G1064 Pages 14

APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY

Scheme for Valuation/Answer Key

Scheme of evaluation (marks in brackets) and answers of problems/key

SEVENTH SEMESTER B.TECH DEGREE EXAMINATION (S), MAY 2019

Course Code: ME405

Course Name: REFRIGERATION AND AIR CONDITIONING

Max. Marks: 100 Duration: 3 Hours

(Note: For problems, proportionate marks shall be awarded for correct steps.)

PART A

Answer any three full questions, each carries 10 marks. Marks

1 a) **COP definition (2 Marks), Tonnes of Refrigeration definition (2 Marks)** (4)

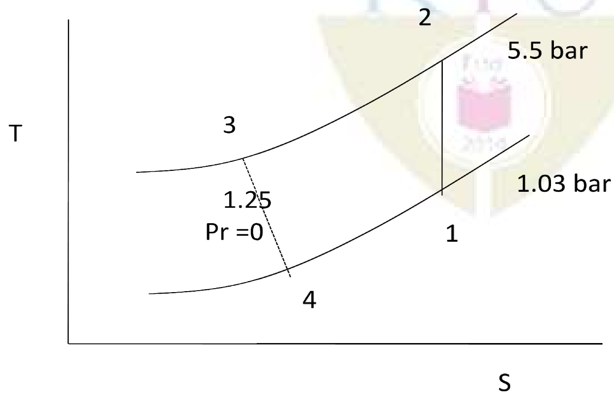
COP is the ratio of refrigeration effect and total work

COP = RE/ W_{net}

Tonnes of a refrigeration is defined as the quantity of heat required to be removed to produce one ton (907 kg) of ice within 24 hrs when the initial condition of water is 0^oC.

1 ton = 907 x 335 / 24 x 3600 = 3.5 kW

b) Figure (1 Mark), Work done /kg of air flow (2 Marks), Refrigerating effect (2 Marks), COP (1 Mark) (6)



P_1 = 1.03 bar = P_4

$T_1 = 12^oC = 285K$

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

$$\frac{T_2}{285} = \left(\frac{5.5}{1.03}\right)^{\frac{0.4}{1.4}}$$

T_2=> 459.95K

$T_3=23^oC$ (given) = 295K

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{n-1}{n}} => \left(\frac{5.5}{1.03}\right)^{\frac{0.25}{1.25}}$$

T_4=211.02K

$W_E = \frac{n}{n-1} R(T_3 - T_4)$ =120.51kJ/Kg

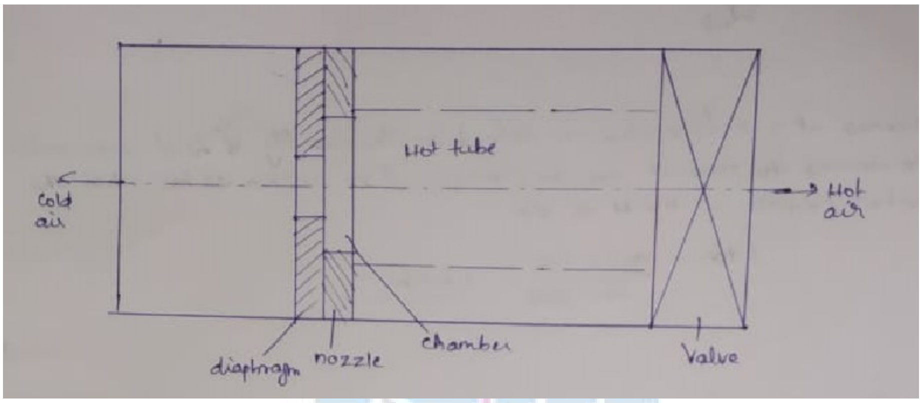
$W_C = \frac{r}{r-1} R(T_2 - T_1)$ = 175.74 kJ/Kg

(i) W_{net} = 175.74 – 120.51 = 55.23kJ/Kg

(ii) RE = C_p (T_1-T_4) = 1.007 (285 – 211.02) = 74.498

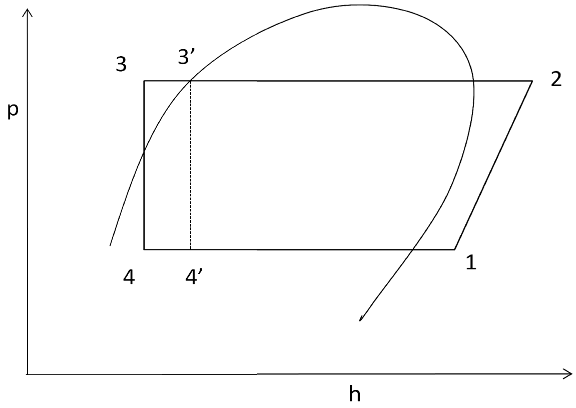
(iii) COP = RE/W_{net} = 74.498/55.23 = 1.348

2 a) **Diagram (1 Mark) Explanation (3 Marks)** (4)



- Compressed air is passed through the nozzle as shown in figure. Here air expands and acquires high velocity due to particular shape of the nozzle.
- A vortex flow is created in the chamber and air travels in spiral like motion along the periphery of the hot side. This flow is restricted by the valve. When the pressure of the air near valve is made more than outside by partly closing the valve, a reversed axial flow through the core of the hot side starts from high pressure to low pressure region. During this process, heat transfer takes place between reversed stream and forward stream.
- Therefore, in air stream through the core gets cooled below the inlet temperature of the air in the vortex tube, while air stream in forward direction gets heated up. The cold stream is escaped through the diaphragm hot in the cold side, while hot stream is passed through opening of the valve. By controlling the opening of the valve, the quality of cold air and its temperature can be varied.

b) **Figure (1 Mark), Solution (5 Marks)** (6)



From Chart of R12

$h_1' = 180\ kJ/kg$

$h_1 = h_1' + C_p(T_1 - T_1') = 180 + 0.983\ (5) = 184.915$ kJ/kg

h_2'=197 kJ/kg

$h_2 = h_2' + C_p(T_2 - T_2')$

$S_1 = S_2 = S_1' + C_p \ln\left(\frac{T_1}{T_1'}\right)$

$= 0.71 + 0.983 \ \ln\left(-\right) = 0.73$

$S_2 = S_2' + C_p \ln\left(\frac{T_1}{T_1'}\right)$

$= 0.68 + 0.983 \ \ln\left(\frac{T_2}{298}\right) = 0.73$

⇨ $T_2 = 313.54$K

$h_2 = h_2' + C_p(T_2 - T_2') = 212$kJ/kg

$h_3' = 59.7\ kJ/kg$

$h_3' = h_3 + C_p(T_3' - T_3)$

$=> h_3 = h_3' = h_3 + C_p(T_3' - T_3) = 59.7 - 0.983\ (4) = 55.768$ kJ/kg = h_4

RE = $h_1 - h_4$ = 184.915 – 55.768 = 129.147 kJ/kg

(i) COP =RE/W_{net} = 4.768

Tonnage = m x RE / 3.5 => m = 0.54 kg/s

Let η_v = volumetric efficiency = 1

$V_f = 0.1596\ m^3/kg$

Actual Volume = Swept volume

⇨ $\frac{m \times V_f}{N} = \frac{\pi}{4} d^2 l$, given d = 1

$$\Rightarrow \frac{0.54 \times 0.1596}{1000} = \frac{\pi}{4} \times d^3 \times 6$$

d = 0.026m = 26mm

(ii) m x v = 0.54 x 0.1596 x 60 = 5.17m^3/min

(iii) d = l = 26mm

3 a) **Figure (1 Mark)** (4)

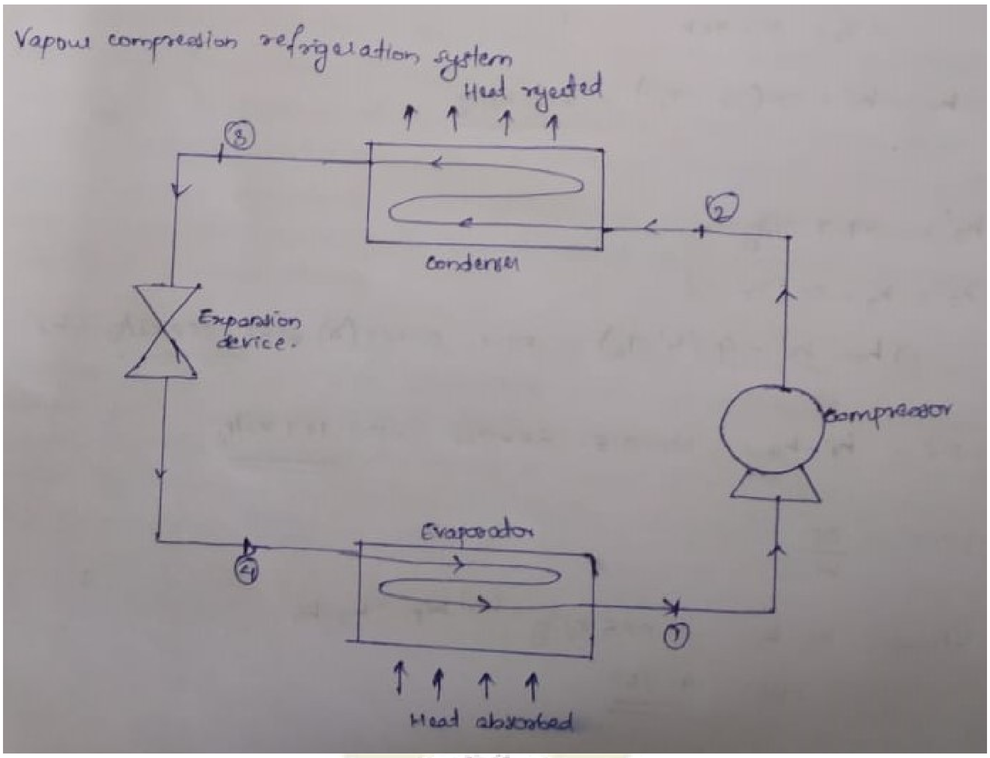
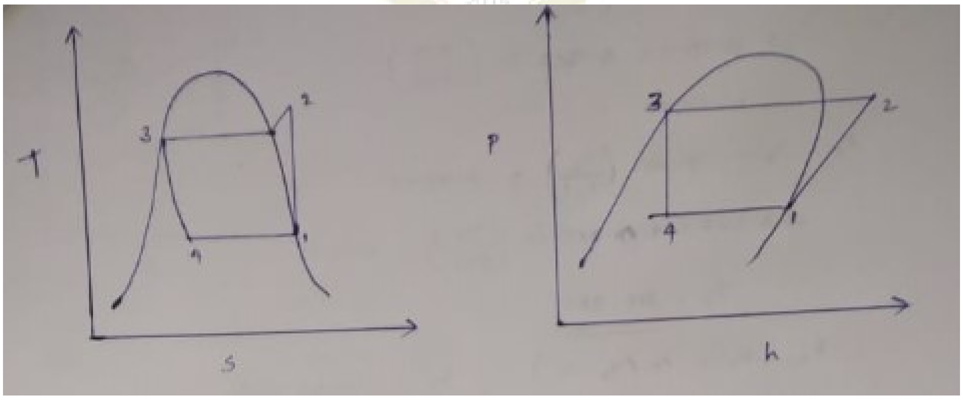


Figure (1 Mark)



Working (4 Marks)

<u>Process 1 – 2</u> Isentropic Compression

The refrigerant leaving the evaporator enters the compressor, where it is compressed isentropically to higher pressure and temperature

<u>Process 2 – 3</u> Constant pressure heat rejection

The high pressure high temperature refrigerant then enters a condenser where it is condensed to lower pressure and temperature.

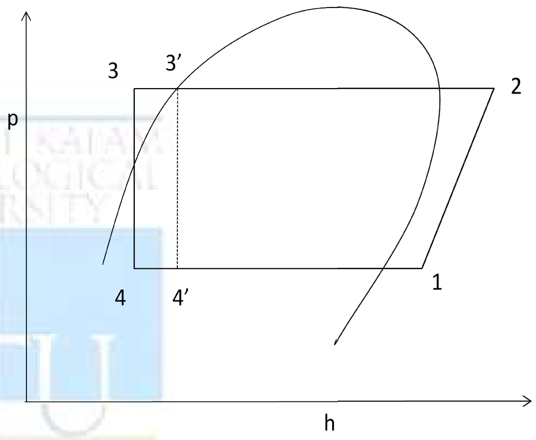
Process 3 - 4 Isenthalpic expansion

The high pressure refrigerant is then expanded isenthalpically in an expansion device to lower pressure and temperature.

Process 4 – 1 Constant pressure heat absorption

The low temperature refrigerant is then passed through evaporator coils where H absorbs latent heat from space to be cooled. The refrigerant get back to the initial temperature and the cycle repeats.

b) **Figure (1 Mark), Solution (5 Marks)** (6)



RE = 2400kJ/min = 40kW

From chart of R 12

$h_1' = 183.19 kJ/kg$

$h_1 = h_1' + C_p(T_1 - T_1') = h_1' + C_p \times 7$ => 190.071kJ/kg

$S_1 = S_2 = S_1' + C_p \ln\left(\frac{T_1}{T_1'}\right) = 0.7277$

$S_2 = S_2' + C_p \ln\left(\frac{T_2}{T_2'}\right)$ => 0.7277

⇨ $0.6853 + 0.983 \ln\left(\frac{T_1}{303}\right) = 0.7277$

$T_2 = 316.35K$

$h_2 = h_2' + C_p(T_2 - T_2')$, $h_2' = 197.62\ kJ/kg$

$h_2 = 212.74kJ/kg$

$h_3' = 64.59 kJ/kg$

$h_3 = h_3' + C_p(T_3' - T_3)$ => 64.59 – 0.983 (6)

$h_3 = 58.692kJ/kg = h_4$

$RE = m(h_1 - h_4)$

(i) m = 0.304 kg/s = 0.304 x 60 = 18.267 kg/min

(ii) Heat removed by condenser = m $(h_2 – h_3)$ = 46.83kg/s

Let volumetric efficiency = 1

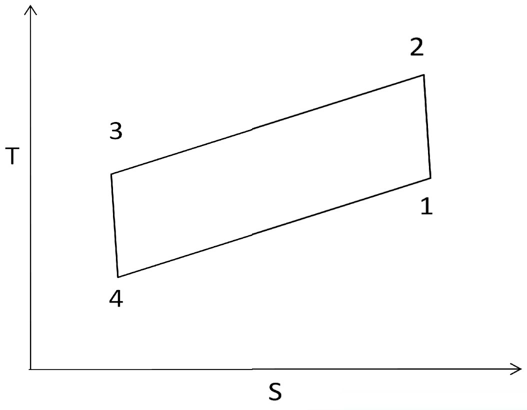
Swept volume = Actual volume

$2 \times \frac{\pi}{4} \times d^2 \times 1.25\, d = \frac{m \times V}{N}$

l = 1.25d

d = 0.021m => 21mm, l = 26.3mm

4 a) **Derivation (4 Marks)** (4)



COP = RE/ WD => $\frac{C_P(T_1-T_4)}{C_p(T_2-T_{3)}-C_p(T_1-T_4)}$

⇨ $\frac{T_4(\frac{T_1}{T_4}-1)}{T_3\left(\frac{T_2}{T_3}-1\right)-T_4\left(\frac{T_1}{T_4}-1\right)}$

⇨ $T_4/(T_3-T_4)$

⇨ $1/(T_2/T_4-1)$

⇨ $\frac{1}{\frac{T_2}{T_4}-1}$

⇨ $\frac{1}{\left(\frac{P_3}{P_4}\right)^{\frac{r-1}{r}}-1}$

⇨ $\frac{1}{(r_p)^{\frac{r-1}{r}}-1}$, where r_p is the pressure ratio

b) **Figure (1 Mark) , Solution (5 Marks)**

$P_1 = 0.6$ bar

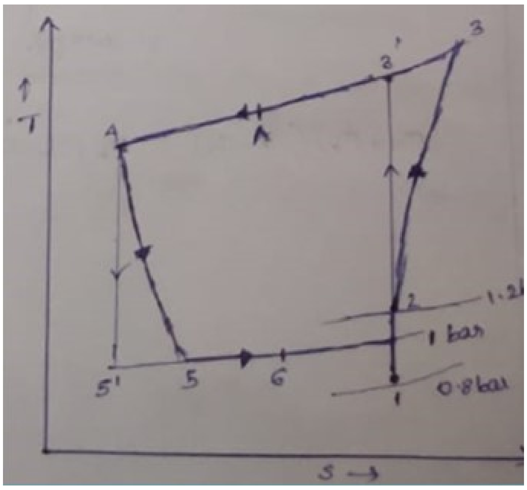
$T_1 = 10^oC = 288K$

$P_2 = 1.2$ bar

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

$=> \frac{T_2}{288} = \left(\frac{1.2}{0.8}\right)^{\frac{0.4}{1.4}}$

$=> T_2 = 317.76K$



$$\eta_c = \frac{T_3' - T_2}{T_3 - T_2} = 0.9$$

$$\frac{T_3'}{T_2} = \left(\frac{P_3'}{P_2}\right)^{\frac{r-1}{r}}$$

$$=> \frac{T_3'}{317.76} = \left(\frac{4.5}{1.2}\right)^{\frac{0.4}{1.4}}$$

$T_3' = 463.56K$

$$\frac{463.56 - 317.76}{T_3 - 317.76} = 0.9$$

$T_3 = 479.76K$

Effectiveness $=> \frac{T_3 - T_A}{T_3 - T_2} = 0.6$

$$=> \frac{479.76 - T_A}{479.76 - 317.76} = 0.6$$

$T_A = 382.56K$

$T_4 = 60^oC = 333K$

$$\frac{T_4}{T_5'} = \left(\frac{P_4}{P_5'}\right)^{\frac{r-1}{r}} => \frac{333}{T_5'} = \left(\frac{4.5}{1}\right)^{\frac{r-1}{r}}$$

$T_5' = 216.68K$

$$\eta_t = \frac{T_4 - T_5}{T_4 - T_5'} = 0.8$$

$$=> \frac{333 - T_5}{333 - 216.68} = 0.8$$

$T_5 = 239.94K$

$T_6 = 25^oC = 298K$

$m_a C_p (T_6 - T_5) = 20 \times 3.5 = 70kW$

$$m_a = \frac{70 \times 1000}{1008\ (298\qquad .94)}$$

$= 1.19kg/s$

$(m_a + m_b)(T_A - T_4) = m_b (T_c - T_A)$

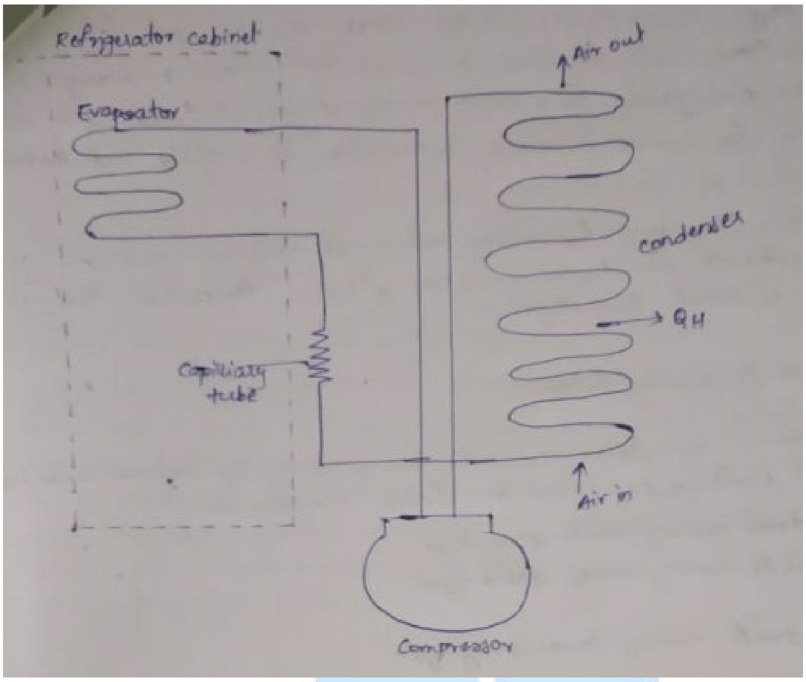
PART B

Answer any three full questions, each carries 10 marks.

5 Diagram (2 Marks), COP (3 Marks), Power (3 Marks), Fluid flow (2 Marks) (10)

6 Ph Chart (2 Marks), block diagram (2 marks), Explanation (6 Marks) (10)

7 a) **Diagram (2 Marks), Explanation (4 Marks)** (6)



Explanation

The function of the compressor is to raise the pressure of gaseous refrigerant coming from the evaporator. By raising the pressure, the boiling point of refrigerant increases. The high pressure and temperature refrigerant while passing through the condenser charges the pahse and condenser in high pressure and temperature is liquid refrigerant.

The room air is at lower temperature than the refrigerant passing through the condenser, hence condensation takes place and vapour refrigerant converted to liquid refrigerant. Now, refrigerant which is at high pressure and temperature passes through the capillary tube, due to throttling effect, temperature and pressure of refrigerant decrease. Majority of cooling is produced at this point in a refrigerator.

This low temperature low pressure refrigerant now passes through the evaporator where refrigerant in liquid phase takes heat from foods and stuff.

This low pressure vapour refrigerant again circulated to compressor and cycle continuously as long as the compressor is in running condition.

b) **Explanation (4 Marks)** (4)

Deep freezing - it is used for storing items which are perishable like raw food items, fruits, ice creams, and industrial items requiring up to -18 degrees centigrade for a longer period of time but not later than as specified for a product in order to maintain its quality and flavour.

Cold storage – it is used for cooling house hold items or medicines that are not perishable for shorter duration of time. Temperature that is maintained is about 3 – 8 degrees.

8 **Figure (3 Marks), Explanation (7 Marks)** (10)

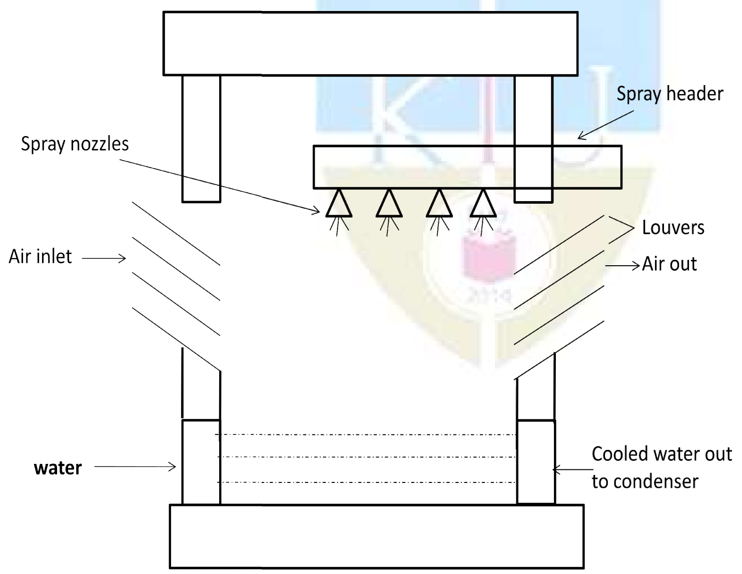
Natural draft cooling towers.

In this air is circulated inside this cooling tower by natural correction. The natural draft cooling tower are further classified as

(i) Natural draft cooling tower spray type

(ii) Natural draft cooling tower splash type

Natural draft cooling tower spray type



The entire system is housed inside a box shaped structure which also accommodates spray headers, spray nozzles and louvers. The louvers are placed on the sides to enhance natural circulation of air inside the cooling tower. To prevent the carryover of water droplets to the atmosphere the louvers are slanted towards the inside.

The warm water from the condenser is fed to the spray header by means of a pump. The spray header is located on top. The spray nozzles spray with the warm water inside the tower. The air from the atmosphere comes in contact with the warm water, thereby causing some water droplets to evaporate. The evaporating water also absorbs some amount of heat from surrounding water which causes the remaining water to cool. A makeup line which may be controlled by a simple float, may be used to make up the loss of water due to evaporation. The cooled water may be then taken back to the condenser.

Natural draft cooling tower splash type.

This type is similar to that of spray type instead of a spray header a water box is used. The water box has small holes at the bottom. It also contains decking inside the tower. The hot water from the condenser enters the water box and splashes via holes in the water box on the decking. The main objective of the decking is to increase the surface area of contact of air with warm the water. This type is 20 -030% more effective than the spray type.

PART C

Answer any four full questions, each carries 10 marks.

9 a) (6)

Case - 1

DBT = 25°C, $\phi = 70\%$ from tables $P_{v,s} = 0.031$

$\phi = \frac{P_v}{P_{v,s}} \Rightarrow P_v = 0.022183$ bar

$P_t - P_v = P_a \Rightarrow 1.03125 - 0.022183 = 0.9778$ bar

$W_1 = 0.622 \frac{p_v}{p_a} = 0.01411$ kg/kg da

When air is compressed $P_t = 2$ bar

then $p_{v_2} = 2 p_{v_1} = 0.044$ bar and $p_{v_2} > p_{v,s}$

∴ condensation takes place.

$$\therefore W_2 = 0.622 \frac{p_{v,s}}{(P - p_{v,s})} = \frac{0.622 \times 0.03169}{(2 - 0.03169)}$$

$= 0.01$ kg/kg da

∴ Condensation is $W_1 - W_2 = 0.0041$ kg

b) **Definition (1 Mark each)** (4)

a) DPT – Dew Point Temperature – it is the temperature of air recorded by thermometer when the moisture present in it begins to condense.

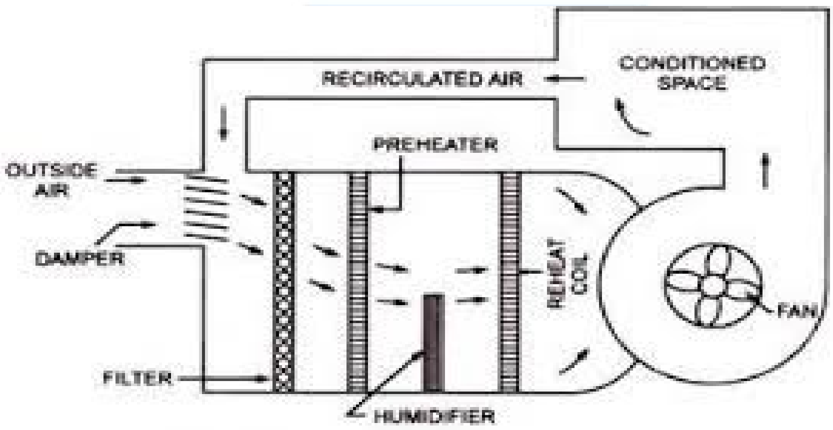
b) RH – Relative humidity – it is the ratio of actual mass of water vapour in a given volume of moist air to the mass of water vapour in same volume of saturated air $\phi = P_v/P_s$

c) WBT – wet bulb temperature – it is the temperature of air recorded by a thermometer, when its bulb is surrounded by wet cloth exposed to air

d) SHF – Ratio of Sensible heat to the Total heat SH/(SH + LH) = SH/TH

10 a) **Figure (2 Marks), Explanation (4 Marks)** (6)

Winter air conditioning system



The outside air flows through a damper and mixes up with the re-circulated air. The mixed air passes through a filter to remove dirt, dust and other impurities. The air now passes through a preheat coil inorder to prevent the possible freezing of water and to control the evaporation of water and humidifies. After that, the air is made to pass through a reheat coil to bring the air to he designed dry bulb temperature. Now, the conditioned air is supplied to the conditioned space by a fan. From the conditioned space, a part of used air is exhausted to the atmosphere by exhaust fan or ventilators. The remaining part of used air is again conditioned.

b) **Derivation 4 Marks** (4)

11 a) **Explanation 5 Marks** (5)

This method of sizing used for supply, exhaust and return air duct system and employs the same friction lose per foot of length for the entire system.

The equal friction method is superior to velocity reduction method since it requires less balancing for symmetrical layouts.

If a design has a mixture of short and long runs, the shortest run requires considerable damping.

Such a system is different to balance since equal friction method makes no provision for equalizing pressure drops in branches or for providing the same static pressure behind each air terminal.

The method establishes an equal friction drop for each 100ft of duct throughout duct system.

b) **Definition (5 Marks)** (5)

Packaged air conditioning system

It is one kind of the split air conditioning commonly used in home small office. Packaged air condition has power, wind and strong advantages. Pricing starting point is also relatively high. Usually it is applied to a larger area of the room, whether buy hanging air conditioning or cabinet air conditioning needs to be determined according to the actual needs of the user.

Central air conditioning system

It is a system in which air is cooled at a central location and distributed to and from rooms by one or more fans and duct work. The work of an air conditioner is what makes the whole process of air conditioning possible. The compression of the refrigerant gas enables it to discharge heat out of the house. It also have strong advantages. Starting price is very high.

12 a) $t_{db} = 24^oC$ $P_s = 0.02982bar = 2.982kPa$ (6)

$t_{wb} = 18^oC$ $P_{wb} = 2.062kPa$, $P_b = 101.325kPa$

$P_r = P_{wb} - \frac{(P_b - P_{wb})-(t_{db}-t_{wb})}{1547- \ .44\ t_{db}} = 2.062 - \frac{(101.325-2.062)(24-18)}{1547-1.44\times 24}$

=>1.668kPa

Relative humidity,

$$\emptyset = \frac{P_v}{P_s} = \frac{1.668}{2.982} = 0.559 => 56\%$$

Humidity $\omega = 0.622 \times \frac{P_v}{P_b - P_v} = 0.622 \times \frac{1.668}{101.325-1.668}$

=0.0104 kJ/kg dry air

Enthalpy of dry air $h_a = C_{pa} \times t_d$ = 1.005 x 24 = 24.12 kJ/kg –(4 Marks)

At P_b =80kPa

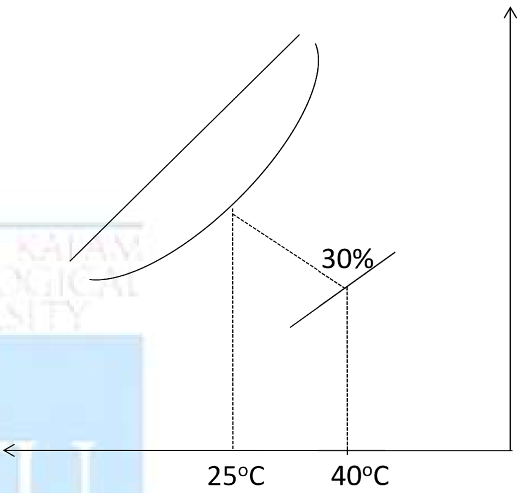
$$\emptyset = \frac{P_v}{P_s} = 56\%$$

$$\omega = 0.622 \times \frac{P_v}{P_b - P_v} = 0.622 \times \frac{1.668}{80 - 1.668}$$

= 0.0132 kJ/kg dry air

Enthalpy $h_o = C_{pa}\, t_d$ = 24.12 kJ/kg ---- (2 Marks)

b) **Figure (1 Mark), Solution (3 Marks)** (4)



$t_1 = 40^oC$

$\eta_{air\ washer} = 0.85$

$\varphi_1 = 30\%$

Air washer is used to cool and humidity at constant enthalpy

$t_{adp} = 25^oC$

$$\eta = \frac{t_1 - t_2}{t_1 - t_{adp}} = 0.85$$

$$\Rightarrow \frac{40 - t_2}{40 - 25} = 0.85$$

$$\Rightarrow t_2 = 27.25^oC$$

From psychometric chart, properties of humid air

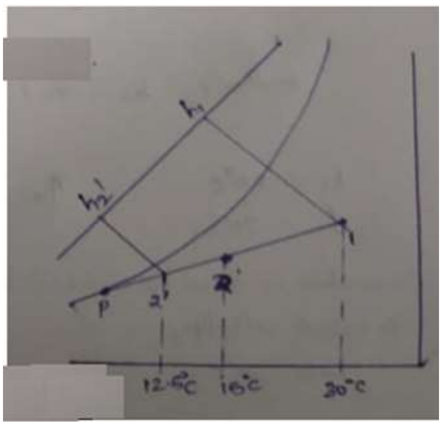
ω = 19.4g/kg dry air

ϕ = 85%

h = 76kJ/kg

$t_{\omega b} = 25^oC$

13 **Figure (2 Marks), Solution (8 Marks)** (10)



from chart,

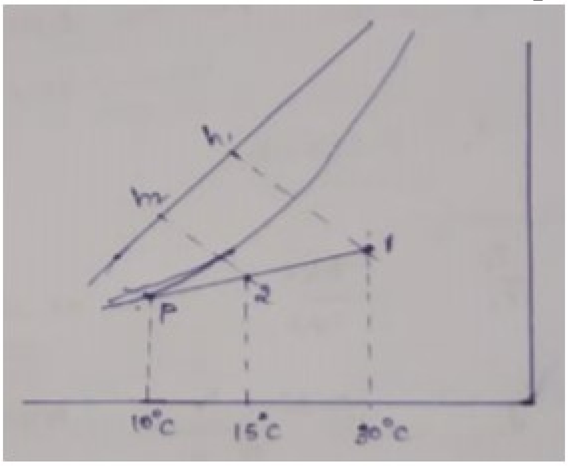
(i) Adp = 10°C (by extending to saturation)

(ii) By pass factor BF => $\frac{t_2 - t_p}{t_1 - t_p}$ = 0.25

(iii) Heat transfer = $m(h_1 - h_2)$ => h_1 = 57.9kJ.kg, h_2 = 37kJ/kg m(h$_1$ – h$_2$) = 20.9kJ/kg

x 2.5 = 52.25kJ

$BF_2 = BF/2 = 0.25/2 = 0.125$



(iv) $\frac{t_2'-t_{adp}}{t_1'-t_{adp}} = 0.125 =>$

$t_2 => 12.5^oC$

$h_1 = 57.9$kJ.kg, $h_2 = 37$kJ/kg

From chart,

$\omega_2' = 8$ g/kg

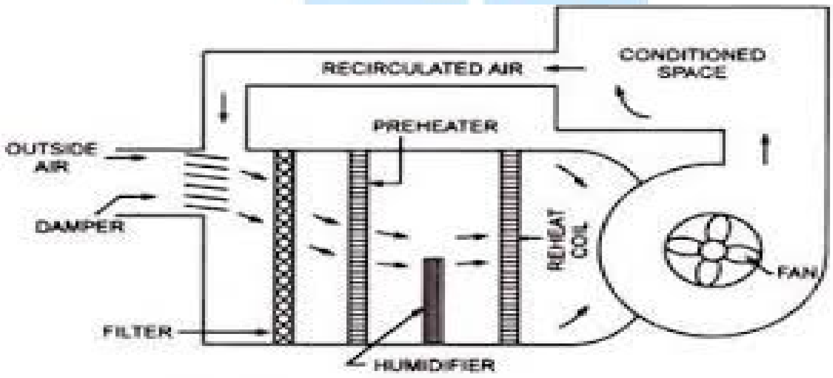
$\phi_2' = 90\%$

$h_2' = 33$kJ/kg

(v) m($h_1 – h_2'$) = 57.9 – 33 =24.9 x 2.5 kJ/kg = 62.25kJ

14 **Figure (4 Marks), Solution (6 Marks)** (10)

Year round air conditioning system



The year round air conditioned systems should have equipment for both the summer and winter air conditioning.

The outside air flows through the damper and mixed up with re-circulated 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 operating the coil at a temperature lower than the dew point temperature.

In winter, the cooling coil is made inoperative and heating coil operates to heat the air. The spray type humidifier is also made use of in the dry season to humidify the air.

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