B.E.

Seventh Semester Examination, May-2009

Refrigeration and Air Conditioning (ME-403-E)

Note : Attempt any **five** questions. All questions carry equal marks.

Q. 1. (a) Differentiate between refrigeration and air conditioning. 10

Ans. Refrigeration : Refrigeration is the removal of heat from a space at a temperature lower than the surrounding temperature. If we remove a bucket of H_2O from a tank, the surrounding water rushes in to fill the cavity. Similarly heat rushes into replace the heat removed.

Insulation reduces the in-rush of heat. Whatever heat enters through the insulation into the refrigerated space has to be removed with the help of refrigerating machine. The refrigerating machine gets rid of the energy received by it, by rejecting it to the surroundings in the form of heat.

Air Conditioning : The history behind the air-conditioning is more than hundred years old. The human life is becoming more uncomfortable in rapidly developing cities like NewYork and Tokyo due to increase in population and industrial growth. Full air-conditioning signifies the automatic control of an atmospheric environment either for comfort of human beings or animals or for the proper performance of some industrial or scientific process.

Q. 1. (b) Describe the various methods of refrigeration. 10

Ans. (i) Ice Refrigeration : Here, temperatures inside an ice refrigerator are controlled by the flow of cooled air over the ice and through the cabinet. Temperature usually range between 5°C and 10°C. With the development of mechanical refrigeration, the preservation of ice and its use for refrigeration purposes on large scale has disappeared, but even now-a-days the ice is used on commercial bases in hotels for keeping the drinks cold.

(ii) Evaporative Refrigeration : Here, heat is absorbed when a liquid evaporates. Evaporation of water is an example. Evaporation of moisture from the skin surface of a man helps to keep him cool. Another common application of this principle is the desert bag used to keep drinking water cool.

Another common application of water evaporation of the refrigeration is the method of making artificial snow.

(iii) Steam-Jet Refrigeration System : This system uses the principle of boiling water below 100°C if the pressure on the surface of the water is reduced below atmospheric pressure.

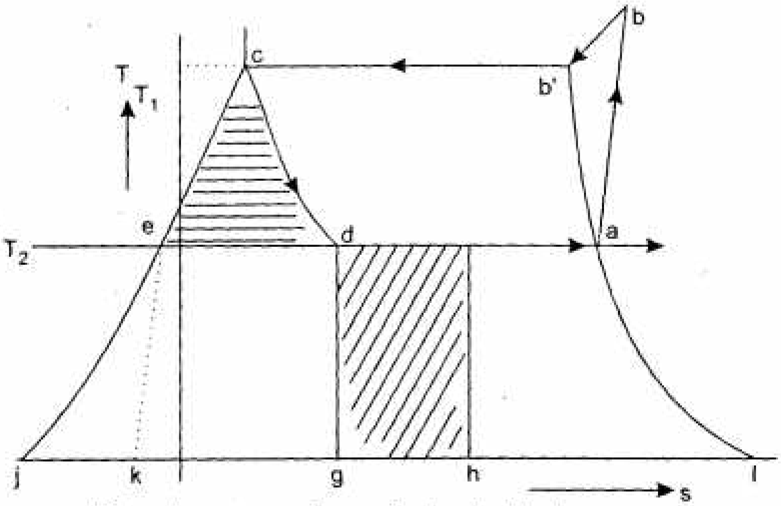
Water boils at 6°C if the pressure on the surface is 5 cm $H_2O$and 10°C if the pressure is 65 cm of water. The very low pressure or high vacuum on the surface of water can be maintained by throttling the steam through the jets/nozzles.

Q. 2. (a) In an ammonia vapour compression refrigerator condensation and evaporation takes place at 11·28 bar and 2·57 bar respectively. The temperature at the end of compression is 50°C and there is no under cooling. One ton of ice is to be formed per hour at –5°C from water at 10°C. Assuming the specific heat of ice as 2·09, the latent heat 335 kJ/kg and C_P of the superheated ammonia vapour as 2·93, calculate the power required to drive the machine : 20

For ammonia

Temp °C	Enthalpy Liquid (kJ/kg)	Enthalpy Latent (kJ/kg)	Entropy Liquid (kJ/kg-K)	Entropy Latent (kJ/kg-K)
30	322·2	1146·4	1·23	1·055
−12·25	124·7	127	0·505	4·99

Ans.



Actual heat removed from the water cooler condensing heat lost

$$= 1 \cdot 2 \times 4 \cdot 2 \left[\frac{100(26-6)}{60} \right] = 108 \text{ kJ/min}$$

$$= 2 \cdot 8 \text{ kJ/sec}$$

We have to find out the condition at point b.

Entropy at a = entropy at b

$$4 \cdot 77 = 4 \cdot 76 + 0 \cdot 676 \log_e \frac{T_s}{(26+273)}$$

$$T_s = 303 \cdot 5\text{K}$$

$$= 30 \cdot 5°\text{C}$$

Where T_s is the temperature at pressure existing at point b.

Total heat at point $b = 568 \cdot 8 + 0 \cdot 676 (303 \cdot 5 - 299)$

$= 588 \cdot 2$ kJ/kg

Work done $= 588 \cdot 2 - 576 \cdot 25$

$= 11 \cdot 95$ kJ/kg

Net refrigerating effect = Heat at a − Heat at d

= Heat at a − Heat at e

$= 576 \cdot 25 - 445$

$= 131 \cdot 25$ kJ/kg

Mass flow of $F_{-12} = \frac{168}{131 \cdot 25} = 1 \cdot 28$ kg/min

Work done/min $= 1 \cdot 28 \times 11 \cdot 95$ kJ/min

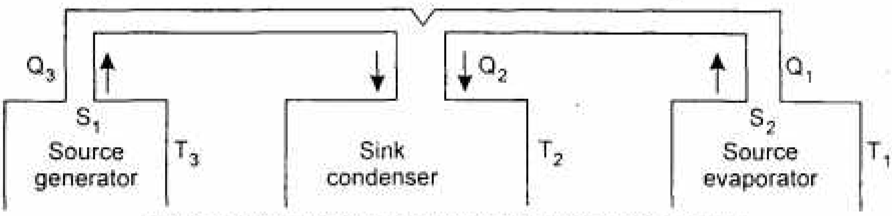
Power required to run the compressor

$$= \frac{1 \cdot 28}{60} \times 11 \cdot 95$$

$$\boxed{= 0 \cdot 255 \text{ kW}} \qquad \textbf{Ans.}$$

Q. 3. (a) Derive an expression for COP of an ideal vapour absorption system and prove that COP depends on efficiency of Carnot engine working between the same temperature limits. 10

Ans.



Refrigeration of heat flow of Electronic refrigeration

In the electronics refrigerator or absorption refrigerator, the heat Q_3 is given in generator at T_3, heat Q_1 is absorbed at T_1 from the evaporator and heat Q_2 is discharged in the condenser and absorber at T_2.

For reversible system, the initial entropy of the system must be equal to the entropy of the system after the change in its condition.

$$\frac{Q_3}{T_3} + \frac{Q_1}{T_1} = \frac{Q_2}{T_2} \qquad \text{...(i)}$$

As there are 2 heat sources and one heat sin k, the flow of heat is shown in fig.

The coefficient of performance of the system is defined as :

$$\text{C.O.P.} = \frac{Q_1}{Q_3} \qquad \text{...(ii)}$$

From equations (i) and (ii)

$$Q_1 = Q_3 \frac{\left[\frac{1}{T_3} - \frac{1}{T_2}\right]}{\left[\frac{1}{T_2} - \frac{1}{T_1}\right]}$$

$$= Q_3 \frac{(T_2 - T_3)}{T_3 T_2} \frac{T_2 T_1}{T_1 - T_2}$$

$$Q_1 = Q_3 \frac{T_1}{T_3} \left[\frac{T_3 - T_2}{T_2 - T_1}\right]$$

Substituting the value, we get

$$\text{C.O.P.} = \frac{T_1}{T_3} \left[\frac{T_3 - T_2}{T_2 - T_1}\right]$$

$$\boxed{\text{C.O.P.} = \frac{T_1}{T_2 - T_1} \times \frac{T_3 - T_2}{T_3}}$$

This formula can be used for all types of absorption refrigeration system as Q_2 is the total quantity of heat discharged in absorber and condensor at temperature T_2.

Q. 3. (b) What are the advantages and disadvantages of steam jet refrigeration system over other types of refrigeration system?

Ans. Advantages : (i) It is flexible in operation, cooling capacity can be easily and quickly changed.

(ii) It has no moving parts as such it is vibration free and simple.

(iii) It has relatively less plant weight (kg/ton) and therefore foundation of the plants of 200 tons can be easily installed.

(iv) It can be installed out of doors.

(v) The use of direct evaporator of water is particularly advantageous in dealing with heat sensitive foods or chemicals, where the cooling produced by the evaporation reduces the processing temperature and presents breakdown.

Disadvantages :

(i) The use of direct evaporation to produce chilled water is usually limited as tremendous volumes of vapour is to be handled.

(ii) About twice as much heat must be removed in the condenser of steam jet unit per ton of refrigeration compared with the vapour compression system.

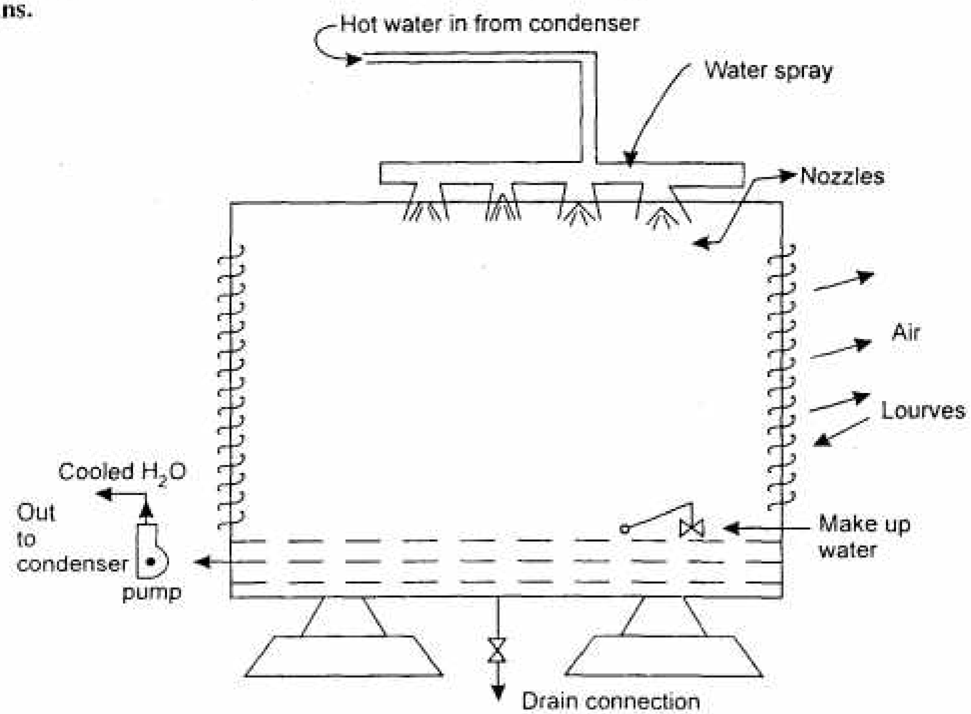
(iii) The system is useful for comfort air-conditioning but is not particularly feasible for water temperature below 40°C.

Q. 4. (a) Explain the working of the following types of cooling towers with neat sketches :

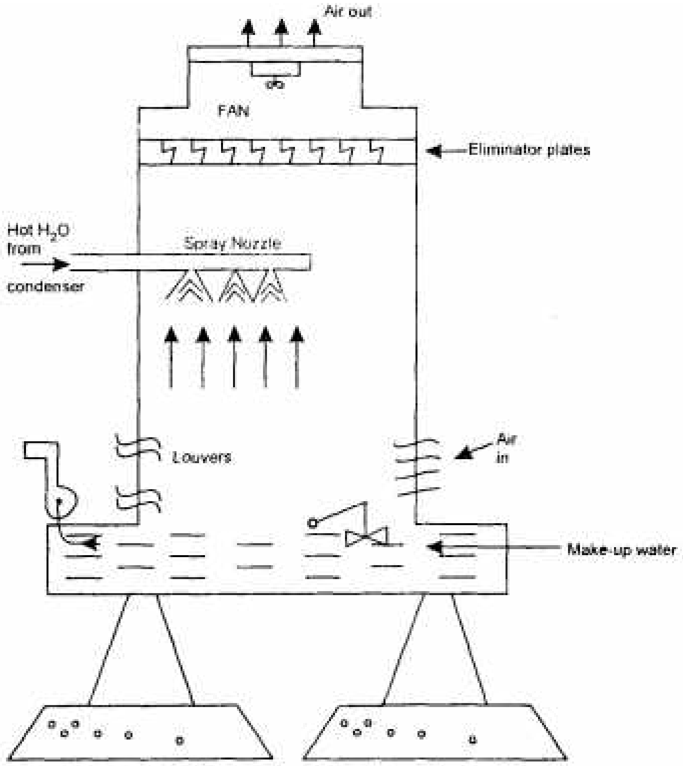
(i) Automobile cooling tower **(ii) Mechanical draft cooling tower**

(iii) Forced draft cooling tower **And specify their applications.**

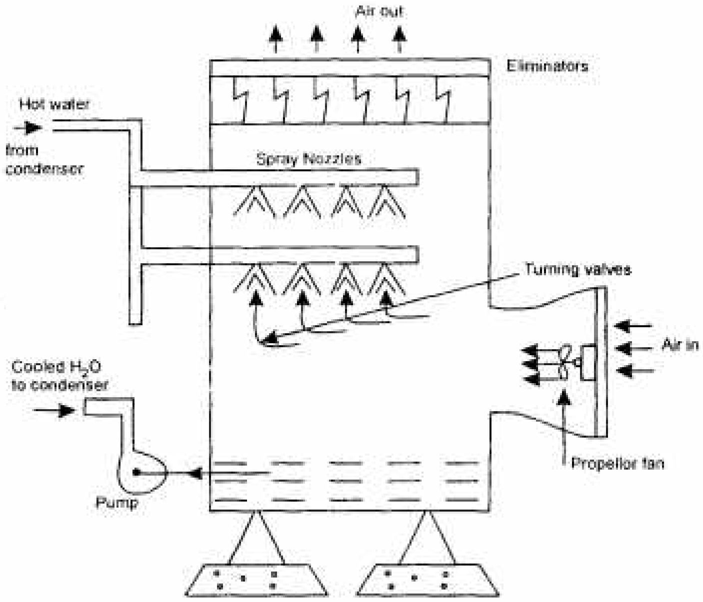
Ans.



(a) Automobile cooling tower



(b) Mechanical draft cooling tower



(c) Forced draft cooling tower

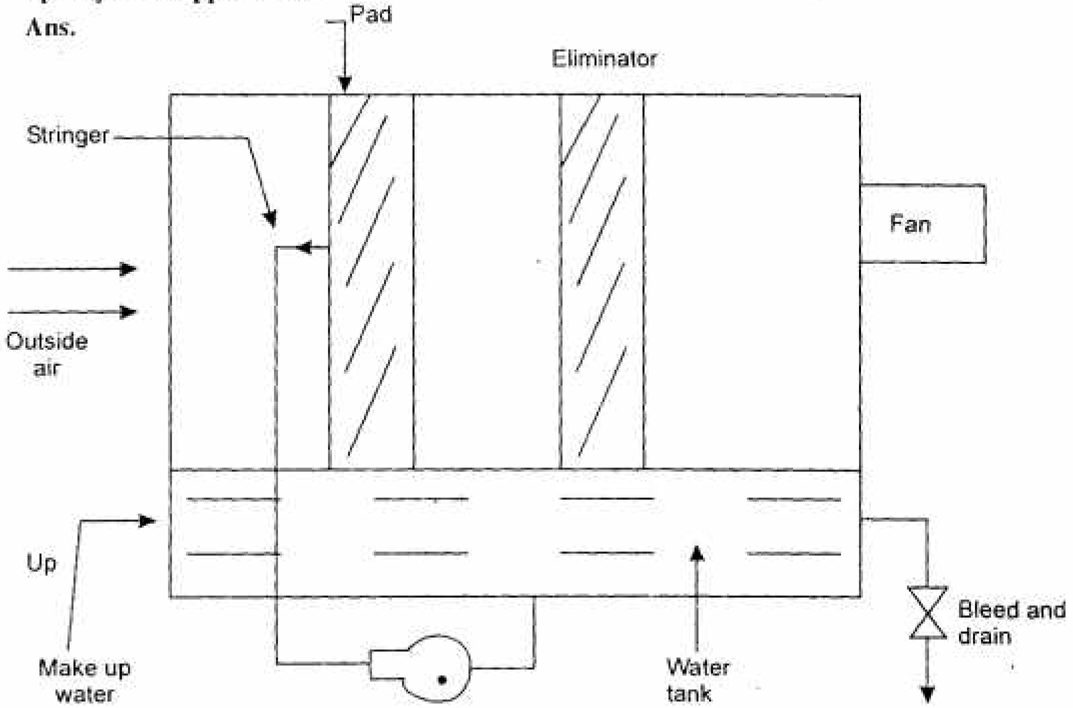
Q. 4. (b) Explain the working of the following types of evaporators with neat sketches :

(i) Flooded evaporator **(ii) Natural convection evaporator**

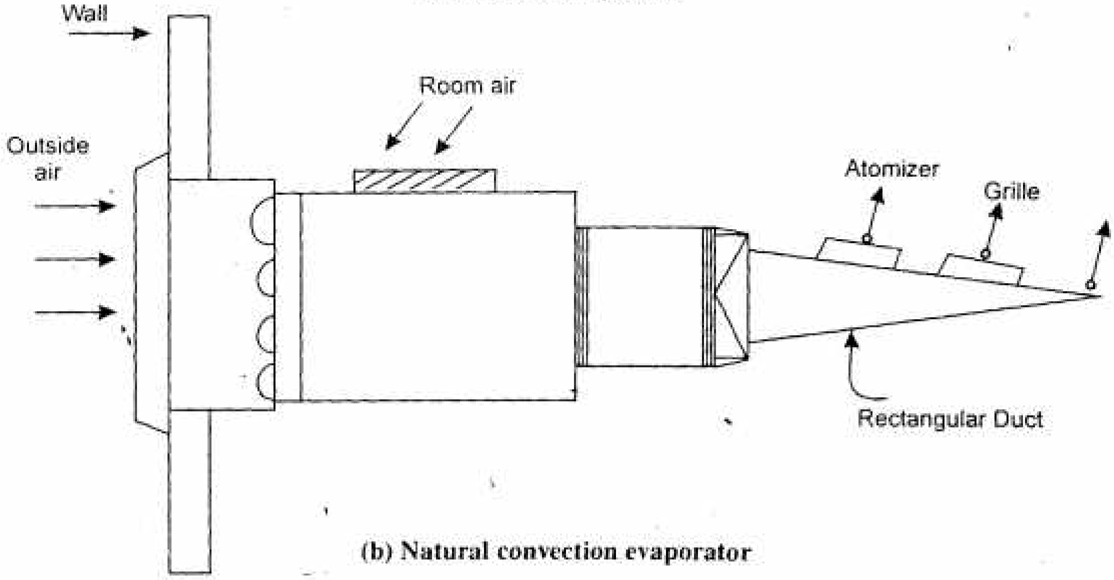
(iii) Shell and coil evaporator **(iv) Shell and tube evaporator**

Specify their application.

Ans.

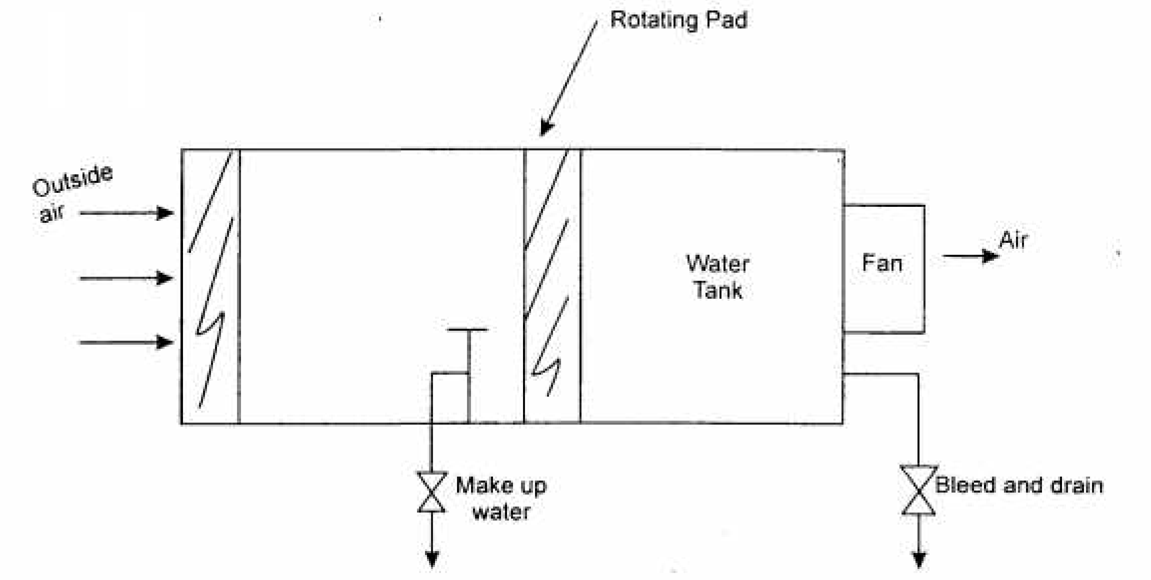


(a) Flooded evaporator

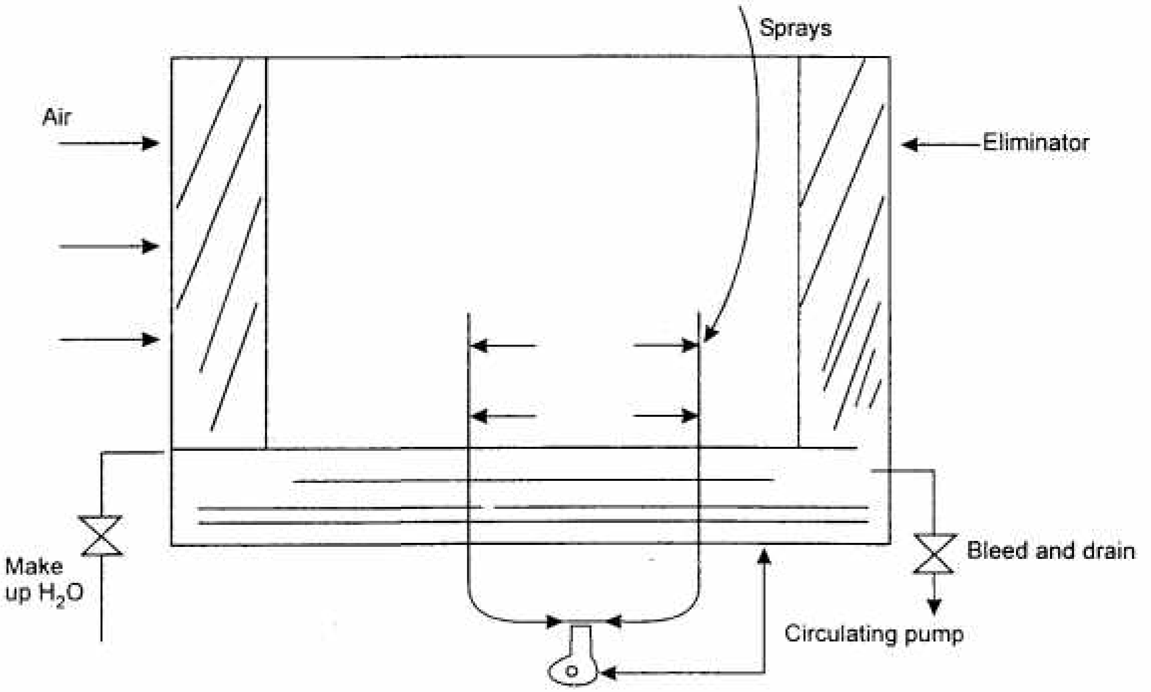


(b) Natural convection evaporator

/



(c) Shell and coil evaporator



(d) Shell and tube evaporator

Applications : The different industries are listed below where the applications of evaporative cooling will be more economical :

(a) Bakeries (b) Dry cleaners

(c) Foundries (d) Glass industries

(e) Laundries (f) Plastic industries

(g) Pottery (h) Rubber

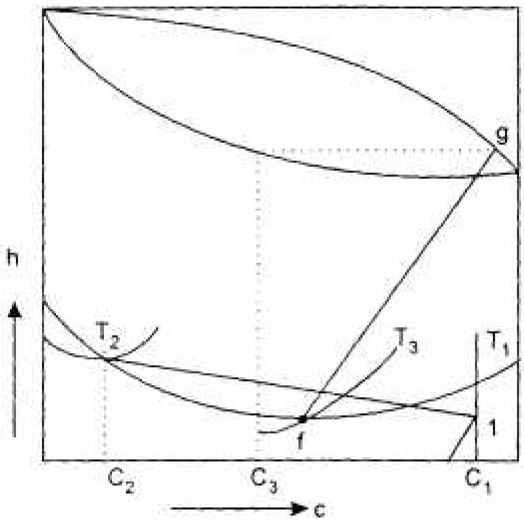
(i) Steel (j) Textile plant etc.

Q. 5. (a) A mixture of dry and water vapour is at a temperature of 22°C under a total pressure of 730 mm Hg. The dew point temperature is 15°C. Find : (i) Partial pressure of water vapour, (ii) RH, (iii) Specific humidity, (iv) Enthalpy of air per kg of dry air, (v) Specific volume of air per kg of dry air.

Ans. Locate point 1 and point 2 on h-c chart and join them. The concentration of resulting mixture is given as :

$$C_3 = C_1 + \frac{m_2}{m_1 + m_2}(C_2 - C_1)$$

$$= 0 \cdot 6 + \frac{3}{6+3}(0 \cdot 3 - 0 \cdot 6) = 0 \cdot 5$$



Draw a line vertically through C_3 which cuts the line 1-2 at point 3.

Again the isotherm $f3g$ should be drawn by trial and error as explained. Thus, locate the point f and g on h-c chart

$$T_3 = 48°C$$
$$h_3 = 155 \cdot 4 \text{ kJ/kg of mixture}$$
$$C_f = 0 \cdot 495$$
$$C_g = 0 \cdot 995$$
$$R_H = 0 \cdot 495$$

$$\text{Partial pressure} = \frac{\text{length} f_3}{\text{length} f_g}$$

$$= 0 \cdot 08$$

Specific humidity = 0·8%

Specific volume = 08% vapour and 99·2% liquid

Q. 5. (b) A sling psychometric reads 40°C DBT and 35°C WBT. Calculate the following :
(i) Specific humidity
(ii) Relative humdity
(iii) Dew-point temperature
(iv) Enthalpy of mixture
(v) Specific volume of the mixture.
Assume pressure of atmosphere air to be 1·013 bar. 10

Ans. At 7 bar (from steam table)

$$T_g = 165°\text{C}$$

$$h_g = 2762 \text{ kJ/kg}$$

$$s_g = 6 \cdot 705 \text{ kJ/kg-K}$$

$$\text{Specific humidity} = \frac{h_a - h_b}{h_a - h_b'} = \frac{2762 - h_b'(0 \cdot 9)}{2762 - 1861}$$

$$= 1 \cdot 951$$

$$\text{Relative humidity} = \frac{h_a - h_d}{h_a - h_a'} = \frac{2275 - 16 \cdot 8}{24\, a_2}$$

$$= 2309 \cdot 5 \text{ kJ/kg}$$

Dew point temperature = 35 · 2°C

$$\text{Specific volume of mixture} = 0 \cdot 495 \left[\left(\frac{120 + 273}{-3 + 273}\right)\left(\frac{27 + 3}{120 - 27}\right)\right]$$

= 17% vapour ; 83% liquid **Ans.**

Q. 6. Following data were collected in connection with design of air-conditioning of a theatre :

Total Seating Capacity = 370 persons

Atmospheric condition = 39°C DBT and 75% RH

Comfort condition required = 24°C DBT and 55% RH

Sensible heat given per person = 340 kJ/hr

Latent heat given per person = 150 kJ/hr

Sensible heat due to solar radiation and infiltrated air = 20,00,000 kJ/hr

Latent heat due to infiltrated air = 70,000 kJ/hr

Quantity of fresh air supplied = 0 · 45 m^3/person/min

Desirable temperature rise in theatre = 9°C

Assume the re-circulated air is mixed with fresh air after leaving the conditioner.

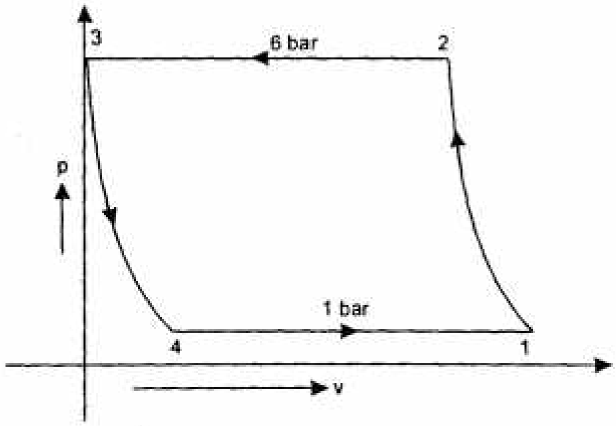
Compute the following :

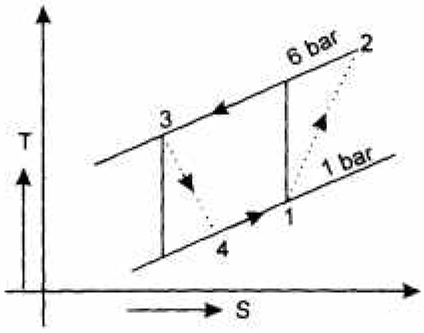
(a) % of total air circulated

(b) Refrigeration capacity of conditioner coil

Assume the air leaves the conditioner with 100% RH.

Ans.





$$T_2 = (7+273)\left(\frac{6}{1}\right)^{0.2} = 250 \times 1.43$$

$$= 400.6 \text{ K}$$

$$\frac{T_4}{T_3} = \left(\frac{p_1}{p_2}\right)^{\frac{1.3-1}{1.3}}$$

$$T_4 = (37+273)\left(\frac{1}{6}\right)^{0.23} = \frac{310}{1.51}$$

$$= 205.3 \text{ K}$$

$$\% \text{ of total air circulated} = \frac{\theta r}{\omega_n} \times 100$$

$$= \frac{\theta r}{\theta_c - \theta_e} \times 100$$

$$\theta_r = C_p (T_1 - T_4) = 1 \cdot 05 (280 - 205 \cdot 3)$$
$$= 78 \cdot 54 \text{ kJ/kg}$$
$$\omega_n = \theta_c - \theta_r$$
$$= 16 \cdot 61 \text{ kJ/kg}$$

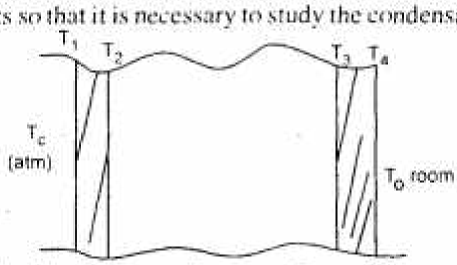
Hence

(i) $$\% = \frac{78 \cdot 54}{16 \cdot 0} \times 100 = \boxed{47 \cdot 34\%}$$ **Ans.**

(ii) Capacity $$= \frac{m\theta_r}{3 \cdot 5} \text{ as 1 ton} = 3 \cdot 5 \text{ kJ/sec}$$
$$= \frac{0 \cdot 5 \times 78 \cdot 54}{3 \cdot 5} = \boxed{11 \cdot 22}$$ **Ans.**

Q. 7. Explain the following with neat diagram :
(a) Shell and coil condensor
(b) Thermostatic expansion valve
(c) Winter and summer air conditioning

Ans. (a) Shell and Coil Condensor : Condensation is known as phase heat transfer which is quite common in all refrigeration plants so that it is necessary to study the condensation heat transfer phenomenon.



Nusselt proposed an equation for finding out heat transfer coefficient of condensation side for film wise condensation as :

$$h_a = 0 \cdot 943 \left[\frac{g \cdot \rho^2 \cdot h_{fg} \cdot k^3}{\mu L (T_s - T_\omega)} \right]^{1/4} \quad ...(i)$$

If the condensation occurs on a horizontal tube, then L is replaced by 2·50, which D is the outside diameter of the tube.

$$h_a \text{ (horizontal)} = 0 \cdot 725 \left[\frac{g \cdot \rho^2 h_{fg} \cdot k^3}{\mu D (T_s - T\omega)} \right]^{1/4} \quad ...(ii)$$

Dividing equation (i) and (ii)

$$\frac{h_a \text{ (vertical)}}{h_r \text{ (horizontal)}} = \frac{0 \cdot 943}{0 \cdot 725} \left[\frac{D}{L} \right]^{1/4}$$

$$= 1 \cdot 276 \left[\frac{D}{L} \right]^{1 4}$$

If $D = 3$ cm, $L = 20$ cm

$$\frac{h_a\,(v)}{h_a\,(h)} = 0{\cdot}7$$

∴ This shows that condenser tubes always give better performance in horizontal position.

(b) Thermostatic Expansion Valve : The thermostatic expansion valve controls the flow of refrigerant through the vaporator in such a way that the quality of the vapour leaving the evaporator will be always in superheated condition.

Its operation is used for maintaining a constant degree of superheat at evaporator outlet.

Here, $P_b = P_s + P_e$

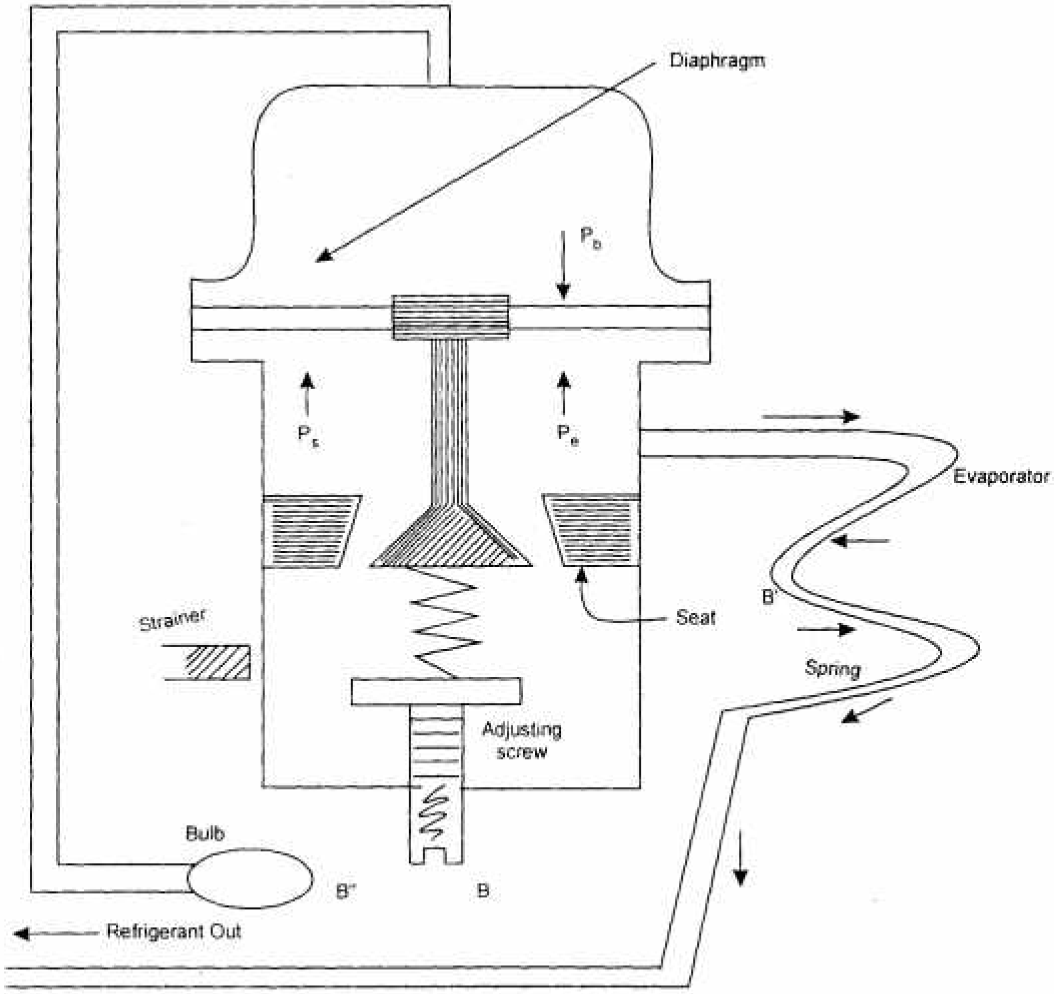


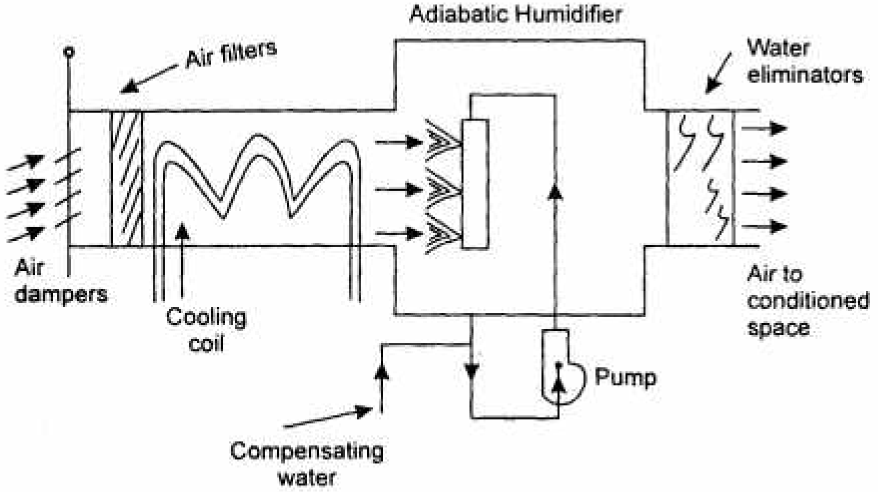
Fig. Thermostatic Expansion Valve

(c) Summer Air-Conditioning System : Used for hot and dry outdoor conditions like Nagpur, Delhi, Bhopal and other places.

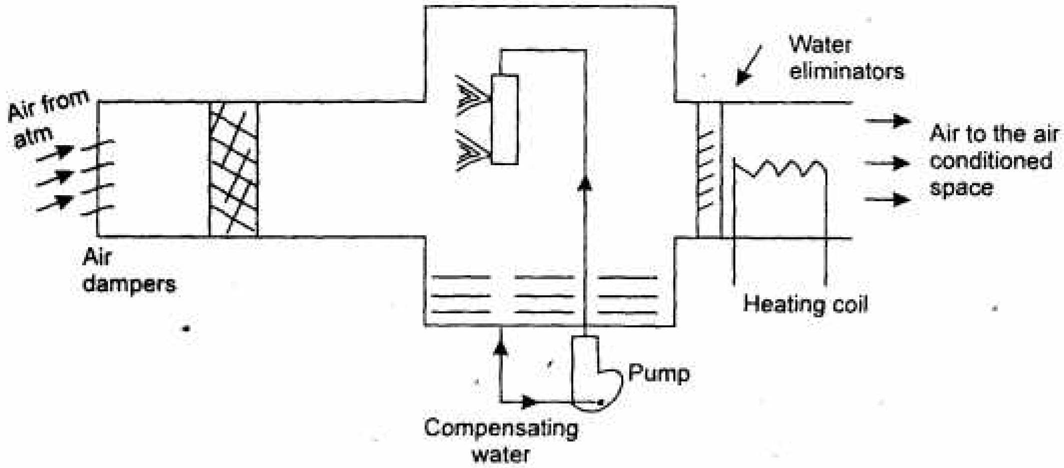
$$B = \frac{\text{Distance } (4-2)}{\text{Distance } (4-1)}$$

$$\eta_h = \frac{T_2 - T_3}{T_2 - T_5} \times 100$$

Capacity of cooling coil $= \frac{V}{V_s}\left(\frac{h_3 - h_1}{3 \cdot 5}\right)$ tons of refrigeration where V is the volume of air heated m^3 per second where V_s is the specific volume.



(a) Summer Air-Conditioning System



(b) Winter Air-conditioning System

Q. 8. Write short notes on :

(a) Necessity of aircraft cooling

(b) Effects of operating conditions on COP of VCRS

(c) Necessity of Multistage Compression

(d) Properties of air

Ans. (a) Necessity of Aircraft Cooling : Air-conditioning in aircraft is more difficult with the vehicles moving on ground because of extreme cold conditions at high altitudes and rapid changes of the surrounding atmosphere. The introduction of high speed jet transport air planes in passenger services has greatly increased the importance of aircraft air-conditioning in recent years. These aircraft carry as many as 700 people at supersonic speed and at altitudes upto 15,000 m. The basic principles of air-conditioning the stores, resturants, homes are also applicable to air planes. However, the equipments must meet additional requirements as it must be compact, light weight, accessible for quick inspection, vibration free and it must not be capable of responding to rapid changes of ambient temperature and pressure as airplane climbs and descent.

(b) Effects of Operating Conditions on COP of VCRS : (i) When the vapour is dry and saturated at the end of compression,

$$\text{COP} = \frac{R}{W} = \frac{h_a - h_c}{h_b - h_a}$$

(ii) When the vapour is met at the end of compression

$$\text{COP} = \frac{R}{W}$$

(iii) When liquid heats are not given

$$\text{COP} = \frac{R}{W}$$

$$= \frac{\left[\frac{x_1\, hhg'}{1} \times \frac{T_2}{T_1} - C_p\,(T_1 - T_2) + T_2\, C_{p1}\,\log_e\left(\frac{T_1}{T_2}\right)\right]}{\left[C_{pl}\,(T_1 - T_2) - T_2\, C_{p1}\,\log_e\left(\frac{T_1}{T_2}\right) + \frac{x_1 h_{fg}'}{1}\,(T_1 - T_2)\right]}$$

(iv) When the vapour is superheated after compression

$$\text{COP} = \frac{R + R_1}{W + W_1}$$

(v) When undercooling is done, the pressure of liquid refrigerant remains same but temperature is reduced.

(c) Necessity of Multistage Compression : Multistage compression is used to improve COP of the system mass of refrigerant passing through compressor is given by

$$\text{MCl} = \frac{3 \cdot 5T}{h_2 - h_1}$$

The dual compression is used to replace 2 compression which are required for multiexpansion valve system. The object of this system is to combine 2 separate systems into one without affecting the performance of the system.

In the simplest type of dual compressor, there are 2 valves, one low pressure suction, other high pressure delivery valve and medium pressure suction ports. Dual compressor shows considerable variation in design, particulary with regard to the location of valves and ports and method of operating the valves.

This type of arrangement is not frequently used in practice except in some special cases due to its complexity of design and working.

(d) Psychrometric Properties of Air :

Dry Air : The dry air is considered as a mixture of N_2 and O_2 neglecting the small percentages of other gases. The volumetric composition of air is about 79% N_2 and 21% O_2 and the molecular weight of dry air is taken as 29 approximately.

Moist Air : It is a mixture of dry air and water vapour. The quantity of water vapour present in the air depends upon the temperature of air and its quantity may change from zero to maximum.

Water Vapour : The water vapour present in air is known as moisture and its quantity in air is an important factor in all air conditioning systems.

Specific humidity (humidity ratio) is the mass of water vapour per kg of dry air. It is given in grams per kg of dry air.

Degree of Saturation : It is defined as the ratio of mass of water vapour associated with unit mass of dry air to mass of water vapour associated with unit mass of dry air saturated at the same temperature.