APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY

Scheme of Valuation/Answer Key

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

SEVENTH SEMESTER B.TECH DEGREE EXAMINATION, DECEMBER 2018

Course Code: ME405

Course Name: REFRIGERATION AND AIR CONDITIONING

Max. Marks: 100 Duration: 3 Hours

(Candidate who solve the problems with P-h chart, can be given full credit)

PART A

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

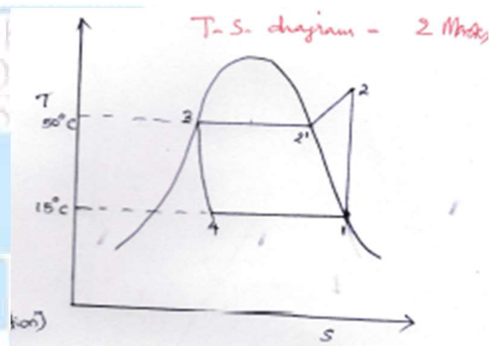
1 a) T-S Diagram – 2 marks, theoretical piston displacement of compressor – 2 marks, Power requirement – 2 marks, COP – 1 mark. (7)

<u>Given</u>

$T_1 = T_4 = 15^oC = 288K$

$T_2' = T_3 = 50^oC = 323K$

m $(h_2 - h_3)$ = 100 MJ/hr = 27.78kW



<u>From tables of R-134a</u>

$S_1 = S_2 = S_{1}g$ = 1.7203 (by interpolation), $h_2' = h_{2}g$ = 428.63kJ/kg

$S_2' = S_{2}g$ = 1.7078 $h_3 = h_{3}f$ = 271.59kJ/kg

$h_1 = h_{1}g$ = 407.155 kJ/kg (by interpolation)

v_1 = 0.042145 m^3/kg (by interpolation)

$S_2 = S_2' + cp_g \ln(T_2/T_2')$

$1.7203 = 1.7078 + 1.218 \ln(T_2/323)$

=> T_2 = <u>326.33K</u>

$h_2 = h_2' + cp_g (T_2 – T_2')$

$h_2' = h_2'g$ = 423.63 kJ/kg

=> h_2 = 423.63 + 1.218 (326.33 – 323)

= <u>427.686kJ/kg</u>

m $(h_2 – h_3)$ = 27.78kW,

m = 27.78/ (427.686 – 271.59) = <u>0.178kg/s</u>

(i) Theoretical piston displacement of compressor = m x v_1

= 0.178 x 0.042145

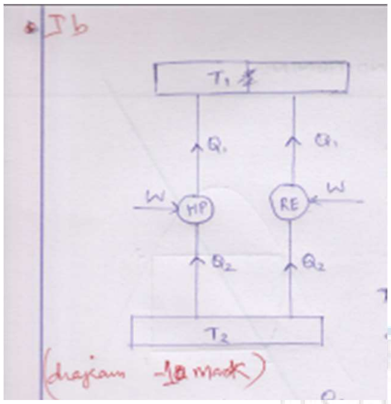
= <u>7.5 x 10^{-3} m^3/s</u> ---(2 marks)

(ii) Power requirement = m ($h_2 - h_1$)

= 0.178 (427.686 – 407.155)

= 3.655kW ---- (2 marks)

(iii) COP = m ($h_2 - h_3$) / m ($h_2 - h_1$) = 27.78 / 3.655 = 7.6 ------ (1 mark)

b) 

(Diagram - 1 Mark, Proof - 2 Marks) (3)

Consider a heat pump and a refrigerator absorbing same amount of heat from low temperature reservoir and getting the same work W and releasing same amount of heat to the high temperature reservoir.

The aim of heat pump is to heat the space.

So released heat = Q_1, absorbed heat = Q_2

$$COP_{HeatPump} = \frac{Q_1}{Q_1 - Q_2} = \frac{Q_1}{W}$$

The aim of refrigerator is to cool a space by absorbing heat from that space.

Heat absorbed = Q_2

Released = Q_1

$$COP_{Refrigerator} = \frac{Q_2}{Q_1 - Q_2} = \frac{Q_2}{W}$$

$$COP_{Refrigerator} + 1 = \frac{Q_2}{Q_1 - Q_2} + 1 \Rightarrow \frac{Q_2 + Q_1 - Q_2}{Q_1 - Q_2} \Rightarrow \frac{Q_1}{Q_1 - Q_2}$$

$$= COP_{HeatPump}$$

LHS = RHS

$$\therefore COP_{HeatPump} = COP_{refrigerator} + 1$$

2 a) (T-S Diagram – 2 marks, Determination of state points – 3 marks, COP = 1 mark, Power required – 1 mark) (7)

Given

$$V = 1000\,km/hr = \frac{1000 \times 5}{18} = 277.78\,m/s$$

Capacity = 100TR = 350 kW

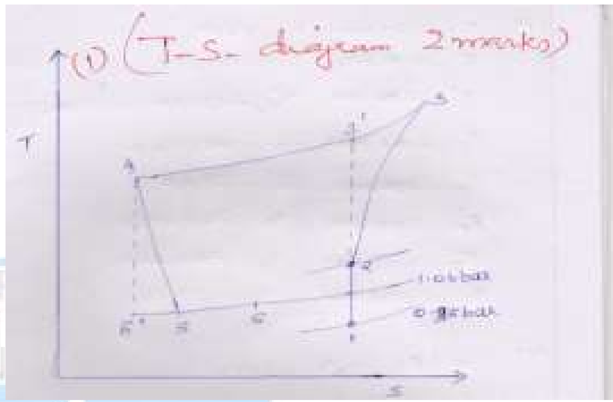
Pressure ratio of compressor $\frac{P_3}{P_2} = 4.5$

$P_1 = 0.35$ bar, $T_1 = -10^oC = 263K$

$\varepsilon_{heatexchanger} = 0.95$, $\eta_c = 0.8$, $\eta_e = 0.8$

$P_6 = 1.06$ bar

$T_6 = 25^oC = 298K$



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

$$= 263 + \frac{(277.78)^2}{2 \times 1005}$$

$$T_2 = \underline{\underline{301.39K}}$$

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

$$\Rightarrow P_2 = P_1 \times \left(\frac{T_2}{T_1}\right)^{\frac{\gamma}{\gamma-1}} = 0.35 \times \left(\frac{301.39}{263}\right)^{\frac{1.4}{0.4}}$$

$$\underline{\underline{P_2 = 0.56 bar}}$$

ii) Determination of state points

$$P_3 = 4.5 \times 0.56 = \underline{\underline{2.54 bar}}$$

$$\frac{T_3'}{T_2} = \left(\frac{P_3'}{P_2}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{2.54}{0.56}\right)^{\frac{0.4}{1.4}} \Rightarrow T_3' = 301.39 \times 1.586 = \underline{\underline{463.19K}}$$

$$\eta_c = \frac{T_3' - T_2}{T_3 - T_2} = 0.8 \Rightarrow T_3 = T_2 + \frac{T_3' - T_2}{0.8} = 301.39 + \frac{463.19 - 301.39}{0.8}$$

$$T_3 = \underline{\underline{503.64K}}$$

$$\varepsilon = \frac{T_3 - T_4}{T_3 - T_2} = 0.95$$

$$T_4 = T_3 - (T_3 - T_2) \times 0.95$$
$$= 503.64 - (503.64 - 301.39) \times 0.95$$
$$T_4 = 311.50K$$

$$\frac{T_4}{T_5'} = \left(\frac{P_4}{P_5'}\right)^{\frac{r-1}{r}} = \left(\frac{2.54}{1.06}\right)^{\frac{0.4}{1.4}} \Rightarrow T_5' = \frac{T_4}{1.284} = 242.673K$$

$$\eta_c = \frac{T_4 - T_5}{T_4 - T_5'} \Rightarrow T_5 = T_4 - (T_4 - T_5') \times 0.8$$
$$= 311.50 - (311.50 - 242.673) \times 0.8$$
$$T_5 = \underline{\underline{256.44K}}$$

(i)

$P_1 = 0.35bar \quad T_1 = 263K$

$P_2 = 0.56bar \quad T_2 = 301.39K$

$P_3' = 2.54bar \quad T_3' = 463.19K$

$P_3 = 2.54bar \quad T_3 = 503.64K$

$P_4 = 2.54bar \quad T_4 = 311.5K$

$P_5' = 1.06bar \quad T_5' = 242.673K$

$P_5 = 1.06bar \quad T_5 = 256.44K$

$P_6 = 1.06bar \quad T_6 = 298K$

(ii)

$$mC_p(T_6 - T_5) = 350kW$$

$$m = \frac{35 \times 10^3}{1005(298 - 256.44)} == \underline{\underline{8.38kg/s}}$$

$$W_c = mC_p(T_3 - T_2)$$
$$= 8.38 \times 1.005(503.64 - 301.39)$$
$$= 1703.3kW$$

$$W_e = mC_p(T_4 - T_5)$$
$$= 8.38 \times 1.005(311.5 - 256.44)$$
$$= 463.7kW$$

$$W_{Total} = 1239.6kW$$

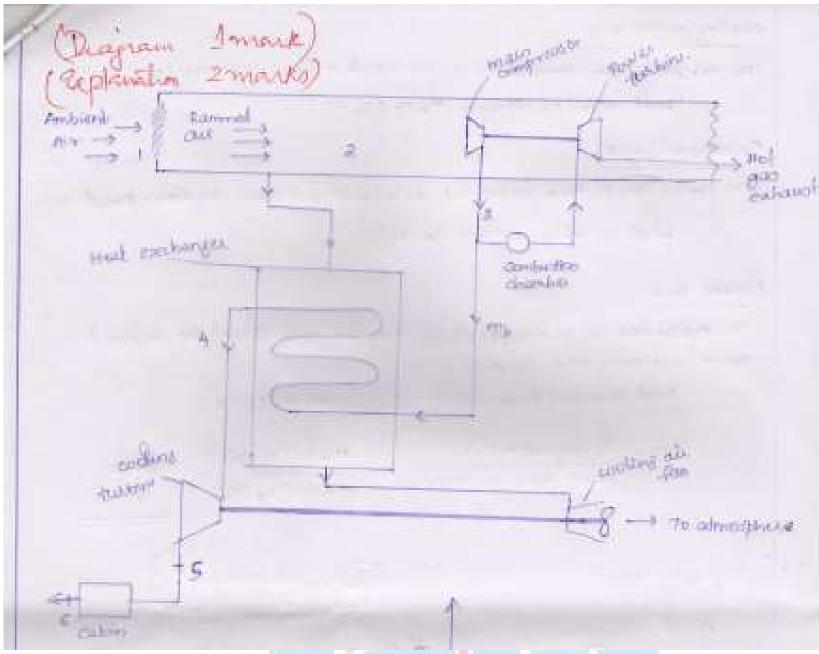
$$COP = \frac{RE}{W} = \frac{350}{1239.6} = 0.282$$

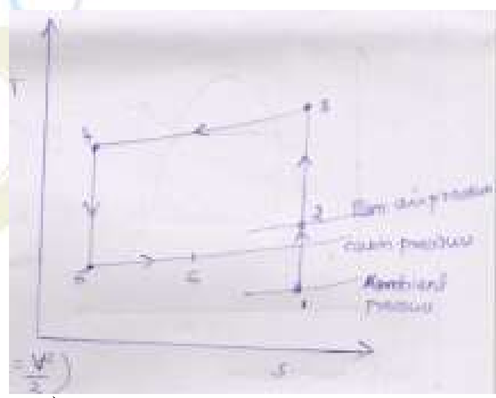
------ (1 Mark)

(iii) Power required = Work done by compressor

$$= mC_p(T_3 - T_2)$$
$$= 1703.3kW$$ ----------(1 Mark)

b) Diagram – 1 mark, Explanation – 2 marks (3)





Process 1-2 (Ramming process)

The ambient air enters the inlet and is slowed down and kinetic energy is converted to pressure energy.

If velocity of air is V, then

$$T_2 = T_1 + \frac{V^2}{2C_p} \text{ (from } h_2 - h_1 = \frac{V^2}{2})$$

Process 2-3 (Compression in main compressor)

The rammed air is then compressed in a compressor to 4 to 5bar. Then a part of this compressed air is bled for refrigeration system and remainder is led to the combustion chamber. The hot combustion products expands in the power turbine, work is utilized to run the compressor.

Work input to the compressor

$W_c = m_b C_p (T_3 - T_2)$

Cooling process 3 – 4

The air bled from compressor is cooled in a heat exchanger

Heat rejected $Q_{rej.} = m_b C_p (T_3 – T_4)$

Expansion 4 – 5

The cooled air is then expanded in a cooling turbine cabin pressure

Work =>$W_{exp} = m_b C_p (T_4 – T_5)$

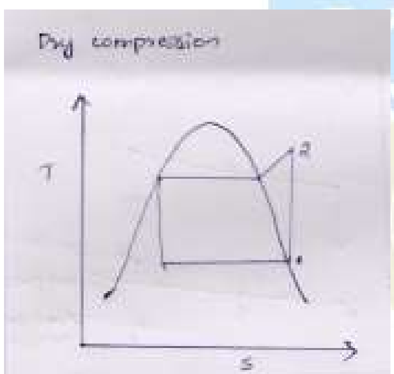
Process 5 – 6

This air is supplied to the cabin where it absorbs heat from the cabin and reaches to state point 6.

Heat absorbed from cabin, $Q_{abs} = m_b C_p (T6 – T5)$

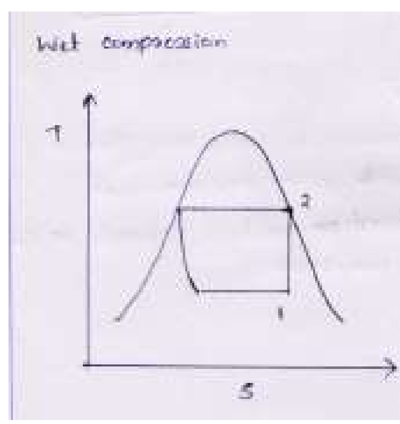
$$COP = \frac{RE}{Work \cdot input \cdot to \cdot compressor} = \frac{m_b C_p (T_6 - T_5)}{m_b C_p (T_3 - T_2)} = \frac{T_6 - T_5}{T_3 - T_2}$$

3 a) T-S Diagram - $1\frac{1}{2}$ *marks* , Explanation - $1\frac{1}{2}$ *marks* (3)



if the vapour is perfectly dry when at the beginning of the compression, the compression is called dry compression. In dry compression, vapour throughout the process lies in the super-heated region.

In wet compression, the vapour is wet or just dry at the end of the compression. The vapour remains wet throughout the compression process.



b) T-S Diagram - 2 marks, Piston displacement – 2 marks, Heat rejected – 2 marks, Carnot COP and Actual COP – 1 mark (7)

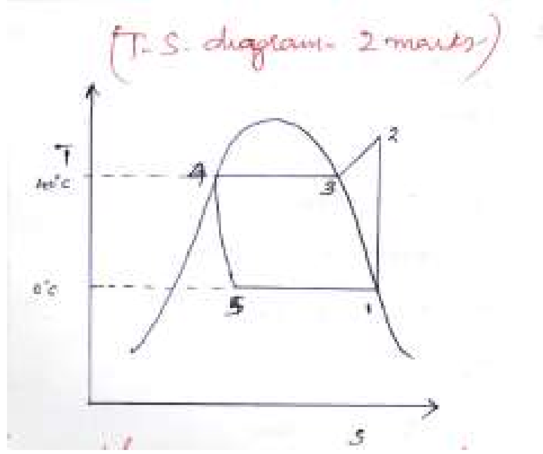
(Candidate who solve the problem with P-h chart, can be given full credit)

Given

$T_1 = T_5 = 0^o C = 273K$

$T_3 = T_4 = 40^0 C = 313K$

$RE = 15TR = 15 \times 3.5 = 52.5kW$



From tables of Freon-12

$S_1 = S_2 = S_{1g} = 0.6965$

$S_3 = S_{3g} = 0.6825$

$S_2 = S_3 + C_p \ln \frac{T_2}{T_3}$

$\Rightarrow 0.6965 = 0.6825 + 1.14 \times \ln \frac{T_2}{313}$

$\Rightarrow T_2 = 316.86K$

$h_3 = h_{3g} = \underline{\underline{203.20kJ/kg}}$

$\Rightarrow h_2 = h_3 + C_p(T_2 - T_3)$

$= 203.2 + 1.14(316.86 - 313)$

$h_2 = \underline{\underline{207.6kJ/kg}}$

$h_5 = h_4 = h_4 f = \underline{\underline{74.59kJ/kg}}, h_1 = h_{1g} = \underline{\underline{187.53kJ/kg}}$

$m(h_1 - h_5) = 52.5$

$m = \frac{52.5}{h_1 - h_5} \Rightarrow \frac{52.5}{187.53 - 74.59} = \underline{\underline{0.465kg/s}}$

$V_1 = V_g = 0.0565m^3/s$

(i) Piston displacement = mv_g=$\underline{0.0258m^3/s}$ -----(2 marks)

(ii) Heat rejected $= m(h_2 - h_4) = 0.465(207.6 - 74.59) = \underline{\underline{61.823kW}}$ -----(2 marks)

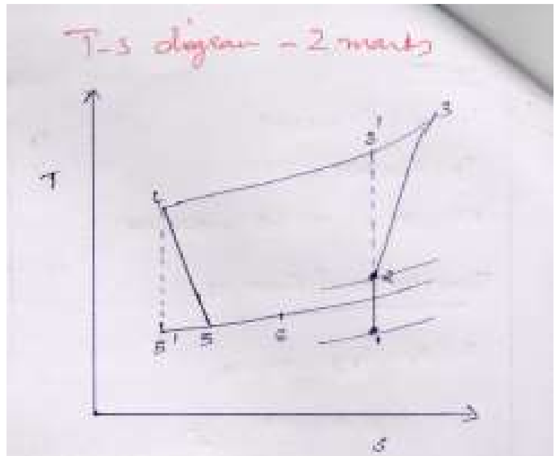
(iii) Actual COP $= \frac{52.5}{m(h_2 - h_1)} = \frac{52.5}{0.465(207.6 - 187.53)} = 5.628$

Carnot COP $= \frac{273}{313 - 273} = 6.825$ --------- (1 mark)

4 T-S Diagram – 2 marks, mass of air calculated per minute – 2 marks, COP – 3 marks (7)

Given

$Capacity = 25 tonnes$
$= 25 \times 3.5$
$= 87.5 KW$
$T_1 = 16^o C = 289K$
$T_2 = 302K, P_2 = 0.96 bar$
$P_3' = P_3 = P_4 = 4.8 bar$
$T_4 = 66^o C = 339K$
$P_5' = P_5 = P_6 = 1 bar$
$T_6 = 26^o C = 299K$
$\eta_c = \eta_t = 0.9$
$c_p = 1.005 kJ/kgK$
$\gamma = 1.4$



$$\frac{T_3'}{T_2} = \left(\frac{P_3'}{P_2}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow \left(\frac{4.8}{0.96}\right)^{\frac{0.4}{1.4}} \Rightarrow T_3' = 302 \times 1.5838$$
$$T_3' = \underline{\underline{478.31K}}$$
$$\eta_c = \frac{T_3' - T_2}{T_3 - T_2} = 0.9 \Rightarrow T_3 = T_2 + \frac{T_3' - T_2}{0.9} = 302 + \frac{478.31 - 302}{0.9}$$
$$T_3 = \underline{\underline{497.9K}}$$

$$\frac{T_4}{T_5'} = \left(\frac{P_4}{P_5'}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow \left(\frac{4.8}{1}\right)^{\frac{0.4}{1.4}} = 1.565 \Rightarrow T_5' = \underline{\underline{216.55K}}$$
$$\eta_t = \frac{T_4 - T_5}{T_4 - T_5'} = 0.9 \Rightarrow T_5 = T_4 - (T_4 - T_5') \times 0.9$$
$$= 339 - (339 - 216.55) \times 0.9$$
$$T_5 = \underline{\underline{228.79K}}$$

(i) $m(h_6 - h_5) = m \times c_p (T_6 - T_5) = 87.5 \Rightarrow m = \frac{87.5}{1.005(299 - 228.79)} = 1.24 kg/s$

------ (2 marks)

(ii)

$W_c = mc_p (T_3 - T_2) = 1.24 \times 1.005 (497.9 - 302) = \underline{\underline{244.13 kw}}$
$W_t = mc_p (T_4 - T_5) = 1.24 \times 1.005 (339 - 228.79) = \underline{\underline{137.34 kw}}$
$W_{total} = W_c - W_t = 106.79$ ------ (3 Marks)
$COP = \frac{RE}{W_{total}} = \frac{87.5}{106.79} = \underline{\underline{0.819}}$

b) Derivation with P-V or T-S diagram – 2 marks, Limitation – 1mark (3)

PART B

Answer any three full questions, each carries 10 marks.

5 Figure of the system – 3 marks (10)

P-h diagram – 2 marks

Explanation - 5 marks

6 Schematic diagram – 2 marks (10)

P-h & T-S diagram – 2 marks

Explanation of the system – 6 marks

7 Diagram of the refrigerator showing temperature gradient inside refrigerator – 4 marks, (10)

Working of domestic refrigerator – 6 marks

8 Flooded evaporator – Labelled sketch – 4 marks (10)

Explanation of working - 4 marks

Any application – 2 marks

PART C

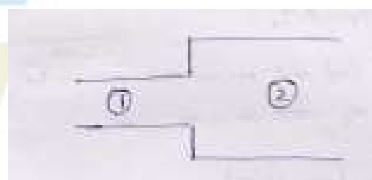
Answer any four full questions, each carries 10 marks.

9 a) Derivation with sketch – 4 marks (4)

b) <u>Given</u> (6)

$V_1 = 12m/s$, $A_2 = 2\ A_1$

To find $P_1 - P_2$



From revised Bernoulli's equation,

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + \frac{P_{loss}}{\rho}; \text{since} (Z_1 = Z_2)$$

$$\frac{P_1 - P_2}{\rho g} = \frac{V_2^2 - V_1^2}{2g} + \frac{P_{loss}}{\rho g}$$

Flow rate remains same (AV = constant) since density is assumed to be constant.

$$A_1 V_1 = A_2 V_2$$
$$A_2 = 2A_1$$
$$\therefore V_2 = \frac{V_1}{2} = 6m/s$$

------ (2 marks)

$$\Rightarrow \frac{P_1 - P_2}{\rho g} = \frac{6^2 - 12^2}{2g} + \frac{P_{loss}}{\rho g}$$

From Borda carnot equation,

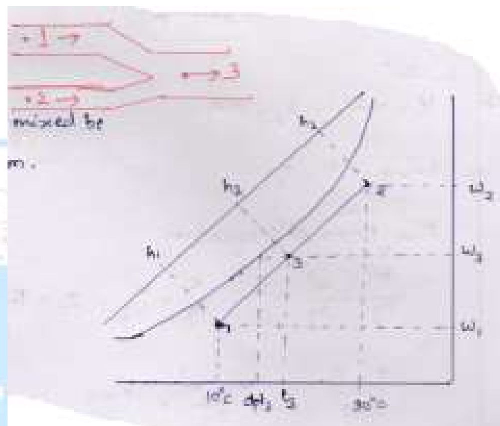
$$P_{loss} = \frac{V_1^2 \rho}{2}\left(1-\frac{A_1}{A_2}\right)^2 = \frac{12^2 \times \rho}{2}\left(1-\frac{1}{2}\right)^2 \Rightarrow \frac{12^2}{8} \times \rho$$

$$\frac{P_1 - P_2}{\rho g} = \frac{36-144}{2g} + \frac{12^2}{8g}$$

$$\frac{P_1 - P_2}{\rho} = -36, P_2 - P_1 = 36 \times 1000 = 36000 Pa$$

Increase in pressure = 36000Pa = 36KPa ----------(4 Marks)

10 a) Representation in schematic and psychrometric chart – 2 marks, Determination of properties- 4 marks. (6)



t_1=10°C, ϕ_1=70%

t_2=30°C, ϕ_2=80%

let mass of first and second air mixed be m_1 and m_2, and m_1=m_2=m

From psychometric chart,

h_1=24kJ/kg, h_2 = 85kJ/kg

w_1=5.5g/kg, w_2 = 21.5g/kg

From formula of energy balance

$m_1h_1 + m_2h_2 = m_3h_3$

$mh_1 + mh_2 = 2mh_3$ ($m_1=m_2=m$, $m_3=m_1+m_2$)

$$\Rightarrow h_3 = \frac{h_1 + h_2}{2} = \frac{24+85}{2} = \frac{109}{2} = 54.5 kJ/kg$$

$m_1w_1 + m_2w_2 = m_3w_3$

$$W_3 = \frac{W_1 + W_2}{2} = \frac{5.5+21.5}{2} = \frac{27}{2} = 13.5 g/kg$$

Mark point 3 with h_3 and w_3

Read all the values corresponding to that point

t_3 = 20.2°C , h_3 = 54.5 kJ/kg

ϕ_3 = 90% , w_3 = 13.5g/kg of dry air

WBT = 19.2°C

DPT = 18.5°C

b) Definition of each term – 1 mark each (CSHF/GSHF can be given credit) (4)

11 Representation of points on psychometric chart – 4 marks, Space relative humidity – 3 marks, Mass flow rate of supply air – 3 marks (10)

<u>Given</u>

Sensible load = 50kw

Latent load = 10kw

Supply condition = 10^{o}C dbt, ϕ =90%

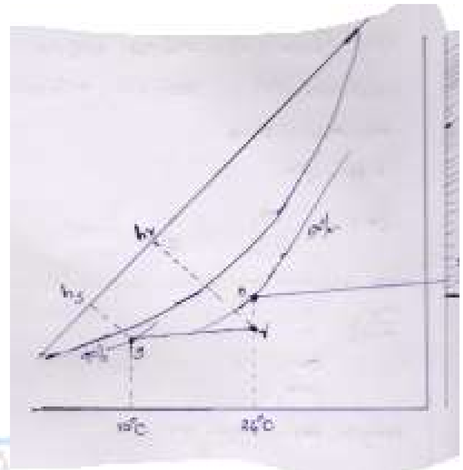
Space condition = 24^{o}C dbt

<u>To find</u>

(i) SHF

(ii) Space relative humidity

(iii) Mass flow rate of supply air



(i) SHF = Sensible load / (Sensible load + Latent load)

= 50/60 = 0.833

Mark SHF and draw SHF line from 24^{o}C dbt, 50% RH (as per ASHRAE chart)

Mark supply condition 10^{o}C dbt, 90% RH (s)

Draw a line parallel to SHF line through (s) to 24^{o}C dbt line that will be room or space condition (r)

Now read different properties of space condition from psychometric chart

h_r = 44kJ/kg, h_s = 28KJ/kg

(ii) Space relative humidity = 42% (from chart) -------- (3 marks)

(iii) Mass flow rate of supply air, m = Total heat / (h_r - h_s)

⇨ (Sensible heat + latent heat)/ (hr - hs)

=(50 + 10) / (44 - 28) => 60/16 = <u>3.75kg/s</u> -------- (3 Marks)

12 Representation of process on psychometric chart – 4 marks, BPF of coil – 1 mark, Supply and outdoor air quantities – 1 mark, CSHF/GSHF – 2 marks, Cooling coil load – 2 marks. (10)

<u>Given</u>

Q_s = 50kW

$Q_L = 5kW$

Space/ room (r) = 24°C dbt, 50% RH

Outdoor (o) = 35°C dbt, 40% RH

$m_0 : m_{rc} = 0.25$

ADP = 8°C

SHF = $Q_s / (Q_s + Q_L) = 50/55 = \underline{0.91}$

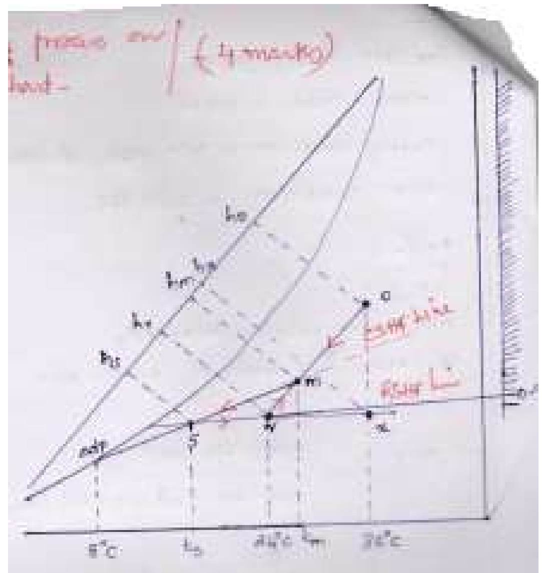
Mark outdoor and room conditions

$m_o/m_{rc} = ¼$

$\therefore\ m_o/m_r = 4$

Length m_r = length OR /5

Mark m in the chart, read the values of m from the chart.



$t_m = 26.2°C$, $h_m = 52kJ/kg$

draw SHF line through 24°C 50% RH (room condition)

mark ADP on saturated line and join m and ADP. This m, ADP and SHF line meet at a point S- Supply condition.

Read the values of S from chart.

$t_s = 19.5°C$, $h_3 = 42.5kJ/kg$

(i) BPF of coil = $(t_s - t_{adp}) / (t_m - t_{adp})$ = (19.5 – 8)/ (26.2 – 8) = $\underline{0.632}$ ---- (1 Mark)

(ii) mass of air supplied = $(Q_s + Q_L) / (h_r - h_s)$

From chart $h_r = 48kJ/kg$, $h_s = 42.5$ kJ/kg

m_s = 55/ (48- 42.5) =$\underline{10\ kg/s}$ = mass of supply air

$m_o + m_{rc} = 10 \Rightarrow 5\ m_o = 10$, $m_o = \underline{2kg/s}$ = mass of outdoor air ----- (1 mark)

(iii) CSHF = $(Q_s + OASH)/(Q_t + OATH)$

OASH = outside air sensible heat

OATH = outside air total heat

$Q_s = 50$ kW, $Q_L = 5kW$

OALH = $m_o (h_o - h_x)$

= 2 (72 – 60) = 24kJ/kg

OASH = $m_o(h_x – h_2)$ $h_2 = 48kJ/kg$

= 2 (60 – 48) = 24kJ/kg

CSHF = $(Q_s + OASH)/ (Q_s + OASH + Q_L + OALH)$

= (50+24)/ (50+24+5+24) =74/103 = $\underline{0.718}$ ------------- (2 marks)

(iv) Cooling coil load = $m_s(h_m - h_s)$

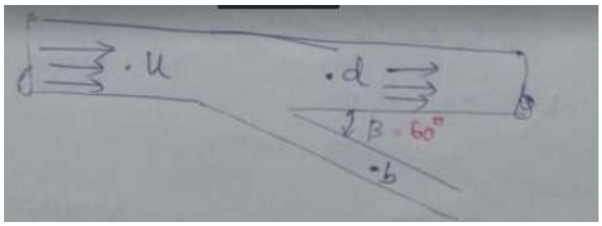
$= 10\ (52 - 42.5) = \underline{95kW}$ ---------- (2 marks)

13 a) Major assignments – 3 marks (3)

b) Flow diagram – 3 marks (3)

c) Major components in the A/C system – 4 marks (4)

14 (10)



$V_u = 10m/s$, $V_d = 6.67m/s$, $V_b = 5.56m/s$

$\rho = 1.225kg/m^3$

(a)

$$P_{loss} = \frac{V_d^2 \rho}{2}(0.4)\left(1 - \frac{V_2}{V_u}\right)^2 Pa$$

$$= \frac{(6.67)^2}{2} \times 1.225 \times 0.4\left(1 - \frac{6.67}{10}\right)^2$$

$$= \underline{\underline{1.2Pa}}$$

------ (2 marks)

Substituting into the revised Bernoulli's equation

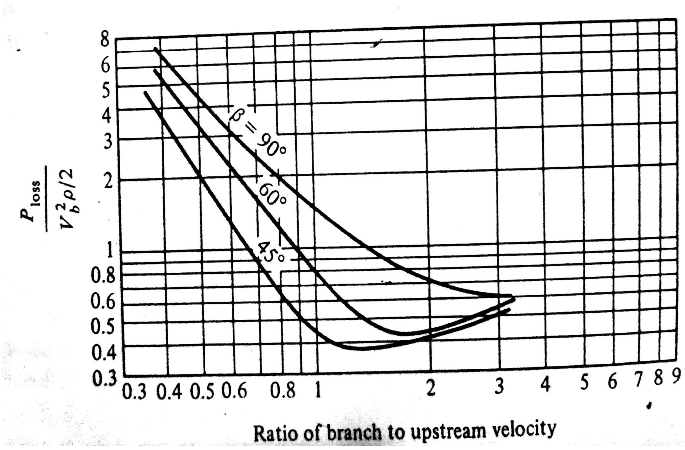
$$P_2 = \rho\left(\frac{P_1}{\rho} + \frac{V_1^2}{2} - \frac{V_2^2}{2} - \frac{P_{loss}}{\rho}\right)$$

$$P_d = 500 + \frac{10^2 \times 1.225}{2} - \frac{6.67^2 \times 1.225}{2} - 1.2$$

$$= \underline{\underline{533Pa}}$$ ---------- (3 marks)

(b) from the graph pressure loss from the upstream position to the branch duct

$\frac{V_b}{V_u} = 0.556$ for a 60° take off



$$\frac{P_{loss}}{\left(V_b^2 \rho/2\right)} = 2.5$$

$$\therefore P_{loss} = \frac{2.5(5.56)^2(1.225)}{2} = \underline{\underline{47.3Pa}}$$

------ (2 marks)

Substituting in revised Bernoulli's equation

$$P_b = 1.225\left(\frac{500}{1.225} + \frac{10^2}{2} - \frac{5.56^2}{2} - \frac{47.3}{1.225}\right) = \underline{\underline{495P_a}}$$ -----(3Marks)

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