# B.E.

## Seventh Semester Examination, 2009-2010

# Refrigeration & Air Conditioning (ME-403-E)

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

**Q. 1. (a) Differentiate Between the refrigeration and air conditioning.**

**Ans. Difference between Refrigeration & Air-Conditioning :**

The air conditioning is that branch of engineering science which deals with the study of conditioning of air i.e., supplying & maintaining desirable atmospheric condition for human comfort, irrespective of external conditions.

This subject, in its broad sense, also deals with the conditioning of air for industrial purposes, food processing, storage of food & other material.

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

**Ans. Various Method of Refrigeration System :**

(i) Simple air cooling system.

(ii) Simple air evaporative cooling system.

(iii) Boot strap air cooling system.

(iv) Boot strap air evaporative cooling system.

(v) Reduced Ambient air cooling system.

(vi) Regenerative air cooling system.

**Simple air Cooling System :**

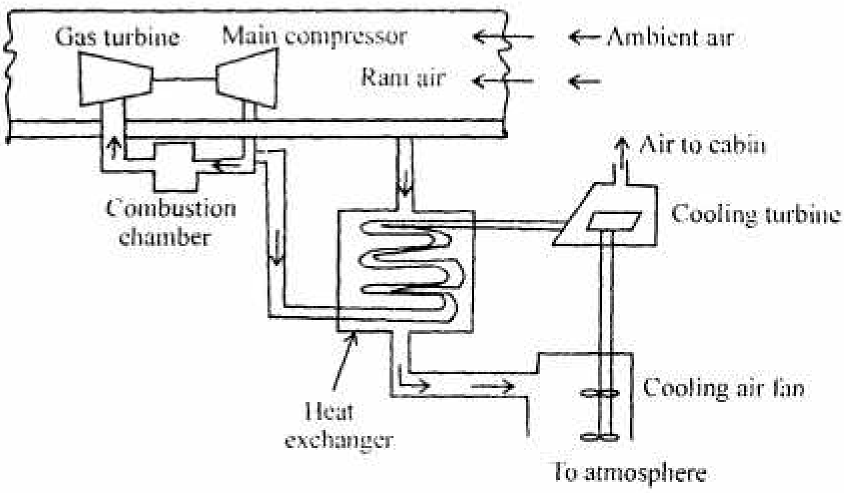


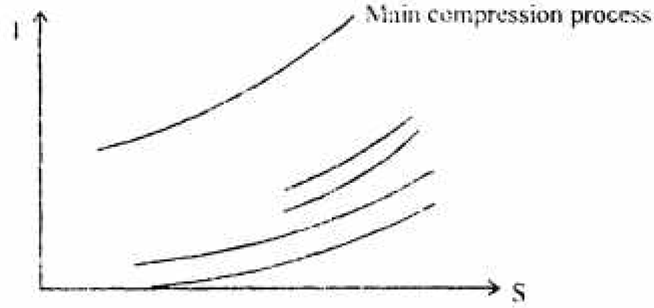

*Fig. Simple air cooling system*

Various process discussed as below :

**(a) Ramming Process :**

$P_1$, $T_1$ = Pressure & temperature of ambient air.

Ambient air is rammed isentropically from $P_1$ & $T_1$ to $P_2$ & $T_2$.




From energy equation $\quad K.E. = \frac{V^2}{2000} \text{ kJ/kg}$

$$h_2 - h_1 = \frac{V^2}{2000}$$

$$C_p T_2 - C_p T_1 = \frac{V^2}{2000}$$

$$T_2 = T_1 + \frac{V^2}{C_p 2000}$$

$$\frac{T_2}{T_1} = 1 + \frac{V^2}{2000 C_p T_1}$$

&

$$\frac{T_2'}{T_1} = 1 + \frac{V^2}{2000 C_p T_1}$$

$$C_p - C_V = R \Rightarrow C_p\left[1 - \frac{C_v}{C_p}\right] = R$$

$$C_p = \frac{\gamma R}{\gamma - 1}$$

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

**(ii) Compression Process :** Isentropic compression of air in the main compressor is represented by line 2'-3.

$$W_c = m_a C_p \left(T_3' - T_2'\right)$$

$m_a$ = Mass of air bled from main compressor for refrigeration purposes.

**(iii) Cooling Process :** Compressed air is cooled by the ram in the heat exchanger. Shown by curve 3'–4.

$$Q_R = m_a C_p \left(T_3' - T_4\right)$$

**(iv) Expansion Process :** Cooled air is expanded isentropically in cooling turbine.

$$W_E = m_a C_p \left(T_4 - T_5'\right)$$

**(v) Refrigeration Process :** Air from cooling turbine is sent to cabin & cool pit gets heated by heat of equipment & occupancy.

$$R_E = m_a C_p \left(T_6 - T_5\right)$$

$$\text{C.O.P. of air cycle} = \frac{\text{Refrigerating effect produced}}{\text{Work done}}$$

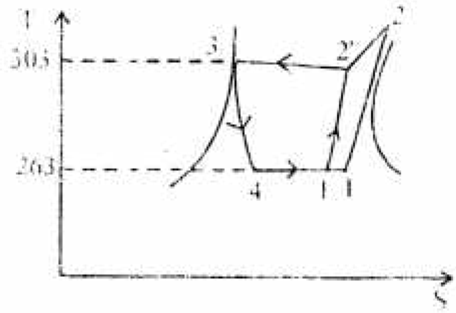
$$= \frac{m_a C_p \left(T_6 - T_5'\right)}{m_a C_p \left(T_3' - T_5'\right)} = \frac{T_6 - T_5}{T_3 - T_2}$$

**Q. 2. An ammonia refrigeration machine works between the temperatures of –10°C and 30°C. The vapour leaves the compressor in dry and saturated condition and temperature of the liquid refrigerant leaving the condenser is 30°C. Find the kilograms of ice produced per kW-hour assuming actual COP is 65% of theoretical. The quantity of heat carried per kg of ice is 370 kJ/kg. The properties of ammonia are given below :**

| Temp°C | $h_f$ (kJ / kg) | $h_{fg}$ (kJ/kg) | $s_f$ (kJ / kg – K) | $s_g$ (kJ/kg-K) |
|---|---|---|---|---|
| 30 | 28.5 | 290.8 | 0.099 | 1.055 |
| –10 | –8.84 | 323 | –0.033 | 1.191 |

**Ans.** Given that,

$$T_1 = T_4 = -10°C$$
$$= 263\,K$$
$$T_2' = T_3' = 303\,K$$
$$h_{f_3} = h_{f_2} = 28.5\,kJ/kg$$
$$h_{f_1} = h_{f_4} = -8.84\,kJ/kg$$
$$h_{fg_2} = 290.8\,kJ/kg,\; h_{fg_1} = 323\,kJ/kg$$




Assume $C_p = 1.09$

Entropy at point 2

$$S_2 = S_2' + 2.3\,C_p \log\left(\frac{T_2}{T_2'}\right)$$

$$1.991 = 1.055 + 2.3 \times 1.09 \log\left[\frac{T_2}{303}\right]$$

$$\Rightarrow \quad \log\left[\frac{T_2}{303}\right] = \frac{.936}{1.09 \times 2.3}$$

$$T_2 = 440.137$$

Enthalpy at saturated vapour at point 2

$$h_2 = h_2' + C_p\left(T_2 - T_2'\right)$$

$$= 290 + 1.09(440.137 - 303) = 439:47$$

$$(C.O.P.)_{Th} = \frac{h_1 - h_{f_3}}{h_2 - h_1}$$

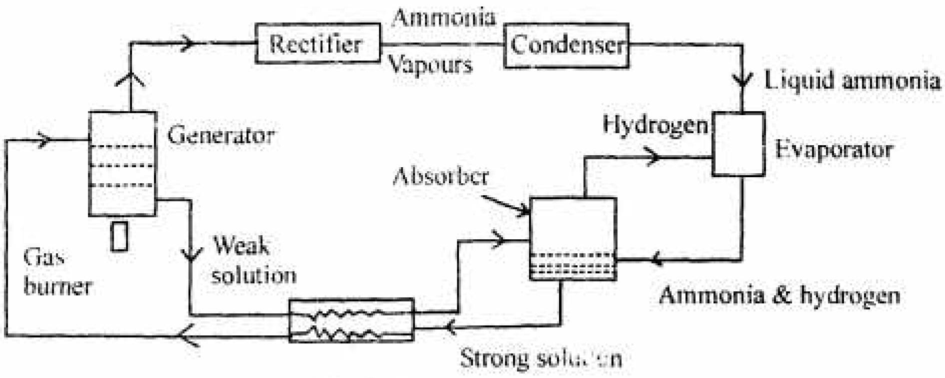
$$= \frac{323 - 28.5}{439.47 - 323} = 2.52$$

$$(C.O.P.)_{act} = .65 \times (COP)_{Th}$$

$$(C.O.P.)_{act} = 1.6435.$$

**Q. 3. (a) Draw a neat compact diagram of Electro-Lux refrigerator and explain its working principle. What is the important role of hydrogen in this refrigeration system? What are its advantages over absorption type refrigeration system?**

**Ans. Electro-Lux Refrigerator :**




(i) Invented by Swedish Engineer in 1925.

(ii) This type of refrigerator is also called three fluid absorption system.

**Principle of Working :**

(i) Strong $NH_3$ solution from absorber through heat exchanger is heated in the generator by applying heat from external source usually a gas burner.

During this process $NH_3$ vapours are removed from solution & passed to condenser.

(ii) A rectifier is fitted before the condenser removes the water vapour from the $NH_3$, so that dry $NH_3$ vapours are supplied to condenser.

(iii) The hot weak solution left behind in the generator flow to absorber through the heat exchanger. This hot weak solution while passing through the exchanger is cooled. The heat removed by weak solution is utilized to raise the temperature of strong solution passing through heat exchanger.

(iv) The ammonia vapours in condenser are condensed using external cooling source.

(v) The liquid refrigerant leaving the condenser flows under gravity to evaporator where it meets the hydrogen gas.

(vi) The $H_2$ gas which is being fed to evaporator permit the liquid $NH_3$ to evaporate at a low pressure & temperature.

(vii) During the process of evaporation the $NH_3$ absorbs latent heat from refrigerated space & thus produces cooling effect.

$$\text{C.O.P.} = \frac{\text{Heat absorbed in evaporator}}{\text{Heat supplied to generator}}$$

**Advantages :**

(i) The main purpose of this system is to eliminate the pump so that in absence of moving parts, the machine became noiseless.

(ii) There is little chance for the leakage.

(iii) Total amount of refrigerant used is small.

**Role of $H_2$ :**

(i) Hydrogen being the lightest gas, used to increase the rate of evaporation of liquid $NH_3$ passing through evaporator.

(ii) It is also non-corrosive & insoluble in water.

(iii) Used in low pressure side of system.

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

**Ans. Advantages of Steam Jet Refrigeration System :**

(i) It is simple in construction & rigidly designed.

(ii) It is vibration free system as pump are the only moving parts.

(iii) It has low maintenance cost, low production cost & highly reliability.

(iv) It has relatively less plane mass.

(v) It uses water as refrigerant, as water is safe to use as it is non-poisonous & inflammable.

(vi) System has ability to adjust quickly to load variation.

(vii) Running cost of this system is quite low.

**Disadvantages :**

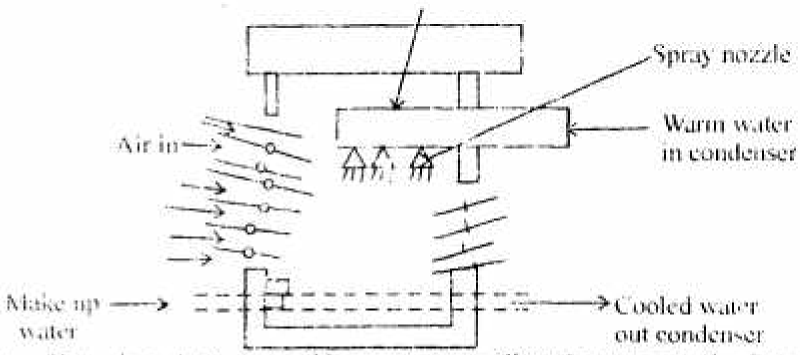
(i) System is not suitable for water temperature below 4°C.

(ii) For proper functioning of this system, maintenance of high vacuum in evaporator is necessary.

This is done by direct vapourisation to produce chilled water which is usually limited as tremendous volume of vapour is to be handled.

**Q. 4. (a) Explain the working of the following types of cooling towers with neat sketches :**
**(i) Atmospheric cooling tower (ii) Mechanical draft cooling tower (iii) Forced draft cooling tower.**
**And specify their applications.**

**Ans. (i) Atmospheric Cooling Tower :** Atmospheric natural draft cooling tower (Spray type).




(i) It consists of box-shaped structure with lower covers allow the atmospheric air to pass through the tower, but slant down towards the inside of tower to retain water in it.

(ii) The frame work & covers are made up of steel. The size of cooling tower depends upon the capacity of the unit. The atmospheric natural draft cooling tower should be located in the open space where the air can flow freely through them.

**(ii) Mechanical Draft Cooling Tower :** (i) In this cooling system, fans are used to force the air through them.

(ii) May use centrifugal or propeller fans.

**Advantages :**

(i) Mechanical draft cooling towers are smaller in size.

(ii) The cooling capacity of mechanical draft cooling towers can be controlled by controlling the amount of forced air.

(iii) The mechanical draft cooling tower can be located inside the building because they do not depend upon atmospheric air.

**Disadvantages :**

(i) It requires additional power to operate the fans.

(ii) The maintenance of fans, motor & control increases the operating cost.

**(iii) Forced Draft Cooling Tower :**

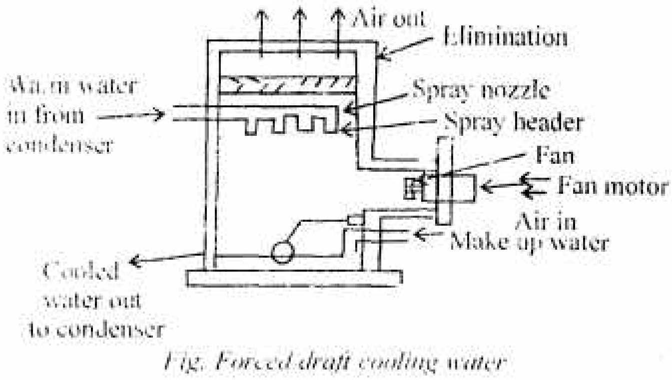



*Fig. Forced draft cooling water*

(i) In this tower, a fan forces the air through the tower. In its operation, the water from the condenser is sprayed at the top of tower through the nozzle.

(ii) The air is forced upward through the tower by the propellor fan provided on the side near the bottom of tower as shown in fig.

(iii) The condenser-warm water is cooled by means of evaporation as discussed earlier.

(iv) The effectiveness of cooling tower may be improved by increasing the height of tower, area of water surface exposed to air or velocity of air.

**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. (i) Flooded Evaporator :**

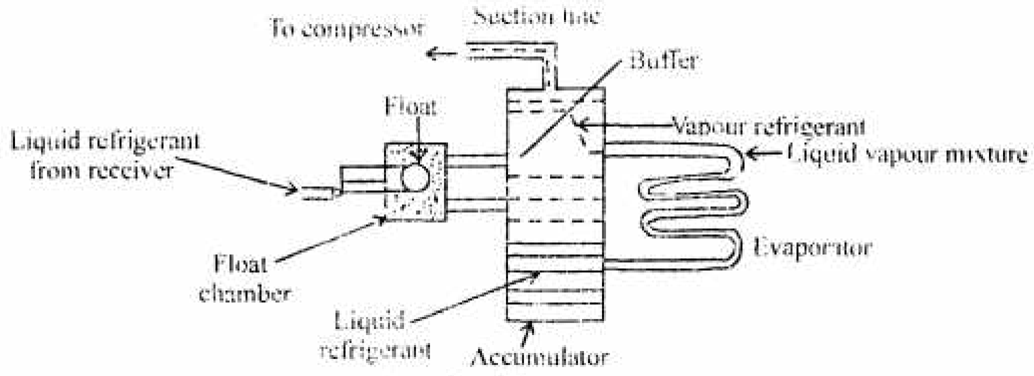



*Fig. Flooded Evaporator*

(i) In a flooded evaporator, a constant liquid refrigerant level is always maintained.

(ii) A float control valve is used as an expansion device which maintain constant liquid level in evaporator.

(iii) The liquid refrigerant from the receiver passes through a low side float control valve & accumulator before entering the evaporator coil.

(iv) The accumulator serves a storage tank for a liquid refrigerant. It maintain constant liquid level in the evaporator & helps to separate the liquid refrigerant from the vapour returning to the compressor.

(v) The accumulator supplies more liquid to evaporator in order to keep liquid level falls down.

(vi) Since the float within float chamber rest on liquid refrigerant at the same level as that in the accumulator, therefore the float also falls down & open the float valve.

**Advantage :** The advantage of flooded evaporator is that the whole surface of evaporator coil is in contact with liquid refrigerant under all load conditions.

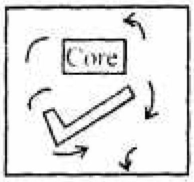
It gives high latent heat transfer rates than a dry expansion evaporator of same size.

**Disadvantage :** It is more expensive to operate because it requires more refrigerant charge.

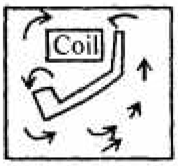
**Application :** Mostly applied in chemical & food processing industry.

Another type of flooded evaporator is the plate evaporator which is found in cold storages boxes & freezers.

**(ii) Natural Convection Evaporator :**




*(a) Air Circulation without Baffles*




*(b) Air Circulation with baffles*

(i) The natural convection evaporators are used where low air velocity & minimum hydration of product is desired.

(ii) The evaporator coil should be placed as high as possible in the refrigerator because the cold air falls down as it leaves the evaporator.

(iii) The velocity of air over the evaporator coil conside-able affects the capacity.

In this, the velocity of air depends upon the temperature difference between the evaporator & space to be cooled.

**Application :** Used in domestic refrigerator, water cooler & small freezers.

**(iii) Shell and Coil Evaporator :**

Are generally dry expansion evaporator to chill water.

Cooling coil is a continuous tube that can be in form of a single or double spiral.

The shell may be sealed or open.

The sealed shells are usually found in shell & coil evaporator are used to cool drinking water.

**Applications :** Used in home freezer, beverage cooler etc.

**(iv) Shell and Tube Evaporator :**

(i) It consists of a number of horizontal tubes enclosed in a cylindrical shell.

(ii) The inlet & outlet headers with perforated metal tube sheet are connected at each end of tubes.

(iii) When it is operated as dry expansion evaporator, the refrigerant circulates through the tubes & the liquid to cooled fills the space around the tubes within the shell.

(iv) The flooded shell & tube evaporators are used for refrigerating units of 10 to 5000 TR capacity.

**Applications :** These are generally used to chill water or brine solution.

House-hold refrigerator, home freezers, beverage coolers, ice-cream cabinets, locker plants etc.

**Q. 5. (i) Prove that the relation between degree of saturation and relative humidity is given by 10 an expression**

$$\Phi = \frac{\mu p_1}{P_1 - (1-\mu)p_{vs}}$$

**Ans.** Relative humidity

$$(\phi) = \frac{m_v}{m_s}$$

Let $P_v$, $V_v$, $T_v$, $m_v$ & $R_v$ = Pressure, volume, temperature, mass & gas constant respect for water vapour in actual condition.

$P_s$, $V_s$, $T_s$, $m_s$ & $R_s$ = Corresponding value for water vapour in saturated air.

We know, water vapour in actual condition

$$P_v V_v = m_v R_v T_v \quad ...(i)$$

For saturated air ⇒ $$P_s V_s = m_s R_s T_s \quad ...(ii)$$

According to definition ⇒ $V_v = V_s$ & $T_v = T_s$

$$R_v = R_s = 0.461$$

From equations (i) & (ii)

$$\phi = \frac{m_v}{m_s} = \frac{P_v}{P_s}$$

We know that degree of saturation

$$\mu = \frac{P_v\left[1-\frac{P_s}{P_b}\right]}{R_s\left[1-\frac{P_v}{P_b}\right]} = \phi\left[\frac{1-\frac{P_s}{P_b}}{1-\phi\frac{P_s}{P_b}}\right]$$

∴ $$\boxed{\phi = \frac{\mu P_b}{P_b-(1-\mu)P_s}}$$

**Q. 5. (ii) A sling psychometric reads 44°C DBT and 30°C WBT, calculate the following :**

**(a) Specific humidity**

**(b) Relative humidity**

**(c) Dew-point temperature**

**(d) Enthalpy of mixture**

**(e) Specific volume of the mixture.**

**Assume pressure of atmosphere air to be 1.013 bar.**

**Ans. (a) Specific Humidity :**

$$t_d = 44°C,\ t_w = 30°C$$

$$P_b = 1.013 \text{ bar}$$

$$P_w = 0.0425 \text{ (steam table)}$$

Partial pressure of water vapour

$$P_v = P_w - \frac{(P_b - P_w)(t_d - t_w)}{1544 - 1.44\,t_w}$$

$$= .0425 - \frac{(1.013 - .0425)(44 - 30°)}{1544 - 1.44 \times 30}$$

$$P_v = .0334468 \text{ bar}$$

∵ Dew point temperature is saturation temperature corresponding to the partial pressure of water vapour

($P_v$): From steam table, corresponding

$$P_v = 0.033 \text{ bar}$$

$$t_{dp} = 25°C$$

**(b) Relative Humidity :** From steam table, we find the pressure corresponding to temperature 44°C.

$$P_s = 0.0911 \text{ bar}$$

Relative humidity $\phi = \frac{P_v}{P_s} = \frac{.0334468}{0.0911}$

$$= .367$$

$$\phi = 36.7\%$$

**(c) Specific Humidity :**

$$W = \frac{0.622 P_v}{P_b - P_v} = \frac{0.622 \times .0334468}{1.013 - 0.0334468}$$

$$= 0.0212 \text{ kg / kg of dry air}$$

$$= 21.2 \text{ g/kg of dry air}$$

**(d) Degree of Saturation :**

Specific humidity of saturated air

$$W_s = \frac{0.622 P_s}{P_b - P_s} = \frac{0.622 \times .0911}{1.013 - 0.0911}$$

$$= .06146 \text{ kJ / kg of air}$$

Degree of saturation $= \frac{W}{W_s} = \frac{.0212}{.06146}$

$$\mu = .3449$$

$$\mu = 34.49\%$$

**(e) Vapour Density :**

$$\rho_v = \frac{W(P_b - P_v)}{R_a T_d} = \frac{.0212(1.013 - .0334468).10^5}{287(273 + 44)}$$

$$= .02287 \text{ kg / m}^3 \text{ dry air.}$$

**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 $m^3$/person/min

***Desirable temperature rise in theatre***

= 8°C

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

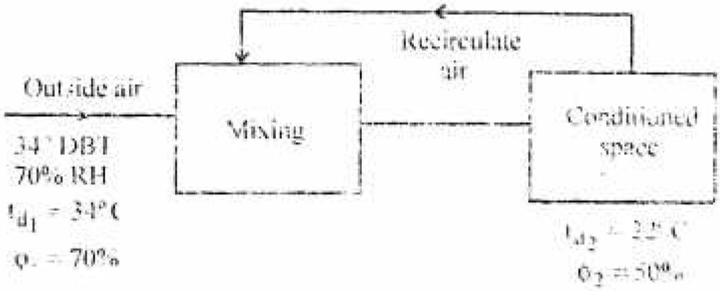
**Compute the following :**

***(a) % of total air circulated***

**(b) Refrigeration capacity of conditioner coil**

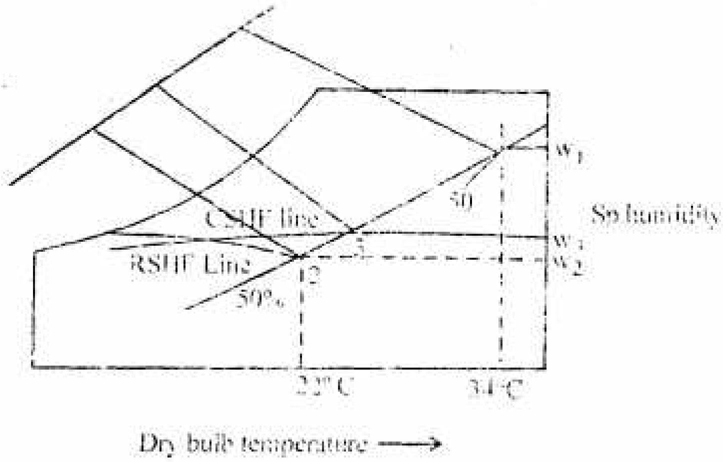
**Assume the air leaves the conditioner with 100% RH.**

**Ans.**




**Room Sensible Heat Factor :**

$$RSHF = \frac{RSH}{RSH + RLH} = \frac{22}{22 + 5} = 0.8148$$

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**Supply Air Flow Rate :** $0.4\,m^3$ / Person / min

$$= 0.4 \times 350 = 140\,m^3 / \text{min}$$

$$RSH = 0.02044\,v\left(t_{d_2} - t_{d_4}\right)$$

$$\frac{320}{60} = 0.02044 \times 140\left(22 - t_{d_4}\right)$$

$$\boxed{t_{d_4} = 18.85^\circ}$$

**Q. 7. Explain the following with neat diagram :**

**(a) Water cooled condensers**

**(b) Solenoid control valve**

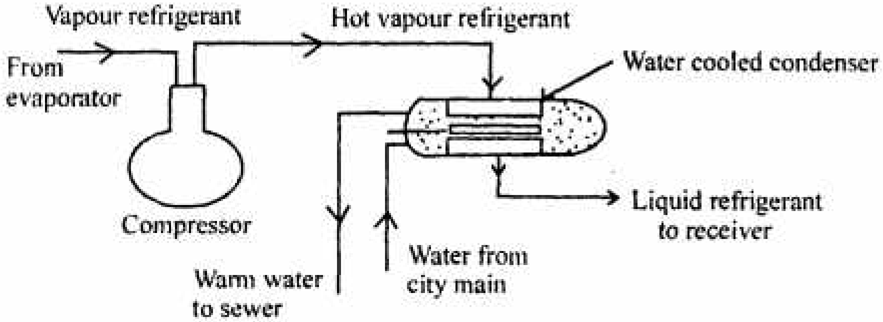
**(c) Cooling and dehumidifying coils.**

**Ans. (a) Water Cooled Condensers :** A water cooled condenser in which water is used as condensing medium.

Water cooled condenser may use either of following two water system.

(i) Waste water system (ii) Recirculated water system :

**(i) Waste Water System :**




In this system the water after circulating in the condenser is discharged to a sender as shown in fig.

This system used on small unit & in location where large quantities of fresh inexpensive water & sewer system large enough to handle the waste water are available.

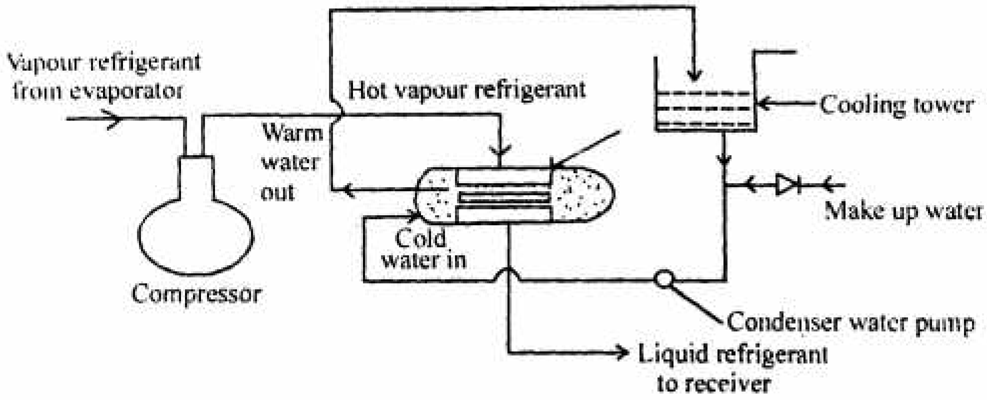
**(ii) Recirculated Water System :**

(i) The same water circulating in condenser is cooled & used again & again.

(ii) It requires some type of cooling device such as cooling water tower & spray ponds.

(iii) The warm water from condenser is to led to the where it is cooled by self evaporation into a stream of air.

(iv) The water pump are used to circulate the water through the system & then to cooling tower which is usually located on roof.




(v) The make-up water simply replaces the water that evaporates from the cooling tower or spray pond.

**(b) Solenoid Control Valve :** A solenoidal valve is an electromagnetic valve for use with liquid or gas. The valve is controlled by an electrical current through a solenoidal coil.

The solenoid valve may have 2 or more parts in the case of 2 port valves the flow is switched on or off. Multiple soienoidal valve can be placed together manifold.

**Working Principle :** It has 2 main parts :

(i) Solenoid

(ii) Valve

Solenoid converts electrical energy into mechanical energy which in turn. open & close the valve mechanically.

**(c) Cooling and Dehumidifying Coils :**

(i) The cooling system utilize 2 stage condensing unit connected with refrigerant piping to two face split cooling coil in an air handling outdoor unit for mixed air preparation.

(ii) At low loads of required refrigeration & at temperature below 50°F at the dehumidification stage the coil are freezing & the ice are closing 2/3 of air pass through the surface, causing a general malfunction of whole system. The low load control of the DX coil system seems to it through the compressor unloading & not by pass.

**Q. 8. Write short notes on :**

**(a) Necessity of air craft refrigeration**

**(b) Effects of operating conditions on COP of VCRS**

**(c) Necessity of compound compression**

**(d) Psychometric Processes**

**Ans. (a) Necessity of Air Craft Refrigeration :**

The advent of high speed passenger air craft, jet aircraft & missiles has introduced the need for compact & simple refrigeration system, capable of high capacity with minimum reduction of pay-load.

When the power requirement, needed to transport the additional weight of refrigerating system are taken into account, the air cycle system usually prove to be efficient.

**(b) Effects of Operating Conditions on COP of VCRS.**

**(i) Effect of Suction Pressure :**

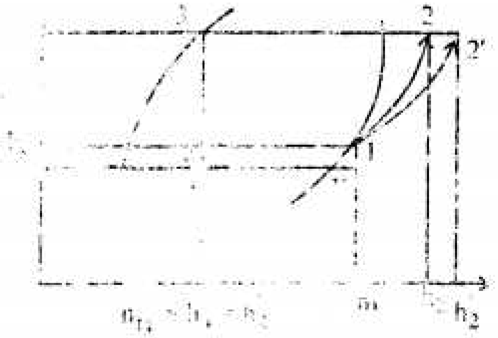
Suction pressure decreases due to the frictional resistance of flow of refrigerant let us consider a theoretical vapour compression cycle 1'–2'–3–4' when suction pressure decreases from $P_s$ to $P_s'$ as shown in p-h diagram. It may be noted that

Decrease in suction pressure

(i) Decreases the refrigerating effect from $(h_1 - h_4)$ to $h_1' - h_4'$.

(ii) Increases the work required for compression from $(h_2 - h_1)$ to $(h_2' - h_1')$.

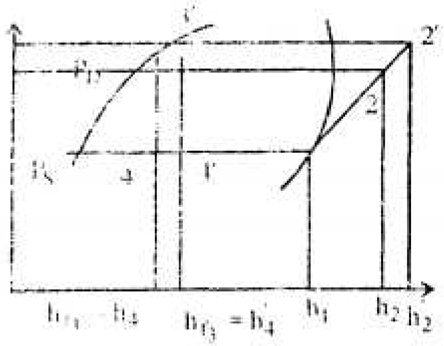
(iii) Decrease in suction pressure, net effect is to decreases the C.O.P. of refrigerating system for same amount of refrigeration.




Refrigeration capacity of system decreases & the refrigeration cost increases.

**(ii) Effect of Discharge Pressure :** The discharge pressure increases due to frictional resistance of flow of refrigerant

Let us consider a theoretical vapour compression cycle 1–2'–3'–4' when discharge pressure increases from $P_D$ to $P_D'$. It may be noted that increases in discharge pressure,




(i) Decrease the refrigerating effect from $(h_1 - h_4)$ to $(h_1 - h_4')$ &.

(ii) Increase the work required for compression $(h_2 - h_1)$ & to $(h_2' - h_1)$.

**(c) Necessity of Compound Compression :**

(i) In simple vapour compression refrigeration system in which low pressure vapour refrigerant from evaporator is compressed in single stage & then delivered to a condenser at high pressure.

(ii) But sometime, the vapour refrigerant is required to be delivered at a very high pressure as in case of low temperature refrigerating system.

(iii) In such cases either we should compress the vapour refrigerant by employing a single stage compressor with a very high pressure ratio between the condenser & evaporator or compressor it in two or compressed placed in series.

(iv) This compression carried out in two or more compressor called compound or multistage compressors

**Advantages of Compound Compression :**

(i) Workdone per kg of refrigerant is reduced in compound compression.

(ii) Improves the volumetric $\eta$ for given pressure ratio

(iii) Reduces the leakage loss considerably.

(iv) Gives more uniform torque so small size of flywheel needed.

(v) Provides effective lubrication because of lower temperature range.

(vi) Reduces the cost of compressor.

**(d) Psychometric Processes :** Various Psychometric Process :

(i) Suitable heating

(ii) Sensible cooling

(iii) Humidification & dehumidification

(iv) Cooling & adiabatic humidification

(v) Cooling & humidification by water injection

(vi) Heating & humidification

(vii) Humidification by steam injection

(viii) Adiabatic chemical dehumidification

(ix) Adiabatic mixing of air stream.