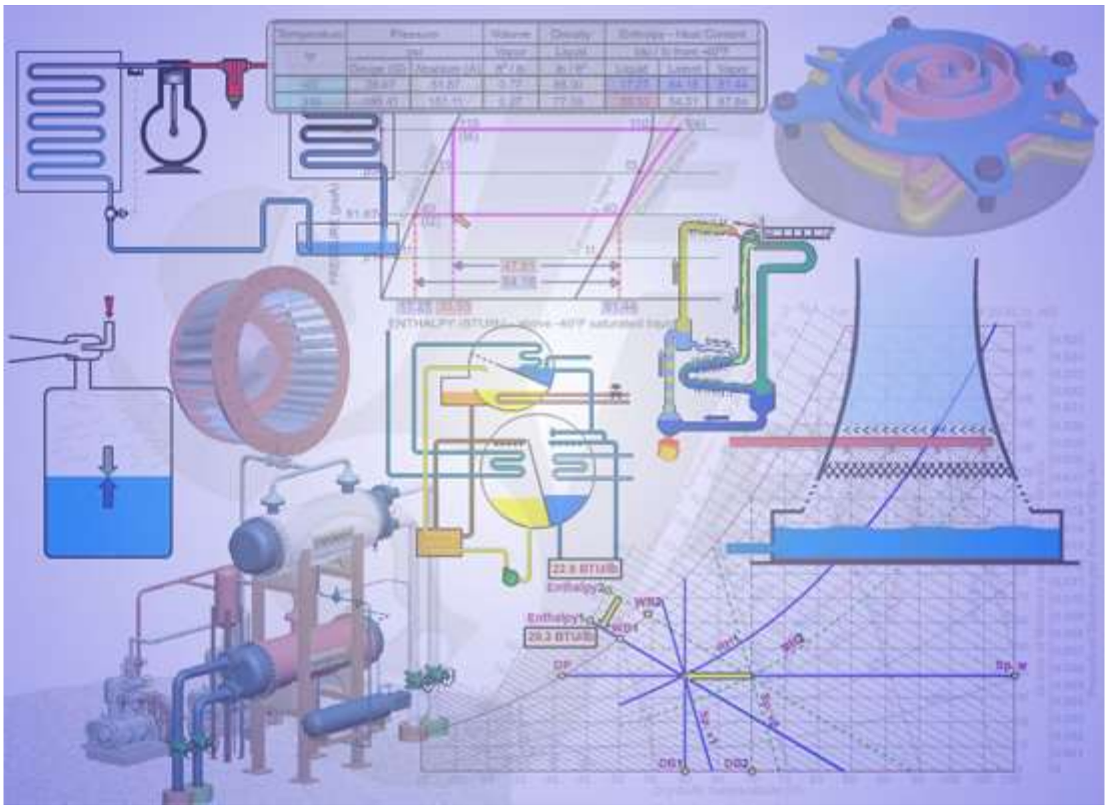
NILASAILA INSTITUTE OF SCIENCE & TECHNOLOGY
SERGARH-756060, BALASORE (ODISHA)
(Approved by AICTE& affiliated to SCTE&VT, Odisha)

Refrigeration andAir Conditioning

(Th- 05)



FIFTH SEMESTER

MECHANICAL ENGINEERING

Prepared By: ***Er.Manoranjan Beher***

CONTENTS

CHAPTER - 01

AIR REFRIGERATION CYCLE

Learning Objectives :

AIR REFRIGERATION CYCLE.

Definition of refrigeration and unit of refrigeration.

Definition of COP, Refrigerating effect (R.E)

Principle of working of open and closed air system of refrigeration.

Calculation of COP of Bell-Coleman cycle and numerical on it.

Definition of Refrigeration And Unit of Refrigeration.

- The term Refrigeration may be defined as the process of removing heat from a substance under controlled condition.
- It also includes the process of reducing and maintaining the temperature of a body below the general temp. of its surrounding.

Unit of Refrigeration :

- Unit of refrigeration is "Tonne of Refrigeration".
- It is denoted by TR

A tonne of refrigeration is defined as the amount of refrigeration effect produced by the uniform melting of one tonne of ice from and at 0^0C in 24 hour.

But latent heat of Ice is 335 KJ/Kg

So, 1 TR = 335 X 1000 KJ in 24 hour

$$= \frac{1000 X 335}{24 x 60} = 232.6 \text{ KJ/min}$$

❖ But in actual practice 1 TR = 210 KJ/min

Definition of Co-efficient of performance (COP):

- COP is defined as the ratio of heat extracted in the refrigerator to the work done on the refrigerator.
- It is also called Theoretical COP

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

Where

Q = Amount of heat extracted in the refrigerator

W = Amount of work done

- Value of COP is always greater then one .

Refrigeration Effect (RE) :

Refrigeration Effect is "the quantity of heat that each pound of refrigerant absorbs from the refrigerated space to produce useful cooling"

Principle of working of open and closed air system of refrigeration

Air Refrigeration Cycle :

- Here air is used as working medium to extract heat
- Heat carrying capacity per Kg of air is very less.
- Its COP is very less.
- It is used in air refrigeration unit due to low weight and volume of the equipment.

Open Air Refrigeration Cycle :

- In this cycle, air is directly led to the space to be cooled, allowed to circulated through the cooler and then returned to the compressor to start another cycle.

Disadvantages :

1. Size of compressor and expander is large
2. Moisture is regularly carried away.
3. Frost is formed which can clog the line
4. A drier is used

Closed Air Refrigeration Cycle :

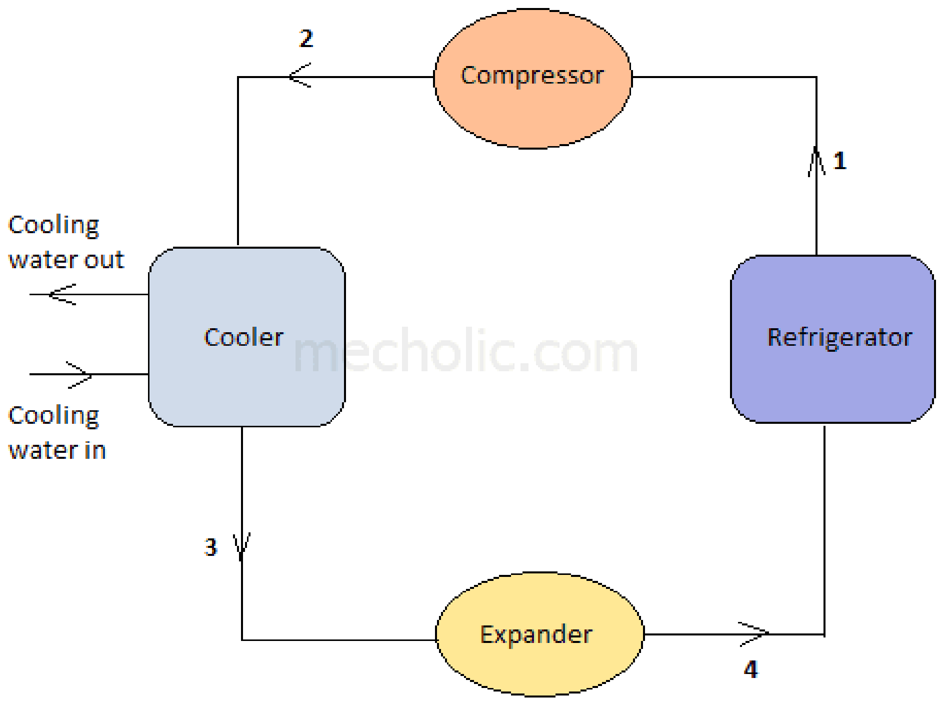
- Here the air is passed through the pipes.
- Air is used for absorbing heat from the other fluid (Brine) and thus cooled brine is circulated in the space to be cooled.

Advantages :

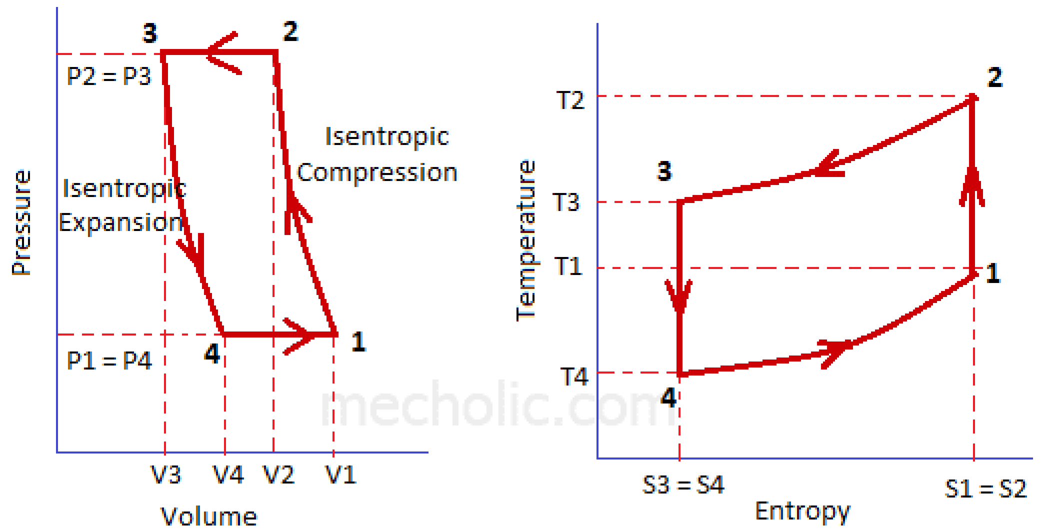
1. It can work at higher suction pressure
2. Volume of air handled by Compressor and expander is less
3. Operating pressure ratio can be reduced
4. Higher COP

Bell-Coleman Cycle (Reverse Brayton Cycle) :

- It is a air refrigeration cycle where refrigerant is air.
- It consists of Compressor, A Cooler, an Expander and Refrigerator.



Bell-Coleman cycle is represented in P-V and T-S diagram below. It consists of two isentropic process and two isobaric process.



(a) P-V Diagram (b) T-S Diagram

Process 1-2 : Isentropic Compression Process :

- The cold air from the refrigerator enter the compressor

- Its pressure Increased by the compressor, hence temp. also increases.
- No heat added or extracted during this process.

Process 2-3 : Constant Pressure Cooling Process :

- Warm air passes through the cooler.
- Temp. reduced from T_2 to T_3 at constant pressure.
- Heat rejected by the air during this process

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

Process 3-4 : Isentropic Expansion Process :

- Air enter the expander and expanded from pressure P_3 to P_4 .
- Temp. decreases from T_3 to T_4.
- No head added or extracted.

Process 4-1 : Constant Pressure Expansion Process :

- The cold air passes through refrigerator
- It is expanded at constant pressure.
- Temp. increases from T_4. To T_1
- Head absorbed by the air during this process

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

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

= Heat rejected – Heat absorbed

$$= Q_R - Q_A = C_p (T_2 - T_3) - C_p (T_1 - T_4)$$

Coefficient of performance,

$$COP = \frac{Heat\ absorbed}{Work\ done}$$

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

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

$$COP = \frac{T_4(\frac{T_1}{T4} - 1)}{T_4(\frac{T_2}{T_3} - 1) - T_4(\frac{T_1}{T_4} - 1)}$$

where $\gamma = Cp/Cv$

For isentropic expansion process 3-4:

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

Since, $P_2 = P_3$ and $P_1 = P_4$, therefore from the above equations:

$$\frac{T_2}{T_{14}} = \frac{T_3}{T_4} \text{ or } \frac{T_2}{T_3} = \frac{T_1}{T_4}$$

Substituting this in the COP equation:

$$\textbf{COP} = \frac{T_4}{T_3 - T_4} = \frac{1}{\frac{T_3}{T_T} - 1}$$

$$= \frac{1}{\left(\frac{P_3}{P_4}\right)^{\frac{y-1}{y}} - 1}$$

$$= \frac{1}{\left(\frac{P_2}{P_1}\right)^{\frac{y-1}{y}} - 1}$$

$$\textbf{COP} = \frac{1}{(r_p)^{\frac{y-1}{y}} - 1}$$

r_p = Compression or expansion ration = $\frac{P_2}{P_1} = \frac{P_3}{P_4}$

Advantages of the Bell Coleman air refrigeration system

1. Cheap and abundant refrigerant, highly reliable: Air is used as refrigerant, which is easily available and inexpensive.
2. Charging of refrigerant is very easy.
3. Design and construction is simple, No complicated parts and its maintenance cost is low.
4. Refrigerant (Air) is non-toxic, non-flammable, non-corrosive. There is no danger of any kind of leakage.
5. There is no phase change (liquid- gas) during the operation of system.
6. The cold air can be directly used for refrigeration; it is useful in aircraft refrigeration at high altitude.
7. There would be no significant change in the performance of air refrigeration if it is operated much away from its design conditions.
8. It can produce very high temperature differences between hot and cold region. So the same system can be used for both cooling and heating effects. It also helps to achieve very low temperature.

9. Air refrigeration is used in aircraft due to availability cold air at high altitude and it can can achieve both air-conditioning, as well as the pressurization of the cabin.

Disadvantages of the Bell Coleman air refrigeration system

1. Lower C.O.P. compared to other refrigeration cycle.
2. Running cost is high.
3. The mass of air required to circulate in the system is very high when compared to other type of refrigeration cycle due to low specific heat capacity.
4. System components are bulky, large space per ton of refrigeration.
5. The chance of frosting at expander is more due to moisture content in the air.
6. Air contains pollutant particle, so do regular cleaning of air filter in open system.

NUMERICALS

1. In a refrigeration plant working on Bell Coleman cycle, air is compressed to 5 bar from 1 bar. Its initial temperature is 10°C. After compression, the air is cooled up to 20°C in a cooler before expanding back to a pressure of 1 bar. Determine the theoretical C. O.P. of the plant and net refrigerating effect. Take cp = 1.005 kJ /kg K and cv = 0.718 kJ/kg K.

Solution. Given : $p_2 = p_3$ = 5 bar; $p_1 = p_4$ = 1 bar; T1 = 10°C = 10 + 273 = 283 K ; T3 = 20°C = 20 + 273 = 293 K; Cp = 1.005 kJ/kg K; cv= 0.718 kJ/kg K

The p-v and T-s diagrams for a refrigeration plant working on Bell-Coleman cycle, is shown in Fig. (a) and (b) respectively.

Let T_2 and T_4 = Temperature of air at the end of compression and expansion respectively.

We know that isentropic index for compression and expansion process,

$$\gamma = \frac{Cp}{Cv} = 1.005/0.718 = 1.4$$

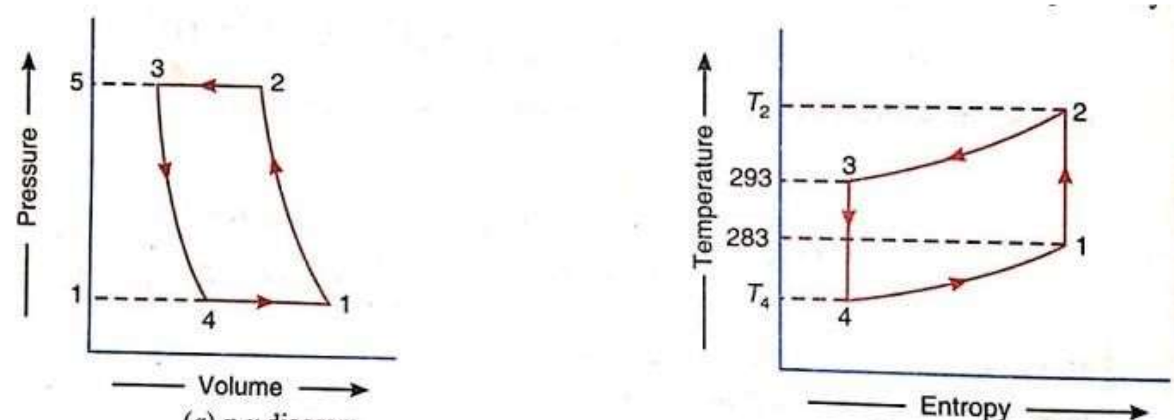
For isentropic compression 1-2,

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{5}{1}\right)^{\frac{1.4-1}{1.4}} = 5^{0.286} = 1.584$$

For isentropic expansion 3-4

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{5}{1}\right)^{\frac{1.4-1}{1.4}} = 5^{0.286} = 1.584$$

$$T_4 = T_3 / 1.0586 = 185 \text{ K}$$



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

Theoretical COP of the plant

$$COP = \frac{T_4}{T_3 - T_4} = \frac{185}{293 - 185} = 1.713$$

Net refrigerating effect :

$$RE = C_P\ (T_1 - T_4) = 1.005\ (283-185) = 98.5 \text{ kJ/kg}$$

2. A refrigerator working on Bell-Coleman cycle operates between pressure limits of 1.05 bar and 8.5 bar. Air is drawn from the cold chamber at 10°C, compressed and then it is cooled to 30°C before entering the expansion cylinder. The expansion and compression follows the law $pv^{1.3}$ = constant. Determine the theoretical C.O.P. of the system.

Solution. Given : $p_1 = p_4 = 1.05$ bar; p_2: $= p_3 = 8.5$ bar; $T_1 = 10°C = 10 + 273 = 283$ K ; $T_3 = 30°C = 30 + 273 = 303$ K ; n = 1.3 The p-v and T-s diagrams for a refrigerator working on the Bell-Coleman cycle is shown in Fig. (a) and (b) respectively.

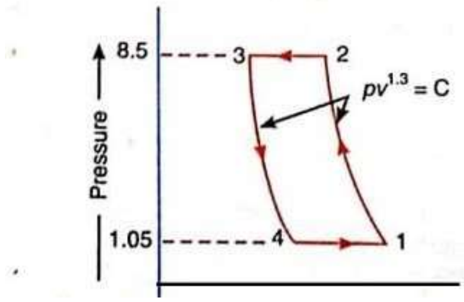
Let T_2 and T_4 = Temperature of air at the end of compression and expansion respectively. Since the compression and expansion follows the law $pv^{1.3}$ = C, therefore

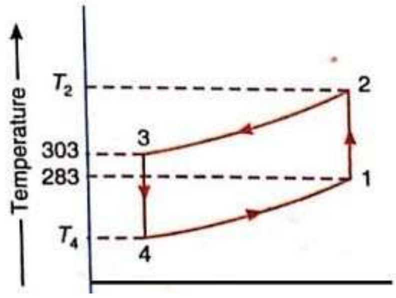
$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = \left(\frac{8.5}{1.05}\right)^{\frac{1.3-1}{1.3}} = 8.1^{0.231} = 1.62$$

$$T_2 = T_1 \times 1.62 = 283 \times 1.62 = 458.5 \text{ K}$$

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{n-1}{n}} = \left(\frac{8.5}{1.05}\right)^{\frac{1.3-1}{1.3}} = 1.62$$

$$T_4 = T_3 / 1.62 = 303 / 1.62 = 187 \text{ K}$$





We know the theoritical COP

$$\text{COP} = \frac{T_1 - T_4}{\frac{n}{n-1}\, x\, \frac{\gamma-1}{\gamma}\,[(T_2 - T_3) - (T_1 - T_4)]}$$

$$= \frac{283 - 187}{\frac{1.3}{1.3-1}\, X\, \frac{1.4-1}{1.4}\, X\, ((458.5 - 303) - (283 - 187))}$$

$$\frac{96}{1.24\ X\ 59.5} = 1.3$$

SHORT QUESTIONS WITH ANSWERS

1. Define COP ? [2010, 2009S, 2007S, 2006S, 2012]

Ans : It is the ratio of refrigerating effect produced to the workdone.

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

Q = Refrigerating effect produced

W = Workdone on the system

2. Define tonne of refrigeration ? Define Unit of refrigerating effect? [2020W, 2010S, 2009S, 2007S, 2006S, 2014S]

It is the amount of Refrigerating effect produced by uniform melting of 1 tonne of ICE from and at 0^0C in 24 hour.

But latent heat of Ice is 335 KJ/Kg

So, 1 TR = 335 X 1000 KJ in 24 hour

$$= \frac{1000X335}{24x60} = 232.6 \text{ KJ/min}$$

- But in actual practice 1 TR = 210 KJ/min

3. What is refrigeration ? [2009S, 2009BP, 2020W]

Ans : Refrigeration is the process of cooling a body below the temperature of its surroundings.

4. Define Open Air Refrigeration Cycle .[2007S]

In this cycle, air is directly led to the space to be cooled, allowed to circulated through the cooler and then returned to the compressor to start another cycle.

5. Define Closed Air Refrigeration Cycle.

Here the air is passed through the pipes. Air is used for absorbing heat from the other fluid (Brine) and thus cooled brine is circulated in the space to be cooled.

LONG QUESTIONS :

1. With neat sketch diagram explain the working principle of domestic refrigerator ? [2020S, 2018BP, 2016S]

2. Describe the reverse Brayton cycle. Derive the COP of the cycle. [2016S, 2018S]

--**--**

CHAPTER – 02

Simple Vapour Compression Refrigeration System

Learning Objectives :

schematic diagram of simple vapors compression refrigeration system'

Types

Cycle with dry saturated vapors after compression.

Cycle with wet vapors after compression.

Cycle with superheated vapors after compression.

Cycle with superheated vapors before compression.

Cycle with sub cooling of refrigerant

Representation of above cycle on temperature entropy and pressure enthalpy diagram

Numerical on above (determination of COP, mass flow)

Introduction

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.

Schematic diagram of simple vapour compressionrefrigeration compression

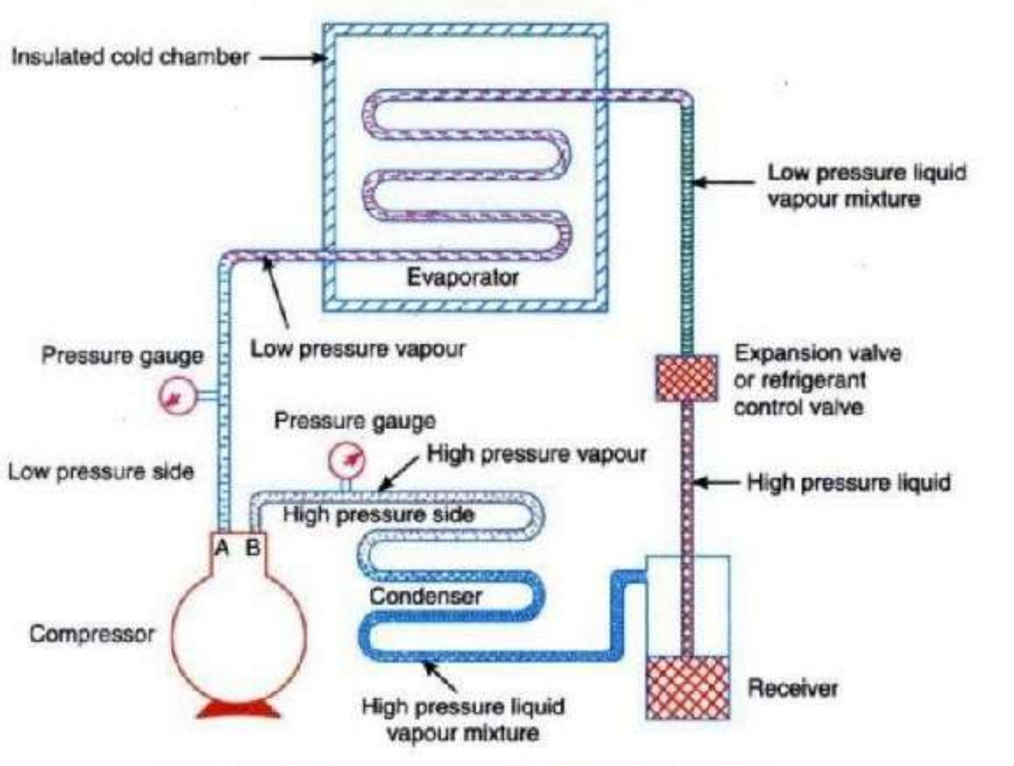


Fig. . Simple vapour compression refrigeration system.

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.

Note: 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).

Types of Vapours compression refrigeration system

Cycle with dry saturated vapours after compression.

Cycle with wet vapours after compression.

Cycle with superheated vapours after compression.

Cycle with superheated vapours before compression.

Cycle with sub cooling of refrigerant

Theoretical Vapour Compression Cycle with Dry Saturated Vapourafter Compression

A vapour compression cycle with ***dry saturated vapour after compression*** is shown on T-s and p-h diagrams below.

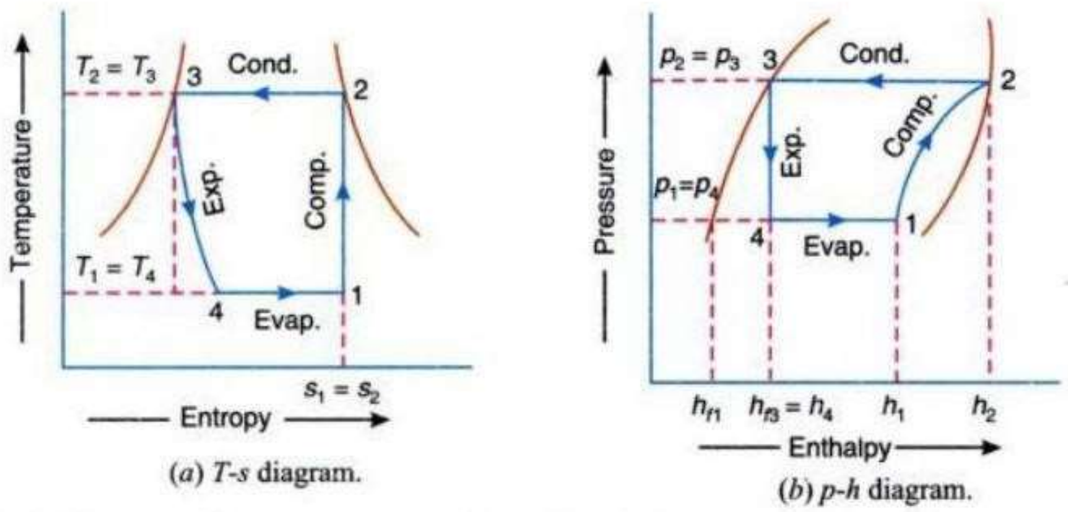


Fig. Theoretical vapour compression cycle with dry saturated vapour after compression.

1. Compression process: The vapour refrigerant at low pressure p1 and temperature T_1 is compressed isentropically to dry saturated vapour as shown by the vertical line 1-2 on T-s diagram and by the curve 1-2 on p-h diagram. The pressure and temperature rises from p_1 to p_2 and T_1 to T_2 respectively.

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

$$w = h_2 - h_1$$

Where h_1 = Enthalpy of vapour refrigerant at temperature T_I, i.e. at suction of the compressor, and h_2 = Enthalpy of the vapour refrigerant at temperature T_2, is i.e. 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 p4 = p1 and temperature $T_4 = T_1$, as shown by the curve 3-4 on T-S diagram and by the vertical line 3-4 on p-h diagram. We have already discussed that some of the liquid refrigerant evaporates as it passes through the expansion valve; but the greater portion is vaporised in the evaporator. We know that during the throttling process, no heat is absorbed or rejected by the liquid refrigerant.

Notes:

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

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

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

4. Vaporising process: The liquid-vapour mixture of the refrigerant at pressure $p_4 = p_1$ and temperature $T_4=T_1$ is evaporated and changed into vapour refrigerant at constant pressure and temperature, as shown by the horizontal line 4-1 on T-S and p-h diagrams. During evaporation, the liquid-vapour refrigerant absorbs its latent heat of vaporisation from the medium (air, water or brine) which is to be cooled. This heat which is absorbed by the refrigerant is called refrigerating effect and it is briefly written as RE. The process of vaporisation continues up to point 1 which is the starting point and thus the cycle is completed. The refrigerating effect or the heat absorbed or extracted by the liquid-vapour refrigerant during evaporation per kg of refrigerant is given by:

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

Where h_{f3} is the Sensible heat at temperature T_3, i.e. enthalpy of Liquid refrigerant leaving the condenser. It can be noticed from the cycle that the liquid-vapour refrigerant has extracted heat during evaporation and the work will be done by the compressor for isentropic compression of the high pressure and temperature vapour refrigerant.

$$\textbf{COP} = \frac{\textbf{Refrigerating effect}}{\textbf{Work Done}} = \frac{(\mathbf{h1 - h4})}{(\mathbf{h2 - h1})}$$

Numerical : 01

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.

Solution

Given: $p_1=p_4=2$ bar; $x_1=0.85$; $x_4=0.19$; w=150kJ/kg; $m_a=4.5$kg/min;

$h_{fg}=1325$kJ/hg; $v_g=0.58m^3$/kg C.O.P.

Since the ammonia vapour at entry to the evaporator (i.e. at point 4) has dryness fraction (x_4) equal to 0.19, therefore enthalpy at point 4,

$h_4=x_4 \times h_{fg}=0.19\times1325=251.75$kJ/kg

Similarly, enthalpy of ammonia vapour at exit i.e. at point 1,

$h_1=x_1 \times h_{fg}=1126.25$ KJ/kg

Therefore heat extracted from the evaporator or refrigerating effect,

$RE=h_1-h_4=1126.25-251.75=874.5$KJ/Kg

We know that work done during compression,

W=150 KJ/kg

Therefore

C.O.P=RE / W =874.5/150=5.83 **(Ans)**

Volume of vapour entering the compressor per minute

We know that volume of vapour entering the compressor per minute

= Mass of refrigerant/ min X Specific volume

= $ma \times v_g=4.5\times0.58=2.61m^3$/min **(Ans)**

Example-02

The temperature limits of an ammonia refrigerating system are 25° C and -10° C. If the gas is dry at the end of compression, calculate the coefficient of performance of the cycle assuming no undercooling of the liquid ammonia. Use the following table for properties of ammonia:

Temperature (°C)	Liquid heat (kJ/kg)	Latent heat (kJ/kg)	Liquid entropy (kJ/kg K)
25	298.9	1166.94	1.1242
-10	135.37	1297.68	0.5443

Solution

Given: T_2=T_3=25°C=25+273=298K; T_1=T_4=−10°C=263K; h_{f3}=h_4=298.9KJ/kg; h_{fg2}=1166.94KJ/kg; s_{f2}=1.1242kJ/kgK; h_{f1}=135.37KJ/kg; h_{fg1}=1297.68KJ/kg; s_{f1}=0.5443KJ/kgK

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

Let x_1 = Dryness fraction at point 1.

We know that entropy at point 1,

$S_1 = S_{f1} + x_1 .. h_{fg1}/T_1$

$= 0.5443 + X_1 . (1297.68/ 263)$

$= 0.5443 + 4.934x\ X_1$ .... (i)

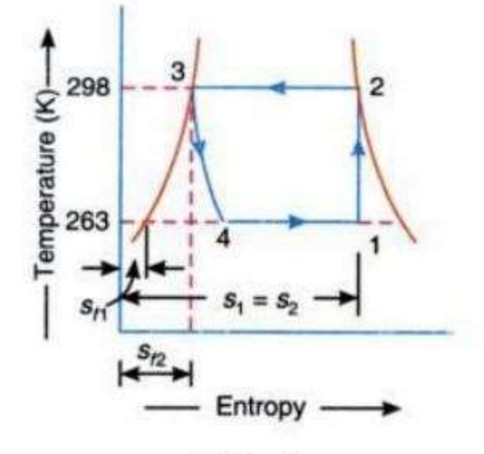
Similarly, entropy at point 2,

$S_2 = S_{f2} + x_1 . h_{fg2}/T_2$

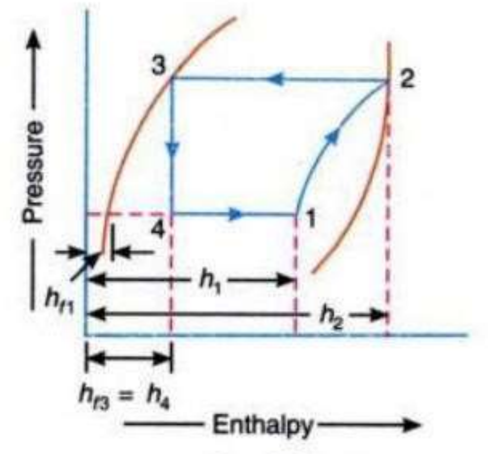
$= 0.5443 + 1166.94/298 = 5.04$ (ii)

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

$0.5443 + 4.934\ x_1 = 5.04$ or $x_1 = 0.91$



(a) T-s diagram.



(b) p-h diagram.

We know that enthalpy at point 1,

$h_1 = h_{f1} + x_1 h_{fg1} = 135.37 + 0.91 \times 1297.68 = 1316.26 kJ/$

and enthalpy at point 2,

$h_2 = h_{f2} + hf_{g2} = 298.9 + 1166.94 = 1465.84 kJ/$

Therefore coefficient of performance of the cycle

$$= \frac{h1 - hf3}{h2 - h1}$$

$$= \frac{1316.26 - 298.9}{1465.84 - 1316.26}$$ **(Ans)**

Theoretical Vapour Compression Cycle with Wet Vapourafter Compression

Example 4

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: $T_2=T_3=25°C=25+273=298K$; $T_1=T_4=-5°C=-5+273=268K$; $x_1=0.6$;
$h_{f3}=hf2=164.77kJ/kg$; $h_{f1}=h_{f4}=72.57kJ/kg$; $s_{f2}=0.5978kJ/kgK$; $s_{f1}=0.2862kJ/kgK$;
$h'_2=282.23kJ/kg$; $h'1=321.33kJ/kg$; $s'_2=0.9918kJ/kgK$; $s'_1=1.2146kJ/kgK$; $h_{fg2}=117.46kJ/kg$;
$h_{fg1}=248.76kJ/kg$

The T-s and p-h diagrams are shown below.

First of all, let us find the dryness fraction at point 2, i.e. x_2.

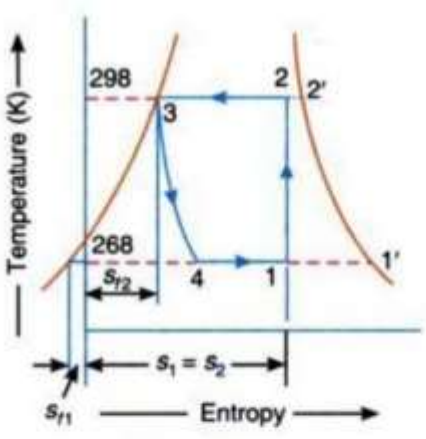
We know that the entropy at point 1,

$$S_1=S_{f1}+X_1h_{fg1}/T_1=0.2862+0.6\times248.76/268=0.8431...(i)$$

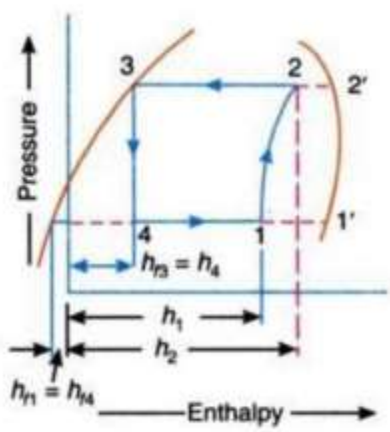
Similarly, entropy at point 2,

$$s_2=s_{f2}+X_{2.}\ hf_{g2}/T_2=0.5978+x_2\times117.64/298s$$

$$=0.5978=0.3941x_2 ....(ii)$$



(a) T-s diagram.



(b) p-h diagram.

OR $X_2 = 0.622$

We know that enthalpy at point 1,

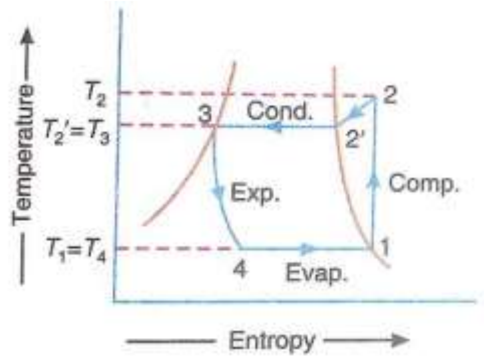
$h_1=h_{f1}+x_1\ h_{fg1} = 72057 + 0.6 \times 248.76 = 221.83$ kJ/Kg

enthalpy at point 2,

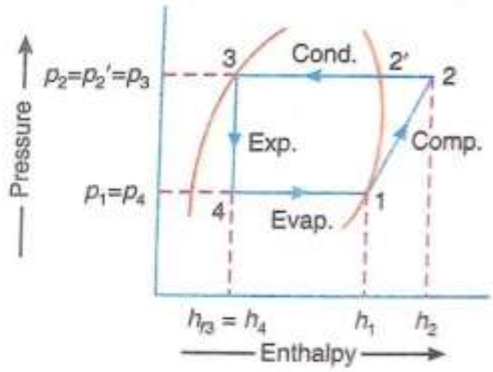
$h_1=h_{f1}+x_2\ h_{fg2} = 164.77 + 0.622 \times 117.46 = 237.83$ kJ/Kg

Theoretical COP $= = \frac{h1-hf3}{h2-h1} = \frac{221.83-164.77}{237.83-221.83} = 57.06/16 = 3.57$

Theoretical Vapour Compression Cycle with Superheated Vapourafter Compression :



(a) T-s diagram.



(b) p-h diagram.

A vapour compression cycle with super heated vapour after compression is shown on T-s and p-h diagram. 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 the entropies at point 1 and 2.

Now the COP can be found out by the formula

$$\text{COP} = \frac{\textit{Refrigerating effect}}{\textit{Work done}} = = \frac{h_1 - h_{f3}}{h_2 - h_1}$$

A little consideration will show that the superheating increases the refrigerating effect and the amount of work done in the compressor. Since the increase in refrigerating effect is less as compared to increase in work done, therefore, the net effect of superheating is to have low coefficient of performance

Example 1

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

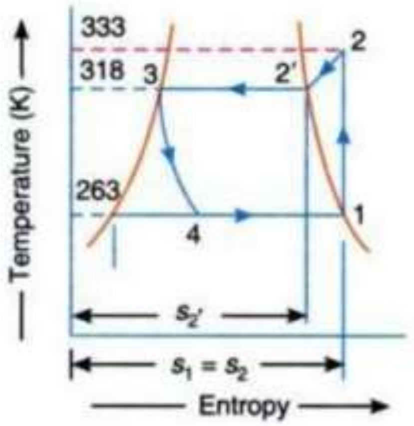
Saturation temp in ^{0}C	**Enthalpy in kJ/Kg**		***Entropy in kJ/Kg K***	
	Vapour	***Liquid***	***Liquid***	***Vapour***
-10^{0}C	***460.7***	***45.4***	***0.183***	***1.637***

45^{0}C	***483.6***	***133.0***	***0.485***	***1.587***

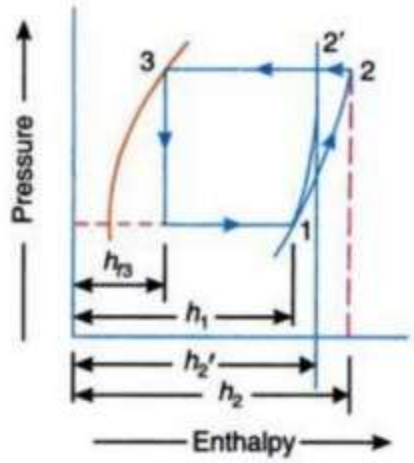
.

Solution 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 ; h1=460.7 ; $h_{2'}$=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 Cp = Cp= Specific heat at constant pressure for superheated vapour.

We know that entropy at point 2,

$S_2 = S_2$'+2.3 $C_{p.}$ log(T_2/T'_2)

1.637=1.587+2.3 C_p log(338/318)

1.637 =1.587+2.3× C_p ×0.02=1.587+0.046cp

Therefore c_p=1.09

and enthalpy at point 2,

$h_2 = h_2$'+ C_p × Degree of superheat

$h_2 = h_2$'+ C_p ($T_2 - T'_2$)

= 483.6+1.09 (333−318)= 500 kJ/kg

Therefore

C.O.P. of refrigerator

$=\frac{h1-hf3}{h2-h1} = \frac{460.7-133}{500-46.7}$ =8.34

Example 2

A refrigeration machine using R-12 as refrigerant operates between the pressures 2.5 bar and 9 bar. The compression is isentropic and there is no undercooling in the condenser.

The vapour is in dry saturated condition at the beginning of the compression. Estimate the theoretical coefficient of performance. If the actual coefficient of performance is 0.65 of theoretical value, calculate the net cooling produced per hour. The refrigerant flow is 5 kg per minute. Properties of refrigerant are

Pressure, bar	saturation tempurate in °C	Enthalpy in kJ/kg		Entropy of saturatedvapour, kJ/kg. K
		Liquid	Vapour	
9.0	36	70.55	201.8	0.6836
2.5	-7	29.62	184.5	0.7001

Take C_p for superheated vapour at 9 bar as 0.64 kJ/kg K.

Solution

Given : $T'_2=T_3= 36°C= 36+273 = 309K$; $T_1=T_4=-7°C=-7+273=266K$;

$T_2'=T_3=36°C=36+273=309K$;$T_1=T_4=-7°C=-7+273=266K$; (C.O.P)actual=0.65 (C.O.P)th, (C.O.P)actual= 0.65 (C.O.P)th; m=5kg/min; $h_{f3}=h4=70.55$ kJ/kg; $h_{f1}=h_{f4}=29.62$kJ/kg; $h_{'2}=201.8$kJ/kg; $h_1=184.5$kJ/kg; $S'_2=0.6836$kJ/kgK; $s_1=s_2=0.7001$kJ/kgK; $c_p=0.64$kJ/kgK

Pressure, bar	saturation tempurate in °C	Enthalpy in kJ/kg		Entropy of saturatedvapour, kJ/kg. K
		Liquid	Vapour	
9.0	36	70.55	201.8	0.6836
2.5	-7	29.62	184.5	0.7001

Theoretical coefficient of performance

First of all, let us find the temperature at point 2 (T2T2)

We know that entropy at point 2,

$s_2=s_2'+2.3c_p\log(T_2/T'_2)$

$0.7001=0.6836+2.3\times0.64\log(T_2/309)$

$\log(T_2/309)=\frac{0.7001-0.6836}{2.3 X 0.64}$

$\log(\frac{T2}{309}) = 1.026$ (Taking antilog of 0.0112)

Therefore

$T_2=1.026309=317$ k

We know that enthalpy of super heated vapour at point 2,

$h_2 = h'_2+c_p(T2-T'2)$

$= 201.8 + 0.64 (317-309) = 206.92$kJ/kg

Therefore theoretical coefficient of performance,

$$(C.O.P)th = \frac{h1-hf3}{h2-h1} = \frac{184.5-70.55}{206.92-184.5} = 5.1 \textbf{ (Ans)}$$

Net cooling produced per hour

We also know that actual C.O.P. of the machine,

$$(C.O.P)actual=0.65\times(C.O.P)th=0.65\times5.1=3.315$$

and actual work done, $W_{actual}=h_2-h_1=206.92-184.5=22.42$ KJ/Kg

We know that net cooling (or refrigerating effect) produced per kg of refrigerant

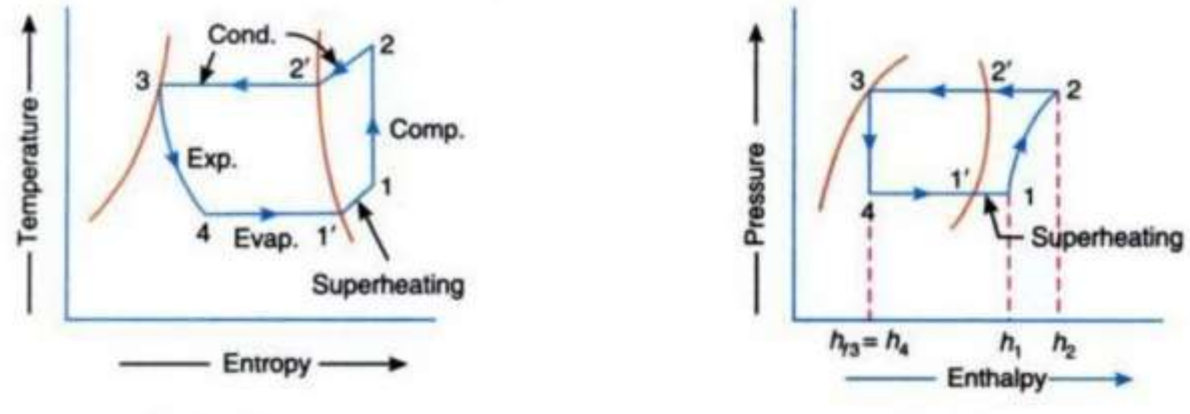
$$=W_{actual}\times(C.O.P)_{actual}=22.42\times3.315=74.3 \text{ KJ/Kg}$$

Therefore net cooling produced per hour

$$= m \times 74.3=5\times74.3=371.5 \text{kJ/min}$$

$$= 371.5/210 = 1.77 \text{ TR}$$

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

The COP can be found out by the formula

$$\textbf{COP} = \frac{Refrigerating\ effect}{Work\ done} = \frac{h1-hf3}{h2-h1}$$

Note : In this cycle, the heat is absorbed in two stages. Firstly from point 4 to point 1' and secondly from point 1' to point 1. The remaining cycle is same as discussed in the previous article.

Example 1 : ***A vapour compression refrigeration plant works between pressure limits of 5.3 bar and 2.1 bar. The vapour is superheated at the end of compression, its temperature beign 37^{0}C. The vapour is superheated by 5 degree Celsius before entering the compressor. If the specific heat of superheated vapour is 0.63 kj/kg K, find the coefficient of performance of the plant. Use the date given in the table below.***

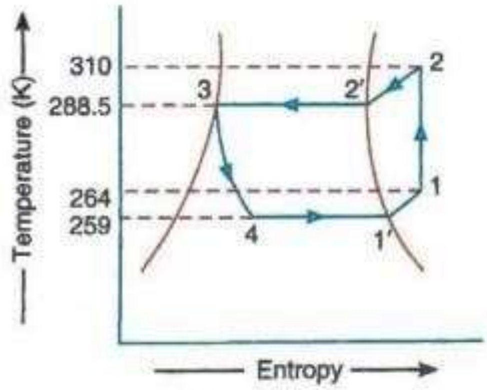
Pressure, bar	Saturation temperature, °C	Liquid heat, kJ/kg	Latent heat, kJ/kg
5.3	15.5	56.15	144.9
2.1	-14.0	25.12	158.7

Solution :

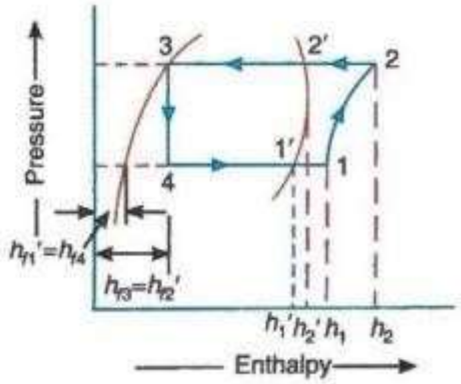
p_2=5.3bar; p_1=2.1bar; T_2=37°C =37+273=310K; $T_1-T'_1$=5°C; cp=0.63kJ /kgK ;

T'_2=15.5°C=15.5+273=288.5K; T'_1=−14°C= −14+273=259K;

h_{f3} =h'_{f2}=56.15kJ/kg; h'_{f1}=25.12kJ/kg; h'_{fg2}=144.9kJ/kg; h'_{fg1}=158.7kJ/kg



(a) T-s diagram.



(b) p-h diagram.

We know that enthalpy of vapour at point 1,

$$h_1=h'_1+c_p(T_1-T'_1)=(h'_{f1}+h'_{fg1})+c_p(T_1-T'_1)$$

$$=(25.12+158.7)+0.635=186.97$$

Similarly, enthalpy of vapour at point 2,

$$h_2 = h'_2 + c_p(T_2 - T'_2) = (h'_{f2} + h'_{fg2}) + c_p(T_2 - T'_2)$$

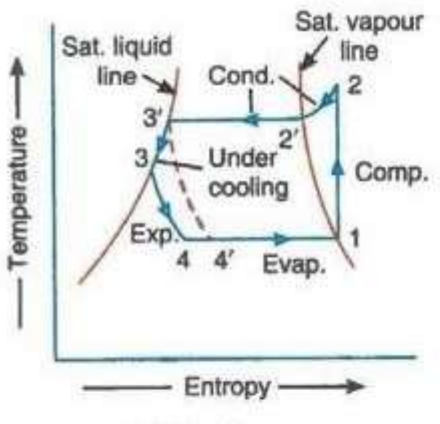
$$= (56.15 + 144.9) + 0.63(310 - 288.5) = 214.6$$

Therefore coefficient of performance of the plant,

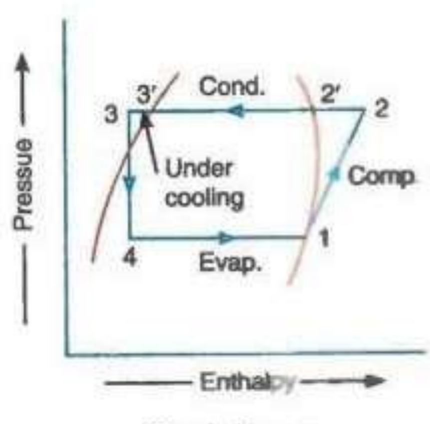
$$C.O.P = \frac{h1 - hf3}{h2 - h1} = \frac{186.97 - 56.15}{214.6 - 186.97} = \mathbf{4.735\ Ans}$$

2.2.5 Theoritical vapour compression cycle with under-cooling or Subcooling of refrigerant

Sometimes, the refrigerant , after condensation process 2'-3', is cooled below the saturation temp (T3') before expansion by throttling. Such a process is called undercooling or subcooling of the refrigerant and is generally done along the liquid line as shown in figure a and b . The ultimate effect of the undercooling is to increase the value of coefficient of performance under the same set of conditions. The process is generally brought about by circulating more quantity of cooling water through the condenser or by using water colder than the main circulating water. This act increases the refrigerating effect both by superheating and undercooling process as compared to a cycle with out them



(a) T-s diagram.



(b) p-h diagram.

In this case, the refrigerating effect or heat absorbed or extracted

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

$$W = h_2 - h_1$$

$$\textbf{COP} = \frac{Refrigerating\ effect}{Work\ done} = \frac{h1 - hf3}{h2 - h1}$$

Note : The value of h_{f3} may be found out from the relation

$h_{f3} = h_{f3}' -$ Cp x Degree of undercooling

Numerical :

A vapour compression refrigerator uses R-12 as refrigerant and the liquid evaporates in the evaporator at - 15°C. The temperature of this refrigerant at the delivery from the compressor is 15°C , when the vapour is condensed at 10°C. Find the co-efficent of performance if

(i) there is no undercooling, and

(ii) (ii) the liquid is cooled by 5°C before expansion by throttling.

(iii) Take specific heat at constant pressure for the superheated vapour as 0.64 kJ/kg K and that for liquid as 0.94 kJ/kg K. 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

Solution

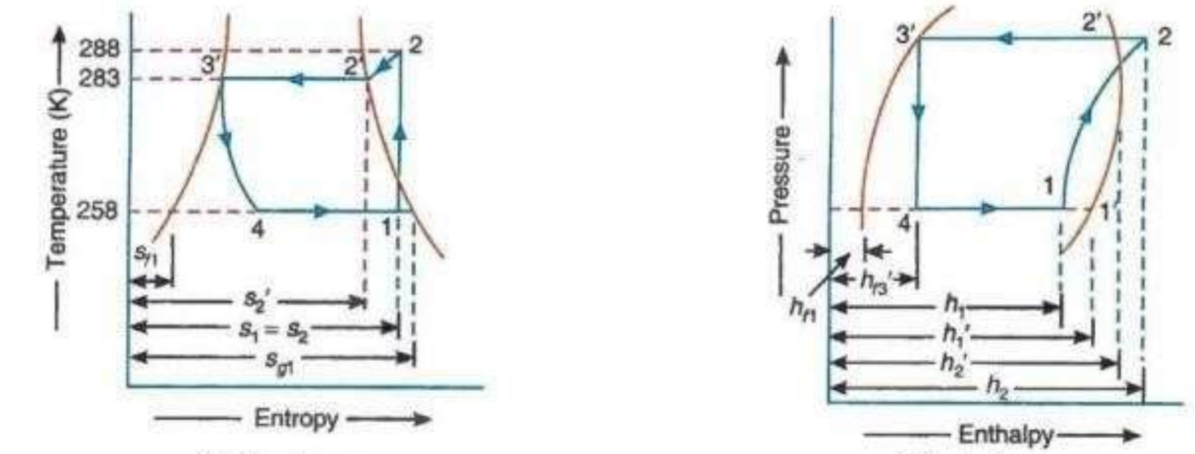
Given :

$T_1 = T_4 = -15°C = -15+273 = 258K$; $T_2 = 15°C = 15+273 = 288K$; $T'_2 = 10°C = 10+273 = 283K$; Cpv=0.64kJ/kgK; Cp1=0.94kJ/kgK;

h_{f1}=22.3kJ/kg; h_{f3}=45.4kJ/kg; h'_1= 180.88kJ/kg; h'_2=19.76kJ/kg; S_{f1}=0.0904kJ/kg; S_{f3}=0.1750kJ/kgK; S_{g1}=0.7051kJ/kgK; S'_2=0.6921kJ/kgK

(i) Coefficient of performance if there is no undercooling

The T-s and p-h diagrams, when there is no undercooling, are shown in Fig a and b respectively.



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

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

We know that entropy at point 1,

$$S_1 = S_{f1} + X_1\, S_{fg1} = S_{f1} + X_1\,(S_{g1} - S_{f1})$$

$$= 0.0904 + X_1\,(0.7051 - 0.0904)$$

$$= 0.0904 + 0.6147\, X_1 \ldots\ldots\ldots\ldots(i)$$

and entropy at point 2,

$$S_2 = S_2' + 2.3\ Cpv\ \log\left(\frac{T_2}{T_{2F}}\right)$$

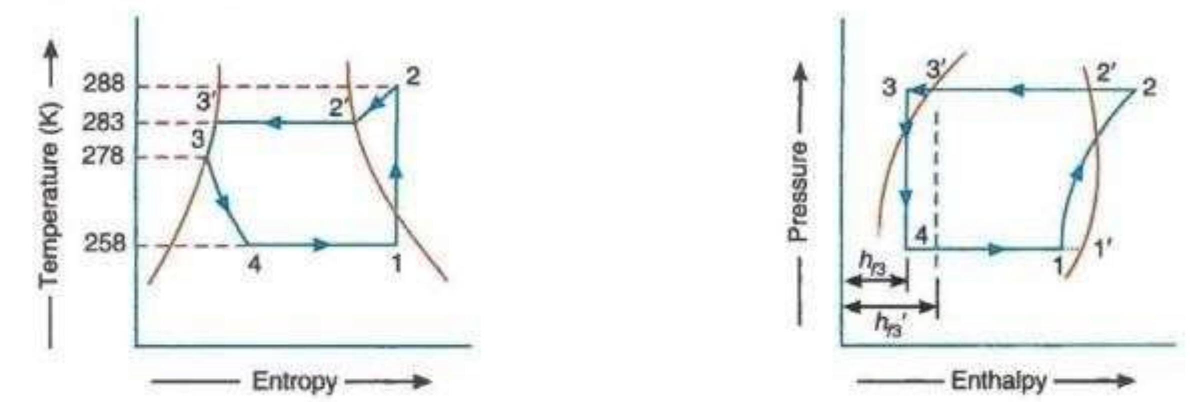
$$= 0.6921 + 2.3 \times 0.64 \times \log\left(\frac{288}{283}\right)$$

$$= 0.7034$$

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

$$0.0904 + 0.6147 x_1 = 0.7034$$

or $x_1 = 0.997$



(a) *T-s* diagram.   Fig. 4.20   (b) *T-s* diagram.

We know that the enthalpy at point 1,

$$h_1 = h_{f1} + xh_{fg1} = h_{f1} + x(h_{g1} - h_{f1})$$

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

and enthalpy at point 2,

$$h_2 = h'_2 + C_{pv}\,(T_2 - T_{'2})$$

$$= 191.76 + 0.64\,(288 - 22.3) = 194.96 \text{kJ/kg}$$

Therefore

$$\text{C.O.P} = \frac{h1 - hf3}{h2 - h1} = \frac{180.4 - 45.4}{194.96 - 180.4} = \mathbf{9.27}$$

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

The T-s and p-h diagrams, when there is an undercooling of 5^0 C, are shown in below (a) and (b) respectively.

We know that enthalpy of liquid refrigerant at point 3

$$h_{f3} = h_{f3}' - Cpl \times h_{f3} = h_{f3}' - cp1 \times \text{degree of undercooling}$$

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

Therefore

$$\text{C.O.P} = \frac{h1 - hf3}{h2 - h1} = \frac{180.4 - 40.4}{194.96 - 180.4} = \mathbf{9.59}$$

2.2.6 Pressure-Enthalpy (p-h) Chart

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). 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.

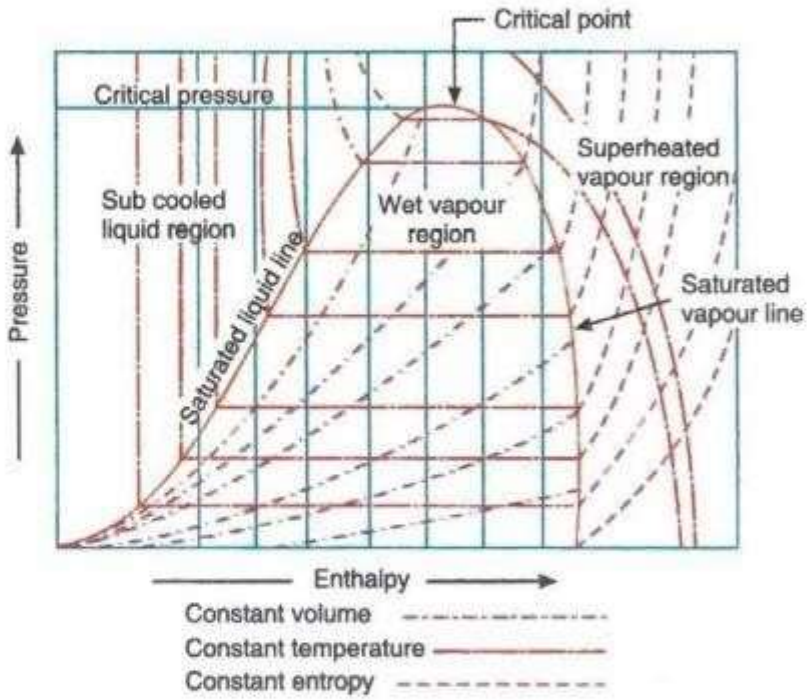


Fig. 4.2. Pressure - enthalpy (*p-h*) chart.

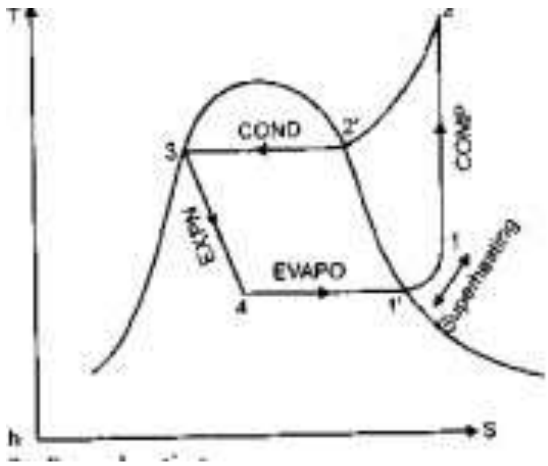
A saturated liquid is one which has a temperature equal to the saturation temperature corresponding to its pressure. The space to the left of the saturated liquid line will, therefore, be sub-cooled liquid region. The space between the liquid and the vapour lines is called wet vapour region and to the right of the saturated vapour line is a superheated vapour region.

.

SHORT QUESTIONS WITH ANSWER

1. Draw the P-H diagram of vapour compression refrigeration system. [2009BP]

Ans :



2. Name the components of vapour compression refrigeration system ? [2007S]

Ans : Compressor, Condenser, Receiver, Expansion valve/ Capillary tube , Evaporator.

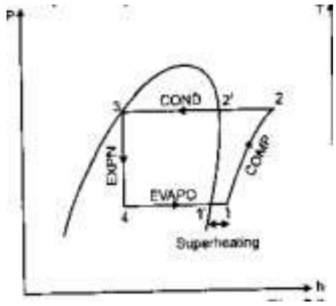
3. What will happened if we use expansion valve in place of throttle valve or capillary tube ?

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

4. What is cooling tower ? [2018]

Ans : A cooling tower is a specialized heat exchanger in which air and water are brought into direct contact with each other in order to reduce the water's temperature. As this occurs, a small volume of water is evaporated, reducing the temperature of the water being circulated through the tower.

5. Draw the P-h diagram with super heated refrigerant before compression. [2017S]



5. What is the function of solenoid valve in vapour compression refrigeration system ? [2014W]

The solenoid valve is used in the refrigeration system to prevent the refrigerating fluid from the high-voltage part from entering the evaporator when the compressor stops. And it also avoids an excessively high low-pressure when the compressor is started next time so as to prevent compressor liquid hammer.

6. Why expansion cylinder are not used in domestic refrigerator?

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

LONG QUESTIONS :

1. Explain the vapour compression refrigeration system with neat sketch ?

2. Compare between vapour compression and vapour absorption system ?

3. What are the factors affecting the performance of simple vapour compression refrigeration system ?

****

CHAPTER – 03

VAPOUR ABSORPTION REFRIGERATION SYSTEM

Learning Objectives :

Simple vapor absorption refrigeration system

Practical vapor absorption refrigeration system

COP of an ideal vapor absorption refrigeration system

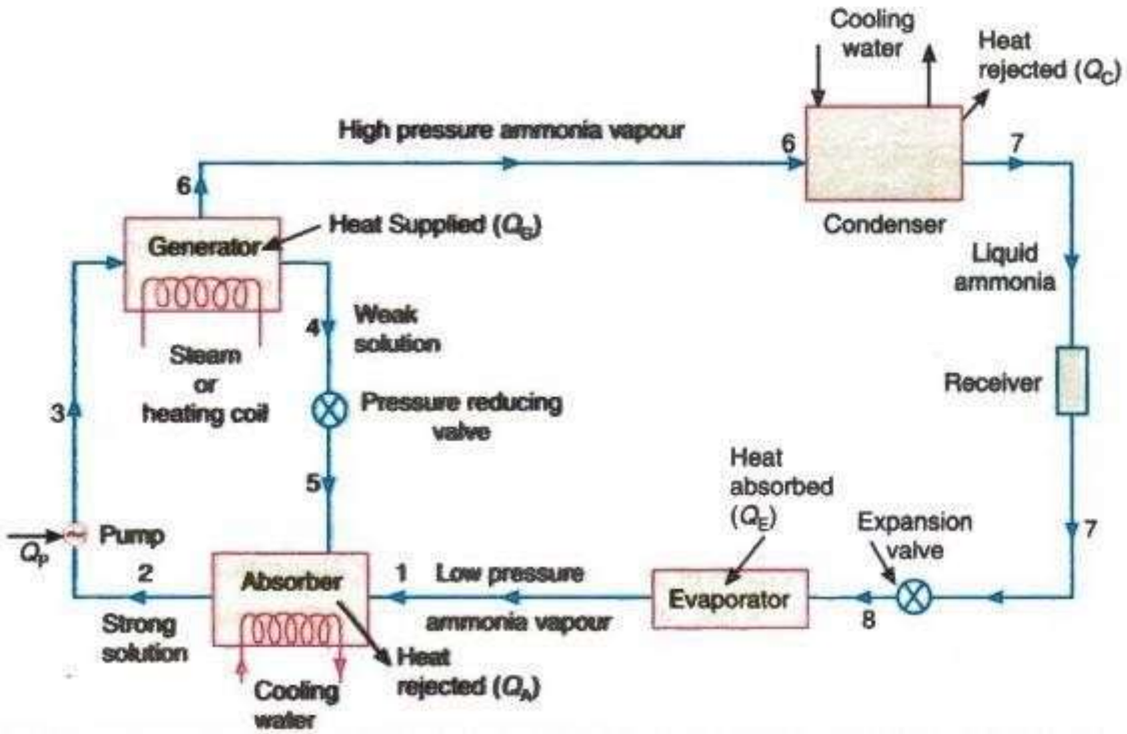
3.4.Numerical on COP.

Simple Vapour Absorption Refrigeration System :

Simple Vapour Absorption System utilizes heat energy rather than mechanical energy. In Vapour Absorption System, absorber, a pump a generator and a pressure reducing valve replace compressor. These parts play out a similar capacity as that of a compressor. In this system, vapour refrigerant comes out from the evaporator. The absorber absorbs the vapour refrigerant. It is absorbed by the weaker solution of refrigerant and forming a solution. The strong solution is pumped to the generator. It is heated by some external force. During the heating process, the vapour refrigerant is driven off by the solution. Then, it enters into the condenser where it is liquefied. The liquid refrigerant flows into the evaporator and completes the cycle. It consist of:

- an absorber
- a pump
- a generator
- a pressure reducing valve
- condenser
- receiver
- expansion valve
- evaporator

Working of the Simple Vapour absorption System



- In this system, the low-pressure ammonia vapour leaves the evaporator. Coldwater in the absorber absorbs the low-pressure ammonia vapour.
- Water lowers the pressure of ammonia in the absorber. Therefore, it draws more of ammonia vapour from the evaporator. The overall temperature of the solution is increased.
- The heat of the solution is removed by the cooling arrangement in the absorber. Water`s absorption capacity is increased. At high-temperature water absorbs less ammonia.
- The liquid pump pumps the strong solution to the generator. The ammonia in the generator is heated by som force, for example, steam or gas.
- During the heating procedure, the ammonia vapour is driven off the arrangement at high pressure. It leaves behind the weak ammonia solution in the generator.
- Weak ammonia solution flows into the absorber at low pressure after passing through the pressure reducing valve.
- 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 expansion valve through the receiver and then to the evaporator. This completes the simple vapour absorption cycle.

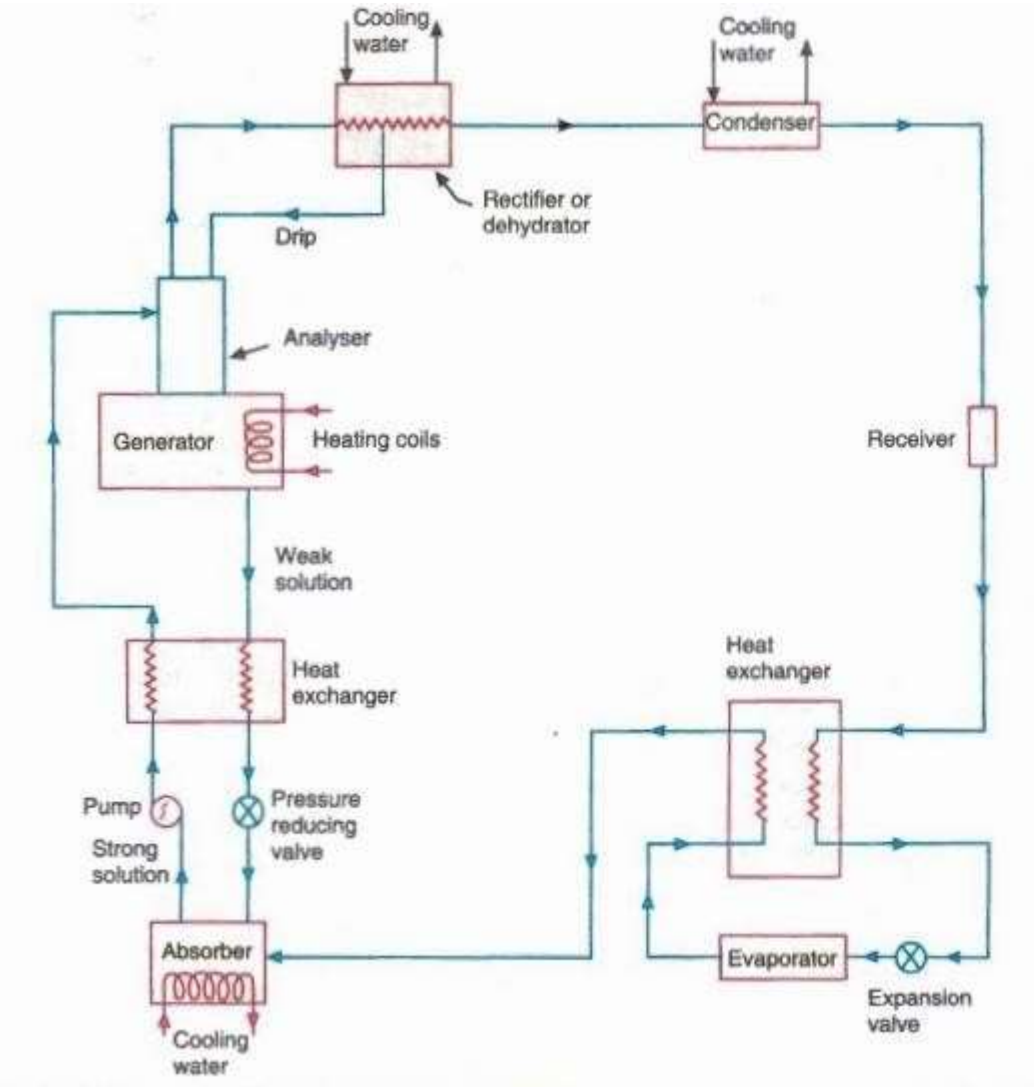
C.O.P of the Simple Vapour absorption System

In this system, the heat consumed by the refrigerant in the evaporator gives the refrigerating effect. The total energy supplied to the system is the sum of work done by the pump and the heat supplied in the generator. Therefore Coefficient of performance of the system is given by

= Heat absorbed in evaporator / Work done by pump + Heat supplied in generator

Describe a practical vapour absorption cycle with a neatsketch for ammonia water system.

The simple absorption system is not very economical. So it is fitted with an analyser, a rectifier and two heat exchangers as shown in figure, to make it more practical.



Analyser: In the simple system some water also vaporizes along with ammonia in the generator. If these unwanted water particles are not removed before entering condenser, they will enter into expansion valve and will freeze and choke the pipeline.

Therefore, an analyser is used above the generator. It consists of series of trays such that strong solution from absorber and aqua from rectifier are introduced on the top tray and flow downwards The vapor rising from generator is cooled due to exposure to considerable liquid surface area and most of water vapour condenses. Since aqua is heated by vapour, less external heat is required in generator.

Rectifier: Its function is to cool further the ammonia vapours leaving analyser so that the vapours condense. This condensate is returned to top of analyser by a drip return pipe. It is also known as dehydrator.

Heat Exchangers: The heat exchanger provided between pump and generator is used to cool the weak hot solution returning from generator to absorber and to heat the strong solution leaving the pump and going to generator. This reduces heat supplied to generator and amount of cooling required for absorber, thus increasing plant economy.

The heat exchanger between condenser and evaporator is called liquid sub-cooler since it sub-cools the liquid refrigerant leaving condenser by low temperature ammonia vapour from evaporator.

In this case the net refrigerating effect is the heat absorbed by the refrigerant in the evaporator. The total energy supplied to the system in the sum of work done by the pump and the head supplied in the generator. Therefore, the coefficient of performance of the system is given by

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

Co-efficient of performance of an ideal vapour absorption refrigeration system

We have discussed earlier that an ideal vapour absorption refrigeration system

a. The heat (Q_G) is given to the refrigerant in 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 (Q_P) is added to the refrigerant due to pumpwork

Neglecting the heat due to pump work (Q_P) , we have according to the first law of thermodynamics,

$$Q_C = Q_G + Q_E$$

Let

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

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

T_E = Temperature at which (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.

$$\frac{Q_G}{T_G} + \frac{Q_E}{T_E} = \frac{Q_C}{T_C}$$

$$= \frac{Q_G + Q_E}{T_C}$$

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

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

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

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

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

Maximum COP is given by

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

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

Numerical : 01

In a vapour absorption refrigeration system, heating, cooling and refrigeration take place at the temperatures of 100^{0}C, 20^{0}C and -5^{0}C respectively. Find the maximum C.O.P of the system.

Solution:

T_G=100^{0}C = 100+273= 373K, T_C = 20^{0}C = 20+273 =293 K, T_E=-5^{0}C = -5+273 = 268K

We know that maximum COP. of the system

$$\text{Maximum C.O.P.} = \left(\frac{T_E}{T_C - T_E}\right) \left(\frac{T_G - T_C}{T_G}\right)$$

$$= \left(\frac{268}{293-268}\right) \left(\frac{373-293}{373}\right) = \mathbf{3.2\ Ans}$$

Numerical : 02

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 - 3° 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 ; = - 5^0 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

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

We know that maximum C.O.P.

$$\text{Maximum C.O.P.} = \left(\frac{T_E}{T_C - T_E}\right)\left(\frac{T_G - T_C}{T_G}\right)$$

$$= \left(\frac{268}{303-268}\right)\left(\frac{393.2-293}{393.2}\right)$$

$$= 1.756 \text{ Ans}$$

Mass of steam required per hour We know that actual C.O.P. = 70% of maximum

C.O.P. = 0.7 x 1.756 = 1.229 :.

Actual heat supplied $= \frac{\text{Refrigeration load}}{\text{Actual C.O.P.}} = \frac{20 \text{ x } 210}{1.229}$ = 3417.4 kJ/min

Assuming that only latent heat of steam is used for heating purposes, therefore from steam tables, the latent heat of steam at 2 bar is

h_{fg}= 2201.6 kJ/kg :. Since its is 90% dry, so its enthalphy is

$h_{fg} = h_{fg}$ x 0.9

Mass of steam required per hour $= \frac{\text{Actual heat supplied}}{\text{hfg x0.9}}$

$$= \frac{3417.4}{1981.44} = 1.724 \text{ kg/min}$$

$$= 1.724\text{x } 60 = 103.48 \text{ kg /h Ans.}$$

SHORT QUESTIONS WITH ANSWER

Q. what is the function of rectifier of a vapour absorption system? [2010 S, 2009 S]

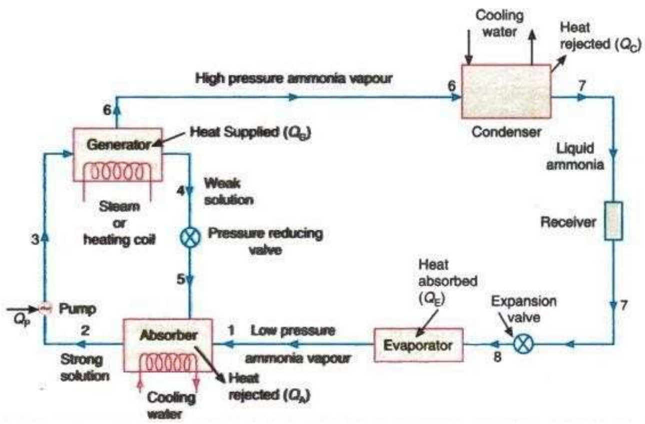
Ans : A rectifier is a water cooled heat exchanger which condenses water vapour and send back to the generator. Thus final reduction or elimination of the percentage of water vapour takes place in the rectifier.

Q. State four advantages of vapour absorption system over SVCRS . [2007S]

Ans :

- VARS Uses heat exchanger to change the condition of refrigerant
- VARS is designed to use waste heat or steam of the plant instead of electricity.
- The only moving part is pump, so noise is very less.
- Performance of VARS at part load is more than SVCRS.

Q. Draw the flow diagram of simple vapour absorption refrigeration system. [2012]



Q. In vapour absorption refrigeration system the compressor is replaced by which equipment

Ans :

Absorber, Pump, Generator, Pressure reducing valve

LONG QUESTIONS:

1. With neat sketch explain the simple vapour absorption refrigeration system.[2007S, 2010S, 2014S]

2. With neat sketch explain the practical vapour absorption refrigeration system [2012W]

3. In a vapour absorption refrigeration system, heating, cooling and refrigeration take place at the temperatures of 100^0C, 20^0C and -5^0C respectively. Find the maximum C.O.P of the system. [2020W]

4. 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 - 3° 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. [2020W]

Chapter – 04

REFRIGERATION EQUIPMENTS

Learning Objectives :

REFRIGERANT COMPRESSORS

Principle of working and constructional details of reciprocating and rotary compressors.

Centrifugal compressor only theory

Important terms.

Hermetically and semi hermetically sealed compressor.

CONDENSERS

Principle of working and constructional details of air cooled and water cooled condenser

Heat rejection ratio.

Cooling tower and spray pond.

EVAPORATORS

Principle of working and constructional details of an evaporator.

Types of evaporator.

Bare tube coil evaporator, finned evaporator, shell and tube evaporator.

Reciprocating Compressors

- The compressors in which the vapour refrigerant is compressed by the reciprocating motion of the piston are called reciprocating compressors.
- The reciprocating compressors are available in sizes as small as 1/12 kW which are used in small domestic refrigerators and up to about 150 kW for large capacity installations.
- The two types of reciprocating compressors in general use are single acting vertical compressors and double acting horizontal compressors.

Principle of operation of the compression cycle :

- Let us consider that the piston is at the top of its stroke as shown in Fig. (a). This is called top dead centre position of the piston. In this position, the suction valve is held closed because of the pressure in the clearance space between the top of the piston and the cylinder head. The discharge valve is also held closed because of the cylinder head pressure acting on the top of it.
- When the piston moves downward (i.e. during suction stroke), as shown in Fig. (b), the refrigerant left in the clearance space expands. Thus the volume of the cylinder (above the piston) increases and the pressure inside the cylinder decreases.

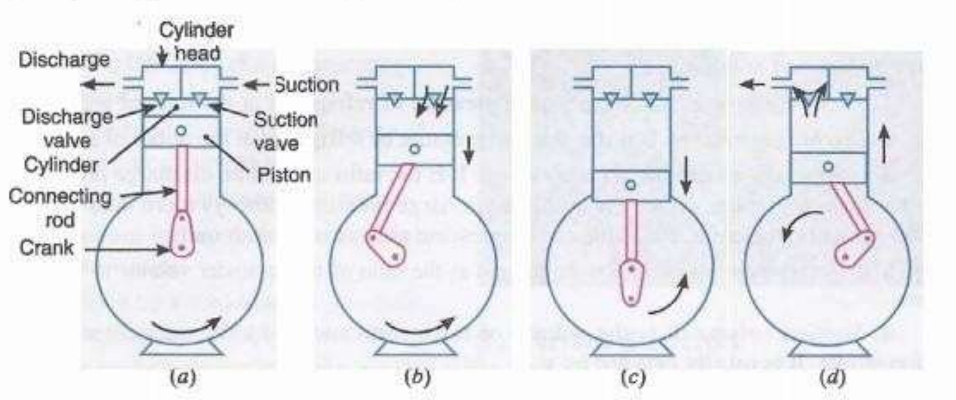


Fig. 9.1. Principle of operation of a single stage, single acting reciprocating compressor.

- When the pressure becomes slightly less than the suction pressure or atmospheric pressure, the suction valve gets opened and the vapour refrigerant flows into the cylinder. This flow continues until the piston reaches the bottom of its stroke (i.e. bottom dead centre). At the bottom of the stroke, as shown in Fig. (c). the suction valve closes because of spring action.
- Now when the piston moves upward (i.e. during compressit stroke), as shown in Fig. (d), the volume of the cylinder decreases and the pressure inside cylinder increases.
- When the pressure inside the cylinder becomes greater than that on the top of discharge valve, the discharge valve gets opened and the vapour refrigerant is discharged into condenser and the cycle is repeated.

Rotary Compressors

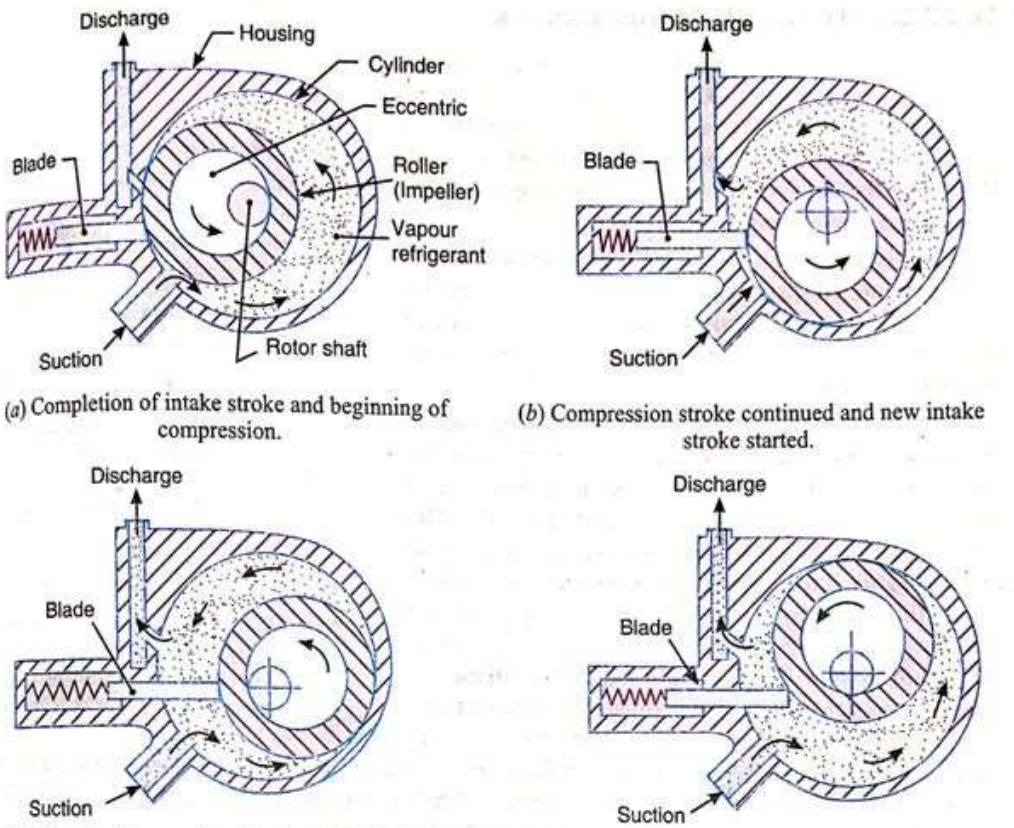
- In rotary compressors, the vapour refrigerant from the evaporator is compressed due to the movement of blades. The rotary compressors are positive displacement type compressors.
- Since the clearance in rotary compressors is negligible, therefore they have high volumetric efficiency.
- These compressors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

Following are the two basic types of rotary compressors :

1. Single stationary blade type rotary compressor

A single stationary blade type rotary compressor. It consists of a stationary cylinder, a roller (or impeller) and a shaft. The shaft has an eccentric on which the roller is mounted.

- A blade is set into the slot of a cylinder in such a manner that it always maintains contacts with the roller by means of a spring.
- The blade moves in and out of the slot to follow the rotor when it rotates.
- When the shaft rotates, the roller also rotates so that it always touches the cylinder wall.
- When the roller rotates, the vapour refrigerant ahead of the roller is being compressed and the new intake from the evaporator is drawn into the cylinder,
- As the roller turns towards mid position, more vapour refrigerant is drawn into the cylinder while the compressed refrigerant is discharged to the condenser.
- At the end of compression stroke, most of the compressed vapour refrigerant is passed through the discharge port to the condenser.
- A new charge of refrigerant is drawn into the cylinder. This, in turn, is compressed and discharged to the condenser.
- In this way, the low pressure and temperature vapour refrigerant is compressed gradually to a high pressure and temperature.



(a) Completion of intake stroke and beginning of compression.
(b) Compression stroke continued and new intake stroke started.
(c) Compression continued and new intake stroke continued.
(d) Compressed vapour discharged to condenser and new intake stroke continued.

. Stationary single blade rotary compressor.

Rotating blade type rotary compressor.

It consists of a cylinder and a slotted rotor containing a number of blades. The centre of the rotor is eccentric with the centre of the cylinder. The blades are forced against the cylinder wall by the centrifugal action during the rotation of the motor.

- The low pressure and temperature vapour refrigerant from the evaporator is drawn through the suction port.
- As the rotor turns, the suction vapour refrigerant entrapped between the two adjacent blades is compressed. The compressed refrigerant at high pressure and temperature is discharged through the discharge port to the condenser.
- The whole assembly of both the types of rotary compressors is enclosed in a housing which is filled with oil.

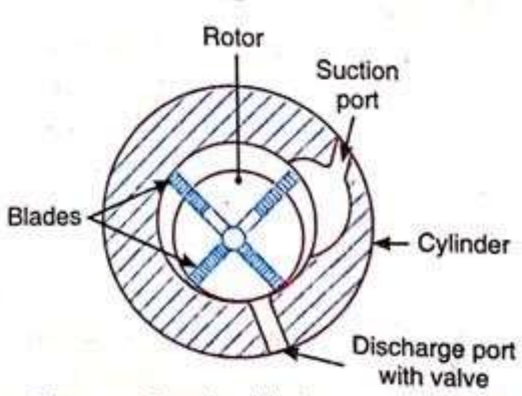


Fig. . . Rotating blade type rotary compressor.

- When the compressor is working, an oil film forms the seal between the high pressure and low pressure side.
- But When the compressor stops, this seal is lost and therefore high Pressure vapour refrigerant will flow into low pressure side.
- In order to avoid this, a check valve is usually provided in the suction line. This valve prevents the high pressure vapour refrigerant from flowing back to the evaporator.

Centrifugal Compressors

This compressor increases the pressure of low pressure vapour refrigerant to a high pressure by centrifugal force.

- A single stage centrifugal compressor consists of an impeller to which a number of curved vanes are fitted symmetrically.
- The impeller rotates in an airtight volute casing with inlet and outlet points.
- The impeller draws in low pressure vapour refrigerant from the evaporator.

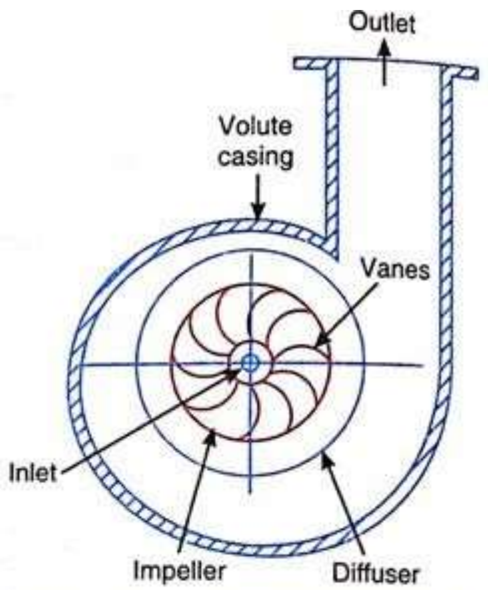


Fig. Centrifugal compressor.

- When the impeller rotates, it pushes the vapour refrigerant from the centre of the impeller to its periphery by centrifugal force.
- The high speed of the impeller leaves the vapour refrigerant at a high velocity at the vane tips of the impeller.
- The kinetic energy thus attained at the impeller outlet is converted into pressure energy when the high velocity vapour refrigerant passes over the diffuser.
- The diffuser is normally a vaneless type as it permits more efficient part load operation which is quite usual in any air-conditioning plant.
- The volute casing collects the refrigerant from the diffuser and it further converts the kinetic energy into pressure energy before it leaves the refrigerant to the evaporator.
-

3 Important Terms :

The following important terms, which will be frequently used in this chapter, should be clearly understood at this stage :

1. **Suction pressure.** It is the absolute pressure of refrigerant at the inlet of a compressor.
2. **Discharge pressure.** It is the absolute pressure of refrigerant at the outlet of a compressor.

3. **Compression ratio (or pressure ratio).** It is the ratio of absolute discharge pressure to the absolute suction pressure. Since the absolute discharge pressure is always more than the absolute suction pressure, therefore, the value of compression ratio is more than unity. Note : The compression ratio may also be defined as the ratio of total cylinder volume to the clearance volume.
4. **Suction volume.** It is the volume of refrigerant sucked by the compressor during its suction stroke. It is usually denoted by v,.
5. **Piston displacement volume or stroke volume or swept volume.** It is the volume swept by the piston when it moves from its top or inner dead position to bottom or outer dead centre position.

Mathematically, piston displacement volume or stroke volume or swept volume,

$\mathbf{V_p = \frac{\pi}{4} D^2 \times L}$, where D = Diameter of cylinder, and L = Length of piston stroke.

6. Clearance factor.

It is the ratio of clearance volume (V_c) to the piston displacement volume (V_p). Mathematically, clearance factor, $C=\frac{Vc}{Vp}$

7. **Compressor capacity.** It is the volume of the actual amount of refrigerant passing through the ri compressor in a unit time. It is equal to the suction volume (v_s). It is expressed in m^2/s.

8. **Volumetric efficiency.** It is the ratio of the compressor capacity or the suction volume (v_s) to the piston displacement volume (v_p).

Mathematically, volumetric efficiency, $\eta_v = \frac{Vs}{Vp}$

Note : A good compressor has a volumetric efficiency of 70 to 80 per cent. 0

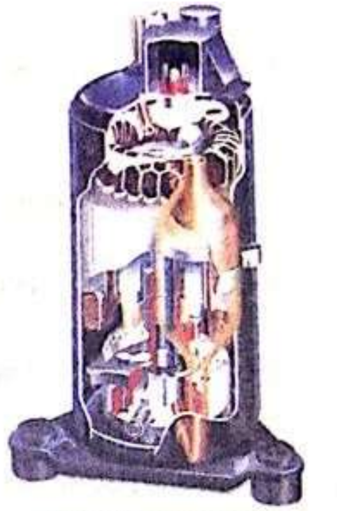
Hermetic Sealed Compressors

When the compressor and motor operate on the same shaft and are enclosed in a common casing, they are known as hermetic sealed compressors. These types of compressors eliminate the use of crankshaft seal which is necessary in ordinary compressors in order to prevent leakage of refrigerant. These compressors may operate on either reciprocating or rotary principle and may be mounted with the shaft in either the vertical or horizontal position. The hermetic units are widely used for small capacity refrigerating systems such as in domestic refrigerators, home freezers and window air conditioners. The hermetic sealed compressors have the following advantages and disadvantages :

Advantages

1. The leakage of refrigerant is completely prevented.
2. It is less noisy.
3. It requires small space because of compactness.
4. The lubrication is simple as the motor and compressor operate in a sealed space with the Iubricating oil.

Internal working of a welded hermetic compressor.


Rotary compressor.

Disadvantages :

1. The maintenance is not easy because the moving parts are inaccessible
2. A separate pump is required for evacuation and charging of refrigerant.

Condenser:

Working of Condenser:

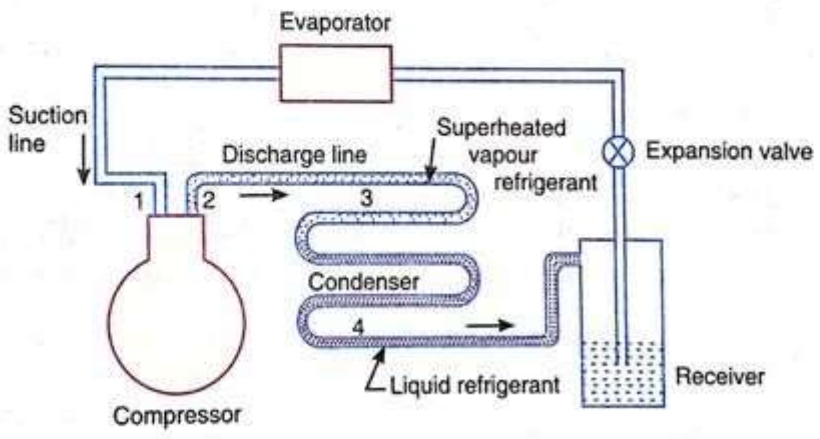
The working of a condenser may be best understood by considering a simple refrigerating system as shown in Fig. The compressor draws in the superheated vapour refrigerant that contains the heat it absorbed in the evaporator.

- The compressor adds more heat (Le. the heat of compression) to the superheated vapour.
- This highly superheated vapour from the compressor is pumped to the condenser through the discharge line.
- The condenser cools the refrigerant in the following three stages :

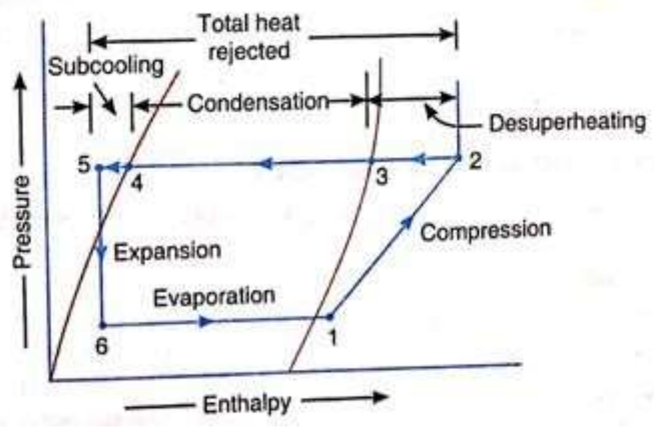
1. First of all, the superheated vapour is cooled to saturation temperature (called &superheating) corresponding to the pressure of the refrigerant. This is shown by the line 2-3 in Fig (b). The desuperheating occurs in the discharge line and in the first few coils of the condenser.

2. Now the saturated vapour refrigerant gives up its latent heat and is condensed to a saturated liquid refrigerant. This process, called condensation, is shown by the line 3-4.

3. The temperature of the liquid refrigerant is reduced below its saturation temperature (i.e. subcooled) in order to increase the refrigeration effect. This process is shown by the line 4-5.



(*a*) Schematic diagram of a simple refrigerating system.



Air Cooled Condenser :

An air-cooled condenser is one in which the removal of heat is done by air. It consists of steel or copper tubing through which the refrigerant flows.

- The size of tube usually ranges from 6 aim to 18 mm outside diameter, depending upon the size of condenser.
- Generally copper tubes are used because of its excellent heat transfer ability. The condensers with steel tubes are used in ammonia refrigerating systems.
- The tubes are usually provided with plate type fins to increase the surface area for heat transfer.

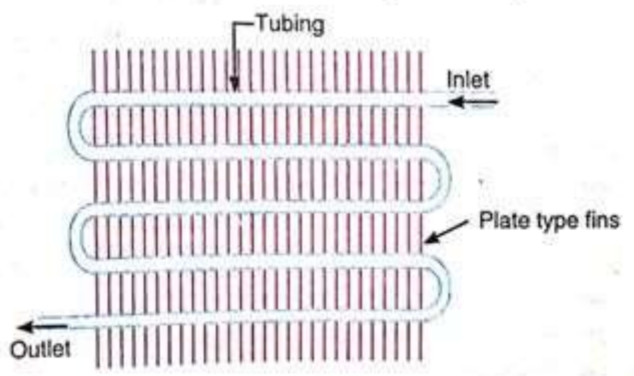


Fig. . Air-cooled condenser.

- The fins are usually made from aluminium because of its light weight. The fin spacing is Quite wide to reduce dust clogging..
- The condensers with single row of tubing provides the most efficient heat transfer.
- The air-cooled condensers may have two or more rows of tubing, but the condensers with up to six rows of tubing are common. Some condensers have seven or eight rows.

Types of Air-Cooled Condensers

Following are the two types of air-cooled condensers :

I. Natural convection air-cooled condensers.

In natural convection air-cooled condenser, the heat transfer from the condenser coils to the air is by natural convection. As the air comes in contact with the warm condenser tubes, it absorbs heat from the refrigerant and thus the temperature of air increases. The warm air, being lighter, rises up and the cold air from below rises to take away the heat from the condenser. This cycle continues in natural convection air-cooled condensers. Since the rate of heat transfer in natural convection condenser is slower, therefore they require a larger surface area as compared to forced convection condensers. The natural convection air-cooled condensers are used only in small-capacity applications such as domestic refrigerators, freezers, water coolers and room air-conditioners.

2. Forced convection air-cooled condensers.

In forced convection air-cooled condensers, the fan is used to force the air over the condenser coils to increase its heat transfer capacity. The forced convection condensers may be divided into the following two groups :

(a) Base mounted air-cooled condensers, and

(b) Remote air-cooled condensers.

Water-Cooled Condensers

A water-cooled condenser is one in which water is used as the condensing medium. They are always preferred where an adequate supply of clear inexpensive water and means of water disposal are available. These condensers are commonly used in commercial and industrial refrigerating units. The water-cooled condensers may use either of the following two water systems :

1. Waste water system, or

2. Recirculated water system.

Types of Water-Cooled Condensers

The water-cooled condensers are classified, according to their construction, into the following three groups :

1. Tube-in-tube or double-tube condensers.

The tube-in-tube or double-tube condenser, as shown in Fig., consists of a water tube inside a large refrigerant tube. In this type of condenser, the hot vapour refrigerant enters at the top of the condenser. The water absorbs the heat tram the refrigerant and the condensed liquid refrigerant flows at the bottom. Since the refrigerant tubes are exposed to ambient air, therefore some of the heat is also absorbed by ambient air by natural convection. The cold water in the inner tubes may flow in either direction

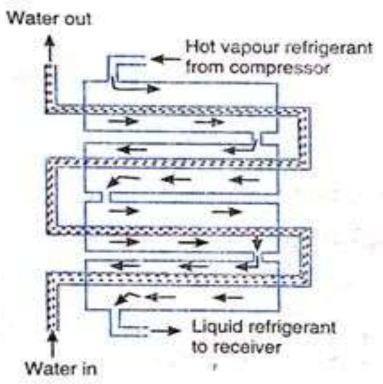


Fig. . Tube-in-tube condenser.

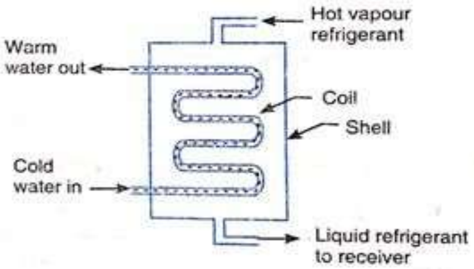
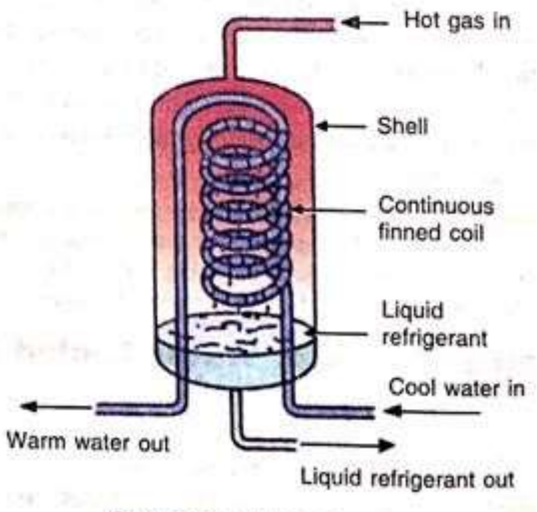


Fig. . Shell and coil condenser.

2. Shell and coil condensers.

A shell and coil condenser, as shown in Fig. , consists of one or more water coils enclosed in a welded steel shell. Both the finned and bare coil types are available. The shell and coil condenser may be either vertical (as shown in the figure) or horizontal. In this type of condenser, the hot vapour refrigerant enters at the top of the shell and surrounds the water coils. As the vapour condenses, it drops to the bottom of the shell which oftop Saves as a receiver. Most vertical type shell and coil condensers use counter-flow water system as it is more efficient than parallel-flow water system. In the shell and coil condensers, coiled tubing is free to expand and attract with temperature changes because of its spring action and can withstand any strain caused by temperature changes.



Shell and coil condenser.

Since the water coils are enclosed in a welded steel shell, therefore the mechanical cleaning of these coils is not possible. The coils are cleaned with chemicals. The shell sad coil condensers are used for units up to 50 tonnes capacity.

3. Shell and tube condensers.

The shell and tube condenser consists of a cylindrical steel shell containing a number of straight water tubes. The tubes are expanded into grooves in the tube sheet holes to form a vapour-tight fit. The tube sheets are welded to the shell at both the ends. The removable water boxes are bolted to the tube sheet at each end to facilitate cleaning of the condenser. The intermediate supports are provided in the shell to avoid sagging of the tubes.

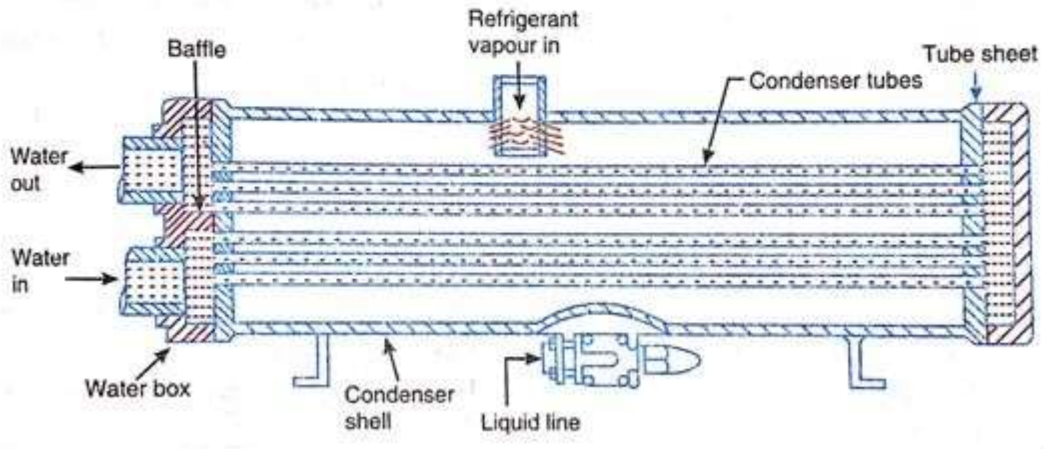


Fig. . Shell and tube condenser.

The condenser tubes are made either from steel or copper, with or without fins. The steel tubes without fins are usually used in ammonia refrigerating systems because ammonia corrodes copper tubing.

- In this type of condenser, the hot vapour refrigerant enters at the top of the shell and condenses as it comes in contact with water tubes.
- The condensed liquid refrigerant drops to the bottom of the shell which often serves as a receiver.

Cooling Towers and Spray Ponds

A cooling tower is an enclosed tower-like structure through which atmospheric air circulates to cool large quantities of warm water by direct contact.

- A spray pond consists of a piping and spray nozzle arrangement suspended over an outdoor open reservoir or pond. It can also cool large quantities of warm water.
- The cooling towers and spray ponds, used for refrigeration and air conditioning systems, cool the warm water pumped from the water-cooled condensers.
- Then the same water can be used again and again to cool the condenser. The principle of cooling the water in cooling towers and spray ponds is similar to that of evaporative condensers, i.e. the warm water is cooled by means of evaporation.
- The air surrounding the falling water droplets from the spray nozzles causes some of the water droplets to evaporate. The evaporating water absorbs latent heat of evaporation from the remaining water and thus cools it.
- The air also absorbs a small amount of sensible heat from the the remaining water. The cooled water collects in the pond or in a sump at the cooling tower which is recirculated through the condenser.

Capacity of Cooling Towers and Spray Ponds

The capacity of cooling towers and spray ponds depends upon the amount of evaporation of water that takes place. The amount of evaporation of water, in turn, depends upon the following factors :

1. The amount of water surface exposed to the air,
2. The length of the exposure time,

3. The velocity of air passing over the water droplets formed in cooling towers, and
4. The wet bulb temperature of the atmospheric air.

Types of Cooling Towers

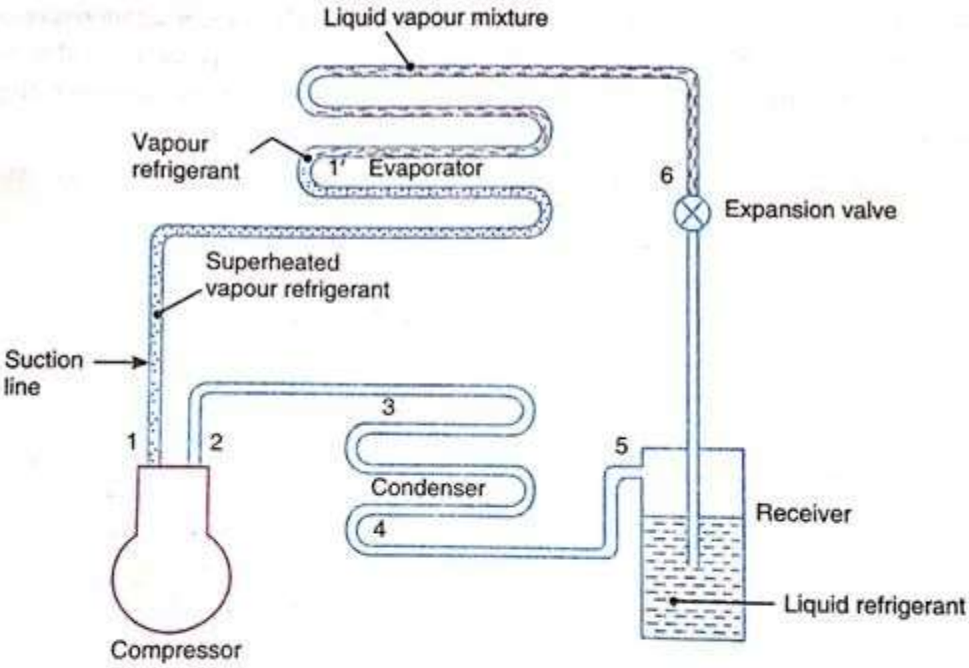
The cooling towers are mainly divided, according to their method of air circulation, into the following two groups :

1. Natural draft cooling towers, and
2. Mechanical draft cooling towers.

In natural draft cooling towers, the air circulates through the tower by natural convection Whereas in mechanical draft cooling towers, the air is forced through the tower by means of fans

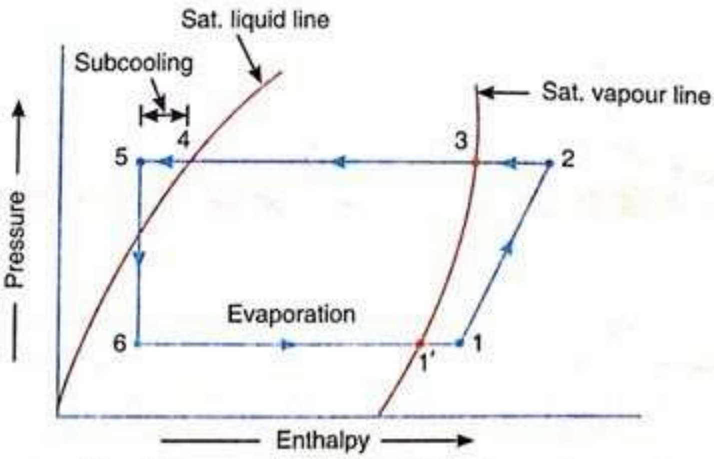
Working of an Evaporator

- The working of an evaporator may be best understood by considering the simple refrigerating system, as shown in Fig. The corresponding p-Is diagram is shown in Fig..
- The point 5 in the figure represents the entry of liquid refrigerant into the expansion valve. Under proper operating conditions, the liquid refrigerant is sub-cooled (i.e. cooled below its saturation temperature).
- The sub-cooling ensures that the expansion valve receives pure liquid refrigerant with no vapour present to restrict the flow of refrigerant through the expansion valve.
- The liquid refrigerant at low pressure enters the evaporator at point 6, as shown in Fig . As the liquid refrigerant passes through the evaporator coil, it continually absorbs heat through the coil walls, from the medium being cooled. During this, the refrigerant continues to boil



(*a*) Schematic diagram of a simple refrigerating system.

(*a*) Schematic diagram of a simple refrigerating system.



(*b*) *p-h* diagram of a simple refrigerating system.

Fig.

(*a*) Schematic diagram of a simple refrigerating system.

and evaporate. Finally at point 1', all the liquid refrigerant has evaporated and only vapour refrigerant remains in the evaporator coil. The liquid refrigerant's ability to convert absorbed heat to latent heat is now used up.

- Since the vapour refrigerant at point 1' is still colder than the medium being cooled, therefore the vapour refrigerant continues to absorb heat. This heat absorption causes an increase in the sensible heat (or temperature) of the vapour refrigerant.
- The vapour temperature continues to rise until the vapour leaves the evaporator to the suction line at point 1. At this point, the temperature of the vapour is above the saturation temperature and the vapour refrigerant is superheated.
- Fig. shows the variation of refrigerant temperature (or sensible heat) and the refrigerant heat content (or enthalpy) within the evaporator. We see that the temperature of the refrigerant is constant during evaporation of the liquid refrigerant from point 6 to and the enthalpy increases steadily.
- It shows that the latent heat is absorbed by the evaporating liquid with no change in temperature.
- Both the temperature and enthalpy of the refrigerant increases from point to 1. At point 1, all the liquid refrigerant has evaporated. The line 1'-1 shows the increase in sensible heat of the vapour refrigerant.

Types of Evaporators

Though there are many types of evaporators, yet the following are important from the subject point of view :

1. According to the type of construction

(a) Bare tube coil evaporator,
(b) Finned tube evaporator,
(c) Plate evaporator,
(d) Shell and tube evaporator,
(e) Shell and coil evaporator, and
(f) Tube-in-tube evaporator,

2. According to the manner in which liquid refrigerant is fed

(g) Flooded evaporator, and
(h) Dry expansion evaporator

3. According to the mode of heat transfer

(i) Natural convection evaporator, and
(j) Forced convection evaporator

4. According to operating conditions

a. Frosting evaporator,
b. Non-frosting evaporator, and
c. Defrosting evaporator

Bare Tube Coil Evaporators

The bare tube coil evaporators are e also known as prime-surface evaporators. Because of its simple construction, the bare compressor tube coil is easy to clean and defrost.

- This type of evaporator offers relatively little surface contact area as compared to other types of Liquid coils.
- The amount of surface area may be refrigerant increased by simply extending the length of the tube, but there are disadvantages of excessive tube length.
- The effective length of the tube is limited by the capacity of expansion valve.
- If the tube is too long for the valves capacity, the liquid refrigerant will tend to completely vaporise early in its progress through the tube, thus leading to excessive superheating at the outlet.
- The long tubes will also cause considerably greater pressure drop between the inlet and outlet of the evaporator.
- This results in a reduced suction line pressure. The diameter of the tube in relation to tube length may also be critical. If the tube diameter is too large, the refrigerant velocity will be too low and the volume of refrigerant will be too great in relation to the surface area of the tube to allow complete vaporisation.
- This, in turn, may allow liquid refrigerant to enter the suction line with possible damage to the compressor (i.e. slugging). On the other hand, if the diameter is too small, the pressure drop due to friction may be too high and will reduce the system efficiency.

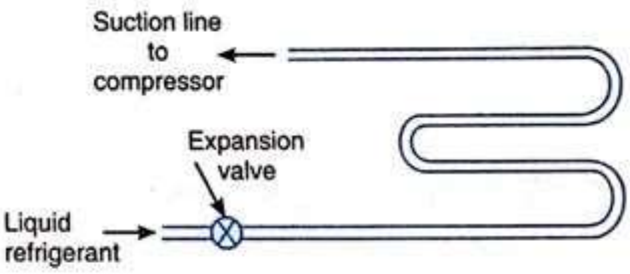


Fig. Bare tube coil evaporator.

- The bare tube coil evaporators may be used for any type of refrigeration requirement. Its use is, however, limited to applications where the box temperatures are under 0°C and in liquid cooling, because the accumulation of ice or frost on these evaporators has less effect on the heat transfer than on those equipped with fins.
- The bare tube coil evaporators are also extensively used in household refrigerators because they are easier to keep clean.

Finned Evaporators

The finned evaporator consists of bare tubes or coils over which the metal plates or fins are fastened.

- The metal fins arc constructed of thin sheets of metal having good thermal conductivity.
- The shape, size or spacing of the fins can he adapted to provide best rate of heat transfer for a given application.
- Since the fins greatly increase the contact surfaces for heat transfer, therefore the finned evaporators are also called extended surface evaporators.

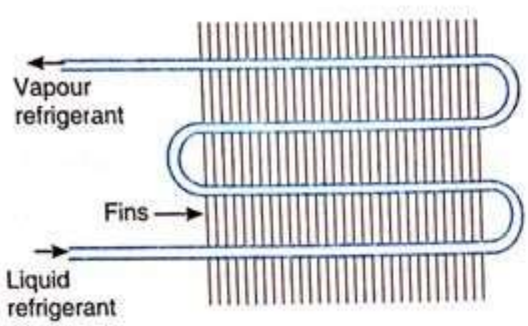


Fig. . Finned evaporator.

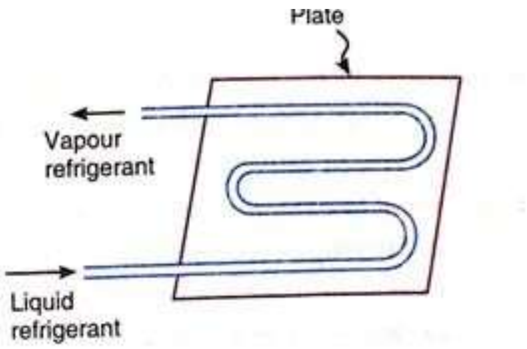


Fig. . Plate evaporator.

- The finned evaporators are primarily designed for air conditioning applications where the refrigerator temperature is above 0°C. Because of the rapid heat transfer of the finned evaporator, it will defrost itself on the off cycle when the temperature of the coil is near 0°C.
- A finned coil should never be allowed to frost because the accumulation of frost between the fins reduces the capacity. The air conditioning coils, which operate at suction temperatures which are high enough so that frosting never occurs, have fin spacing as small as 3 mm.
- The finned coils which frost on the on cycle and defrost on the off cycle have wider fin spacing.

Plate Evaporators

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

Shell and Tube Evaporators

The shell and tube evaporator is similar to a shell and tube condenser. It consists of a number of horizontal tubes enclosed in a cylindrical shell. The inlet and outlet headers with perforated metal tube sheets are connected at each end of the tubes.

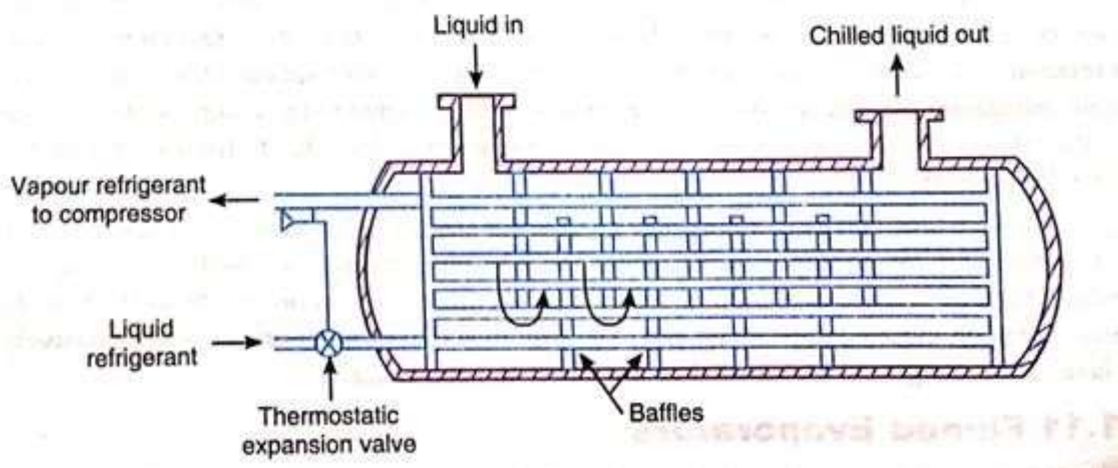


Fig. . Shell and tube evaporator.

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

Shell and Coil Evaporators

The shell and coil evaporators are generally dry expansion evaporators to chill water. The cooling coil is a continuous tube that can be in the form of a single or double spiral. The shell may be sealed or open. The scaled shells are usually found in shell and coil evaporators used to cool drinking water.

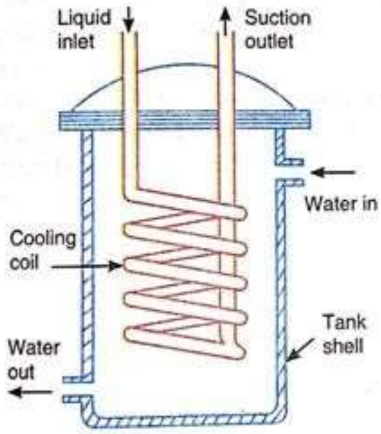


Fig. Shell and coil evaporator.

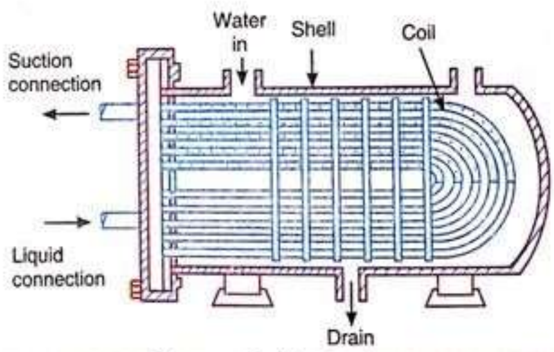


Fig. . Shell and coil evaporator.

The evaporators having flanged shells arc often used to chill water in secondary refrigeration systems. Another type of shell and coil evaporator is shown in Fig. Both types of evaporators are usually used where small capacity (2 to 10 TR) liquid cooling is required. It may be noted that the shell and coil evaporator is restricted to operation above 5°C in order to prevent the freezing problems.

Tube-in-Tube or Double-Tube Evaporators

The tube-in-tube evaporator (or double-tube evaporator) consists of one tube inside another tube. The liquid to be cooled flows through the inner tube while the primary refrigerant or secondary refrigerant (i.e. water, air or brine) circulates in the space between the two tubes. The tube-in-tube evaporator provides high heat transfer rates. However, they require more space than shell and tube evaporators of the same capacity. These evaporators are used for wine cooling and in petroleum industry for chilling of oil.

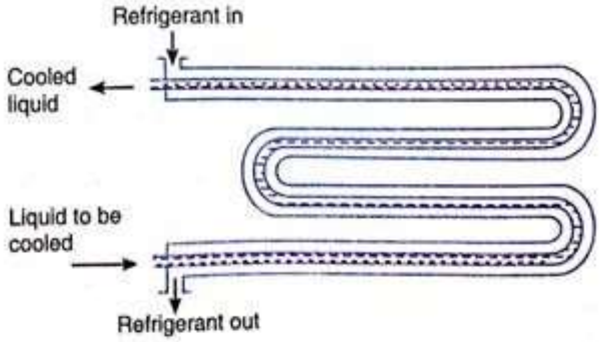


Fig. Tube-in-tube or double-tube evaporator.

SHORT QUESTIONS WITH ANSWER

1. What is the function of rotary compressor ? [Possible]

Ans : The niche services for rotary compressors include Freon and ammonia refrigeration, plant air, some wet services, and services with vacuum suction conditions. Other types of compressors cover a majority of the range of uses. Efficiencies or rotary compressors are better than centrifugal and axial but lower than reciprocating. Speed control is the most obvious way to control capacity for rotary compressors, but they are usually direct driven by motors and run at constant speed.

2. Hermetic Sealed Compressors ? [Possible]

A hermetic or sealed compressor is one in which both compressor and motor are confined in a single outer welded steel shell. The motor and compressor are directly coupled on the same shaft, with the motor inside the refrigeration circuit. Thus the need for a shaft seal with the consequent refrigerant leakage problem was eliminated. All the refrigerant pipeline connections to the outer steel shell are by welding or brazing. The electrical conductors to the motor are taken out of the steel shell by sealed terminals made of fused glass.

3. What is the function of condenser and its type? ? [Possible]

The function of the condenser in a refrigeration system is to transfer heat from the refrigerant to another medium, such as air and/or water. By rejecting heat, the gaseous refrigerant condenses to liquid inside the condenser.

The major types of condensers used are (1) water-cooled, (2) air-cooled, and (3) evaporative. In evaporative condensers, both air and water are used.

Three common types of water-cooled condensers are (1) double pipe, (2) shell and tube), and (3) shell and coil.

4. What is the function of cooling tower and sparay pond ? [2011 W]

The warm water from the condensers needs to be cooled to the lowest practical temperature before being re-used. The cooling process is carried out in cooling towers or spray ponds after which the water is pumped back to the condensers. In cooling towers or spray ponds the exchange of heat between the warm water and ambient air is by, a. conduction between the fine droplets of water and the surrounding air b. evaporative cooling, which is by far the most effective factor.

5. What are the types of evaporator? [2012]

1. According to the type of construction

(k) Bare tube coil evaporator,
(l) Finned tube evaporator,
(m) Plate evaporator,
(n) Shell and tube evaporator,
(o) Shell and coil evaporator, and
(p) Tube-in-tube evaporator,

2. According to the manner in which liquid refrigerant is fed

(q) Flooded evaporator, and
(r) Dry expansion evaporator

3. According to the mode of heat transfer

(s) Natural convection evaporator, and
(t) Forced convection evaporator

4. According to operating conditions

d. Frosting evaporator,
e. Non-frosting evaporator, and
f. Defrosting evaporator

LONG QUESTIONS

1. With neat sketch explain the working principle of reciprocating compresoor ? [2012w]

2. With neat sketch explain the evaporative type vapour condenser ? [2018w]

3. With neat sketch explain the working principle of Centrifugal Compressors ? ? [Possible]

Chapter – 05

REFRIGERANT FLOW CONTROLS, REFRIGERANTS & APPLICATION OF REFRIGERANTS

Learning Objectives :

EXPANSION VALVES

Capillary tube

Automatic expansion valve

Thermostatic expansion valve

REFRIGERANTS

Classification of refrigerants

Desirable properties of an ideal refrigerant.

Designation of refrigerant.

Thermodynamic Properties of Refrigerants.

Chemical properties of refrigerants.

commonly used refrigerants, R-11, R-12, R-22, R-134a, R-717

Substitute for CFC

Applications of refrigeration

cold storage

dairy refrigeration

ice plant

water cooler

frost free refrigerator

Expansion valve :

Types of Expansion Device :

Following are the main types of expansion devices used in industrial and commercial refrigeration and air conditioning system.

1. Capillary tube,
2. Hand-operated expansion valve,
3. Automatic or constant pressure expansion valve,
4. Thermostatic expansion valve,
5. Low-side float valve, and
6. High-side float valve.

Capillary Tube

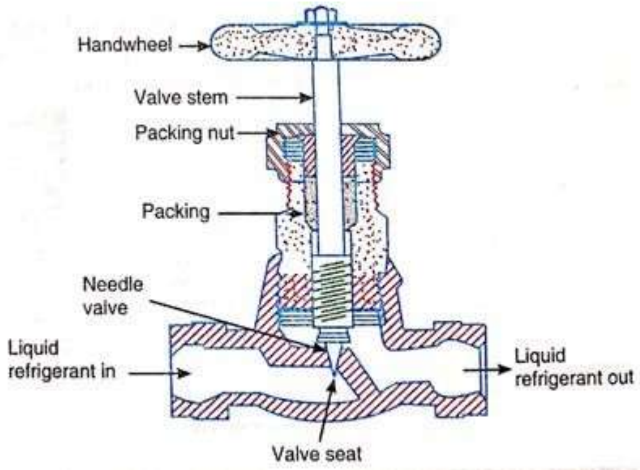
- The capillary tube is used as an expansion device in small capacity hermetic sealed refrigeration units such as in domestic refrigerators, water coolers, room air-conditioners and freezers.
- It is a copper tube of small internal diameter and of varying length depending upon the application.
- The inside diameter of the tube used in refrigeration work is generally about 0.5 mm to 2.25 mm and the length varies from 0.5 m to 5 m.
- It is installed in the liquid line between the condenser and the evaporator
- A fine mesh screen is provided at the inlet of the tube in order to protect it from contaminants.
- A small filter drier is used on some systems to provide additional freeze-up application.
- In its operation, the liquid refrigerant from the condenser enters the capillary tube.

- Due to the frictional resistance offered by a small diameter tube, the pressure drops.
- Since the frictional resistance is directly proportional to the length and inversely proportional to the diameter, therefore longer the capillary tube and smaller its inside diameter, greater is the pressure drop created in the refrigerant flow. In other words, greater pressure difference between the condenser and evaporator

Hand-operated Expansion Valve

- It is the most simple type of expansion valve but it requires an operator to regulate the flow of refrigerant to the evaporator manually.
- The conical-shaped needle valve extends down into the valve port and restricts the flow area through the port.
- When closed, the valve rests on its conical seat.
- The use of hand-operated valve is limited to systems operating under nearly constant loads for long periods of time, such as in ice making plants and cold storages.

- It is not suitable for installations where the intermittently to maintain a constant temperature.

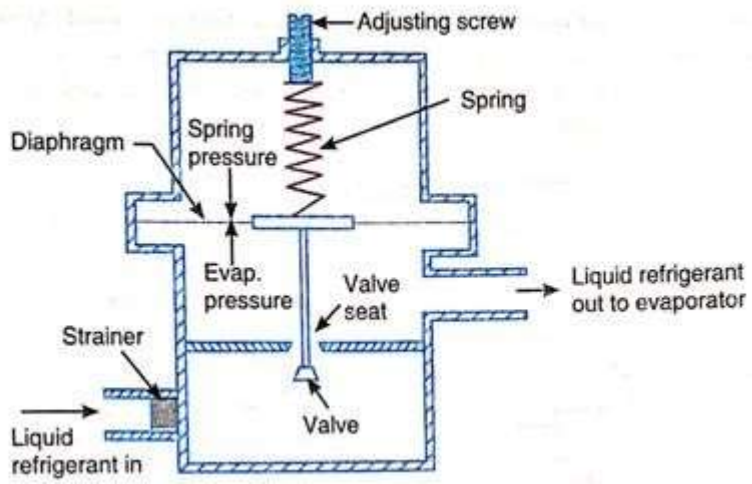


Automatic (or Constant Pressure) Expansion Valve

- The automatic expansion valve is also known as Constant pressure expansion valve, because it maintains constant evaporator pressure regardless of the load on the evaporator. Its main moving force is the evaporator pressure. It is used with dry expansion evaporators where the load is relatively constant.
- It consists of a needle valve and a scat (which forms an orifice), a metallic diaphragm or bellows, spring and an adjusting screw.
- The opening and closing of the valve with respect to the seat depends upon the following two opposing forces acting on the diaphragm :

1. The spring pressure and atmospheric pressure acting on the top of the diaphragm, and

2. The evaporator pressure acting below the diaphragm.

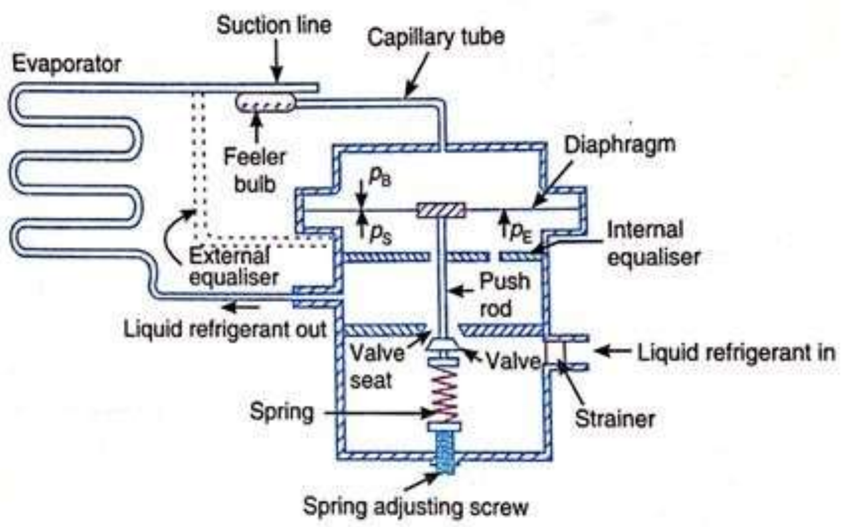


- When the compressor is running, the valve maintains an evaporator pressure in equilibrium with the spring pressure and the atmospheric pressure.

- The spring pressure can be varied by adjusting the tension of the spring with the help of spring adjusting screw.
- Once the spring is adjusted for a desired evaporator pressure, then the valve operates automatically to maintain constant evaporator pressure by controlling the flow of refrigerant to the evaporator.
- When the evaporator pressure falls down, the diaphragm moves downwards to open the valve. This allows more liquid refrigerant to enter into the evaporator and thus increasing the evaporator pressure till the desired evaporator pressure is reached.
- On the other hand, when the evaporator pressure rises, the diaphragm moves upwards to reduce the opening of the valve.
- This decreases the flow of liquid refrigerant to the evaporator which, in turn, lowers the evaporator pressure till the desired evaporator pressure is reached.
- When the compressor stops, the liquid refrigerant continues to flow into the evaporator and increases the pressure in the evaporator. This increase in evaporator pressure causes the diaphragm to move upwards and the valve is closed. It remains closed until the compressor starts again and reduces the pressure in the evaporator.

Thermostatic Expansion Valve

- This is also called a constant superheat valve because it maintains a constant superheat of the vapour refrigerant at the end of the evaporator coil, by controlling the flow of liquid refrigerant through the evaporator.
- The thermostatic expansion valve consists of a needle valve and a seat, a metallic diaphragm, spring and an adjusting screw. In addition to this, it has a feeler or thermal bulb which is mounted on the suction line near the outlet of the evaporator coil. The feeler bulb is partly filled with the same liquid refrigerant as used in the refrigeration system.



Working Principle:

- The thermostatic expansion valve consists of a needle valve, a seat, a metallic diaphragm, a spring, adjusting screw and a feeler bulb.
- The opening or closing of valve depends upon following forces acting on the diaphragm:
    - Spring pressure acting on bottom of diaphragm
    - Evaporator pressure acting on bottom of diaphragm
    - Feeler bulb pressure acting on top of diaphragm
- If load on evaporator increases, it causes the liquid refrigerant to boil faster in evaporator coil. Since feeler bulb is installed on the suction line, therefore it is at the same temperature as refrigerant at that point. So temperature of the bulb increases due to early vaporization of refrigerant.
- Thus the feeler bulb pressure increases and gets transmitted through the capillary tube to the diaphragm. The diaphragm moves downwards, opening the valve to admit more liquid refrigerant into the evaporator.
- This continues till pressure equilibrium on diaphragm is reached, at which feeler bulb pressure acting at top of diaphragm is balanced by spring and evaporator pressure acting at bottom of diaphragm.
- When evaporator load decreases, less liquid refrigerant evaporates in the coil, and the excess liquid flows towards the outlet. This cools the feeler bulb and its pressure and temperature decreases.
- This pressure makes the diaphragm move upward, reducing the valve opening and in turn decreasing refrigerant flow to evaporator. This causes decrease in evaporator pressure and again continues till diaphragm pressure equilibrium is reached.

Classification of Refrigerants :

The refrigerants may, broadly, be classified into the following two groups :

1. **Primary refrigerants, and**
2. **Secondary refrigerants.**

The refrigerants which directly take part in the refrigeration system are called primary refrigerants whereas the refrigerants which are first cooled by primary refrigerants and then us& for cooling purposes are known as secondary refrigerants.

Primary Refrigerate : The refrigerant which directly take part in the refrigeration system are called primary refrigerant.

Secondary Refrigerant : The refrigerant which are first cooled by primary refrigerant and then used for cooling purpose are known as secondary refrigerant Example : Brine Solution (Salt + Water)

The primary refrigerants are further classified into the following four groups :

1. Halo-carbon or organic refrigerants,
2. Azeotrope refrigerants,
3. Inorganic refrigerants, and
4. Hydro-carbon refrigerants.

Brine solution is an example of secondary refrigerant. Brine solution is a solution of water and salt. Since salt decreases the freezing point of the water, so it prevent from freezing.

Desirable Properties of an 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 vaporization,
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,
13. Easy of locating leaks by odour or suitable indicator,
14. Mixes well with oil,
15. High coefficient of performance, and
16. Ozone friendly. The standard comparison of refrigerants, as used in the refrigeration industry, is based on an evaporating temperature of — 15°C and a condensing temperature of + 30° C.

Designation System for Refrigerants

- The refrigerants are internationally designated as **R** followed by certain numbers such as R-11, R-12, R-I14 etc.
- A refrigerant followed by a two-digit number indicates that a refrigerant is derived from methane base while three-digit number represents ethane·base. The number assigned to hydrocarbon and halocarbon refrigerants have a special meaning.
- 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 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 by **R (m-1)(n+1) q where** $n + p + q = 2m + 2$

where m = Number of carbon atoms,

n = Number of hydrogen atoms,

p = Number of chlorine atoms, and

q = Number of fluorine atoms.

As discussed above, the number of the refrigerant is given by $R\ (m - 1)(n + 1)\ (q)$.

I. Dichloro-difluoro-methane

Number of chlorine atoms, p = 2

Number of fluorine atoms, q = 2

and number of hydrogen atoms, n = 0

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

0 + 2 + 2 = 2m + 2 or m = 1

That is 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

We see that 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 i.e. Number of carbon atoms = 2

Or m = 2

Thus the chemical formula for dichloro-tetrafluoro-ethane becomes $C_2C1_2F_4$ and the number of refrigerant becomes R (2-1) (0+1) (4) or R-114.

3. <u>DiChloro-trifluoro-ethane</u>

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

i.e. Number of carbon atoms = 2

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

The inorganic refrigerants are designated by adding 700 to the molecular mass of the compound. For example, the molecular mass of ammonia is 17, therefore it is designated by R-(700 + 17) or 12-717.

Thermodynamic Properties of Refrigerants

1. Boiling temperature.

The boiling temperature of the refrigerant at atmospheric pressure should be low. If the boiling temperature of the refrigerant is high at atmospheric pressure, the compressor should be operated at high vacuum. The high boiling temperature reduces the capacity and operating cost of the system.

2. Freezing temperature

The freezing temperature of a refrigerant should be well below the operating evaporator temperature. Since the freezing temperature of most of the refrigerants are below - 35°C, therefore this property is taken into consideration only in low temperature operation.

3. Evaporator and condenser pressure.

Both the evaporating (low side) and condensing (high side) pressures should be positive (i.e. above atmospheric) and it should be as near to the atmospheric pressure as possible. The positive pressures are necessary in order to prevent leakage. of air and moisture into the refrigerating system. It also permits easier detection of leaks. Too high evaporating and condensing pressures (above atmospheric) would require stronger refrigerating equipment (i.e. compressor, evaporator and condenser) resulting in higher initial cost.

4. Critical temperature and pressure.

The critical temperature of a refrigerant is the highest temperature at which it can be condensed to a liquid, regardless of a higher pressure. It should be ffove the highest condensing temperature that might be encountered. If the critical temperature of a refrigerant is too-near The desired condensing temperature, the excessive power consumption results.

5. Coefficient of performance and power requirements.

For an ideal refrigerant operating between — 15°C evaporator temperature and 30°C condenser temperature, the theoretical coefficient of performance for the reversed Carnot cycle is 5.74.

6. Latent heat of vaporisation.

A refrigerant should have a high latent heat of vaporisation at the evaporator temperature. The high latent heat results in high refrigerating effect per kg of refrigerant circulated which reduces the mass of refrigerant to be circulated per tonne of refrigeration. Table 8.10 shows the refrigerating effect for the common refrigerants operating between — 15°C evaporator temperature and 30°C condenser temperature. It also shows the latent heat, mass of refrigerant circulated per tonne of refrigeration and the volume of the liquid refrigerant per tonne of refrigeration.

7. Specific volume.

The specific volume of the refrigerant vapour at evaporator temperature (Le. volume of suction vapour to the compressor) indicates the theoretical displacement of the compressor. The reciprocating compressors are used with refrigerants having high pressures and low volumes of the suction vapour. The centrifugal or turbo compressors are used with refrigerants having low pressures and high volumes of the suction vapour. The rotary compressors are used with refrigerants having intermediate pressures and volumes of the suction vapour.

Chemical Properties of Refrigerants

1. Flammability : We have already discussed that hydro-carbon refrigerants such as ethane, propane etc. are highly flammable. Ammonia is also somewhat flammable and becomes explosive when mixed with air in the ratio of 16 to 25 per cent of gas by volume. The halo-carbon refrigerants are neither flammable nor explosive.

2. Toxicity : The toxicity of refrigerant may be of prime or secondary importance, depending upon the application. Some non-toxic refrigerants (i.e. all fluorocarbon refrigerants) when mixed with certain percentage of air become toxic. The following table shows the relative toxicity of the common refrigerants. based upon the concentration and exposure time required to produce serious results.

3. Solubility of water : Water is only slightly soluble in R-12. At — 18°C, it will hold six parts per million by weight. The solution formed is very slightly corrosive to any of the common metals. The solubility of water with R-22 is more than R-12 by a ratio of 3 to 1. If more water is present than can be dissolved by the refrigerant, the ice will be formed which chokes the expansion valve or capillary tube used for throttling in the system. This may be avoided by the proper dehydration of the refrigerating unit before charging and by the use of silica gel drier of the liquid line. Ammonia is highly soluble in water. Due to this reason, a wetted cloth is put at the point of leak to avoid harm to the persons working in ammonia refrigerating plants.

4. Miscibility : The ability of a refrigerant to mix with oil is called miscibility. This property of refrigerant is considered to be a secondary factor in the selection of a refrigerant. The degree of miscibility depends upon the temperature of the oil and pressure of the refrigerating vapour.

The freon group of refrigerants are highly miscible refrigerants while ammonia, carbon dioxide, sulphur dioxide and methyl chloride are relatively non-miscible. The non-miscible refrigerants require larger heat transfer surfaces due to poor heat conduction properties of oil. The miscible refrigerants are advantageous from the heat transfer point of view. They give better lubrication as the refrigerant acts as a carrier of oil to the moving parts. The miscible refrigerants also eliminate oil-separation problems and aid in the return of oil from the evaporator.

5. Effect on perishable materials : The refrigerants used in cold storage plant and in domestic refrigerators should be such that in case of leakage, it should have no effect on the perishable materials. The freon group of refrigerants have no effect upon dairy products, meats, vegetables, flowers and furs. There will be no change in colour, taste or texture of the material when exposed to freon. Methyl chloride vapours have no effect upon furs, flowers, eating foods or drinking beverages. Sulphur dioxide destroys flowers, plants and furs, but it does not affect foods . Ammonia dissolves easily in water and becomes alkaline in nature. Since most fruits and vegetables are acidic in nature, therefore ammonia reacts with these products and spoils the taste.

commonly used refrigerants, R-11, R-12, R-22, R-134a, R-717

R-11

R-11 is a colorless and odorless CFC refrigerant that was completely banned from production by 1996 under the Montreal Protocol for depleting the ozone. It is a low-pressure refrigerant that was commonly used in centrifugal chillers and before the 1970's it was used as a propellant for aerosols. The refrigerant is typically stored in orange drums or containers. Chemical Name: Trichlorofluoromethane.

Most Common Replacement: R-123 (HCFC), being phased out in 2020 for the United states and other developed countries.

Refrigerant R12 or Freon 12

Refrigerant R12 or Freon 12 is said to be the most widely used of all the refrigerants being used for different applications. The chemical name of refrigerant R12 is dichlorodifluoromethane and its chemical formula is CCl2F2. The molecular weight of R12 is 120.9 and its boiling point is -21.6 degree F. Since R12 has the molecules of chlorine and fluorine, it is called as chlorofluorocarbon (CFC).

R22

R22, commonly known as "Freon." R22 is an A/C refrigerant — a substance used for cooling in air conditioners— that was once widely used in air conditioning units in homes and businesses alike. But, after years of using R22 in air conditioning units of all sizes, it was discovered that R22 is a dangerous chemical that was significantly contributing to the thinning in the ozone layer.

R134a Refrigerant

R134a is also known as Tetrafluoroethane (CF_3CH_2F) from the family of HFC refrigerant. With the discovery of the damaging effect of CFCs and HCFCs refrigerants to the ozone layer, the HFC family of refrigerant has been widely used as their replacement. It is now being used as a replacement for R-12 CFC refrigerant in the area of centrifugal, rotary screw, scroll and reciprocating compresssors. It is safe for normal handling as it is non-toxic, non-flammable and non-corrosive.

R717 (Ammonia)

R717 (Ammonia) is refrigerant grade Ammonia (NH_3) used in low and medium temperature refrigeration. It is a colourless, pungent, highly toxic gas but is a very efficient refrigerant with zero Global Warming Potential (GWP).

Applications : Industrial Refrigeration

Product Features & Benefits

- Refrigerant can be charged from either the liquid or vapour phase
- Toxic, low-flammability with a safety classification of B2L
- Compressors can be charged with a variety of oils, contact the compressor manufacturer for more information
- Under pressure Ammonia is stored as a liquid
- Moisture content of less than 200ppm

Substitute For CFC

Two of the chemical classes under consideration for replacing CFCs are hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). HCFCs contribute to the destruction of stratospheric ozone, but to a much lesser extent than CFCs. Use of HCFCs as transitional refrigerants will allow industry to phase out the production of CFCs and will offer environmental benefits over the continued use of CFCs. Because they contain hydrogen, HCFCs break down more easily in the atmosphere than do CFCs. Therefore, HCFCs have less ozone depletion potential, in addition to less global-warming potential.

Cold storage

Generally, cold storage is cooled by refrigerator, using the liquid with low gasification temperature as refrigerant, making it evaporate under the condition of low pressure and mechanical control and absorb the heat in the cold storage, finally to achieve the purpose of cooling. The most commonly used is the compressor refrigerator, mainly made up of compressor, condenser, throttle valve and evaporator, and so on. It can be divided into direct cooling and indirect cooling according to the way of evaporation tube device. The direct cooling installs the evaporator in the cold storage, whereas indirect cooling uses blower to suck the air in the cold storage into the air cooling device. The advantage of the air cooling is cooling rapidly, uniform temperature etc.

Dairy refrigeration

Dairy is an indispensable part of the global food system and it plays a crucial role in the sustainability of rural areas in particular. It is a well-known fact that the dairy industry actively contributes to the economies of a number of countries. An increasing demand worldwide is noticeably emerging at present, and the industry is globalising. Milk and dairy products are very essential for human nutrition and development, especially, in children. Although milk is a highly nourishing food, raw fresh milk is highly liable to rot and can be easily spoiled by the growth of microorganisms. Fresh milk is collected from the farm, transported to cooling centres to prevent spoilage, then to processing units to produce other dairy products and finally delivered to the consumers in several ways, as shown in figure 1. The transportation of fresh milk from farms to cooling centres and processing units may take time. Consequently, cooling milk in time becomes major problem associated with raw fresh milk. The milk should be cooled within three to four hours of collecting it from the farm, which otherwise leads to spoilage. Thus, refrigeration plays a vital role in dairy industry.

Ice plant

The function of an ice plant or ice factory is to make or form ice in large quantity and in large size. The ice making process is quite similar to the one we observe in a domestic refrigerator. The only difference lies in the ice making the stage. In the freezer compartment, the tray with water when it comes in contact with very low-temperature environment, becomes ice but in 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

Brine: It is the secondary refrigerant which takes heat from the water and produces ice.

Water cooler

Water coolers usually use a condenser/evaporator type cooling system with a compressor to change the refrigerant state from gas to liquid. Older water coolers, some of which are still in use, used Freon, or R-12 refrigerant to cool the water. This refrigerant has been replaced by what are considered less harmful refrigerants like R-134a, and possibly R-22 depending on when and by whom they were built. Refrigerants are used depending on their boiling point (lower for freezers and ice machines, higher, but still cold for refrigeration units and air conditioning systems), so these are two that fit the temperature range suitable for water coolers.

Frost free refrigerator

This frost forms when water vapor hits the cold coils. The water vapor condenses -- turns to liquid water. Think of the water beading up on a glass of iced tea on a summer day -- that is an example of water vapor in the air condensing. The same thing happens on the ice-cold freezer coils, except that when the water condenses onto the coils it immediately freezes.

A frost-free freezer has three basic parts:

A timer

A heating coil

A temperature sensor

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 off the coils. When all of the ice is gone, the temperature sensor senses the temperature rising above 32 degrees F (0 degrees C) and turns off the heater. Heating the coils every six hours takes energy, and it also cycles the food in the freezer through temperature changes. Most large chest freezers therefore require manual defrosting instead -- the food lasts longer and the freezer uses less power.

SHORT QUESTION WITH ANSWER :

1. Define refrigerant ? [2009s, 2020w]

Ans : Refrigerant is a heat carrying medium used in refrigeration system which absorb heat in evaporator chamber and reject it in condenser.

2. State any four important properties of Freon-12 [2009 BP]

Ans : Non Flammable, Non Toxic, Colorless, Has no smell

3. State four important properties of refrigerant. [2007s]

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

4. What is the use of refrigerant ? [2006s]

Ans : A refrigerant is chemical compound that is used as the heat carrier, which changes from gas to liquid and then back to gas in the refrigeration cycle. Refrigerants are used primarily in refrigerators/freezers, air-conditioning, and fire suppression systems.

5. Define primary and secondary refrigerant. [2012, 2020w]

Ans :

Primary Refrigerate : The refrigerant which directly take part in the refrigeration system are called primary refrigerant.

Secondary Refrigerant : The refrigerant which are first cooled by primary refrigerant and then used for cooling purpose are known as secondary refrigerant Example : Brine Solution (Salt + Water)

6. Write the chemical formula for R11 and R113, R 21, R22, R 13

refrigerant	**chemical**	**name**
R11	CCl_3F	**trichloro-fluoro-methane**
R12	CCl_2F_2	dichloro-difluoro-methane
R13	$CClF_3$	chloro-trifluoro-methane
R21	$CHCl_2F$	Dichlorofluoromethane
R22	$CHClF_2$	**Difluorochloromethane**
R113	$Cl_2FC\text{-}CClF_2$	**trichlorotrifluoroethane**

7. What are the physical properties of refrigerant ? [2020w]

Ans :

- Stability and inertness
- Corrosive
- Viscocity
- Thermal conductivity
- Dielectric strength
- Leakage tendency
- Cost

LONG QUESTIONS

1. State the desirable properties of ideal refrigerant. [2010s, 2009s, 2011w, 2012w, 2014w, 2020w]

2. Explain the working principle of thermostatic expansion valve ?

3. Explain the working principle of Automatic (or Constant Pressure) Expansion Valve ?

4. _. Explain the working principle of hand operated Expansion Valve ?

CHAPTER – 06

PSYCHROMETRICS & COMFORRT AIR CONDITIONING SYSTEM

6. 1 Psychrometric Terms

Though there are many psychrometric terms, yet the following are important from the subject point of view :

1. Dry air.

The pure dry air is a mixture of a number of gases such as nitrogen, oxygen, carbon dioxide, hydrogen, argon, neon, helium etc. But the nitrogen and oxygen have the major portion of the combination. The molecular mass of dry air is taken as 28.966 and the gas constant of air (R a) is equal to 0.287 kJ/kg K or 287 J/kg K. The molecular mass of water vapour is taken as 18.016 and the gas constant for water vapour (Ra) is equal to 0.461 kJ/kg K or 461.J/kg K.

2. Moist air.

It is a mixture of dry air and water vapour. The amount of water vapour present in the air depends upon the absolute pressure and temperature of the mixture. 3. Saturated air. It is a mixture of dry air and water vapour, when the air has diffused the maximum amount of water vapour into it. The water vapours, usually, occur in the form of superheated steam as an invisible gas.

4. Degree of saturation.

It is the ratio of actual mass of water vapour in a unit mass of dry air to the mass of water vapour in the same mass of dry air when it is saturated at the same temperature.

5. Humidity.

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

6. Absolute humidity.

It is the mass of water vapour present in 1 m3 of dry air, and is generally expressed in terms of gram per cubic metre of dry air (g /m3 of dry air)• It is also expressed in terms of grains per cubic metre of dry air. Mathematically, one kg of water vapour is equal to 15 430 grains.

7. Relative humidity.

It is the ratio of actual mass of water ,vapour in a given volume of moist air to the mass of water vapour in the same volume of saturated air at the same temperature and pressure. It is briefly written as R_H.

8. Dry bulb temperature.

It is the temperature of air recorded by a thermometer, when it is not affected by the moisture present in the air. The dry bulb temperature (briefly written as DBT) is generally denoted by td or t_{db}.

9. Wet bulb temperature.

It is the temperature of air recorded by a thermometer, when its bulb is surrounded by a wet cloth exposed to the air. Such a thermometer is called 'wet bulb thermometer. The wet bulb temperature (briefly written as WBT) is generally denoted by tw, or t_{wb}.

10. Wet bulb depression.

It is the difference between dry bulb temperature and wet bulb temperature at any point. The wet bulb depression indicates relative humidity of the air.

11. Dew point temperature.

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

12.Dew point depression.

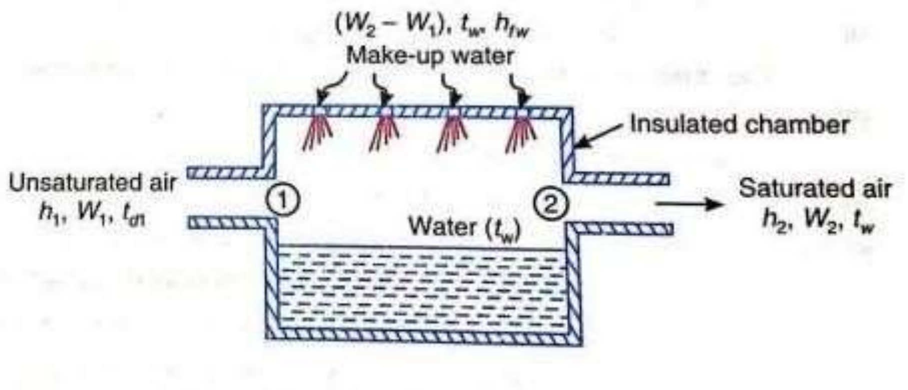
It is the difference between the dry bulb temperature and dew point temperature of air.

6. 2 Thermodynamic Wet Bulb Temperature or Adiabatic Saturation Temperature

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

The equipment used for the adiabatic saturation of air, in its simplest form, consists of an insulated chamber containing adequate quantity of water. There is also an arrangement for extra water (known as make-up water) to flow into the chamber from its top.

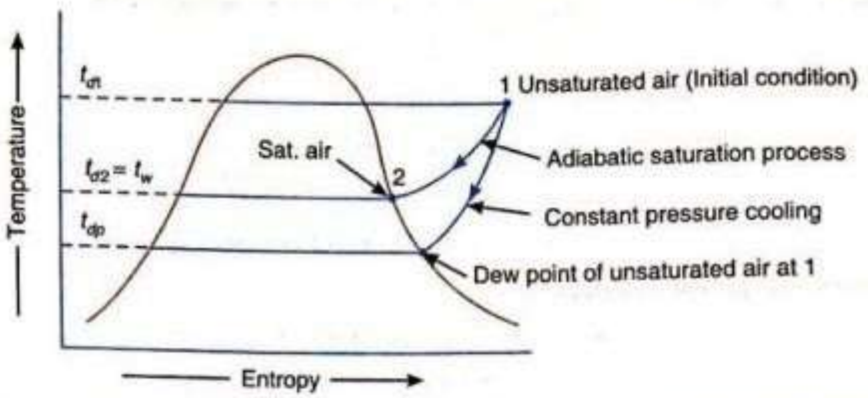
Let the unsaturated air enters the chamber at section 1. As the air passes through the chamber over a long sheet of water, the water evaporates which is carried with the flowing stream of air, and the specific humidity of the air increases.



. Adiabatic saturation of air.

The make-up water is added to the chamber at this temperature to make the water level constant. Both the air and water are cooled as the evaporation takes place. This process continues until the energy transferred from the air to the water is equal to the energy required to vaporise the water. When steady conditions are reached, the air flowing at section 2 is saturated with water vapour. The temperature of the saturated air at section -2 is known as thermodynamic wet bulb temperature or adiabatic saturation temperature.

The adiabatic saturation process can be represented on *T-s* diagram as shown by the curve 1-2



T-s diagram for adiabatic saturation process.

During the adiabatic saturation process, the partial pressure of vapour increases, although the total pressure of the air-vapour mixture remains constant. The unsaturated air initially at dry bulb temperature t_{d1} is cooled adiabatically to dry bulb temperature t_{d2} which is equal to the adiabatic saturation temperature t_w. It may be noted that the adiabatic saturation temperature is taken equal to the wet bulb temperature for all practical purposes.

Let h_1 = Enthalpy of unsaturated air at section 1,

W_1 = Specific humidity of air at section 1,

h_2, W_2 = Corresponding values of saturated air at section 2, and

h_{fw} = Sensible heat of water at adiabatic saturation temperature.

Balancing the enthalpies of air at inlet and outlet (*i.e.* at sections 1 and 2),

$$h_1 + (W_2 - W_1)\, h_{fw} = h_2 \quad \text{... (}i$$

or

$$h_1 - W_1\, h_{fw} = h_2 - W_2\, h_{fw} \quad \text{... (}ii$$

The term $(h_2 - W_2\, h_{fw})$ is known as *sigma heat* and remains constant during the adiabati process.

We know that $h_1 = h_{a1} + W_1\, h_{s1}$

and $h_2 = h_{a2} + W_2\, h_{s2}$

where h_{a1} = Enthalpy of 1 kg of dry air at dry bulb temperature t_{d1},

*h_{s1} = Enthalpy of superheated vapour at t_{d1} per kg of vapour,

h_{a2} = Enthalpy of 1 kg of air at wet bulb temperature t_w, and

h_{s2} = Enthalpy of saturated vapour at wet bulb temperature t_w per kg vapour.

Now the equation (*ii*) may be written as :

$$(h_{a1} + W_1\, h_{s1}) - W_1\, h_{fw} = (h_{a2} + W_2\, h_{s2}) - W_2\, h_{fw}$$

$$W_1\,(h_{s1} - h_{fw}) = W_2\,(h_{s2} - h_{fw}) + h_{a2} - h_{a1}$$

$$\therefore \quad W_1 = \frac{W_2\,(h_{s2} - h_{fw}) + h_{a2} - h_{a1}}{h_{s1} - h_{fw}}$$

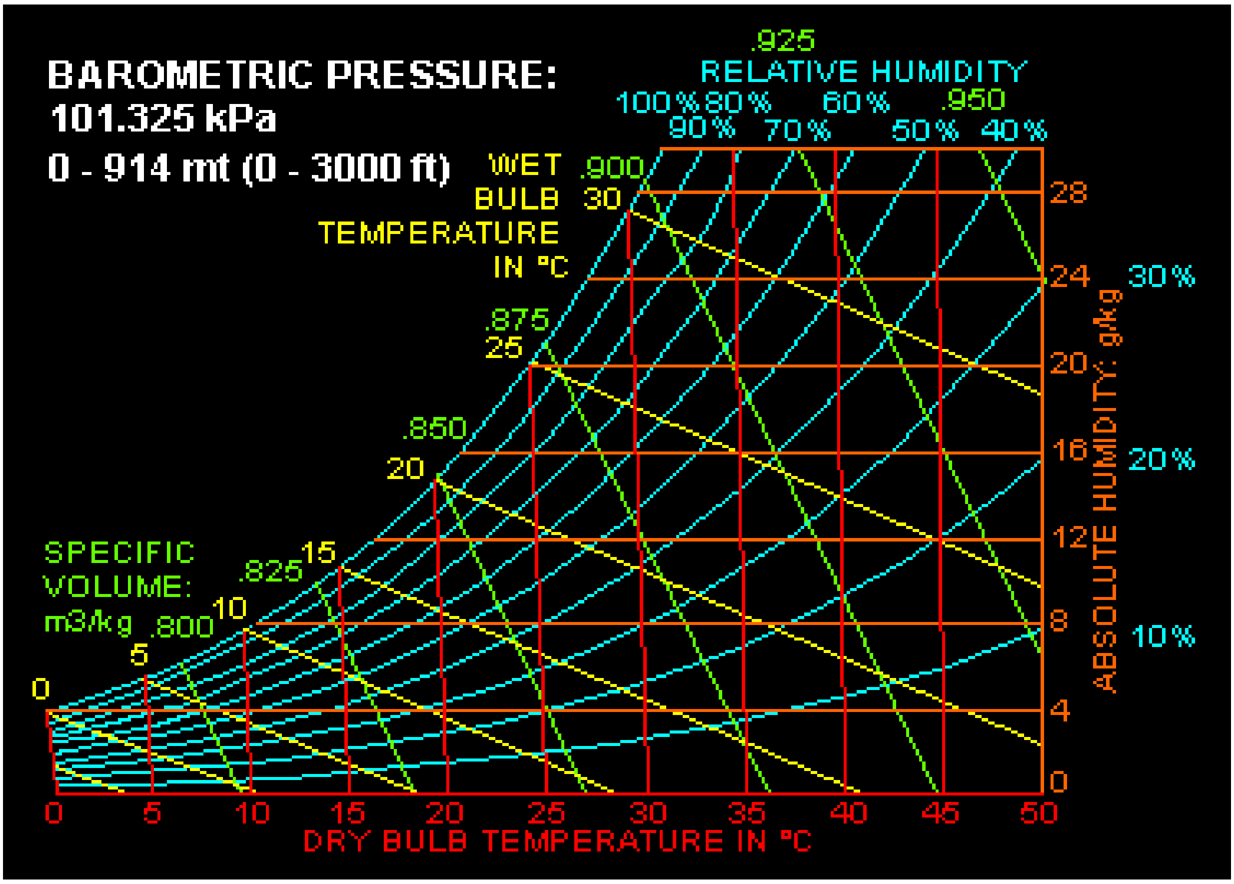
Psychrometric Chart :

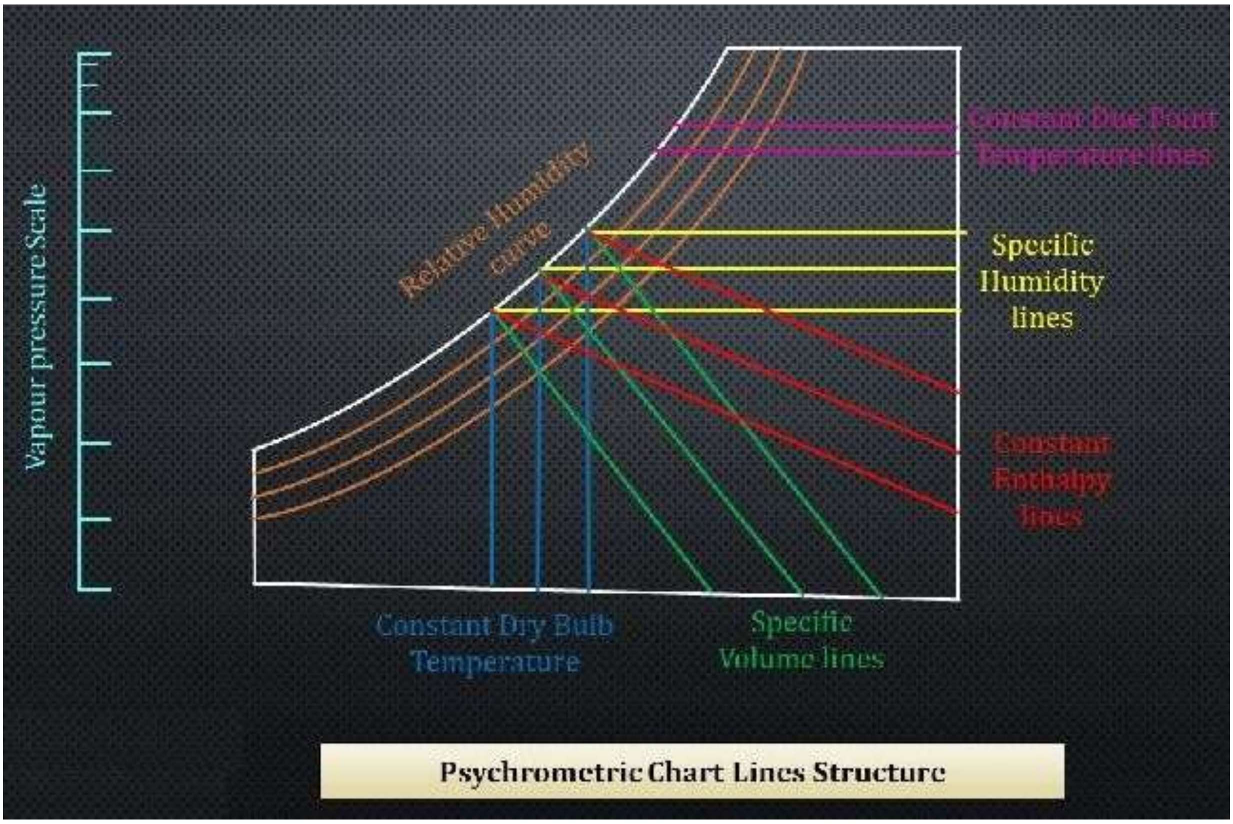
It is the graphical representation of various thermodynamic properties of moist air. The pyschrometric chart is very useful for finding out the properties of air and eliminate a lot of calculations. The psychrometric chart is normally drawn for standard atmosphere pressure of 760 mm of Hg.

Example : 1

For a sample of air having 22 degree DBT, relative humidity 30% at barometric pressure of 760 mm of Hg.

Calculate 1. Vapour pressure 2. Humidity ratio 3. Vapour density and 64. Enthalpy Verify your result by psychro metric chart.





Psychrometric Chart Lines Structure

1. *Vapour pressure*

Let p_v = Vapour pressure.

From steam tables, we find that the saturation pressure of vapour corresponding to dry bulb temperature of 22° C is

$$p_s = 0.026\,42 \text{ bar}$$

We know that relative humidity (ϕ),

$$0.3 = \frac{p_v}{p_s} = \frac{p_v}{0.026\,42}$$

$$\therefore \quad p_v = 0.3 \times 0.026\,42 = 0.007\,926 \text{ bar} \quad \textbf{Ans.}$$

2. *Humidity ratio*

We know that humidity ratio,

$$W = \frac{0.622\, p_v}{p_b - p_v} = \frac{0.622 \times 0.007\,926}{1.013\,08 - 0.007\,926}$$

$$= 0.0049 \text{ kg/kg of dry air} \quad \textbf{Ans.}$$

3. *Vapour density*

We know that vapour density,

$$\rho_v = \frac{W\,(p_b - p_v)}{R_a\, T_d} = \frac{0.0049\,(1.013\,08 - 0.007\,926)\,10^5}{287\,(273 + 22)}$$

$$= 0.005\,82 \text{ kg/m}^3 \text{ of dry air} \quad \textbf{Ans.}$$

4. *Enthalpy*

From steam tables, we find that saturation temperature or dew point temperature corresponding to a pressure of $p_v = 0.007\,926$ bar is

$$t_{dp} = 3.8° \text{ C}$$

and latent heat of vaporisation of water at dew point temperature of 3.8° C is

$$h_{fgdp} = 2492.6 \text{ kJ/kg}$$

We know that enthalpy,

$$h = 1.022\, t_d + W\,(h_{fgdp} + 2.3\, t_{dp})$$

$$= 1.022 \times 22 + 0.0049\,(2492.6 + 2.3 \times 3.8)$$

$$= 22.484 + 12.256 = 34.74 \text{ kJ/kg of dry air} \quad \textbf{Ans.}$$

Verification from psychrometric chart

The initial condition of air *i.e.* 22° C dry bulb temperature and 30% relative humidity is marked on the psychrometric chart at point *A* as shown in Fig. 16.15.

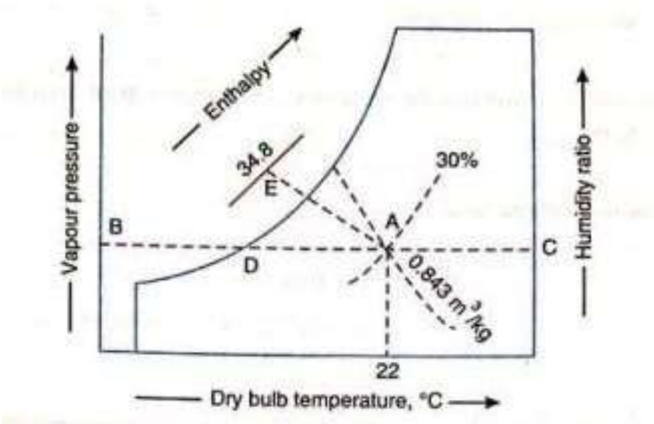
From point *A*, draw a horizontal line meeting the vapour pressure line at point *B* and humidity ratio line at *C*. From the psychrometric chart, we find that vapour pressure at point *B*,

$$p_v = 5.94 \text{ mm of Hg}$$

$$= 5.94 \times 133.3 = 791.8 \text{ N/m}^2 = 0.007\,918 \text{ bar} \quad \textbf{Ans.}$$

and humidity ratio at point *C*,

$$W = 5 \text{ g/kg of dry air} = 0.005 \text{ kg/kg of dry air} \quad \textbf{Ans.}$$



We also find from the psychrometric chart that the specific volume at point A is 0.843 m^3/kg of dry air.

Vapour density. $Þ_v = W/Þ_a = 0.005/0.843 = 0.0058$ kg/m^3 of dry air

Ans. Now from point A. draw a line parallel to the wet bulb temperature line meeting the enthalpy line at point E. Now the enthalpy of air as read from the chart is 34.8 kJ/kg of dry air.

Psychrometric Processes

The various psychrometric processes involved in air conditioning to vary the psychrometric properties of air according to the requirement are as follows :

1. Sensible heating,
2. Sensible cooling.
3. Humidification and dehumidification,
4. Cooling and adiabatic humidification.
5. Cooling and humidification by water injection,
6. Heating and humidification.
7. Humidification by steam injection,
8. Adiabatic chemical dehumidification.
9. Adiabatic mixing of air streams.

Sensible Heating

The heating of air without any change in its specific humidity, is known as sensible heating. Let air at temperature t_{d1}, passes over a heating coil of temperature t_{d3}. It may be noted that the temperature of air leaving the heating coil (t_{d2}) will be less than t_{d3}. The process of sensible heating, on the psychrometric chart, is shown by a horizontal line 1-2 extending from left to right. The point 3 represents the surface temperature of the heating coil.

The heat absorbed by the air during sensible heating may be obtained from the psychrometric chart by the enthalpy difference (h_2-h_1). It may be noted that the specific humidity during the sensible heating remains constant (i.e. $W_1 = W_2$) . The dry bulb temperature increases from

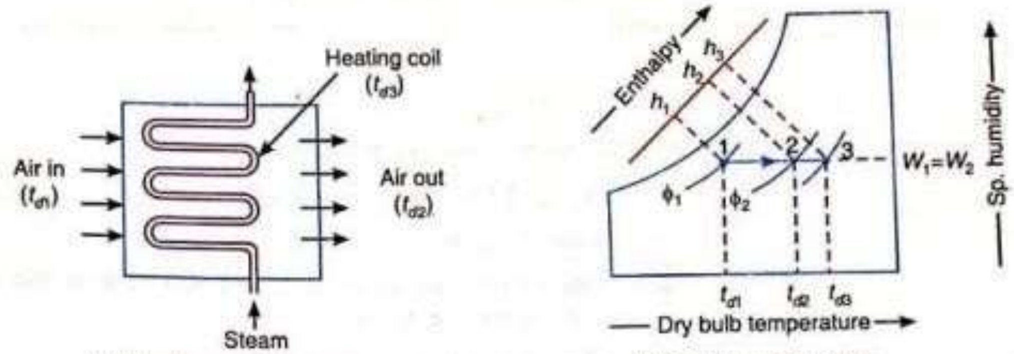
t_{d1}, to t_{d2} and relative humidity reduces from Ø1 to Ø2 .The amount of heat added during sensible heating may also be obtained from the relation

Heat added.

$$\begin{aligned} q &= h_2 - h_1 \\ &= c_{pa}(t_{d2} - t_{d1}) + W\, c_{ps}(t_{d2} - t_{d1}) \\ &= (c_{pa} + W\, c_{ps})(t_{d2} - t_{d1}) = c_{pm}(t_{d2} - t_{d1}) \end{aligned}$$

The term $(c_{pa} + W\, c_{ps})$ is called *humid specific heat* (c_{pm}) and its value is taken as 1.022 kJ /kg K.

∴ Heat added, $q = 1.022\,(t_{d2} - t_{d1})$ kJ/kg



(*a*) Psychrometric process. (*b*) Psychrometric chart.

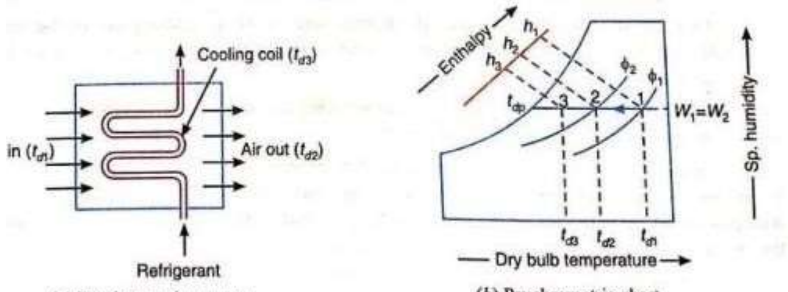
Sensible heating.

Notes : 1. For sensible heating, steam or hot water is passed through the heating coil. The heating coil may be electric resistance coil.

2. The sensible heating of moist air can be done to any desired temperature.

Sensible cooling :

The cooling of air, without any change in its specific humidity, is known as sensible cooling. Let air at temperature t_{d1} passes over a cooling coil of temperature t_{d3} . It may be noted that the temperature of air leaving the cooling coil (t_{d2}) will be more than t_{d3}. The process of sensible cooling, on the psychrometric chart, is shown by a horizontal line 1-2 extending from right to left. The point 3 represents the surface temperature of the cooling coil. The heat rejected by air during sensible cooling may be obtained from the psychometric chart by the enthalpy difference ($h_1 – h_2$). It may be noted that the specific humidity during the sensible cooling remains constant (i.e. $W_1=W_2$). The dry bulb temperature reduces from t_{d1} to t_{d2} and relative humidity increases from (Ø1 to Ø1). The amount of heat rejected during sensible cooling may also be obtained from the relation :



(*a*) Psychrometric process. (*b*) Psychrometric chart.

Sensible cooling.

Heat rejected, $q = h_1 - h_2$

$$= c_{pa}(t_{d1} - t_{d2}) + W c_{ps}(t_{d1} - t_{d2})$$

$$= (c_{pa} + W c_{ps})(t_{d1} - t_{d2}) = c_{pm}(t_{d1} - t_{d2})$$

The term $(c_{pa} + W c_{ps})$ is called *humid specific heat* (c_{pm}) and its value is taken as 1.022 kJ /kg K.

$\therefore$ Heat rejected, $q = 1.022\ (t_{d1} - t_{d2})$ kJ/kg

For air conditioning purposes, the sensible heat per minute is given as

$$SH = m_a\, c_{pm}\, \Delta t = v\, \rho\, c_{pm}\, \Delta t \text{ kJ/min} \qquad \ldots (\because\ m = v\,\rho)$$

where v = Rate of dry air flowing in m^3/min,

ρ = Density of moist air at 20° C and 50% relative humidity = 1.2 kg / m^3 of dry air,

c_{pm} = Humid specific heat = 1.022 kJ /kg K, and

Δt = $t_{d1} - t_{d2}$ = Difference of dry bulb temperatures between the entering and leaving conditions of air in ° C.

Substituting the values of ρ and c_{pm} in the above expression, we get

$$SH = v \times 1.2 \times 1.022 \times \Delta t = 1.2264\, v \times \Delta t \text{ kJ/min}$$

$$= \frac{1.2264\, v \times \Delta t}{60} = 0.020\,44\, v \times \Delta t \text{ kJ/s or kW}$$

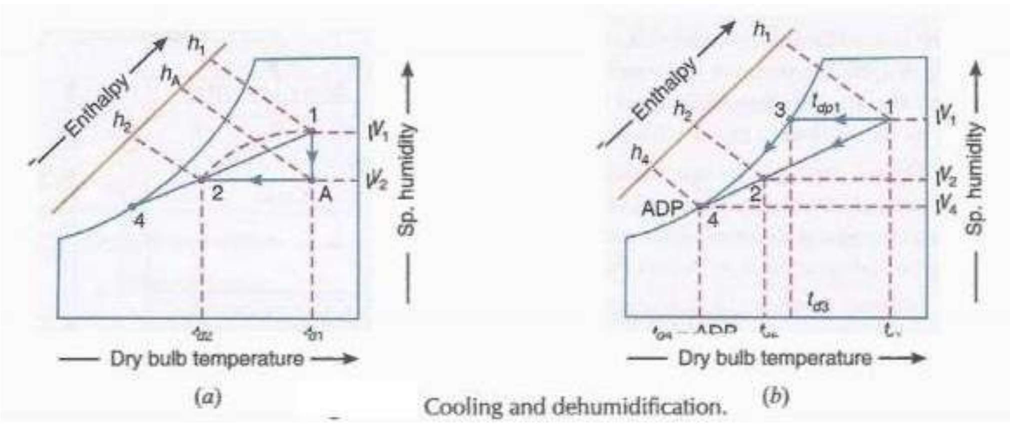
$$\ldots (\because\ 1 \text{ kJ/s} = 1 \text{ kW})$$

Notes : 1. For sensible cooling, the cooling coil may have refrigerant, cooling water or cool gas flowing through it.

2. The sensible cooling can be done only up to the dew point temperature (t_{dp}) as shown in Fig. 16.17 (*b*). The cooling below this temperature will result in the condensation of moisture.

Cooling and Dehumidification

This process is generally used in summer air conditioning to cool and dehumidify the air. The air is passed over a cooling coil or through a cold water spray. In this process, the dry bulb temperature as well as the specific humidity of air decreases. The final relative humidity of the air is generally higher than that of the entering air. The dehumidification of air is only possible when the effective surface temperature of the cooling coil (t_{d4}) is less than the dew point temperature of the air entering coil (t_{dp1}). The effective surface temperature of the coil is known as apparatus dew point briefly written as ADP). The cooling and dehumidification process is shown in fig.



Cooling and dehumidification.

Let t_{d1} = Dry bulb temperature of air entering the coil,

t_{dp1} = Dew point temperature of the entering air = t_{d3}, and

t_{d4} = Effective surface temperature or *ADP* of the coil.

Under ideal conditions, the dry bulb temperature of the air leaving the cooling coil (*i.e.* t_{d4}) should be equal to the surface temperature of the cooling coil (*i.e. ADP*), but it is never possible due to inefficiency of the cooling coil. Therefore, the resulting condition of air coming out of the coil is shown by a point 2 on the straight line joining the points 1 and 4. The by-pass factor in this case is given by

$$BPF = \frac{t_{d2} - t_{d4}}{t_{d1} - t_{d4}} = \frac{t_{d2} - ADP}{t_{d1} - ADP}$$

Also
$$BPF = \frac{W_2 - W_4}{W_1 - W_4} = \frac{h_2 - h_4}{h_1 - h_4}$$

Actually, the cooling and dehumidification process follows the path as shown by a dotted curve in Fig. (*a*), but for the calculation of psychrometric properties, only end points are important. Thus the cooling and dehumidification process shown by a line 1-2 may be assumed to have followed a path 1-*A* (*i.e.* dehumidification) and *A*-2 (*i.e.* cooling) as shown in Fig. 16.29 (*a*). We see that the total heat removed from the air during the cooling and dehumidification process is

$$q = h_1 - h_2 = (h_1 - h_A) + (h_A - h_2) = LH + SH$$

where $LH = h_1 - h_A$ = Latent heat removed due to condensation of vapour of the reduced moisture content $(W_1 - W_2)$, and

$SH = h_A - h_2$ = Sensible heat removed.

We know that sensible heat factor,

$$SHF = \frac{\text{Sensible heat}}{\text{Total heat}} = \frac{SH}{LH + SH} = \frac{h_A - h_2}{h_1 - h_2}$$

Example 1 *In a cooling application, moist air enters a refrigeration coil at the rate of 100 kg of dry air per minute at 35° C and 50% RH. The apparatus dew point of coil is 5° C and by-pass factor is 0.15. Determine the outlet state of moist air and cooling capacity of coil in TR.*

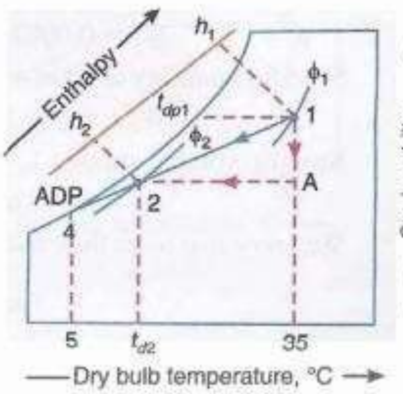
Solution. Given : $m_a = 100$ kg/min ; $t_{d1} = 35°$ C ; $\phi_1 = 50\%$; $ADP = 5°$ C ; $BPF = 0.15$

Outlet state of moist air

Let t_{d2} and ϕ_2 = Temperature and relative humidity of air leaving the cooling coil.

First of all, mark the initial condition of air, *i.e.* 35° C dry bulb temperature and 50% relative humidity on the psychrometric chart at point 1, as shown in Fig. 16.30. From the psychrometric chart, we find that the dew point temperature of the entering air at point 1,

$$t_{dp1} = 23° \text{ C}$$



Since the coil or apparatus dew point (*ADP*) is less than the dew point temperature of entering air, therefore it is a process of cooling and dehumidification.

We know that by-pass factor,

$$BPF = \frac{t_{d2} - t_{d4}}{t_{d1} - t_{d4}} = \frac{t_{d2} - ADP}{t_{d1} - ADP}$$

$$0.15 = \frac{t_{d2} - 5}{35 - 5} = \frac{t_{d2} - 5}{30}$$

$$\therefore \quad t_{d2} = 0.15 \times 30 + 5 = 9.5° \text{ C} \quad \textbf{Ans.}$$

From the psychrometric chart, we find that the relative humidity corresponding to a dry bulb temperature (t_{d2}) of 9.5° C on the line 1-4 is $\phi_2 = 99\%$. **Ans.**

Cooling capacity of the coil

The resulting condition of the air coming out of the coil is shown by point 2, on the line joining the points 1 and 4, as shown in Fig. 16.30. The line 1-2 represents the cooling and dehumidification process which may be assumed to have followed the path 1-*A* (*i.e.* dehumidification) and *A*-2 (*i.e.* cooling). Now from the psychrometric chart, we find that enthalpy of entering air at point 1,

$$h_1 = 81 \text{ kJ/kg of dry air}$$

and enthalpy of air at point 2,

$$h_2 = 28 \text{ kJ/kg of dry air}$$

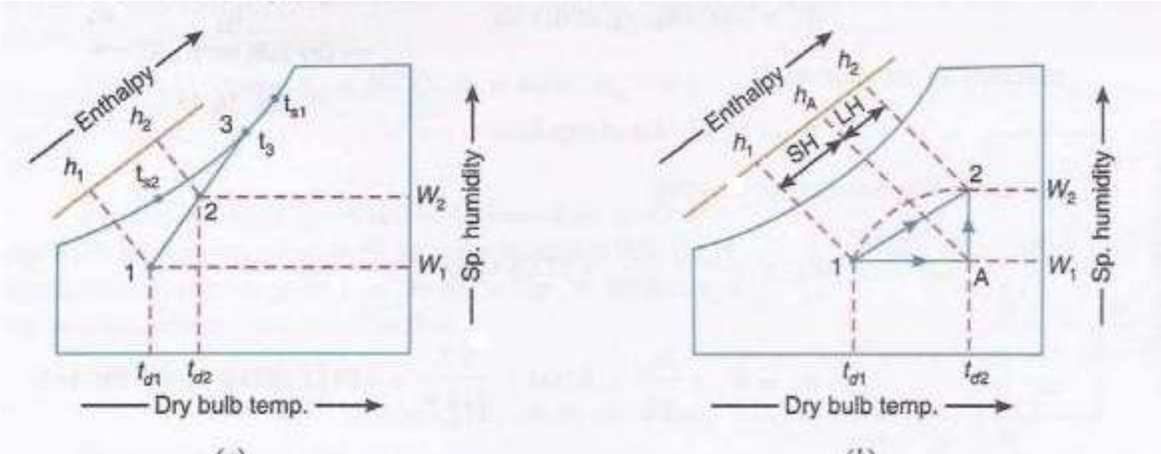
We know that cooling capacity of the coil

$$= m_a (h_1 - h_2) = 100\,(81 - 28) = 5300 \text{ kJ/min}$$

$$= 5300/210 = 25.24 \text{ TR} \quad \textbf{Ans.} \qquad \ldots (\because \; 1 \text{ TR} = 210 \text{ kJ/min})$$

Heating and Humidification

This process is generally used in winter air conditioning to warm and humidify the air. It is the reverse process of cooling and dehumidification. 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 heat of vaporisation of water is absorbed from the spray water itself and hence it gets cooled. In this way, the air becomes heated and humidified. The process of heating and humidification is shown by line 1-2 on the psychrometric chart as shown in Fig. The air enters at condition 1 and leaves at condition 2. In this process, the dry bulb temperature as well as specific humidity of air increases. The final relative humidity of the air can be lower or higher than that of the entering air.



(*a*) (*b*)

Let m_{w1} and m_{w2} = Mass of spray water entering and leaving the humidifier in kg,

h_{fw1} and h_{fw2} = Enthalpy of spray water entering and leaving the humidifier in kJ/kg,

W_1 and W_2 = Specific humidity of the entering and leaving air in kg/kg of dry air,

h_1 and h_2 = Enthalpy of entering and leaving air in kJ/kg of dry air, and

m_a = Mass of dry air entering in kg.

For mass balance of spray water,

$$(m_{w1} - m_{w2}) = m_a (W_2 - W_1)$$

or

$$m_{w2} = m_{w1} - m_a (W_2 - W_1) \quad \ldots (i)$$

and for enthalpy balance,

$$m_{w1}\, h_{fw1} - m_{w2}\, h_{fw2} = m_a (h_2 - h_1) \quad \ldots (ii)$$

Substituting the value of m_{w2} from equation (*i*), we have

$$m_{w1}\, h_{fw1} - [m_{w1} - m_a (W_2 - W_1)]\, h_{fw2} = m_a (h_2 - h_1)$$

$$\therefore \quad h_2 - h_1 = \frac{m_{w1}}{m_a} (h_{fw1} - h_{fw2}) + (W_2 - W_1)\, h_{fw2}$$

The temperatures t_{s1} and t_{s2} shown in Fig. 16.42 (*a*) denote the temperatures of entering and leaving spray water respectively. The temperature t_3 is the mean temperature of the spray water which the entering air may be assumed to approach.

Actually, the heating and humidification process follows the path as shown by dotted curve in Fig. 16.42 (*b*), but for the calculation of psychrometric properties, only the end points are important. Thus, the heating and humidification process shown by a line 1-2 on the psychrometric chart may be assumed to have followed the path 1-*A* (*i.e.* heating) and *A*-2 (*i.e.* humidification), as shown in Fig. 16.42 (*b*). We see that the total heat added to the air during heating and humidification is

$$q = h_2 - h_1 = (h_2 - h_A) + (h_A - h_1) = q_L + q_S$$

where $q_L = (h_2 - h_A)$ = Latent heat of vaporisation of the increased moisture content $(W_2 - W_1)$, and

$q_S = (h_A - h_1)$ = Sensible heat added

We know that sensible heat factor,

$$SHF = \frac{\text{Sensible heat}}{\text{Total heat}} = \frac{q_S}{q} = \frac{q_S}{q_S + q_L} = \frac{h_A - h_1}{h_2 - h_1}$$

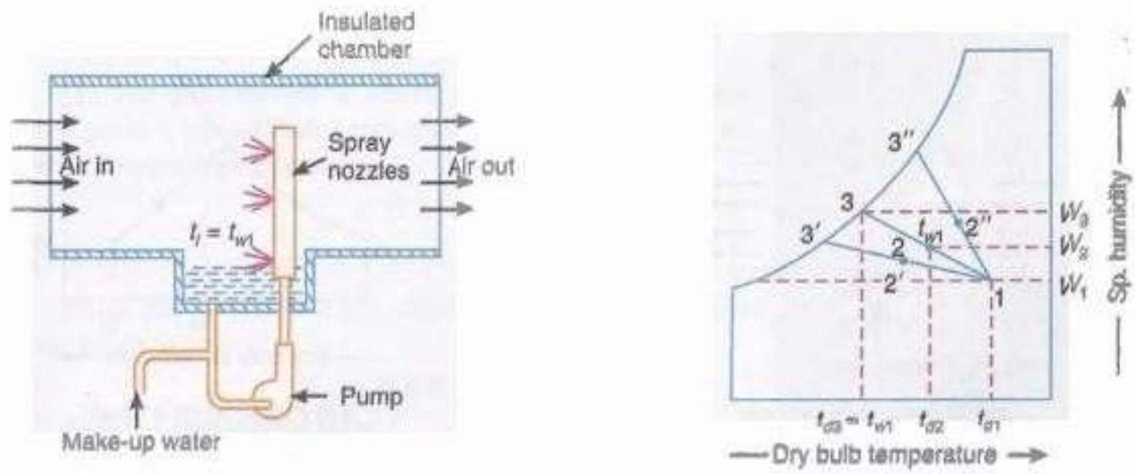
Cooling with Adiabatic Humidification

When the air is passed through an insulated chamber, having sprays of water (known as air washer) maintained at a temperature (t_1) higher than the dew point temperature of entering air (t_{dp1}), but lower than its dry bulb temperature (t_{d1}) of entering air or equal to the wet bulb temperature of the entering air (t_{w1}). then the air is said to be cooled and humidified.

Since no heat is supplied or rejected from the spray water as the same water is re-circulated again and again, therefore, in this case, a condition of adiabatic saturation will be reached. The temperature of spray water will reach the thermodynamic wet bulb temperature of the air entering the spray water.

This process is shown by line 1-3 on the psychrometric chart as shown in Fig (b), and follows the path along the constant wet bulb temperature line or constant enthalpy line. In an ideal case i.e. when the humidification is perfect (or the humidifying efficiency of the spray chamber is 100%), the final condition of the air will be at point 3 (Le. at temperature ta and relative humidity 100%).

In actual practice, perfect humidification is never achieved. Therefore, the final condition of air at outlet is represented by point 2 on the line 1-3, as shown in Fig. (b).



(*a*) Psychrometric process. (*b*) Psychrometric chart.

Fig. 16.35. Cooling with adiabatic humidification.

The effectiveness or the humidifying efficiency of the spray chamber is given by

$$\eta_H = \frac{\text{Actual drop in DBT}}{\text{Ideal drop in DBT}} = \frac{\text{Actual drop in sp. humidity}}{\text{Ideal drop in sp. humidity}}$$

$$= \frac{t_{d1} - t_{d2}}{t_{d1} - t_{d3}} = \frac{W_2 - W_1}{W_3 - W_1}$$

SHF, BPF

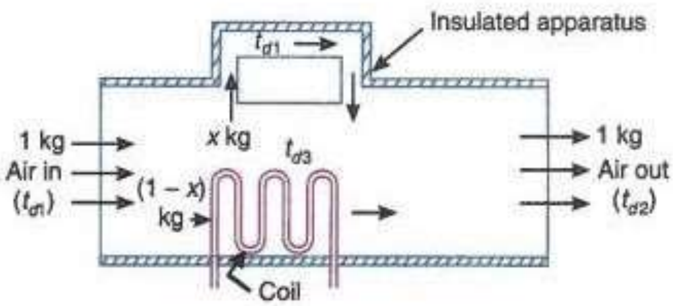
We have already discussed that the temperature of the air coming out of the apparatus (t_{d2}) will be less than t_{d3} in case the coil is a heating coil and more than t_{d3} in case the coil is a cooling coil.

Let 1 kg of air at temperature t_{d1} is passed over the coil having its temperature (*i.e.* coil surface temperature) t_{d3} as shown in Fig. 16.18.

A little consideration will show that when air passes over a coil, some of it (say x kg) just by-passes unaffected while the remaining $(1 - x)$ kg comes in direct contact with the coil. This by-pass process of air is measured in terms of a by-pass factor. The amount of air that by-passes or the by-pass factor depends upon the following factors :

1. The number of fins provided in a unit length *i.e.* the pitch of the cooling coil fins ;
2. The number of rows in a coil in the direction of flow; and
3. The velocity of flow of air.

It may be noted that the by-pass factor of a cooling coil decreases with decrease in fin spacing and increase in number of rows.



. By-pass factor.

Balancing the enthalpies, we get

$$x\, c_{pm}\, t_{d1} + (1 - x)\, c_{pm}\, t_{d3} = 1 \times c_{pm}\, t_{d2} \qquad \text{... (where } c_{pm} = \text{Specific humid heat)}$$

or

$$x\,(t_{d3} - t_{d1}) = t_{d3} - t_{d2}$$

$$\therefore \qquad x = \frac{t_{d3} - t_{d2}}{t_{d3} - t_{d1}}$$

where x is called the *by-pass factor* of the coil and is generally written as *BPF*. Therefore, by-pass factor for heating coil,

$$BPF = \frac{t_{d3} - t_{d2}}{t_{d3} - t_{d1}}$$

Similarly, *by-pass factor for cooling coil,

$$BPF = \frac{t_{d2} - t_{d3}}{t_{d1} - t_{d3}}$$

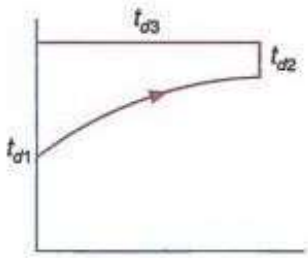


Fig. 16.19

The by-pass factor for heating or cooling coil may also be obtained as discussed below :

Let the air passes over a heating coil. Since the temperature distribution of air passing through the heating coil is as shown in Fig. 16.19, therefore sensible heat given out by the coil,

$$Q_s = U\, A_c\, t_m \qquad \text{... }(i)$$

where U = Overall heat transfer coefficient,

A_c = Surface area of the coil, and

t_m = Logarithmic mean temperature difference.

We know that logarithmic mean temperature difference,

$$t_m = \frac{t_{d2} - t_{d1}}{\log_e \left[\frac{t_{d3} - t_{d1}}{t_{d3} - t_{d2}}\right]}, \text{ and } BPF = \frac{t_{d3} - t_{d2}}{t_{d3} - t_{d1}}$$

$$\therefore \quad t_m = \frac{t_{d2} - t_{d1}}{\log_e (1/BPF)}$$

Now the equation (*i*) may be written as

$$Q_s = U \times A_c \times \frac{t_{d2} - t_{d1}}{\log_e (1/BPF)} \quad \ldots (ii)$$

We have already discussed that the heat added during sensible heating,

$$Q_s = m_a \, c_{pm} \, (t_{d2} - t_{d1}) \quad \ldots (iii)$$

where c_{pm} = Humid specific heat = 1.022 kJ/kg K, and

m_a = Mass of air passing over the coil.

Equating equations (*ii*) and (*iii*), we have

$$UA_c = m_a \, c_{pm} \log_e (1/BPF)$$

$$\log_e \left(\frac{1}{BPF}\right) = \frac{UA_c}{m_a \, c_{pm}}$$

or

$$\log_e (BPF) = -\frac{UA_c}{m_a \, c_{pm}}$$

$$\therefore \quad BPF = e^{-\left(\frac{UA_c}{m_a \, c_{pm}}\right)} = e^{-\left(\frac{UA_c}{1.022 \, m_a}\right)} \quad \ldots (iv)$$

Proceeding in the same way as discussed above, we can derive the equation (*iv*) for a cooling coil.

Note : The performance of a heating or cooling coil is measured in terms of a by-pass factor. A coil with low by-pass factor has better performance.

Sensible Heat Factor (SHF)

As a matter of fact, the heat added during a psychrometric process may be split up into sensible heat and latent heat. The ratio of the *sensible heat to the total heat is known as *sensible heat factor* (briefly written as *SHF*) or *sensible heat ratio* (briefly written as *SHR*). Mathematically,

$$SHF = \frac{\text{Sensible heat}}{\text{Total heat}} = \frac{SH}{SH + LH}$$

where SH = Sensible heat, and

LH = Latent heat.

The sensible heat factor scale is shown on the right hand side of the psychrometric chart.

Adiabatic Mixing

When two quantities of air having different enthalpies and different specific humidities are mixed, the final condition of the air mixture depends upon the masses involved, and on the enthalpy and specific humidity of each of the constituent masses which enter the mixture.

Now consider two air streams 1 and 2 mixing adiabatically as shown in Fig. .

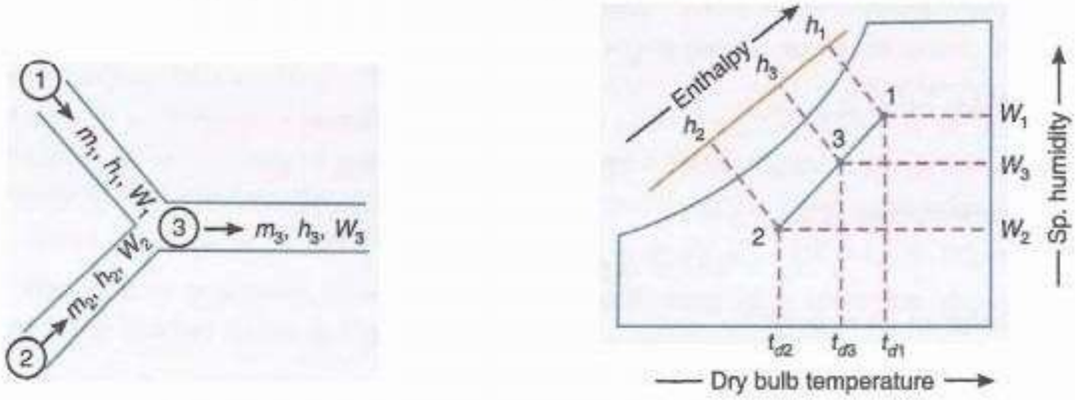
Let m_1 = Mass of air entering at 1,

h_1 = Enthalpy of air entering at 1,

W_1 = Specific humidity of air entering at 1,

m_2, h_2, W_2 = Corresponding values of air entering at 2, and

m_3, h_3, W_3 = Corresponding values of the mixture leaving at 3.



(a) (b)

Fig. .. Adiabatic mixing of two air streams.

Assuming no loss of enthalpy and specific humidity during the air mixing process, we have for the mass balance,

$$m_1 + m_2 = m_3 \quad \ldots (i)$$

For the energy balance,

$$m_1 h_1 + m_2 h_2 = m_3 h_3 \quad \ldots (ii)$$

and for the mass balance of water vapour,

$$m_1 W_1 + m_2 W_2 = m_3 W_3 \quad \ldots (iii)$$

Substituting the value of m_3 from equation (*i*) in equation (*ii*),

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

or

$$m_1 h_1 - m_1 h_3 = m_2 h_3 - m_2 h_2$$

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

$$\therefore \quad \frac{m_1}{m_2} = \frac{h_3 - h_2}{h_1 - h_3} \quad \ldots (iv)$$

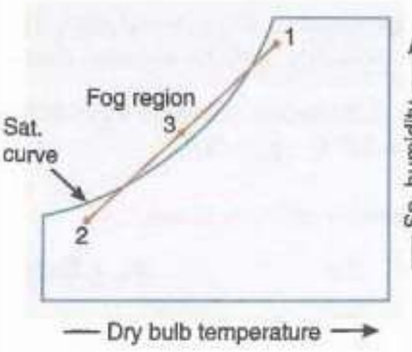
Similarly, substituting the value of m_3 from equation (i) in equation (iii), we have

$$\frac{m_1}{m_2} = \frac{W_3 - W_2}{W_1 - W_3} \quad \text{...}(v)$$

Now from equations (iv) and (v),

$$\frac{m_1}{m_2} = \frac{h_3 - h_2}{h_1 - h_3} = \frac{W_3 - W_2}{W_1 - W_3} \quad \text{...}(vi)$$

The adiabatic mixing process is represented on the psychrometric chart as shown in Fig. (b). The final condition of the mixture (point 3) lies on the straight line 1-2. The point 3 divides the line 1-2 in the inverse ratio of the mixing masses. By calculating the value of W_3 from equation (vi), the point 3 is plotted on the line 1-2.



It may be noted that when warm and high humidity air is mixed with cold air, the resulting mixture will be a fog and the final condition (point 3) on the psychrometric chart will lie to the left or above the saturation curve which represents the fog region, as shown in Fig. The temperature of the fog is that of the extended wet bulb line passing through point 3.

The fog may also result when steam or a very fine water spray is injected into air in a greater quantity than required to saturate the air. Even lesser quantity of steam, if not mixed properly, may result fog.

The fog can be cleared by heating the fog, mixing the fog with warmer unsaturated air or mechanically separating the water droplets from the air.

Numerical on above : Numerical are provided at the end of the chapters.

Effective temperature and comfort chart

The degree of warmth or cold felt by a human body depends mainly on the following three factors : 1. Dry bulb temperature, 2. Relative humidity, and 3. Air velocity. In order to evaluate the combined effect of these factors, the term effective temperature is employed. It is defined as that index which corelates the combined effects of air temperature, relative humidity and air velocity on the human body. The numerical value of effective temperature is made equal to the temperature of still (i.e. 5 to 8 tit/min air velocity) saturated air, which produces the same sensation of warmth or coolness as produced under the given conditions. The practical application of the concept of effective temperature is presented by the comfort chart, as shown in Fig.. This chart is the result of research made on different kinds of people subjected to wide range of environmental temperature, relative humidity and air movement by the American Society of Heating, Refrigeration and Air conditioning Engineers (ASHRAE). It is applicable to reasonably still air (5 to 8 m/min air velocity) to situations where the occupants are seated at rest or doing light work and to spaces whose enclosing surfaces are at a mean temperature equal to the air dry bulb temperature. In the comfort chart, as shown in Fig., the dry bulb temperature is taken as abscissa and the wet bulb temperature as ordinates. The relative humidity lines are replotted from the psychrometric chart.

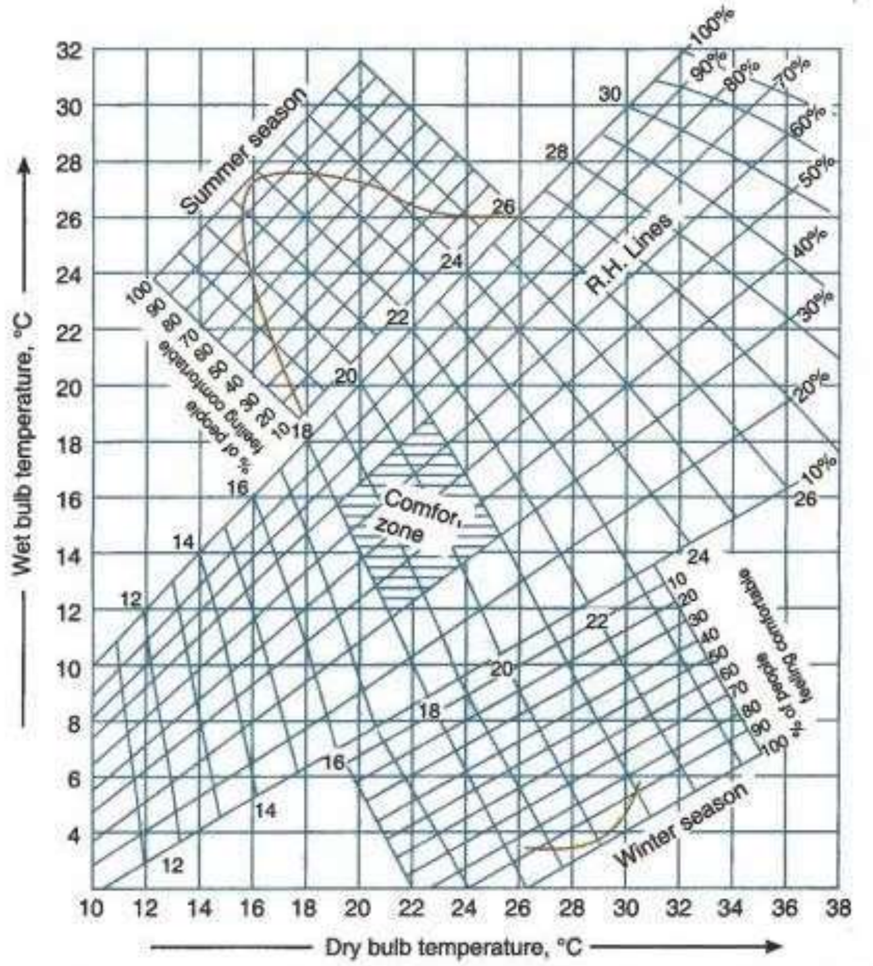
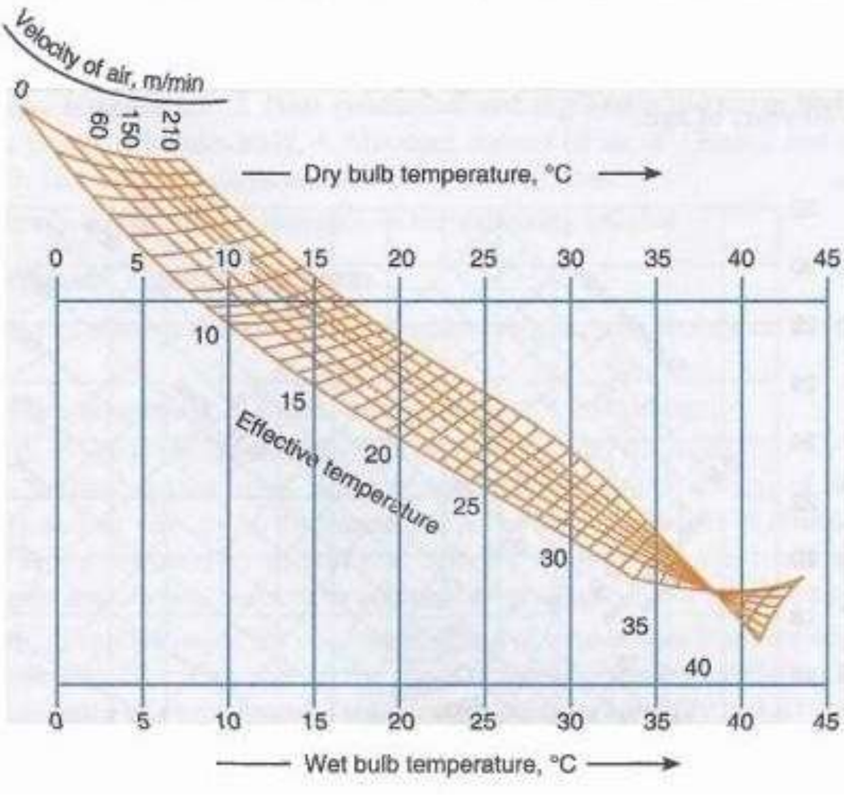


Fig. Comfort chart for still air (air velocities from 5 to 8 m/min)

However, all points located on a given effective temperature line do not indicate conditions of equal comfort or discomfort. The extremely high or low relative humidities may produce conditions of discomfort regardless of the existent effective temperature. The moist desirable relative humidity range lies between 30 and 70 per cent. When the relative humidity is much below 30 per cent, the mucous membranes and the skin surface become too dry for comfort and health. On the other hand, if the relative tumidity is above 70 per cent, there is a tendency for a clammy or sticky sensation to develop. The curves at the top and bottom, as shown in Fig. 17.1, indicate the percentages of person participating in tests, who found various effective temperatures satisfactory for comfort. The comfort chart shows the range for both summer and winter condition within which a condition of comfort exists for most people. For summer conditions, the chart indicates that a maximum of 98 percent people felt comfortable for an effective temperature of 21.6°C . For winter conditions, chart indicates that an effective temperature of 20°C was desired by 97.7 percent people. It has been found that for comfort, women require 0.5°C higher effective temperature than men. AU men and women above 40 years of age prefer 0.5°C higher effective temperature than the persons below 40 years of age.

It may be noted that the comfort chart, as shown in Fig.. does not take into account the variations in comfort conditions when there are wide variations in the mean radiant temperatare (MRT). In the range of 26.5°C, a rise of 0.5°C in mean radiant temperature above the mom dry bulb temperature raises the effective temperature by 0.5°C. The effect of mean radiant temperature on comfort is less pronounced at high temperatures than at low temperatures. The comfort conditions for persons at work vary with the rate of work and the amount of clothing worn. In general, the greater the degree of activity, the lower the effective temperature necessary for comfort. Fig. shows the variation in effective temperature with different air velocities. We see that for the atmospheric conditions of 24°C dry bulb temperature and 16°C wet bulb temperature correspond to about 21°C with nominally still air (velocity 6 m /min) and it is about 17°C at an air velocity of 210 m / min. The same effective temperature is observed at higher dry bulb and wet bulb temperatures with higher velocities. The case is reversed after 37.8°C as in that case higher velocities will increase sensible heat flow from air to body and will decrease comfort. The same effective temperature means same feeling of warmth, but it does not mean same comfort.



SHORT QUESTIONS WITH ANSWER

1. What is dew point temperature? [2010s, 2009s, 2006s]

The dew point is the temperature at which air is saturated with water vapor, which is the gaseous state of water. When air has reached the dew-point temperature at a particular pressure, the water vapor in the air is in equilibrium with liquid water, meaning water vapor is condensing at the same rate at which liquid water is evaporating.

2. Define relative humidity ? [2010s, 2009s, 2006BP]

Ans : It is the ratio of actual mass of water ,vapour in a given volume of moist air to the mass of water vapour in the same volume of saturated air at the same temperature and pressure. It is briefly written as RH.

3. What is the difference between dry bulb and wet bulb temperature ? [2009s, 2009BP, 2007S, 2006S, 2011, 2020]

Dry bulb temperature : It is the temperature of air recorded by a thermometer, when it is not affected by the moisture present in the air. The dry bulb temperature (briefly written as DBT) is generally denoted by td or t_{db}

Wet bulb temperature : It is the temperature of air recorded by a thermometer, when its bulb is surrounded by a wet cloth exposed to the air. Such a thermometer is called 'wet bulb thermometer. The wet bulb temperature (briefly written as WBT) is generally denoted by tw, or t_{wb}.

4. Define relative humidity and humidity ratio ? [2007S, 2006S, 2011]

Relative humidity : It is the ratio of actual mass of water ,vapour in a given volume of moist air to the mass of water vapour in the same volume of saturated air at the same temperature and pressure. It is briefly written as RH.

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

5. Define humidity ratio, relative humidity DBT andWBT ? [2012]

Answer is mentioned above

6. What is saturated air ? [2011]

Saturated air is air that holds water vapor at its highest level. Air is composed of moisture or water vapor, regardless of the amount of pressure and temperature levels.Excess moisture leads to the formation of saturated air as brought about by the conversion of moisture into dew.

7. What is apparatus dew point temperature ? [2009S]

Apparatus Dew Point (ADP) is the effective surface temperature of the cooling coil. It is also the temperature at a fixed flow rate at which both sensible and latent heat gains are removed (from the conditioned space) at the required rates. It is also often called as the 'Coil Temperature'.

8. What is sensible heat factor ? [2014W]

Sensible heat factor is the ratio of sensible heat and Total heat. Sensible heat is the heat which increases or decreases the temperature of the body. Latent heat is the heat which increases the specific humidity without increasing or decreasing the temperature of the body.

9. Define specific humidity ? [2014W]

Specific humidity, mass of water vapour in a unit mass of moist air, usually expressed as grams of vapour per kilogram of air, or, in air conditioning, as grains per pound. The specific humidity is an extremely useful quantity in meteorology.

LONG QUESTIONS:

1. With the help of Psychrometric chart explain the sensible cooling and sensible heating ? [2020W]

2. Describe cooling and dehumidification process of air and show the ADP in psychrometric chart. [2014W]

3. Describe slings psychrometre ? [2010S]

Chapter-07

Air Conditioning System

Learning Objectives *:*

Factors affecting comfort air conditioning. .

Equipment used in an air-conditioning.

Classification of air-conditioning system

Winter Air Conditioning System

Summer air-conditioning system.

Numerical on above

Introduction :

The air conditioning is that branch of engineering science which deals with the study of partitioning of air that is supplying and maintaining desirable internal atmospheric conditions for human comfort , irrespective of external conditions.

Factors affecting comfort air conditioning :

The four important factors for comfort air conditioning are discussed as below

1. Temperature of air.

in Air Conditioning the control of temperature means the maintain of any desirable 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.

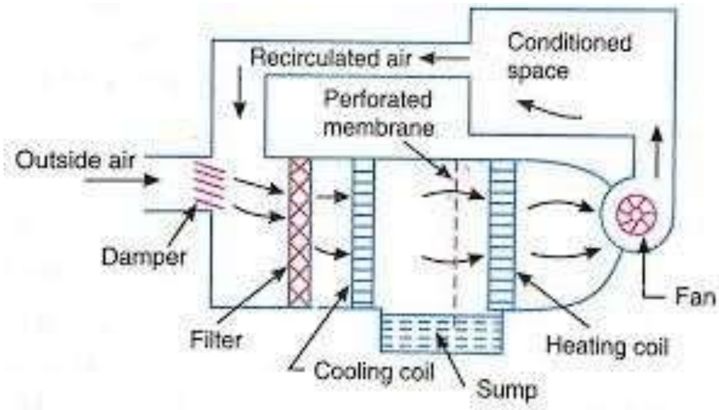
3. according to the arrangement of equipment

a Unitary air conditioning system and

b Central air conditioning system

A. Comfort air conditioning system :

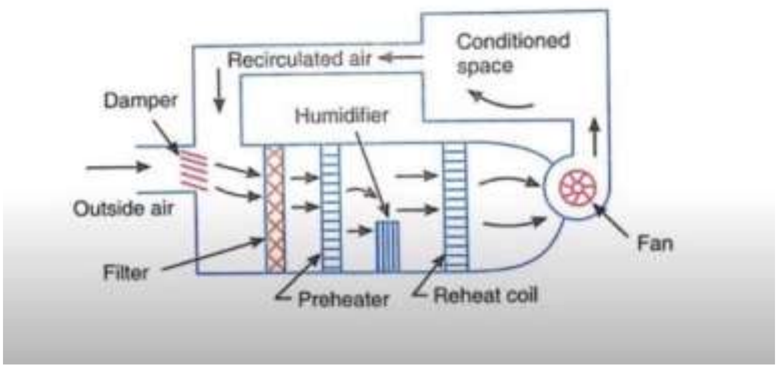
in comfort air conditioning the air is brought to the required dry bulb temperature and relative humidity for the human health comfort and efficiency if sufficient data of required condition is not given then it is assumed to be 21 degree Celsius driver temperature and 50% relative humidity the sensible heat factor is generally kept at following For residence aur private off = 0.9, for restaurant or busy office = 0.8 , Auditorium or cinema hall = 0.7 , Ball room dance hall = 0.6



The comfort air conditioning may be adapted for homes office top restaurants theatres Hospital School etc

B. Industrial air conditioning system :

It is an important system of air conditioning these days in which the inside dry bulb temperature and relative humidity of the air is kept constant for proper working of the machines and for the proper Research and manufacturing processes. Some of the sophisticated electronic and other machines need a particular dry bulb temperature and relative humidity. Sometimes these machines are required a particular method of psychrometric processes . This type of air conditioning system is used in textile mill, paper mill, machine parts manufacturing plant ,Tool Room, photo processing plants etc.



Winter airconditioning system :

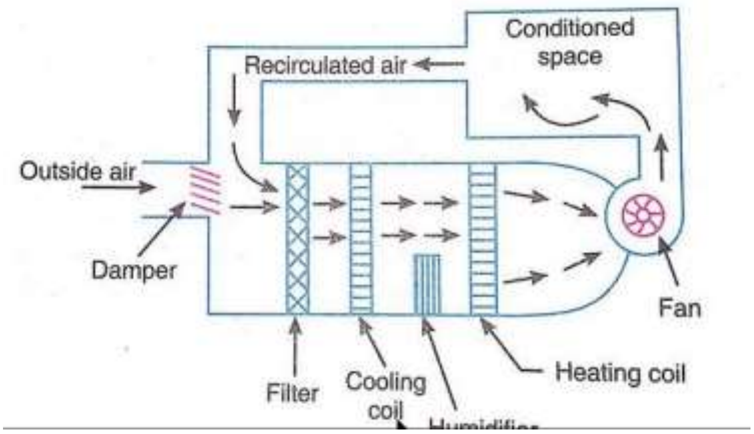
Winter air conditioning system in winter air conditioning the air is heated which is generally accompanied by humidification. the schematic arrangement of the system is shown in the figure. The outside air flows through a damper and mixtures up with recirculated air which is obtained from the conditioned space. The mixed air passes through a filter to remove dirt, dust, and other impurities. The air now passes through a preheated coil in order to prevent the possible freezing of water and to control the evaporation of water in the humidifier. After, the air is made to pass through a reheat coil to bring the air to the designed dry bulb temperature.

Summer Air Conditioning System :

It is the most important type of air conditioning, in which the air is cooled and generally dehumidified. The schematic arrangement of a typical summer air conditioning system is shown figure. The outside air flows through the damper, and mixes up with recirculated air (which is obtained from the conditioned space). The mixed air passes through a filter to remove dirt, dust and other impurities. The air now passes through a cooling coil. The coil has a temperature much below the required dry bulb temperature of the air in the conditioned space. The cooled air passes through a perforated membrane and loses its moisture in the condensed form which is collected in a sump. After that, the air is made to pass through a heating coil which heats up the air slightly.-This is done to bring the air to the designed dry bulb temperature and relative humidity. 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 (known as recirculated air) is again conditioned as shown in Fig. 18.5. The outside air is sucked and made to mix with the recirculated air in order to make up for the loss of conditioned (or used) air through exhaust fans or ventilation from the conditioned space.

Year-Round Air Conditioning System

The year-round air conditioning system should have equipment for both the summer and winter air conditioning. The schematic arrangement of a modem summer year-round air conditioning system is shown in Figure.



The outside air flows through the damper and mixes up with the recirculated air (which is obtained from the conditioned space). The mixed air passes through a filter to remove dirt, dust and other impurities. In summer air conditioning, the cooling coil operates to cool the air to the desired value. The dehumidification is obtained by operating the cooling coil the dew point temperature (apparatus dew point). In winter, the cooling the heating coil operates to heat the air. The spray type humidifier is season to humidify the air.

SHORT QUESTION WITH ANSWER

1. What is the function of air filter in Air conditioning ? [2011]

Ans : The air in the HVAC system passes through the air filter. The filter's job is to catch particulates and pollutants such as dust, mold, pet dander and fungal spores. The mesh that is the main namesake of the filter that air passes through becomes denser, thus catching these materials and not hindering the flow of air. If you don't change your air filter as frequently as you should, the air can't pass through as easily, as well as more and more particulars have the chance of getting through the mesh, thus harming indoor air quality.

2. Name four importance of Air conditioning ? [2007 S, 2020W]

1. It's literally a life saver
2. Better air quality
3. Fewer insects and parasites
4. Improved work force efficiency
5. Prevents electronic devices from overheating

3. What is the use of Air filter and blower in air conditioning ? [2020W]

.The filter's job is to catch particulates and pollutants such as dust, mold, pet dander and fungal spores.

An air conditioner uses blowers to transfer the warm air away from any space and replace it with cold air. It also maximizes airflow for better circulation and machine function. But contrary to popular belief, an air conditioner blower comes in different forms and sizes, depending on the air conditioning system itself. The four most commonly used types are the propeller fan, centrifugal fan, vane-axial fan and the tube-axial fan.

LONG QUESTIONS :

1. With neat diagram explain the working principle of Summer air conditioning system ? [2006W,2014W 2018S]

2. Describe the different components of air distribution system a and ducting ? [2010S]

3. Explain detail specification of room air conditioning ? [2006S]

4. Give classification of air conditioning system ? [2006W]

5. Explain the working of a desert cooler ? [2006W, 2014W]

6. Explain in detail about the summer air conditioning and winter air conditioning system. [2020w]

6. With neat sketch explain the thermostatis expansion valve? [ ]