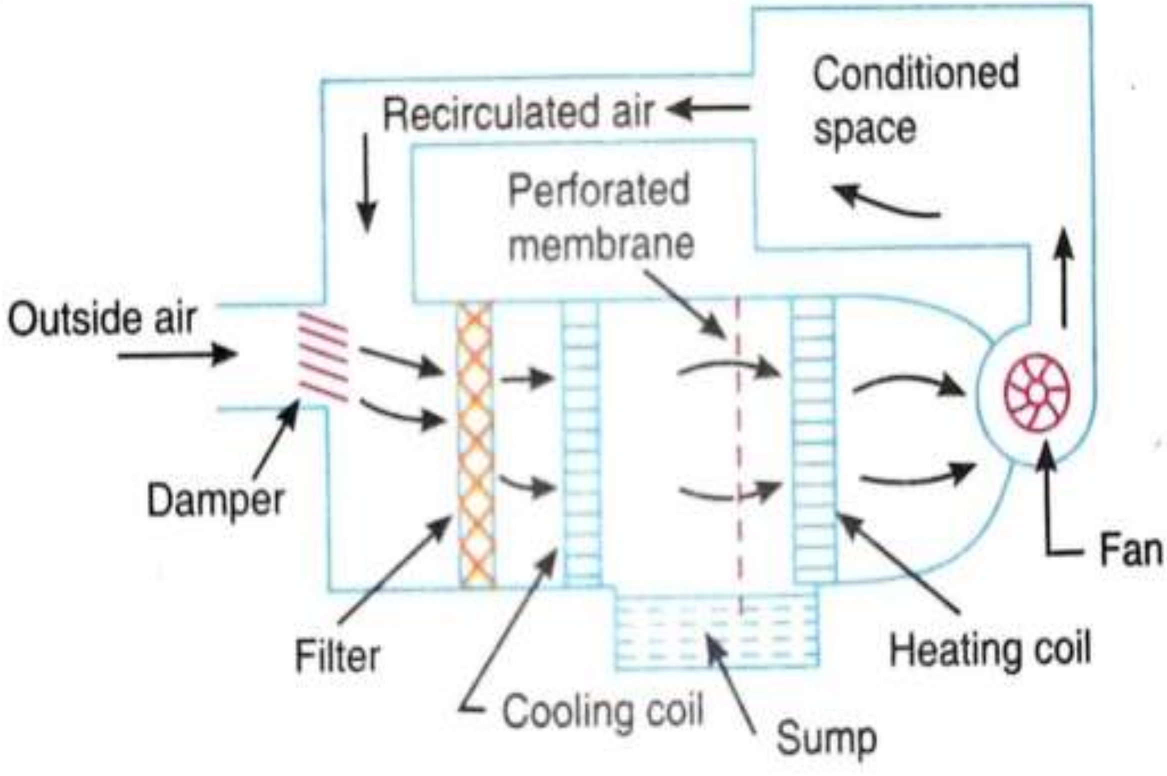
So in order to get the desired dry bulb temperature, again the process of reheating is done where the desired percentage 40% RH is also obtained.

7.A damper is used in order to control the area and have an intake of the required amount of air.

Summer Air Conditioning System:

Initially, during summer, the dry bulb temperature is high and the relative humidity of air is low.

Relative humidity should not be less than 60% according to the comfort conditions for summer air conditioning.



Summer air conditioning system

Working of Summer air conditioning system:

1. The outside air(atmospheric air) flows through the air filter to remove impurities or dust particles present in the air. The air now passes through a cooling coil.

2. The coil has a temperature much below the required dry bulb temperature of the air and very high relative humidity in the conditioned space.

So the cooled air is pumped into a dehumidifier, where it loses its moisture in the conditioned space.

3. After that, the air is made to pass through a heating coil which heats the air slightly.

This is done to bring the air to the designed DBT and relative humidity(RH).

4. 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 atmosphere by the exhaust fans or ventilators.

The remaining part of the used air is again conditioned.

5. The outside air is sucked and it is made to mix with the recirculated air to make up for the loss of conditioned air through exhaust fans or ventilation from the conditioned space.