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ESE 2020 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

TEST-1

Section-A: Thermodynamics

Section-B: Refrigeration and Air Conditioning

Name : ....

Roll No :

Test Centres | **Student's Signature**

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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. Answer must be written in English only.
3. Use only black/blue pen.
4. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	
Q.2	
Q.3	
Q.4	
Section-B	
Q.5	
Q.6	
Q.7	
Q.8	
Total Marks Obtained	253

Signature of Evaluator: Az

Cross Checked by

Section A : Thermodynamics

Q.1 (a) Which is more effective way to increase the efficiency of a Carnot engine: to increase T_1, keeping T_2 constant; or to decrease T_2, keeping T_1 constant? (Assume $T_1 > T_2$)

[12 marks]

Sol → let T_1 increase by ΔT, and T_2 = const.

η of carnot engine → $1 - \frac{T_2}{T_1}$

$\eta_1 = 1 - \frac{T_2}{T_1 + \Delta T}$ — (1). also $\left(\frac{d\eta}{dT_1}\right)_{T_2 = cons} = \frac{T_2}{T_1^2}$ → (A)

let T_2 decrease by ΔT and T_1 = const.

$\eta_2 = 1 - \frac{(T_2 - \Delta T)}{T_1}$ — (2) also $\left(\frac{d\eta}{dT_2}\right)_{T_1 \, const} = \frac{-1}{T_1} = -\frac{T_1}{T_2^2}$ → (B)

eqⁿ (2) − (1)

$\eta_2 - \eta_1 = -\left(\frac{T_2 - \Delta T}{T_1}\right) + \frac{T_2}{T_1 + \Delta T}$

$= \frac{(T_1 + \Delta T)(\Delta T - T_2) + T_1 T_2}{T_1(T_1 + \Delta T)}$

$= \frac{T_1 \Delta T - T_1 T_2 + \Delta T^2 - T_2 \Delta T + T_1 T_2}{T_1(T_1 + \Delta T)}$

$= \frac{(T_1 - T_2)\Delta T + \Delta T^2}{T_1(T_1 + \Delta T)}$ — (3)

Also $T_1 > T_2$ ⇒ $\left(\frac{d\eta}{dT_2}\right)_{T_1} > \left(\frac{d\eta}{dT_1}\right)_{T_2}$

From eqⁿ (3) $\eta_2 - \eta_1$ = +ve ⇒

It is more effective to ↑ η of Carnot engine by decreasing T_2 rather to increase T_1 by same amount.

12

Section A : Thermodynamics

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$$= \frac{(T_1 + \Delta T)(\Delta T - T_2) + T_1 T_2}{T_1 (T_1 + \Delta T)}$$

$$= \frac{T_1 \Delta T - T_1 T_2 + \Delta T^2 - T_2 \Delta T + T_1 T_2}{T_1 (T_1 + \Delta T)}$$

$$= \frac{(T_1 - T_2)\Delta T + \Delta T^2}{T_1 (T_1 + \Delta T)} \quad -(3)$$

Also $T_1 > T_2$ => $\left(\frac{d\eta}{dT_2}\right)_{T_1} > \left(\frac{d\eta}{dT_1}\right)_{T_2}$

From eq^n (3) $\eta_2 - \eta_1$ = +ve =>

It is more effective to ↑ η of Carnot engine by decreasing T_2 rather to increase T_1 by same amount.

Q.1 (b) Define irreversibility for a process. State and prove Gouy-Stodala theorem for both closed and open system.

[12 marks]

Sol. Irreversibility account for loss in available energy during a process occurring in irreversible nature. It occur due to entropy generation taking place. It is difference between Reversible work and actual work.

Gouy stodala state that Irreversibility is To times entropy generation occuring.

$$W_{rev} = (U_1 - U_2) - T_0(S_1 - S_2) \quad \} \; 1 \rightarrow 2.$$

$$W_{actual} = Q - (U_2 - U_1)$$

$$\text{Irreversibility} = W_{rev} - W_{actual}$$

$$= (U_1 - U_2) - T_0(S_1 - S_2) - Q - (U_1 - U_2)$$

$$= T_0(S_2 - S_1) - Q$$

Q = heat loss from system

−Q = heat gain by surrounding

$$= T_0 \left[(S_2 - S_1) + \frac{Q_{sur}}{T_0}\right]$$

$$= T_0 \left[S_2 - S_1 + \frac{Q_{sur}}{T_0}\right]$$

$$= T_0 \left[\Delta S_{sys} + \Delta S_{sur}\right]$$

$$\boxed{\text{Irreversibility} = T_0 \times S_{gen}}$$

→ gouy-stodala theorem

For open system SFEE $W_{actual} = (h_1 - h_2) - Q$.

$$\text{Irreversibility} = (h_1 - h_2) - T_0(S_1 - S_2) - [h_1 - h_2 - Q]$$

Q = loss to sur

$$= T_0(S_2 - S_1) + Q = T_0\left[S_2 - S_1 + \frac{Q}{T_0}\right] = T_0 S_{gen}$$

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Refer for steady flow

Q.1 (c) Consider steady heat transfer through a 5 × 7 m^2 brick wall of a house of thickness 30 cm. On a day when the temperature of outdoors is –10°C, the house is maintained at 25°C. The temperature of outer and inner surfaces of brick wall are measured to be 0°C and 20°C respectively and the rate of heat transfer through the wall is 1035 W.

Determine:

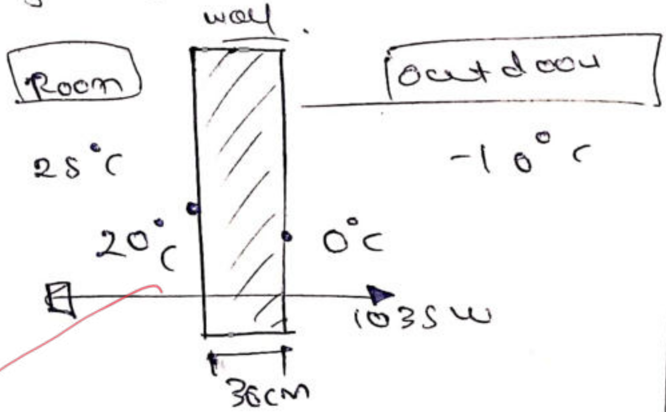
1. The rate of entropy generation in the wall,
2. Rate of total entropy generation associated with this heat transfer process.

[12 marks]

Assume →
1> Q = 1035 = const i.e steady state maintain
2> one dimensional, steady state.

Sol

Given $Q_{wall} = 1035 W$



Entropy eq^n →

$\dot{S}_{in} - \dot{S}_{out} + S_{gen} = \left(\frac{dS}{dt}\right)$

Assume steady state $\frac{dS}{dt} = 0$

=> $S_{gen} = \dot{S}_{out} - \dot{S}_{in}$

1> $(S_{gen})_{wall} = \left(\frac{Q}{T}\right)_{out} - \left(\frac{Q}{T}\right)_{in}$

$= \frac{1035}{273} - \frac{1035}{273+20} = 0.2587$ W/K

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2> $(S_{gen})_{total}$ = due to tempt difference b/w Room and outdoor

$= \frac{1035}{273-10} - \frac{1035}{273+25}$

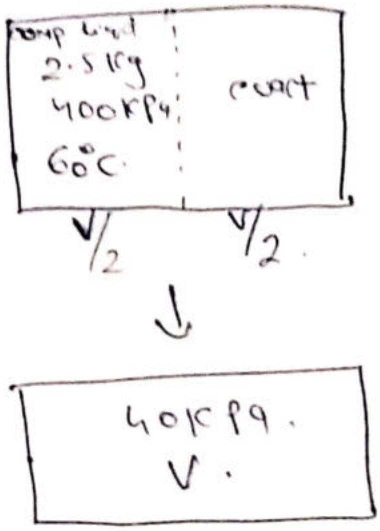
$= 0.4622$ W/K → Comment → due to more tempt difference ($\dot{S}_{gen}$) this case is Greater.

Q.1 (d) A rigid tank is divided into two equal parts by a partition. One part of tank contains 2.5 kg of compressed liquid water at 400 kPa and 60°C while the other part is evacuated. The partition is now removed and the water expands to fill the entire tank. Determine the entropy change of water during this process if final pressure in tank is 40 kPa. [Use the steam tables provided at end of question paper/QCAB]

[12 marks]

Soln →

let V = total volm Rigid tank.



State (1) →

400 kPa, 60°C, compressed liquid →

from table →

$v_1 = 0.001017\ m^3/kg$

$S_1 = 0.8320\ m^3/kg$

⇒ compressed liquid properties best approximated w.r.t temp.

→ Vol $\frac{V}{2} = v \times 2.5$ ⇒

$V = (2 \times v_1 \times 2.5)\ m^3$

final spec volume $= v_2 = \frac{V}{M} = 2v_1$

$= 2 \times 0.001017$

$= 2.034 \times 10^{-3}\ m^3/kg$

12

pressure = 40 kPa.

at 40 kPa, $v_g = 3.9933$, $v_f = 0.001026$

⇒ wet state

$2.034 \times 10^{-3} = x\, v_g\ (3.9933)$

x ⇒

$x = 5.094 \times 10^{-4}$

$S = S_f + x S_{fg} = 1.0261 + x\, 6.6430$

$= 1.0294$

entropy change $= 2.5\,[1.0294 - 0.8310]$

$= 0.4937\ kJ/K$.

Q.1 (e) A 30-litre electrical radiator containing heating oil (ρ = 950 kg/m^3, c_p = 2.2 kJ/kgK) is placed in a 50 m^3 room. Both the room and oil in radiator are initially at 10°C and 1 atm. The radiator with a rating of 1.8 kW is now turned on. At the same time, heat is lost from the room at an average rate of 21 kJ/min. After some time, the average temperature is measured to be 20°C for the air in the room and 50°C for oil in radiator then the radiator is turned off for the day. Determine:

1. Time for which heater is kept on.
2. Cost of electricity for a year if unit cost of electricity is 0.5 paisa per Watt-hour.

Assume the room is well sealed so that their are no air leaks.

[12 marks]

Sol. ~~Let ρ of air in room = 1 kg/m^3~~

Mass of air in room =

$PV = mRT$

$(1.013\times10^5)\times 50 = m\times 287\times(273+10)$

$[m_{air} = 63.46\ kg]$

Applying 1st law for room air + oil

$$Q = W + \Delta U$$

~~$Q_{absorb\ from\ Radiator} + Q_{loss\ from\ room} = 0 + mC_v(T_F - T_i) = 63.46\times0.718\times(20-10)$~~ (given 21 kJ/min)

~~$[Q_{from\ radiator} = 455.64\ kJ - 21t]$~~

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Let t = time for which heater is on.

$W_{electrical}$ = Increase in int energy of system + $Q_{loss\ room}$.

$$1.8\,t = (mC_p\Delta t)_{oil} + (mC_v\Delta T)_{room\ air} + Q_{loss\ room}$$

[ΔU oil] = sensible energy.

$$1.8\,t = (30\times10^{-3})\times950\times2.2\times(50-10) + 63.46\times0.718\times(20-10) + \frac{21}{60}\times t.$$

[t = 2043.89 sec = 34.06 min]

2) cost of electricity

Total kWhr used = $1.8 \times \frac{34.06}{60}$ × 365 day/year

= 1.021 kWhr.

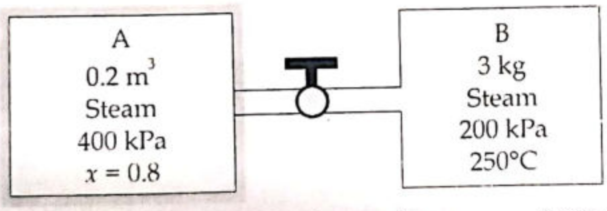
cost = $(0.5 \times 10^{-2} \times 1.021 \times 10^3)$ Rs per Whr

Rs = 5.109 per Whr. Ans

Rs 1859.

Q.2 (a) Two rigid tanks are connected by a valve. Tank A is insulated and contains 0.2 m^3 of steam at 400 kPa and 80% quality. Tank B is uninsulated and contains 3 kg of steam at 200 kPa and 250°C. The value is now opened and steam flows from tank A to tank B until the pressure in tank A drops to 300 kPa. Upto this instant, 900 kJ of heat is transferred from tank B to surroundings at 0°C. Assuming the steam remaining inside tank A to have undergone a reversible adiabatic process. Determine:

1. the final temperature in tank A at this instant.
2. internal energy of steam in tank B at this instant.



[Use the steam tables provided at end of question paper/QCAB]

[20 marks]

Q.3 (a) A fluid is confined in a cylinder by a spring-loaded, frictionless piston so that the pressure in fluid is a function of volume, $P = aV + bV^2$. The internal energy of fluid is given by the following equation.

$$U = 50 + 2.18\, PV$$

Where, U is in kJ, P in kPa and V in cubic meter.

If state of fluid changes from an initial state of 170 kPa, 0.03 m³ to a final state of 400 kPa, 0.06 m³ with no work other than that done on piston. Find direction and magnitude of work and heat transfer.

[15 marks]

Sol → W.D

Assume
1) Reversible process.
2)

$W = \int p\, dV$

given = $p = aV + bV^2$

State ① → 170 kPa, 0.03 m³ ⟶ 400 kPa, 0.06 m³.

$170 = a \times 0.03 + b \times 0.03^2$

$400 = a \times 0.06 + b \times 0.06^2$

15

Solving $a = 4666.66$

$b = 33333.33$

$W = \int_1^2 (aV + bV^2)\, dV$ (KJ).

$W = \left[\frac{aV^2}{2} + \frac{bV^3}{3}\right]_{0.03}^{0.06} = \frac{4666.66}{2}\left[0.06^2 - 0.03^2\right] + \frac{33333.33}{3}\left[0.06^3 - 0.03^3\right]$

[W = 8.399 KJ] +ve, from system to surrounding.

$\Delta U = U_2 - U_1$

$= (50 + 2.18 P_2 V_2) - (50 + 2.18 P_1 V_1)$

$= 2.18 (P_2 V_2 - P_1 V_1) = 2.18 \times 400 \times 0.06 - 170 \times 0.03 \times 2.18$

$\Delta U = 41.202$

1st law $Q = \Delta U + W = 41.202 + 8.399$
$= 49.601 kJ$

$Q = 49.601 kJ$ +ive, surrounding to fluid.

heat delivered to the system

Q.3 (b) A lead storage battery is used in an automobile is able to deliver 6 MJ of electrical energy. This energy is available for starting the car. Let compressed air be considered for doing an equivalent amount of work in starting the car. The compressed air to be stored at 10 MPa, 45°C. What is volume of tank that is required to let compressed air have an exergy of 6 MJ? For air, $Pv = 0.287T$ where T is in K, P in kPa and v in m^3/kg. Take surrounding pressure and temperature as 100 kPa and 25°C respectively.

[15 marks]

Soln compressed air → 10 MPa, 45°C, V m³.
m = mass of air. — (1).

V = volume of tank
$T_0 = 25°C = 298 K$
$P_0 = 100 kPa$ } given..

Exergy at state 1 = 6 MJ = $\frac{6 \times 10^3 kJ}{m}$/kg

exergy at state 1 given by

$\psi = (U_1 - U_0) - T_0 (S_1 - S_0) - P_0 (V_0 - V_1)$ — (1).

(6)

equivalent amount of work is done by allowing to expand in piston-cylinder and MU's $P_0 (V_0 - V_1)$ work done against atm.

$U_1 - U_0 = C_v (T_1 - T_0) = 0.718 \times (45 - 25)$
$= 14.36 kJ/kg$.

$\frac{6 \times 10^3 \times 0.287 \times (273+45)}{10 \times 10^3 \times V} = 14.36 - 298 \left[0.718 \ln\left(\frac{318}{298}\right) + 0.287 \ln\left(\frac{V}{V_0}\right)\right]$ (1.005)

$- 100 \times (V_0 - V)$.

$\frac{10 \times 10 V}{318} = \frac{100 V_0}{298} \Rightarrow V_0 = 93.71 V$

$\rightarrow \frac{54.759}{V} = 14.36 - 298 \times \left[0.0466 + 0.287 \ln \left(\frac{V}{93.71 V}\right)\right] - 100 (93.71 - 1) \times V$

$\frac{54.759}{V} = 388.77 - \left(\frac{9271 V}{M}\right)^{M}$

$m = 109.56 V$

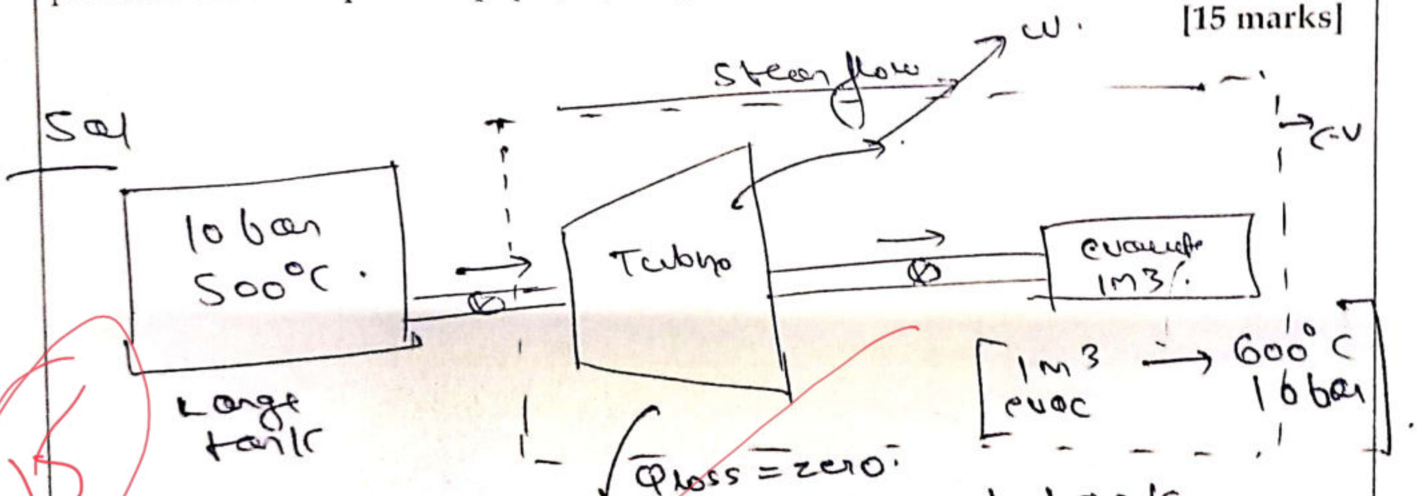
After solving $[V = 0.3585 \, m^3]$

$0.18 \, m^3$

Q.3 (c) A large vessel contains steam at a pressure of 10 bar and temperature of 500°C. This large vessel is connected to a steam turbine through a valve followed by a small initially evacuated tank with a volume of 1 m³. During emergency power requirement, the valve is opened and tank is filled with steam until pressure is 10 bar. The temperature of tank is then 600°C. Calculate the amount of work developed by turbine in kJ and draw the control volume. Assume the process takes place adiabatically. [Use the steam tables provided at end of question paper/QCAB]

[15 marks]

Sol



CV = combined Turbine + small tank.

Let M = mass in C.V = mass stored in small tank

Apply unsteady flow E.E in C.V.

$M_{in} h_{in} - W_{TUR} = M_2 U_2 - M_1 U_1$ (→ 0)

$(M_1 = 0)$ no steam

$(M_{in} = M_2)$

[final steam in C.V gets stored at 600°C, 10 bar in tank (small)]

$W_{turbine} = m_{in} h_{in} - m_2 u_2 = m_2 (h_{in} - u_2)$

at 10 bar, 600°C,

$u_2 = 3297.5$ kJ/kg

$v_2 = 0.4011$ m³/kg

10 bar, 500°C

$h = 3479.1$ kJ/kg

$m_2 = \frac{1}{0.4011} = 2.493$ kg

$W_{Turbine} = 2.493 [3479.1 - 3297.5]$

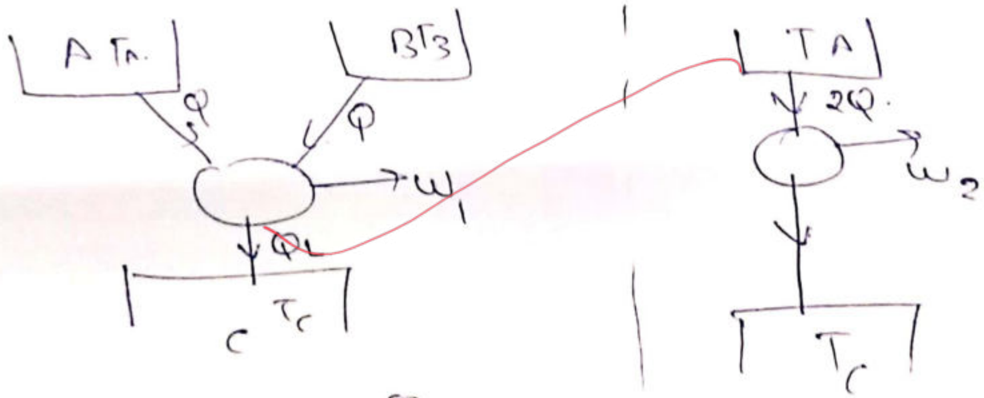
$[W_T = 452.75 \text{ kJ}]$ Ans.

Q.3 (d) A reversible engine works between three thermal reservoir A, B and C. The engine absorbs an equal amount of heat from thermal reservoirs at A and B kept at temperature T_A and T_B respectively and rejects heat to thermal reservoir C kept at temperature T_C. The efficiency of engine is α times the efficiency of reversible engine which works between two thermal reservoirs A and C. Prove that

$$\left(\frac{T_A}{T_B} = (2\alpha - 1) + 2(1 - \alpha)\frac{T_A}{T_C}\right)$$

[15 marks]

Sol^n



15

$\eta_1 = \frac{W_1}{2Q} = \frac{2Q - Q_L}{2Q}$

$\eta_2 = 1 - \frac{T_C}{T_A}$

Rev H.E $\Rightarrow \frac{Q}{T_A} + \frac{Q}{T_B} = \frac{2Q - W_1}{T_C}$

$\frac{1}{T_A} + \frac{1}{T_B} - \frac{2}{T_C} = -\frac{W_1}{Q T_C}$

$\Rightarrow \frac{T_C}{2}\left[\frac{2}{T_C} - \frac{1}{T_A} - \frac{1}{T_B}\right] = \alpha\left(1 - \frac{T_C}{T_A}\right)$

$\eta_1 = \frac{T_C}{2}\left[\frac{2}{T_C} - \frac{1}{T_A} - \frac{1}{T_B}\right]$,

$\frac{1}{T_C} - \frac{1}{2T_A} - \frac{1}{2T_B} = \alpha - \frac{\alpha T_C}{T_A}$

as $\frac{2}{T_C} - \frac{1}{T_A} - \frac{1}{T_3} = \frac{1}{T_C}\left(2\alpha - \frac{2\alpha T_C}{T_A}\right)$ Multiply by T_A

$\frac{2T_A}{T_C} - 1 - \frac{T_A}{T_3} = \frac{1}{T_C}\left(2\alpha T_A - 2\alpha T_C\right)$

$\frac{T_A}{T_3} = \frac{2T_A}{T_C} - 1 - \frac{2\alpha T_A}{T_C} + \frac{2\alpha T_C}{T_C}$

$= \frac{2T_A}{T_C}(1-\alpha) + (1-2\alpha) \times -1$

$$\frac{T_A}{T_3} = (2\alpha - 1) + 2(1-\alpha)\frac{T_A}{T_C}$$

Hence proved.

Q.4 (a) A 0.25 m^3 insulated piston-cylinder device initially contains 0.7 kg of air at 20°C. At this state, the piston is free to move. Now air at 500 kPa and 70°C is allowed to enter the cylinder from a supply line until the volume increases by 50 percent. Using constant specific heats at room temperature. Determine:

1. The final temperature
2. The work done
3. The entropy generation

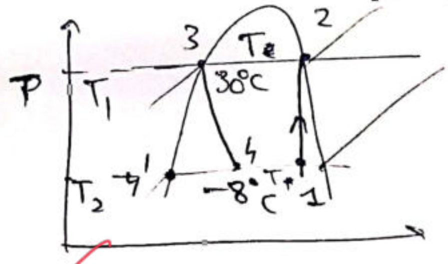
For air $c_p = 1.005$ kJ/kgK, $R = 0.287$ kJ/kgK

[20 marks]

Section B : Refrigeration and Air Conditioning

Q5 (a) A refrigerator machine working on vapour compression refrigeration cycle. The temperature of refrigerant in the evaporator coil is –8°C and it leaves the compressor as dry saturated at a temperature of 30°C. The mean specific heat of liquid refrigerant between the above temperatures is 1.228 kJ/kgK. The enthalpy of evaporation at 30°C is 177.86 kJ/kg. Find the COP of machine neglecting losses in the system.

[12 marks]



s

Sol. $\Delta S = \left(\frac{h_{fg}}{T}\right)$.

$h_1 - h_4' = (s_1 - s_4')T_2$

$= (s_2 - s_4')T_2$.

$s_3 - s_4' = c \ln\left(\frac{T_1}{T_2}\right) = 1.228 \ln\left(\frac{273+30}{273-8}\right)$

$= 0.164$ kJ/kgK. ← (1)

$s_2 - s_3 = \frac{177.86}{273+30} = 0.5869$ kJ/kgK. ← (2)

Add (1) and (2).

$s_2 - s_4' = 0.5869 + 0.164 = 0.750$ kJ/kgK

$h_1 - h_4' = 0.750 \times (273 - 8) = 199.014 \text{ kJ/kg}$ — (3)

$h_3 - h_4' = c(T_3 - T_2) = 1.228(30 + 8)$ — (3)

$= 46.664 \text{ kJ/kg}$

$h_2 - h_3 = \underline{177.86}$ — (4)

Eqn 3', 3, 4 → $h_2 - h_1 = -199.014 + (177.86 + 46.664)$

$h_2 - h_1 = \underline{25.51}$

$COP = \dfrac{Q_{abs\ expansion}}{W_{compress}} = \dfrac{177.86 - 25.51}{25.51}$

$\boxed{COP = 5.972}$

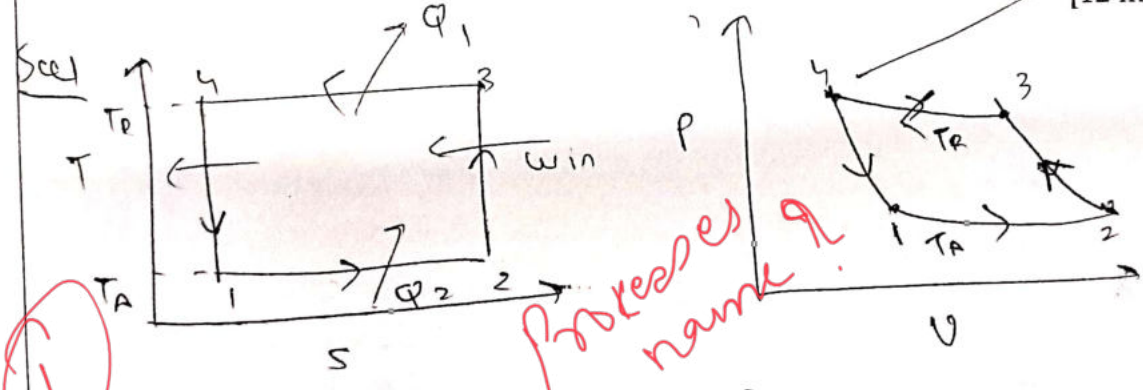
6.012 Ans

(11)

5(b) A gas is used as refrigerator in reverse Carnot refrigeration cycle. Draw T-s and P-v diagram with heat rejection and heat absorption temperature of T_R and T_A respectively. Show that this cycle requires two compressors and two expanders. Find their work requirement and COP of cycle.

[12 marks]

Sol



(1)

$COP = \dfrac{c_p(T_2 - T_1)}{c_p(T_3 - T_2) - c_p(T_4 - T_1)}$

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

$=$

$$COP = \frac{Q_2}{W_{net}} = \frac{T_A(S_2 - S_1)}{T_R(S_4 - S_3) - T_A(S_2 - S_1)}$$

$$\left[COP = \frac{T_A}{T_R - T_A}\right] \quad \because (S_2 - S_1 = S_4 - S_3)$$

0 incomplete

Q.5 (c) (i) What are the advantages and disadvantages of air cycle for aircraft refrigeration?
(ii) Explain the concept of effective temperature (ET) used in airconditioning practice. Mention the parameters on which it depends. [CHECK this also]

[6+6 = 12 marks]

Sol i) ADV →

1) can handle high mass flow rate of air.
2) Air is used, no danger of leakage, toxic, flammable & not problem due to
3) No cost of refrigerant.
4) Air is lighter ∴ wt per ton of ref reduces.

Disad 1) Very low COP.
2) Rate of air flow is large ∴ large Wi/put comp reqd.

8

ii) Concept of effective temp is → it is use to consider combined effect of various factors used for comfort.
It is temp which consider combined effect of air temp, relative humidity and air velocity on human body
It provide same sensation as if

proper definition should be given.

saturated air where used.

Parameter → 1) R.H
2) Air temp
3) Air velocity. Age, gender, work

It is used by comfort chart, concept analysis.

Q.5 (d) Thermostatic expansion valve using R-22 in the power assembly is designed to produce 20°C superheat at an evaporator temperature of –10°C. What will be the superheat that it will maintain when evaporator temperature is 0°C? [Use the property tables of R-22 provided at end of question paper/QCAB]

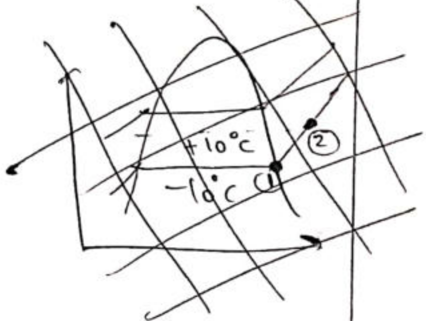
[12 marks]

Soln Thermostatic expansion valve = constant superheat value.

$T_1 = -10°C$

⇒ T_2 at entry of compressor = $-10 + 20°C = 10°C$

P_1 from table at $-10°C$ = 3.543 bar.



P_2 from table at $+10°C$ = 6.807 bar.

(4)

$\Delta P = 6.867 - 3.543$
$= 3.274$ bar.

P at 0°C = T_1' = 4.976 bar.

ΔP = constant

⇒ P at entry of compressor
$= 4.976 - 3.274 = 1.702$ bar. (+) 8.24 bar

Temp at 1.702 bar = from interpolation.

temperature ??

Q.5 (e) The humidity ratio or specific humidity of atmospheric air at 25°C is 10.65 g/kg of dry air. Determine:

1. Partial pressure of vapour
2. Dew point temperature
3. Relative humidity
4. Degree of saturation
5. Enthalpy per kg of dry air

[Use the steam tables provided at end of question paper/QCAB] **[12 marks]**

Soln given $T = 25°C$
$\omega = 10.65 g/kg\,d.A.$

$\omega = \left(0.622 \frac{P_V}{P - P_V}\right)$

$10.65 \times 10^{-3} = 0.622 \left(\frac{P_V}{1.013 - P_V}\right) \Rightarrow \left[P_V = 0.017 \text{ bar} = 1.7 \text{ kPa}\right]$ — (1).

~~(2) DPT = Tsat @ P_V~~
~~from table = 60.06 − $\left(\frac{64.96 - 60.06}{25 - 20}\right)(20 - 17)$~~

~~[T = 57.12 °C] DPT~~

~~$P_s = P_{sat}$ @ 25°C = 3.1698 kPa.~~

~~(3) R.H = $\frac{P_V}{P_s} = \frac{1.7}{3.1698}$ =~~

(12)

(2) DPT = Tsat at 1.7 kPa
= 15° C

(3) R.H = $\frac{P_V}{P_s @ 25°C} = \frac{1.7}{3.1698} = 0.536$

(4) μ = $\frac{\omega}{\omega_s}$ $\omega_s = 0.622 \times \frac{3.1698}{101.3 - 3.1698} = 0.020$

$= \frac{10.65}{20.09} = 0.53$

good

(5) $h = (1.005 \times t + \omega (1.88) t + 2500 \times \omega$
$= (1.005 + 10.65 \times 10^{-3} \times 1.88) \times 25 + 2500 \times 10.65 \times 10^{-3}$

$h = 52.25$ kJ/kg dry air.

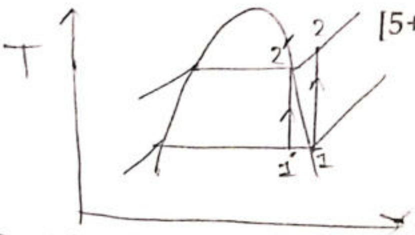
Q.7 (a) (i) State disadvantages of wet compression over dry compression in vapour compression refrigeration system.

(ii) 32.4 tonnes of fish has to be frozen to –30°C per day when the fish enters at 30°C. The specific heat of thawed fish is 3.77 kJ/kg°C and for frozen fish is 1.67 kJ/kg°C. The latent heat of fusion of fish (at 0°C) is 251.2 kJ/kg. If actual COP of refrigeration system is 40% of ideal. Calculate:

1. Refrigeration capacity of the refrigeration system in tons of refrigeration.
2. Electricity cost per year of the refrigeration system, if electricity cost is Rs. 0.5 per kW-hr.

Assume air as secondary refrigerant, for heat transfer in evaporator and condensor 5°C temperature difference is required.

[5+15 = 20 marks]



Sol → 1) (i)

a) wet compression →
as 1' is before sat vap state, Referigation capacity decreases.

b) It reduces compressor life,

c) Difficulty in compression process due to density variation b/w sat liq and sat vap at any dryness fraction. More compression from 1' to 2'.

d) COP reduces.

2) 1) R. capacity →

Q absorb =
$32.4\times10^3\left[3.77\times30 + 251.2 + 1.67\times30\right]$

$= 13.4\times10^6$ KJ per day.

$= 155.4$ KW $= 155.4/3.5$ ton

R. cap = 44.4 ton

2) (COP) given 5°C difference

$\Rightarrow T_2 = -30 \cdot 5 = -35$

$T_1 = 35°C$

$(COP) = 0.4 \times \frac{(273-35)}{35+35} = \boxed{1.36}$

$(W \cdot R)_{dq} = \frac{155.4}{1.36} = 114.26 \, kW$.

20

Cost per yr ⇒

Total kWh per year $= \frac{114.26 \times 24 \times 3600 \times 365}{3.6 \times 10^3}$

$= 10.00 \times 10^5$ kWh.

$(\text{cost}) = 0.5 \times 10.00 \times 10^5 = \boxed{\text{Rs } 50,047}$

Ans.

good

Q.7 (b) State and explain thermodynamic, chemical and physical properties of refrigerant which are considered for selection of refrigerants for use in vapour compression refrigeration system.

[20 marks]

Sol. Thermodynamic prop →

15

① critical properties should be high. critical tempt and pressure should be higher so that desire condenser and evap pressure and tempt can be maintained without superheat.

② High specific heat of vapour so that tempt rise is lesser at inlet of compressor. otherwise W compressor increases.

③ low specific heat of liquid so that larger tempt drop in condenser that will increase Qevaporat absorb.

(4) Low boiling pT, so that low evaporator tempt at lower pressure can be achived.
(5) High latent heat of vap to ↑ ref effect, ↓ condenser size.
(2) chemical prop →

1) chemically stable.
2) should not have corrosion properties.
3) Non toxic
4) Inflammable.
5) should not be odourless, colourless so that can be easily detected.
6) Miscibility with oil is non desirable.

physical prop →

1) Stability and inertness → must be stable at all tempt b/w evap and cond, not decompose.
2) non - corrosive : Chemical property
3) should have low viscosity so that flow in tubes can be maintained easily.
4) Thermal conductivity in liquid and vapour state should be high to reduce size of evap and condensa.
5) cost should be low, easily available,

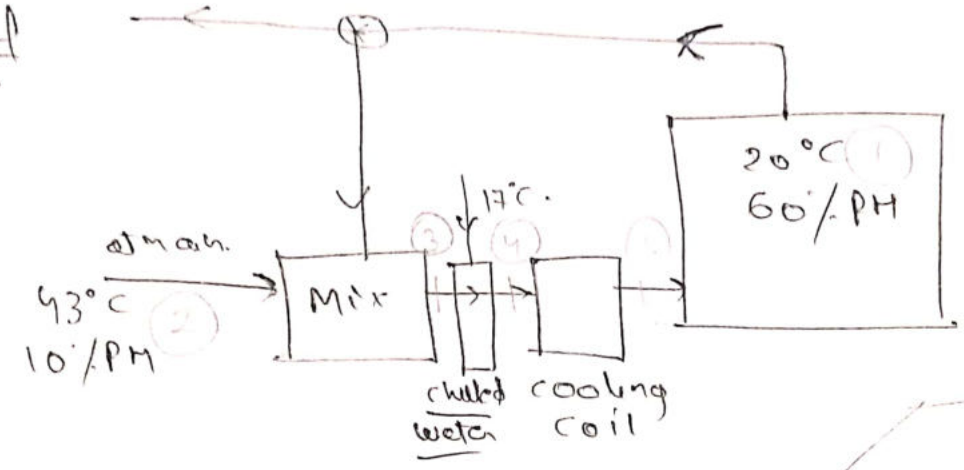
Leak detection

Q.7 (c) An air conditioned auditorium is to be maintained at 20°C and 60% RH and ambient conditions are 43°C and 10% RH. Some part of return air is recirculated and mixed with makeup air. Mixed air is first cooled by adding chilled water at temperature of 17°C and then cooled in a cooling coil where sensible cooling takes place. If volume rate of air entering the auditorium is 504 m^3/min. Determine:

1. Temperature and enthalpy of air after mixing
2. Temperature and enthalpy of air after interacting with chilled water
3. Amount of makeup water in kg/hr
4. Cooling load of coil in tonnes of refrigeration

[Use the psychrometric chart provided at end of question paper/QCAB] **[20 marks]**

Sol

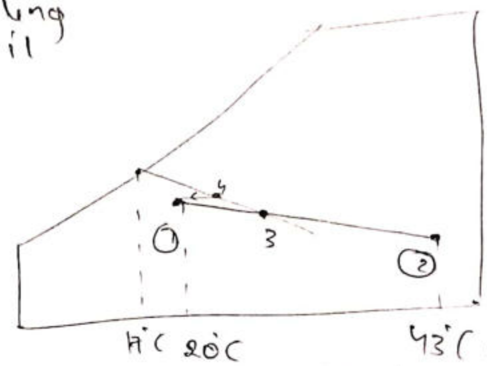


Procedure is correct.

15

→ 3 – 4

(h = c) WBT = C
adiabatic humidification



from chart

1) Temp after mix
$T_3 = 28.5°C$
$h_3 = 47.5$ kJ/kgda.

Refer solution. (Identification of points got wrong).

2) Temp after chill water
$T_4 = 25.5°C$
$h_4 = 47.5$

36 kg/hr.

44

35 kW = 10 TR

3) Amount of water $= \dot{m}(\omega_4 - \omega_3)$
$= (0.0087 - 0.0075)$ kg/da $\times 0.84 \times 504 \times 60$
$= 30.48$ kg/hr.

v at inlet $= 0.84$ kg/m^3

4) cooling load $= \dot{m}(h_4 - h_1) = (47.5 - 42.4) \times \dot{m} = 616.89$ TON

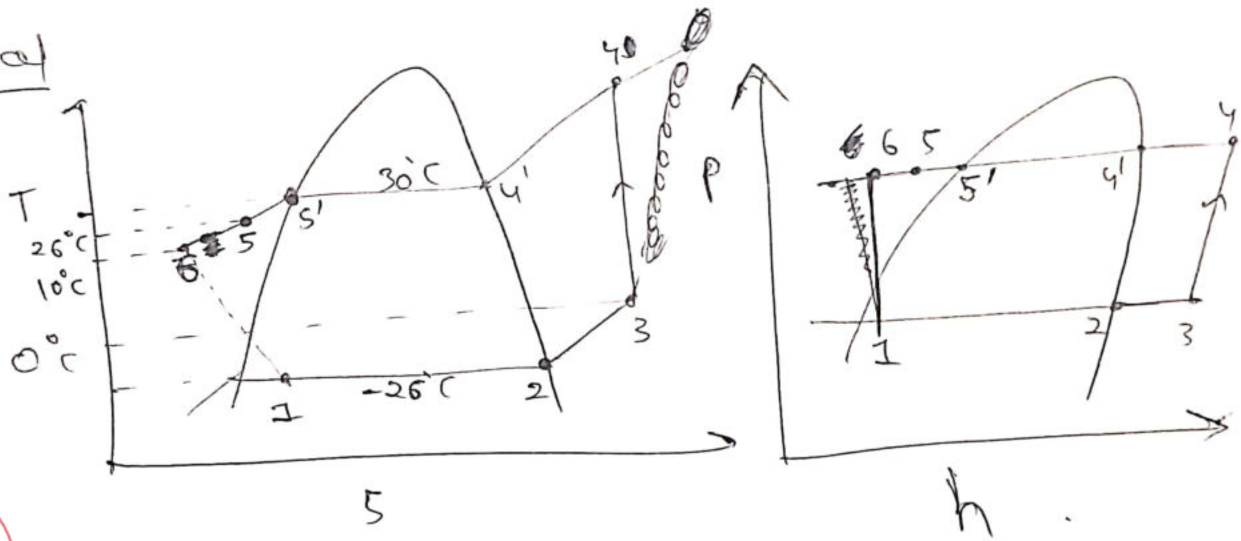
Q.8 (a) A refrigeration system is to be designed for a cooling capacity of 5 TR at saturation pressure corresponding to –26°C and condenser pressure corresponding to 30°C. Refrigerant R-22 is subcooled to 26°C in the condenser and further to 10°C in regenerative heat exchanger. Refrigerant is dry saturated at the exit of the evaporator and the temperature of refrigerant at the inlet of compressor is 0°C. Assume specific heat of refrigerant at liquid state as 1.37 kJ/kgK. Determine:

1. Mass flow rate of refrigerant (in kg/min)
2. Power input to compressor, assuming 80% mechanical efficiency
3. Actual COP of the system
4. Show the processes on T-s and P-h diagram

[Use the property table of R-22 provided at end of question paper/QCAB]

[20 marks]

Sol



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4 – 5 = condenser
5 – 6 = H. Exch.
1 – 2 = evap
$C_l = 1.37$ kJ/kgK

1) from table → $h_5' = 236.31$ kJ/kg

→ $h_6 = h_5' - 1.37(30-10)$
$= 208.91 = h_1$

$h_2 = h_g$ at $-26°C = 394.37$

$(\dot{m}) = \frac{5 \times 3.5 \text{ kW}}{h_2 - h_1} = \frac{5 \times 3.5}{394.37 - 208.91} = 0.0941$ kg/sec

① $[\dot{m} = 5.66$ kg/min$]$.

Scanned with CamScanner

Q.8 (b) In a air refrigeration plant, air is compressed from 1.1 bar, 30°C to 6 bar. Air is then cooled in an air cooler to 10°C before expanding in expansion cylinder.
If compressor follows PV = Constant and expansion cylinder follows $PV^{1.4}$ = Constant then determine:

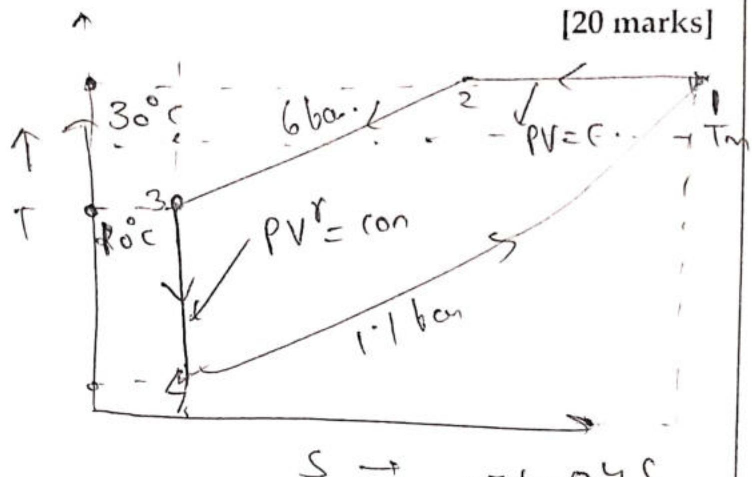
1. Refrigerating effect/kg of air
2. COP of the plant
3. Heat rejected in compressor
4. Mean temperature of heat rejection

For air: $\gamma = 1.4$, $R = 0.287$ kJ/kgK

[20 marks]

Sol →

Assume air = ideal gas.



$$\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}}$$

$\Rightarrow T_4 = 0.615 \times (273 + 10) =$ ~~180~~ 174.045 K.

Given → $T_2 = 30°C$, after air cooler $T_3 = 10°C$.

1) Refg effect →

$R.E = c_p(T_1 - T_4)$
$= 1.005 \times (273 + 30 - 174.045)$
$= 129.599$ kJ/kg.

20 good

2) COP = $\frac{R.E}{(W_{compressor})\ input}$.

W.D in expanding $= c_p(T_3 - T_4)$
$= 1.005[283 - 174.045]$
$= 109.499$ kJ/kg.

W.D in compressing $= P_1 V_1 \ln\left(\frac{6}{1.1}\right)$
$= RT_1 \ln\left(\frac{6}{1.1}\right) = 147.52$ kJ/kg.

(2) → $c_{pv}(T_3 - T_2) = (c_{pL})(T_5 - T_6)$ in H. Exch

$c_{pv}(\ +26) = c_{pL}(26-10)$

$\Rightarrow (c_{pv}) = 0.843 \text{ kJ/kgK}$.

Assume (c_{pv}) = const.

$h_4 - h_4' = 0.843(T_4 - 30°C)$.

$s_3 - s_2 = 0.843 \ln\left(\frac{273}{273-26}\right)$.

from table $s_2 = s_g$ at $-26°C = 1.7953$

$\Rightarrow s_3 = 1.8796 = s_4$.

also $s_4' = s_g$ at $30°C = 1.7120$, $h_4' = h_g$ at $30°C = 414.18$.

$\Rightarrow s_4 - s_4' = c_v \ln\left(\frac{T_4}{273+30}\right)$

$(1.8796 - 1.712) = 0.843 \ln\left(\frac{T_4}{273+30}\right)$

$T_4 = 369.646$.

$h_4 = 414.18 + 0.843(369.64 - 303)$
$= 470.357$ kJ/kg.

power input $= h_4 - h_3$
$= 470.357 - [394.57 + 0.843 \times (26)]$
$= 53.469$ kJ/kg

Actual power $= \frac{53.469 \times 5.66}{0.8 \times 60} = 6.304$ kW

(3) COP $= \frac{5 \times 3.5}{6.304} = 2.775$.

$W_{net\ reqd} = 147.5 - 109.499 = 38.025$ kJ/kg

$COP = \frac{129.599}{38.025} = 3.408$

(3) Heat rejected in compression => SFEE

$[Q = +147.52]$ $[h_1 + W - Q = h_2,\ h_1 = h_2,\ W = Q]$.

(4) Mean temp of heat rejection.

$T_m(S_1 - S_3) = Q_{rej\ compressor} + Q_{rej\ cooler}$

$= 147.52 + 1.005 \times [30 - 10]$

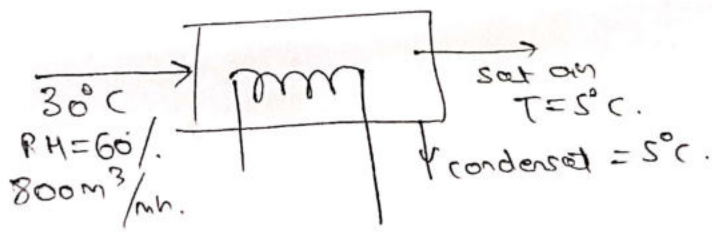
$S_1 - S_3 = c_p \ln\left(\frac{303}{283}\right) + 0.287 \ln\left(\frac{6}{1}\right) = 0.555$

$\left[T_m = \frac{167.62}{0.555} = 302.01K = 29.01\ °C\right]$.

Q.8 (c) Atmospheric air at 30°C dry bulb temperature and 60% relative humidity is passed over a cooling coil at the rate of 800 m^3/min. At exit from the coil, the air is saturated and its temperature is 5°C and the condensate leaves at 5°C. Determine the amount of condensate leaving the coil per minute and refrigeration required in kW. The specific heat of superheated steam may be assumed to be 2 kJ/kg°C. Solve the problem without the use of Psychrometric chart. [Use the steam tables provided at end of question paper/QCAB]

[20 marks]

Sol



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at 30°C $P_s = 4.2469$ kPa

$\Rightarrow P_v = RH \times P_s = 2.5481$.

$\omega_1 = \frac{0.622 \times 2.5481}{101.3 - 2.5481} = 0.01604$ kg/kg d.a

$h_1 = (1.005 + \omega_1 1.88) \times 30 + \omega_1(2500)$

$[h_1 = 71.179$ kJ/kg d.a$]$.

At (2) $T_{sat} = 5^\circ C \Rightarrow P_v = P_g$

$P_v = P_{sat}$ at $5^\circ C$

$= 0.8725$

$$\omega_2 = 0.622 \frac{P_v}{1.01.3 - P_v}$$

$$\omega_2 = 5.403 \times 10^{-3} \text{ kg/kg da.}$$

Amount of condensate $= \omega_1 - \omega_2$

$= 0.0106$ kg/kg da

$h_2 = 1 \times h_a + \omega_2 h_v$

$= 1.005 \times 5 + 5.403 \times 10^{-3} \times 2510.1$

$h_v = h_g$ at $5^\circ C$

$[h_2 = 18.587$ kJ/kg da$]$

$h_1 = 1 \times h_a + \omega_1 (h_v)$

$h_v = h_g @ 2.5481 kPa + [2 \times (30 - T_{sat} \text{ at } P_{v_1})]$

$h_1 = 1.005 \times 30 + 0.01604 \times [2 \times (30 - T_{sat}) + h_g]$. — (1).

By interpolation →.

$$h_g = 2537.4 + \frac{2546.6 - 2537.4}{(3.1698 - 2.3392)} (+2.5481 - 2.3392)$$

$= 2539.7$

$$T_{sat} = 25 - \left(\frac{25 - 20}{3.1698 - 2.3392}\right)(3.1698 - 2.5481)$$

$= 21.26^\circ C$

putting in eq^n (1)

$\Rightarrow [h_1 = 71.167$ kJ/kg da$]$

$$(\dot{m})_{da} = \frac{(800) \times 1.013 \times 10^5}{(273 + 30) \times 287} = 931.9 \text{ kg/min.}$$

(1) condensate $= 0.0106 \times \dot{m} = 9.878$ kg/min

(2) cooling capacity $=$ [illegible] $71.167 - [18.587 + 4.18 \times 5 \times 0.0106]$

$= 52.3$ kJ/kg da

$= 52.3 \times 931.9 = 812.6$ kW

Ans

slight variation

793 kW