

B.E.

Seventh Semester Examination, 2010-2011

Refrigeration & Air Conditioning (ME-403-E)

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

Q. 1. (a) What are the desirable properties of an ideal refrigerant?

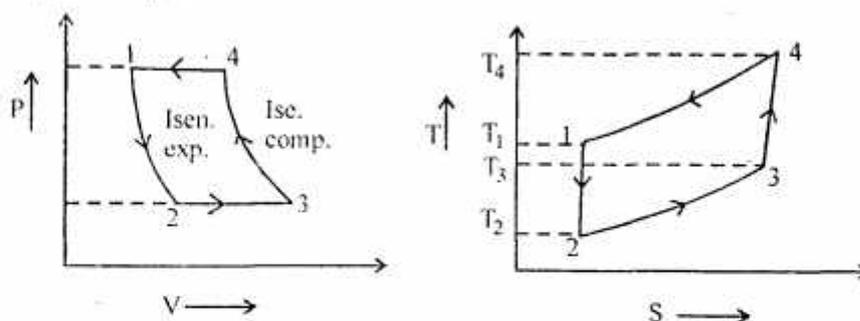
Ans. Desirable Properties of an Ideal Refrigerant : A refrigerant is said to be ideal if it has all of the following properties :

- (i) Low boiling point.
- (ii) High critical temperature.
- (iii) High latent heat of vaporisation.
- (iv) Non-corrosive to metal.
- (v) Non-toxic.
- (vi) Low specific heat of liquid.
- (vii) Low cost.
- (viii) Non-flammable and non-explosive.
- (ix) Low specific volume of vapour.
- (x) Mixes well with oil.

Q. 1. (b) Prove that performance factor of Bell-Coleman cycle refrigeration system is given by

$$COP = T_2 / (T_3 - T_2)$$

Ans. Bell Coleman Cycle :



The four process of the cycle are as follows :

- (i) Isentropic compression process (3-4).
- (ii) Constant process cooling process (4-1)

Heat rejected, $Q_{4-1} = C_p (T_4 - T_1)$

- (iii) Isentropic expansion process.

- (iv) Constant pressure expansion process

Heat absorbed, $Q_{2-3} = C_p (T_3 - T_2)$

Workdone during the cycle per kg of air

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

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

$$\text{COP} = \frac{\text{Heat extracted}}{\text{Work done}}$$

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

Since the ratio of expansion is the same as the ratio of compression so as to maintain upper and lower limits of pressure the same.

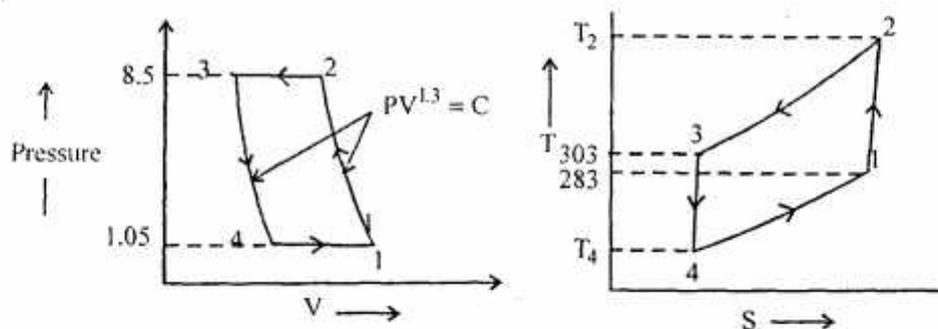
$$\frac{T_4}{T_3} = \frac{T_1}{T_2} \Rightarrow T_4 = T_3 \times \frac{T_1}{T_2}$$

$$\text{COP} = \frac{T_3 - T_2}{(T_3 \times (T_1 / T_2)) - (T_3 - T_2)} = \frac{T_3 - T_2}{(T_1 / T_2)(T_3 - T_2) - (T_3 - T_2)}$$

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

Q. 2. (a) A refrigerator working on Bell-Colman Cycle operates between pressure limits of 1.05bar and 8.5 bar. Air is drawn from the cold chamber at 10°C. Air coming out of compressor is cooled to 30°C before entering the expansion cylinder. The expansion and compression follow the law $PV^{1.3} = \text{constant}$. Determine the theoretical C.O.P. of the system.

Ans.



The compression and expansion follows the law $pV^{1.3} = C$

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

∴

$$T_2 = T_1 \times 1.62 = 283 \times 1.62$$

$$T_2 = 458.5 \text{ K}$$

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

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

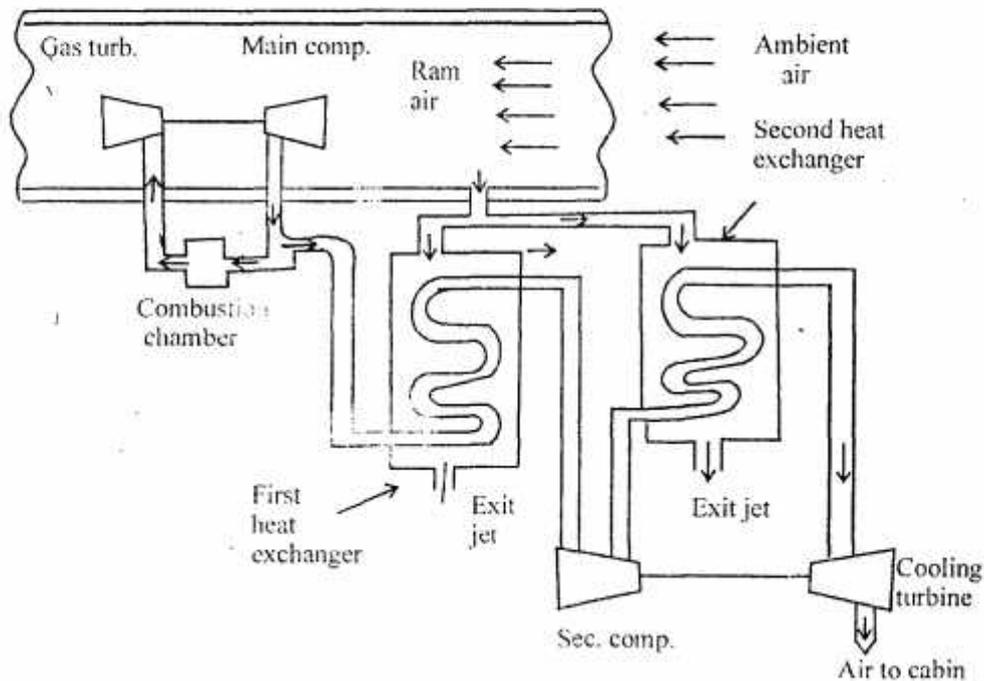
Now,
$$\text{C.O.P.} = \frac{T_1 - T_4}{\frac{n}{n-1} \times \frac{\gamma-1}{\gamma} [(T_2 - T_3) - (T_1 - T_4)]} \quad [\because \text{taking } \gamma = 1.4]$$

$$\text{COP} = \frac{283 - 187}{\frac{1.3}{1.3-1} \times \frac{1.4-1}{1.4} [(458.5 - 303) - (283 - 187)]}$$

$$\text{COP} = \frac{96}{1.24 \times 59.5} = 1.3$$

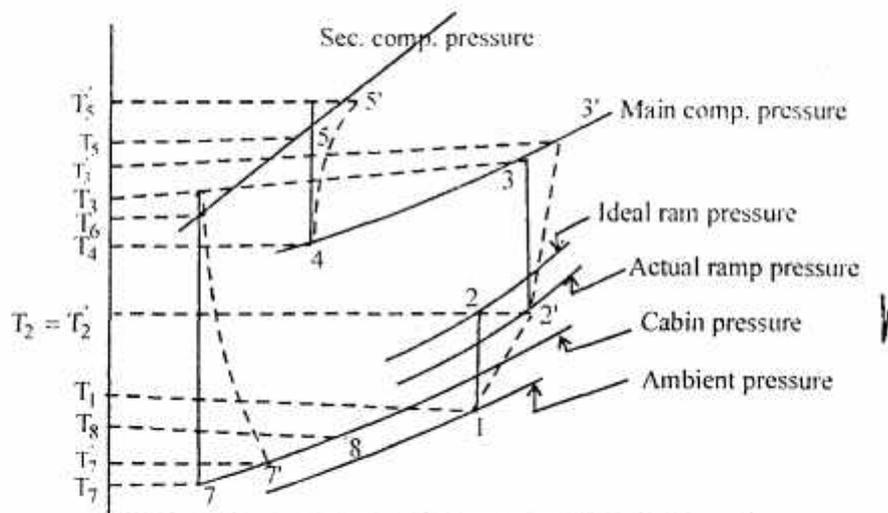
Q. 2. (b) Describe with a sketch a boot strap cycle of fair refrigeration system.

Ans. Boot-Strap Cycle of Air Refrigeration System : This system has two heat exchangers instead of one and a cooling turbine drives a secondary compressor instead of cooling fan. The air bled from the main compressor is first cooled by the ram air in the first heat exchanger. This cooled air after compression in the secondary compressor is led to the second heat exchanger where it is again cooled by the ram air before passing to the cooling turbine.



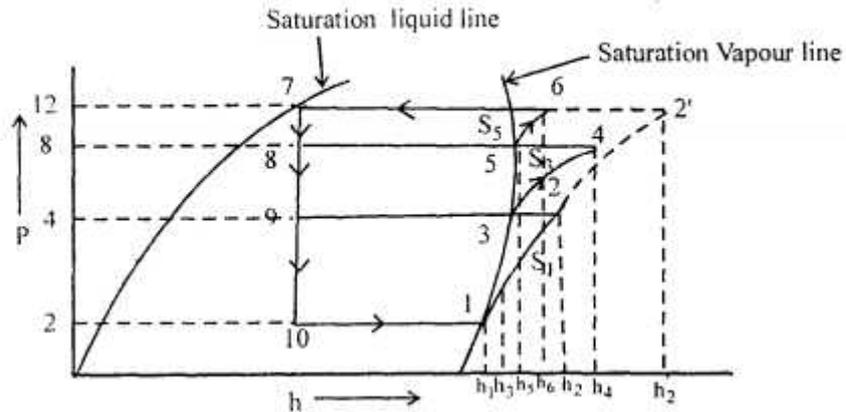
The various processes are as follows :

- (i) The process 1-2 represents the isentropic ramming of ambient air from pressure p_1 and temperature T_1 to pressure p_2 and temperature T_2 . The process 1-2' represents the actual ramming process because of internal friction due to irreversibilities.
- (ii) The process 2'-3 represents the isentropic compression of air in the main compressor and process 2'-3' represents the actual compression of air because of internal friction due to irreversibilities.
- (iii) The process 3'-4 represents the cooling by ram. The pressure drop in the heat exchanger is neglected.
- (iv) The process 4-5 represents the isentropic compression of cooled air from first heat exchanger in the secondary compressor. The process 4-5' represents the actual compression process because of internal friction due to irreversibilities.
- (v) The process 5'-6 represents the cooling by ram air in the second heat exchanger. The pressure drop in the heat exchanger is neglected.
- (vi) The process 6-7 represents the isentropic expansion of cooled air in the cooling turbine upto the cabin pressure. The process 6-7' represents actual expansion of the cooled air in the cooling turbine.
- (vii) The process 7'-8 represents the heating of air up to the cabin temperature T_8 .



Q. 3. A three-stage ammonia refrigeration system with flash intercooling operates between the overall pressure limits 2 bar and 12 bar. The flash intercooler pressures are 4 bar and 8 bar. If the load on the evaporator is 10TR. Find the power required to run the system and compare the C.O.P. of the system with that of simple saturation cycle working between the same overall pressure limits.

Ans.



The various values as read from P-h diagram enthalpy of saturation vapour refrigerant entering the low pressure compressor at point 1.

$$h_1 = 142 \text{ kJ / kg .}$$

Entropy of saturation vapour refrigerant at point 1,

$$s_1 = 5.564 \text{ kJ / kg.K}$$

Enthalpy of superheated vapours at point 2.

$$h_2 = 1515 \text{ kJ / kg}$$

Enthalpy and entropy of saturation vapour at point 3,

$$h_3 = 1442 \text{ kJ / kg}$$

$$s_3 = 5.367 \text{ kJ / kg}$$

Similarly,

$$h_4 = 1525 \text{ kJ / kg}$$

$$h_5 = 1461 \text{ kJ / kg}$$

$$s_5 = 5.1186 \text{ kJ / kg.K}$$

$$h_6 = 1500 \text{ kJ / kg}$$

Enthalpy of saturation liquid refrigerant leaving the condenser at point 7.

$$h_{f7} = h_8 = h_9 = h_{10} = 328 \text{ kJ / kg}$$

Power required to run the system :

Mass of refrigerant.

$$m_1 = \frac{210Q}{h_1 - h_{f7}} = \frac{210 \times 10}{1420 - 328} = 1.92 \text{ kg / min.}$$

Mass of liquid refrigerant after the first stage of compression.

$$m_2 = \frac{m_1 (h_2 - h_3)}{h_3 - h_{f7}} = \frac{1.92(1515 - 1442)}{1442 - 328} = 0.126 \text{ kg / min}$$

∴ Mass of refrigerant passing through I.P. compressor,

$$m_3 = m_1 + m_2 = 1.92 + 0.126 = 2.046 \text{ kg / min.}$$

Mass of liquid refrigerant evaporated in the flash intercooler after the second stage of compression.

$$m_4 = \frac{m_3 (h_4 - h_5)}{h_5 - h_{f7}} = \frac{2.046(1525 - 1461)}{14610 - 328} = 0.116 \text{ kg / min.}$$

∴ Mass of refrigerant passing through H.P. compressor

$$m_5 = m_3 + m_4 = 2.046 + 0.116 = 2.162 \text{ kg / min.}$$

Workdone in L.P. compressor,

$$w_L = m_1 (h_2 - h_1) = 1.92(1515 - 1420) = 182.4 \text{ kJ / min.}$$

Workdone in I.P. comp.

$$w_I = m_3 (h_4 - h_3) = 2.046(1525 - 1442) = 169.8 \text{ kJ / min.}$$

Workdone in H.P. compressor

$$w_H = m_5 (h_6 - h_5) = 2.162(1500 - 1461) = 84.3 \text{ kJ / min}$$

Total workdone,

$$w = w_L + w_I + w_H = 436.5 \text{ kJ / min.}$$

∴ Power required to run the system

$$= 436.5 / 60 = 7.27 \text{ kW}$$

Comparison of COP of the system with that of simple saturation cycle.

$$R_E = m_1 (h_1 - h_{10}) = 210Q = 210 \times 10 = 2100 \text{ kJ / min}$$

$$\text{COP of the system} = \frac{R_E}{w} = \frac{2100}{436.5} = 4.81$$

Workdone in the compressor for simple saturation cycle.

$$w_I = m_1 (h_2' - h_1) = 1.92(1670 - 1420) = 480 \text{ kJ / min}$$

$$\text{COP} = \frac{R_E}{w_I} = \frac{2100}{480} = 4.375$$

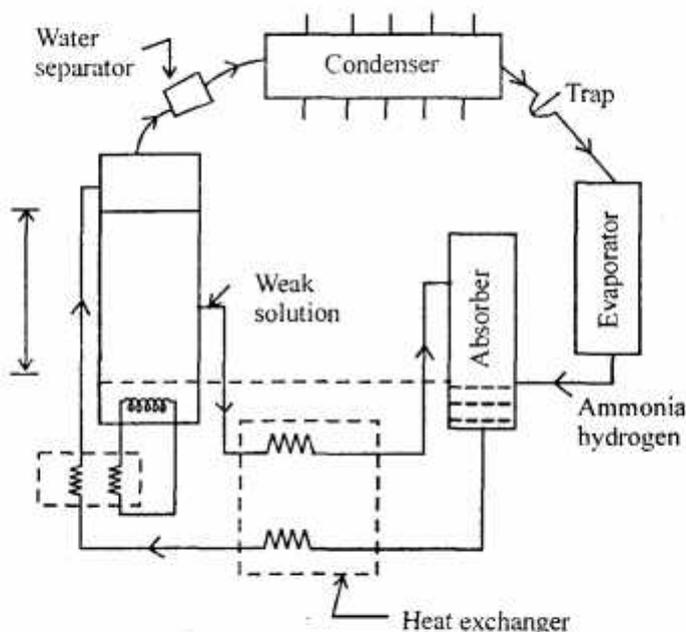
∴ Percentage increase in COP at compared to simple sat. cycle,

$$= \frac{4.80 - 4.375}{4.375} \times 100 = 9.9\% \quad \text{Ans.}$$

Q. 4. (a) Explain in Electrolux refrigerator with neat and clean diagram.

Ans. Electrolux Refrigerator : Fig. shows the outline of an electrolux refrigerator which works on a three fluid absorption system. A three fluid system employs a refrigerant, a solvent and an inert gas and eliminates the aqua pump from the system thus making it completely free from moving parts.

Ammonia gas coming out of the boiler is passed through the rectifier which is provided between the boiler and the condenser so as to prevent the entry of any water vapour into the evaporator where it would freeze and choke the machine. After this the gas is liquified in the condenser from where it gravitates into a U-tube gas seal containing liquid ammonia and then enters the evaporator.



The whole plant is charged to a pressure of about 14 bar. The evaporator contains hydrogen at a pressure of 12 bar. Therefore as soon as ammonia enters the evaporator. Its pressure falls to 2 bar. Due to low temperature ammonia evaporates taking its latent heat from the refrigerated space.

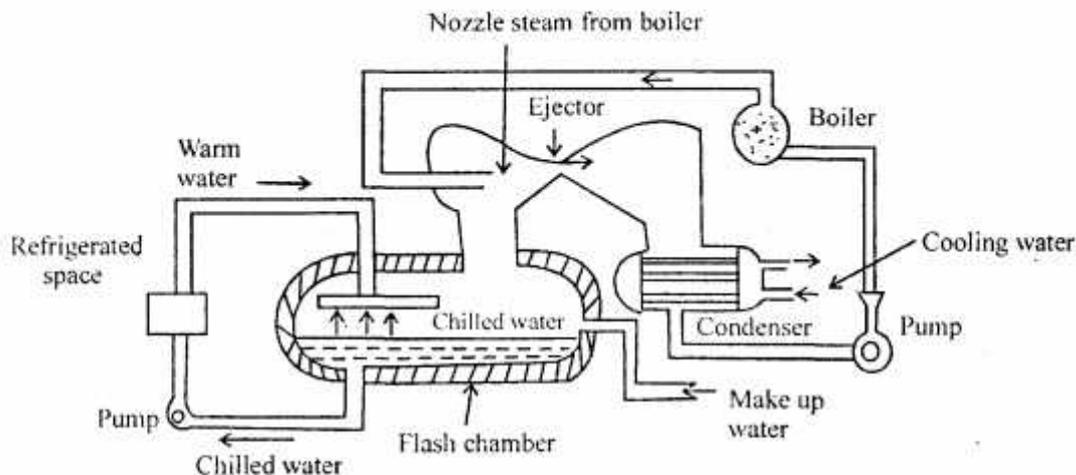
Since the total pressure on the high and low sides are equal so the only pressure head against which the liquid is to be forced so that it may enter boiler's 'h'. The necessary pumping action to overcome this head is achieved by applying a small amount of heat to the coil. This way the ammonia vapour continuously circulates and thus produces cold in the evaporator.

As the circulation of the refrigerant in the unit is effected by gravity instead of moving parts so the machine is very compact, durable and easy to regulate.

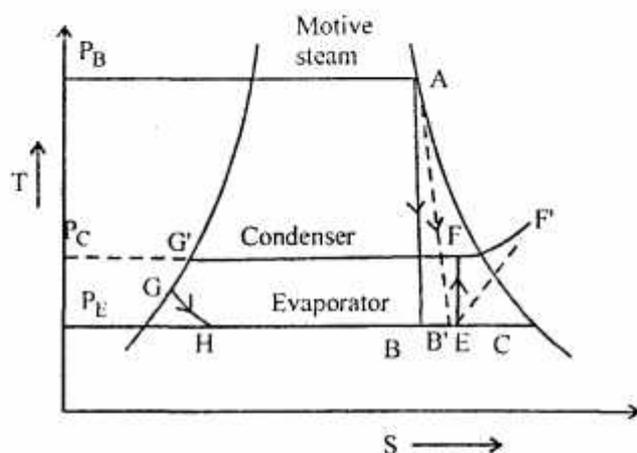
Q. 4. (b) With the help of neat sketch and T-S diagram, explain the working of steam jet refrigeration

system.

Ans. Steam Jet Refrigeration System :



T-S Diagram :



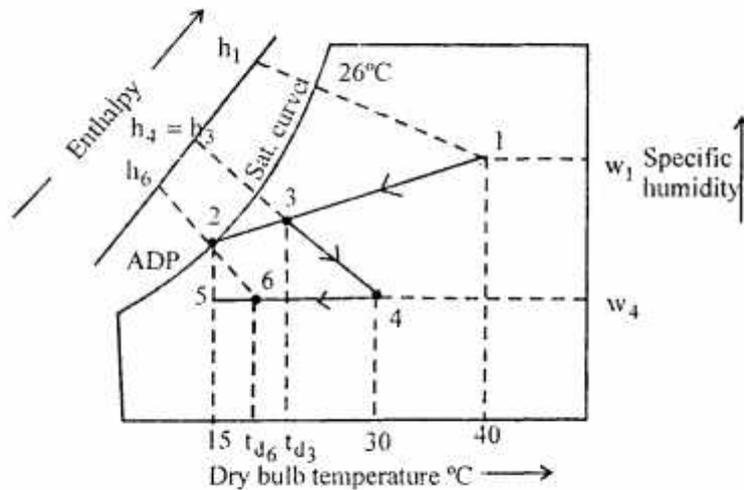
The flash chamber or evaporator is a large vessel and is heavily insulated to avoid the rise in temperature of water due to high ambient temperature. It is fitted with perforated pipes for spraying water. The warm water coming out of the refrigerated space is sprayed into the flash water chamber where some of which is converted into vapours.

The high pressure steam from the boiler is passed through the steam nozzle thereby increasing its velocity. This high velocity steam in the ejector would entrain the water vapours from the flash chamber. Which would result in further formation of vapours. The mixture of steam and water vapour passes through the venturi-tube of the ejector and gets compressed. The temperature and pressure of the mixture rises considerably and fed to the water cooled condenser where it gets condensed. The condensate is again fed to the boiler as feed water. A constant water level is maintained in the flash chamber and any loss of water due to evaporation is made up from the make-up water line.

Q. 5. 300 m^3 of air is supplied per minute from out-door conditions of 40°C by dry bulb temperature and 26°C wet bulb temperature to an air-conditioned room. The air is dehumidified first by a cooling coil having bypass factor of 0.32 and dew point temperature 15°C and then by a chemical dehumidifier. Air leaves the chemical dehumidifier at 30°C dry bulb temperature. Air is then passed over a cooling coil whose surface temperature is 15°C and by-pass factor of 0.26.

Calculate the capacities of the two cooling coils and dehumidifier.

Ans.



From psychrometric chart, we find that specific humidity of air at point 1,

$$w_1 = 0.0156 \text{ kg / kg of dry air}$$

Enthalpy of air at point 1,

$$h_1 = 80.6 \text{ kJ / kg of dry air}$$

Specific volume of air at point 1

$$V_{s1} = 0.94 \text{ m}^3 / \text{kg of dry air}$$

Enthalpy of air at point 3 and 4,

$$h_3 = 54.5 \text{ kJ / kg of dry air}$$

$$h_4 = h_3 = 54.5 \text{ kJ / kg of dry air}$$

Specific humidity at point 4

$$w_4 = 0.0094 \text{ kg / kg of dry air}$$

Enthalpy of air at point 6.

$$h_6 = 43 \text{ kJ / kg of dry air}$$

Mass of air supplied,

$$m_a = \frac{V_1}{V_{s1}} = \frac{300}{0.94} = 319 \text{ kg / min.}$$

The capacity of the first cooling coil

$$= m_a (h_1 - h_3) = 319(80.6 - 54.4) = 8326 \text{ kJ / min.}$$

And capacity of the second cooling coil,

$$= m_a (h_4 - h_6) = 319(54.5 - 43) = 3668 \text{ kJ / min.}$$

We know that the capacity of the dehumidifier.

$$= m_a (w_1 - w_4) = 319(0.0156 - 0.0094) = 1.98 \text{ kg / min.}$$

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

Total Seating Capacity = 350 persons

Atmospheric condition = 34°C DBT and 70% RH

Comfort condition required = 22°C DBT and 50% RH

Sensible heat given per person = 320 kJ/hr

Latent heat given per person = 100 kJ/hr

Sensible heat due to solar radiation and infiltrated air = 16,00,000 kJ/hr

Latent heat due to infiltrated air = 80,000 kJ/hr

Quantity of fresh air supplied = 0.4 m³ / person / min

Desirable temperature rise in theatre = 8°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.

Aus. From the psychrometric chart,

$$V_{s1} = 0.897 \text{ m}^3 / \text{kg of dry air}$$

Enthalpy, $h_1 = 80.6 \text{ kJ / kg}$

$$h_2 = 58.2 \text{ kJ / kg}$$

$$h_A = 66 \text{ kJ / kg}$$

Mass of infiltration air,

$$m_1 = \frac{V_1}{V_{s1}} = \frac{400}{0.897} = 446 \text{ kg / h}$$

Sensible heat gain due to infiltration air,

$$= m_1 (h_A - h_2) = 446(66 - 58.2) = 3480 \text{ kJ / h}$$

$$= 3480 / 3600 = 0.97 \text{ kW}$$

$$\begin{aligned}\text{Latent heat gain} &= m_1 (h_1 - h_A) = 446(80.6 - 66) = 6512 \text{ kJ/h} \\ &= 6512 / 3600 = 1.8 \text{ kW}\end{aligned}$$

$$\begin{aligned}\text{Sensible heat gain from persons} &= Q_s \text{ person} \times \text{number of person} \\ &= 58 \times 50 = 2900 \text{ W} = 2.9 \text{ kW}\end{aligned}$$

$$\begin{aligned}\text{Latent heat gain from persons,} &= Q_L \text{ per person} \times \text{Number of persons} = 44 \times 50 = 2.2 \text{ kW}\end{aligned}$$

$$\begin{aligned}\text{Sensible heat gain from employees} &= 58 \times 5 = 290 \text{ W}\end{aligned}$$

$$\text{Latent heat gain} = 76 \times 5 = 380 \text{ W}$$

$$\begin{aligned}\text{RSH} &= 6.2 + 2 + 2.9 + 0.97 + 2.9 + 0.29 + 0.17 \\ &= 15.43 \text{ kW}\end{aligned}$$

$$\begin{aligned}\text{Total latent heat gain,} & \\ \text{RLH} &= 0.7 + 1.8 + 2.2 + 0.38 + 0.3 \\ &= 5.38 \text{ kW}\end{aligned}$$

$$\text{RSHF} = \frac{\text{RSH}}{\text{RSH} + \text{RLH}} = \frac{15.43}{15.43 + 5.38} = 0.741$$

From psychrometric chart, we find that specific volume,

$$V_{s4} = 0.8$$

Enthalpy of air $h_4 = 45 \text{ kJ/kg}$ of dry air

Percentage of total air circulated

Mass of fresh air supplied,

$$m_f = \frac{V_f}{V_{s1}} = \frac{1600}{0.897} = 1784 \text{ kg/h}$$

Mass of recirculated air,

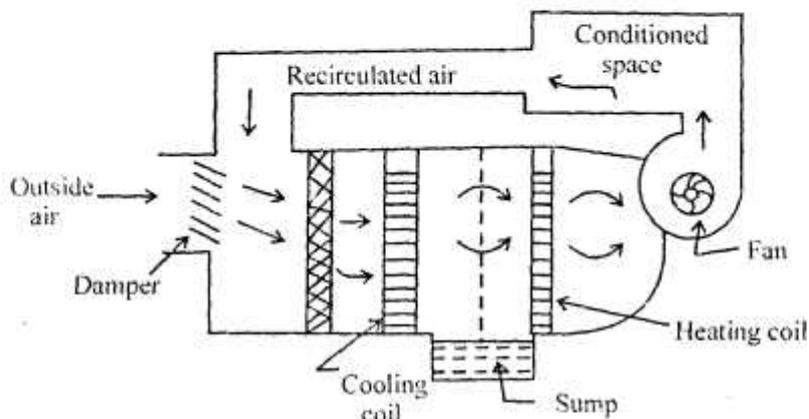
$$\begin{aligned}&= m_a - m_f = 5675 - 1784 \\ &= 3891 \text{ kg/h}\end{aligned}$$

$$\begin{aligned}\% \text{ of air circulated} &= \frac{3891}{5675} = 0.686 = 68.6\% \quad \text{Ans.}\end{aligned}$$

Q. 7. (a) Explain summer air conditioning system with a neat sketch.

Ans. Summer Air Conditioning System : The outside air flows through the damper and mixes up with recirculated air the mixed air passes through the filter to remove dirt, dust and other impurities. The air now

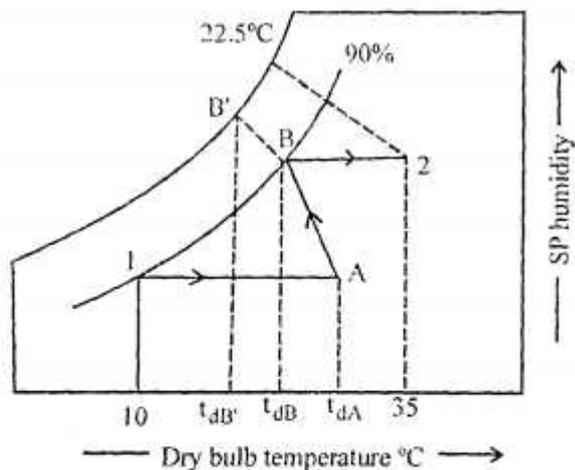
passes through a cooling coil. The coil has a temperature much below the required dry bulb temperature of the air in the conditioned space. The cooled air passes through a perforated membrane and loses its moisture in the condensed form which is collected in a sump. After that the air is made to pass 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 ventilators. The outside air is sucked and made to mix with the recirculated air in order to make up for the loss of conditioned air through fans from the conditioned space.

Q. 7. (b) Air at 10°C DBT and 90% RH is to be brought to 35°C DBT and 22.5°C WBT with the help of winter air conditioner. If the humidified air comes out of the humidifier at 90% RH, draw the various processes involved on a skeleton psychrometric chart and find the temperature to which the air should be preheated and efficiency of the air washer.

Ans.



(i) From the psychrometric chart, the temperature to which the air should be pre-heated (corresponding to point A) is

$$t_{dA} = 31.2^{\circ}\text{C}$$

(ii) From the psychrometric chart, we find that

$$t_{dB} = 18.5^{\circ}\text{C} \text{ and } t_{dB'} = 17.5^{\circ}\text{C}$$

Efficiency of the air washer.

$$= \frac{\text{Actual drop in DBT}}{\text{Ideal drop in DBT}}$$

$$= \frac{t_{dA} - t_{dB}}{t_{dA} - t_{dB'}}$$

$$= \frac{31.2 - 18.5}{31.2 - 17.5} = 0.927$$

$$= 92.7\% \quad \text{Ans.}$$

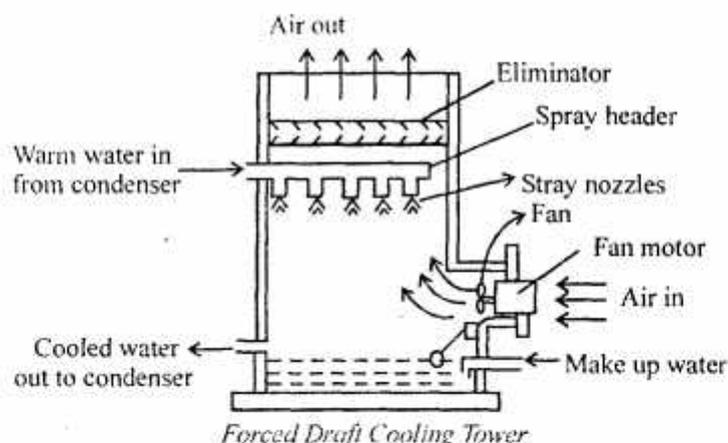
Q. 8. Write notes on :

(a) Forced draft cooling tower

(b) Flooded evaporator

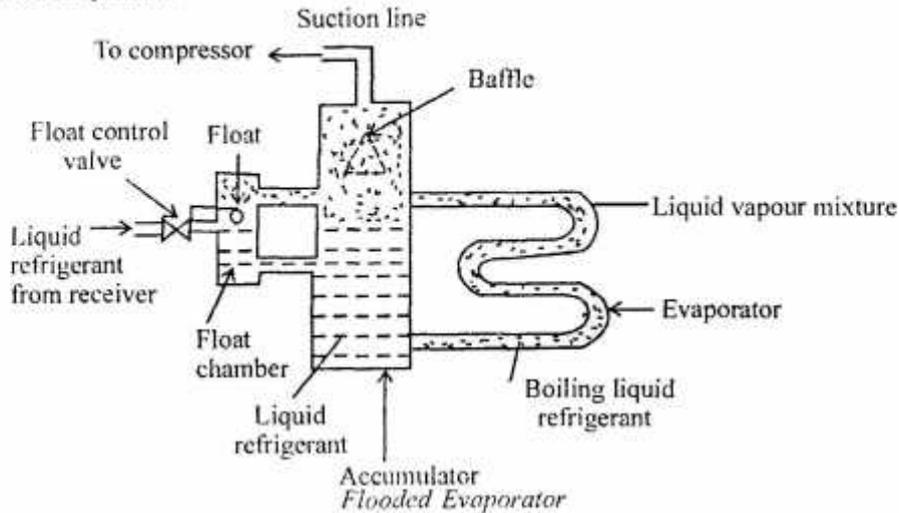
(c) Rotary compressors.

Ans. (a) Forced Draft Cooling Tower :



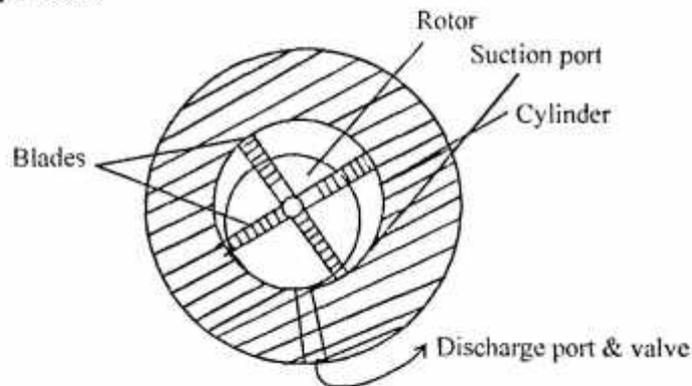
In the forced draft cooling tower, a fan forces the air through the tower. In its operation, the warm water from the condenser is sprayed at the top of the tower through the spray nozzle. The air is forced upward through the tower by the propeller fan provided on the side near the bottom of the tower. The condenser warm water is cooled by means of evaporation. The effectiveness of the cooling tower may be improved by increasing the height of the tower.

(b) Flooded Evaporator :



In a flooded evaporator, a constant liquid refrigerant level is always maintained. A float control valve is used as an expansion device which maintains constant liquid level in the evaporator. The liquid refrigerant from the receiver passes through a low side float control valve and accumulator before entering the evaporator coil. The accumulator supplies more liquid to the evaporator in order to keep the liquid refrigerant in the evaporator at proper level. In this way, the level of liquid refrigerant in the accumulator also falls down. Since the float within the float chamber rest on liquid refrigerant at the same level as that in the accumulator, therefore the float also falls down and open the float valve.

(c) Rotary Compressors :



Rotating Blade Type Rotary Compressor

The 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 cylinder the blade are forced against the cylinder wall by the centrifugal action.

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.