18ME302   THERMODYNAMICS   Nov 2019   III Semester.

SOLUTION & SCHEME

1. a) Thermodynamic System: It is defined as a quantity of matter or region in space upon which attention is concentrated in the analysis of a problem.

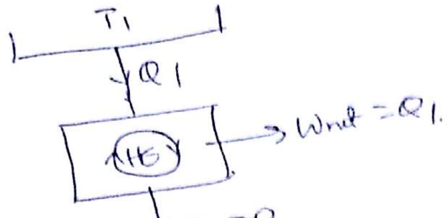
b) Path and process: The succession of states passed through during a change of state is called the path of the change of state. When the path is completely specified, the change of state is called a process.

c) When a body A is in thermal equilibrium with a body B, and also separately with a body C, then B and C will be in thermal equilibrium with each other. It is known as Zeroth law of T.D.

d) During throttling process Enthalpy is Constant

e) PMM-2

A Heat engine which produce net work in a cycle by exchanging heat with only one reservoir is known as PMM-2
[It violates Kelvin-Planck Statement of 2nd law of T.D].



PMM-2

f) Processes of a Carnot cycle

1. Isothermal Expansion
2. Adiabatic Expansion
3. Isothermal Compression
4. Adiabatic Compression

Reversible processes.

g) Carnot theorem

It states that of all ~~&~~ heat engines operating between a given constant temp source and a given constant temp. sink, none has a higher efficiency than a reversible engine.

h) Available energy and Unavailable energy

The part of the low grade energy which is available for conversion is referred to as available energy, while the part which, according to second law, must be rejected, is known as Unavailable energy.

(a) The maximum work output obtainable from a certain heat input in a cyclic HE is called as available energy. The minimum energy that has to be rejected to the sink by the second law is called as the Unavailable energy.

i) Dryness fraction of steam.

It is defined as the mass fraction of vapour in ~~a~~ a liquid vapour mixture.

$$x = \frac{m_v}{m_v + m_l}$$

j) Basic Components of a steam power plant

1. Boiler
2. Steam Turbine
3. Condenser
4. Pump

=

1 a) Work and heat:

Work is said to be done by a system if the sole effect on things external to the system can be reduced to the raising of a weight.

Heat is defined as the form of energy that is transferred across the boundary by virtue of a temp. difference.

Open system and closed system

Open system is one in which matter crosses the boundary of the system. There may be energy transfer also.

In a closed system there is no mass transfer across the system boundary.

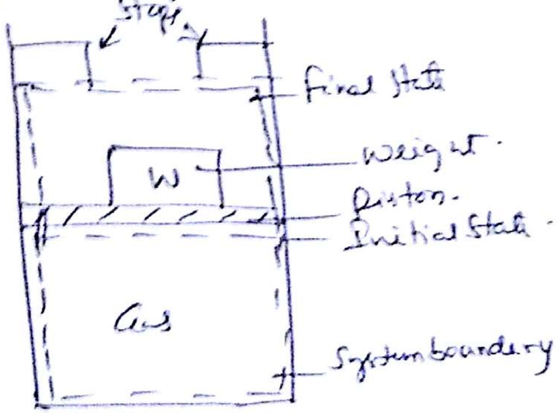
Macroscopic and microscopic point of view

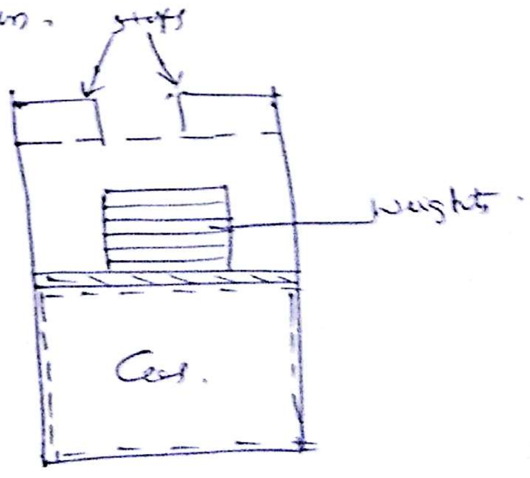
In the macroscopic approach, a certain quantity of matter is considered, without the events occuring at the molecular level being taken into account.

In microscopic point of view the behavior of the substance (system) is studied at molecular level.

2b) Quasistatic process.

Characteristic feature: - "Infinite slowness" is the characteristic feature of the quasi static process.





Let us consider a system of gas contained in a cylinder. The system is initially in an equilibrium state, represented by p_1, v_1, t_1. The weight of the piston balances the upward force exerted by the gas.

Case II If the weight is removed, the piston will move up till it hits the stops. The system again comes to an equilibrium state. But the intermediate states passed through by the system are non equilibrium states.

Case I. Single weight on the piston is made up of many very small pieces of weights.
If these weights are removed one by one slowly from the top of the piston, at any instant of the upward travel of the piston, if the gas system is isolated, the departure of the state of the system from the thermodynamic equilibrium state will be infinitesimally small. So every state passed through by the system will be an equilibrium state. Such a process, which is a locus of all the equilibrium states, is known as quasi static process.

(OR)

2 a) First law for a cycle.

$$\oint dQ = \oint dW.$$

Joules experiment

First law for a change of state

$$Q - W = \Delta E.$$

(or) $Q = \Delta E + W.$

During a change of state, net energy transfer will be stored in the system. Energy in storage is neither heat nor work, and is given the name internal energy or simply the energy of the system.

3 b) $P_1 = 1\text{ bar},\ P_2 = 2\text{ bar}$ $\quad U_1 = 512\text{ kJ}$

$V_1 = 1.5\text{ m}^3,\ V_2 = 0.75\text{ m}^3$ $\quad U_2 = 690\text{ kJ}$

(i) Process 1-2 $\quad P_1V_1 = P_2V_2 \Rightarrow V_2 = \frac{P_1}{P_2} \times V_1 = 0.75\text{ m}^3$.

$$W_{1-2} = P_1V_1 \ln\left(\frac{V_2}{V_1}\right) = \left(100\ \frac{kN}{m^2} \times 1.5\right) \ln\left(\frac{0.75}{1.5}\right)$$

$$= -104\text{ kJ}.$$

1st law for process 1-2

$$dQ = dU + dW = (U_2 - U_1) + (-104\text{ kJ})$$

$$Q_{12} = (690 - 512) + (-104) = 74\text{ kJ}.$$

(ii) Process 2-3: $\quad W_{23} = 0,\quad Q_{23} = -150\text{ kJ}.$

Apply 1st law for process 2-3

$$Q_{23} = W_{23} + (U_3 - U_2)$$

$$-150 = 0 + (U_3 - U_2) \Rightarrow -150 = (U_3 - 690)$$

$$\therefore U_3 = 540\text{ kJ}$$

(iii) Process 3-1 . $\quad W_{31} = 50\text{ kJ}. \quad U_3 = 540\text{ kJ},\ U_1 = 512\text{ kJ}$

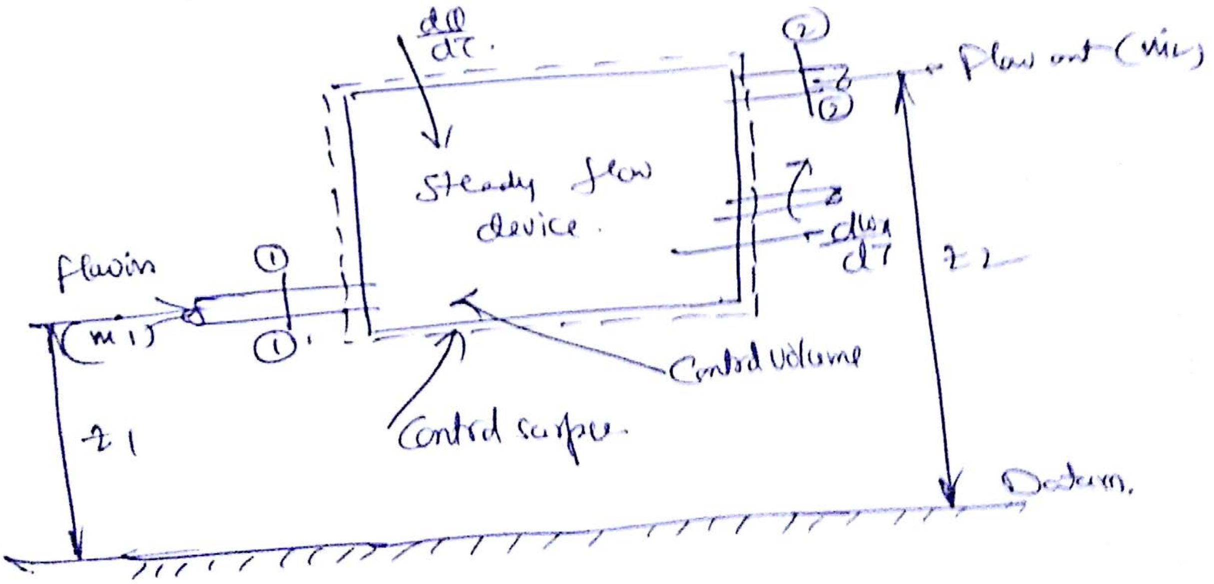
Apply 1st law for process 3-1

$$Q_{31} = (U_1 - U_3) + W_{31} = (512 - 540) + 50 = 22\text{ kJ}.$$

$$\therefore Q_{31} = 22\text{ kJ}$$

UNIT – II

4(a) Derivation of SFEE.



Let us Consider a Steady flow device. ① & ② are entrance (30)
and exit sections.

Let A_1 & A_2, C.S. areas at ① & ②. τ, Time (sec)

$\dot{m}_1$ & $\dot{m}_2$, mass flow rates at ① & ②

P_1 & P_2, pressures, N/m^2; v_1 & v_2 → sp. volume, m^3/kg.

V_1 & V_2 — Velocities at ① & ② m/s; Z_1 & Z_2, elevation of ① & ②, m.

$\frac{dQ}{d\tau}$ = Net rate of HT through the Control Surface, J/s

$\frac{dW_x}{d\tau}$ = Net rate of work transfer through the control surface, J/s.

Mass balance.

$$\dot{m}_1 = \dot{m}_2 \Rightarrow \frac{A_1V_1}{v_1} = \frac{A_2V_2}{v_2} \rightarrow ①$$

Energy balance.

$$W = W_x - p_1v_1 dm_1 + p_2v_2dm_2$$

$$W = W_x - p_1v_1 + m_2 p_2v_2 \rightarrow ②$$

$$\frac{dw}{d\tau} = \frac{dW_x}{d\tau} - \dot{m}_1 p_1 v_1 + \dot{m}_2 p_2 v_2$$

Energy entering = Energy leaving

$$\dot{m}_1 e_1 + \frac{dQ}{d\tau} = \dot{m}_2 e_2 + \frac{dw}{d\tau}. \rightarrow ③$$

Sub ② in ③

$$\dot{m}_1 e_1 + \frac{dQ}{d\tau} = \dot{m}_2 e_2 + \frac{dW_x}{d\tau} - \dot{m}_1 p_1 v_1 + \dot{m}_2 p_2 v_2.$$

$$\therefore \dot{m}_1 e_1 + \dot{m}_1 p_1 v_1 + \frac{dQ}{d\tau} = \dot{m}_2 e_2 + \dot{m}_2 p_2 v_2 + \frac{dW_x}{d\tau} \rightarrow ④$$

where $e_1 = e_k + e_p + u = \frac{V^2}{2} + zg + u$.

Substitute in ④

$$\dot{m}_1\left(\frac{V_1^2}{2} + z_1g + u_1\right) + \dot{m}_1 p_1 v_1 + \frac{dQ}{d\tau} = \dot{m}_2\left(\frac{V_2^2}{2} + z_2g + u_2\right) + \dot{m}_2 p_2 v_2 + \frac{dW_x}{d\tau}.$$

$$\dot{m}_1\left(h_1 + \frac{V_1^2}{2} + z_1g\right) + \frac{dQ}{d\tau} = \dot{m}_2\left(h_2 + \frac{V_2^2}{2} + z_2g\right) + \frac{dW_x}{d\tau} \rightarrow \text{SFEE}$$

where $\dot{m}_1 = \dot{m}_2 = \dot{m} = \frac{dm}{d\tau}$.

Dividing eqn. by $\frac{dm}{d\tau} = \dot{m}$

$$\left(h_1 + \frac{V_1^2}{2} + z_1g\right) + \frac{dQ}{dm} = \left(h_2 + \frac{V_2^2}{2} + z_2g\right) + \frac{dW_x}{dm} \rightarrow \text{SFEE}$$

Ans $T_1 = 10^\circ C$, $P_1 = 100$ kPa ; $h_1 = $ [illegible] kJ/kg
$T_2 = 200^\circ C$, $P_2 = 600$ kPa, $h_2 = $ [illegible] kJ/kg.

Case I $V_1 = V_2 = 0$, To find $\frac{\dot{W}_{shaft}}{\dot{m}}$

SFEE

$$\left(h_1 + \frac{V_1^2}{2} + gz_1\right) + \frac{\dot{Q}}{\dot{m}} = \left(h_2 + \frac{V_2^2}{2} + gz_2\right) + \frac{\dot{W}_{sh}}{\dot{m}}$$

$$\therefore \frac{\dot{W}_{sh}}{\dot{m}} = h_1 - h_2 = \text{[illegible]} = \text{[illegible] kJ/kg.}$$

(-ve) sign indicates that work is done on the gas

Case II $V_1 = 50$ m/s, $V_2 = 150$ m/s

SFEE

$$\left(h_1 + \frac{V_1^2}{2} + gz_1\right) + \frac{\dot{Q}}{\dot{m}} = \left(h_2 + \frac{V_2^2}{2} + gz_2\right) + \frac{\dot{W}_{sh}}{\dot{m}}$$

$$\therefore \frac{\dot{W}_{sh}}{\dot{m}} = (h_1 - h_2) + \left(\frac{V_1^2 - V_2^2}{2}\right) = (\text{[illegible]}) + \left(\frac{50^2 - 150^2}{2}\right)$$

$$= -\text{[illegible] J/kg} = -152.9 \text{ kJ/kg.}$$

(Ans)

5(a) Clausius statement of Second law of T.D

It is impossible to construct a device which, operating in a cycle, will produce no effect other than the transfer of heat from a cooler to hotter body.

Kelvin Planck statement of Second law of T.D

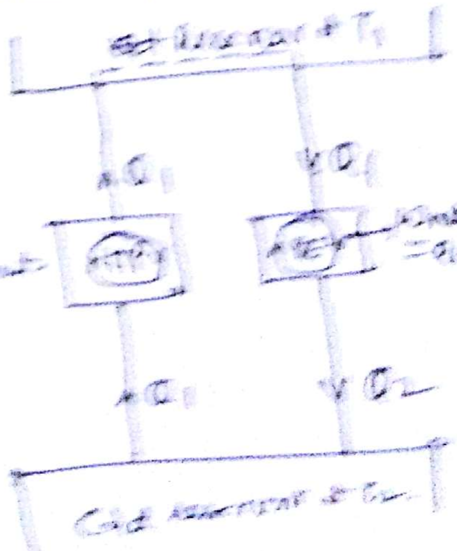
It is impossible for a HE to produce net work in a complete cycle if it exchanges heat only with bodies at a single fixed temp.

Equivalence of the two statements of Second law of T.D

It can be proved that the violation of one statement implies the violation of the other.

Let us consider a cyclic HP or device transfers heat from a low temp reservoir (T_2) to a high temp reservoir (T_1) with no other effect i.e. violating Clausius statement.

Let us consider a cyclic HE "E" operating between the same thermal reservoirs, producing work in one cycle. The rate of working of the HE is such that it should



the amount of heat Q_1 from the hot reservoir equal to that discharged by the heat pump. Then the hot reservoir may be eliminated and the heat Q_1 discharged by the pump is fed to the HE. So we see that the heat pump and the heat engine together constitute a HE operating in a cycle and producing net work while exchanging heat only with reservoir at a single fixed temp. (T_2). This violates the Kelvin planck statement.

5(b) Heat pump and Reservoir.

Refrigerator is a device, maintaining a body at a temp. lower than the ambient temp. (With external work input)

Heat pump is a device, maintaining a body at a temp. higher than the ambient temp. (With external work input).

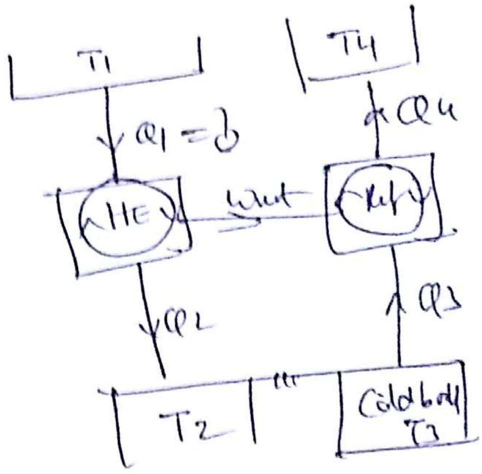
Problem.

Given

$\eta_{HE} = 0.3$

$(COP)_{Ref} = 5$

$Q_3 = 1\ MJ = 1000\ kJ$.



$$(COP)_{ref} = 5 = \frac{Q_3}{W_{net}}$$

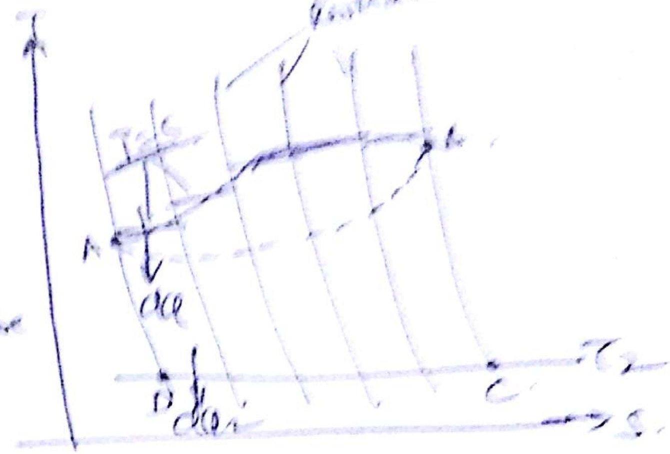
$$\therefore W_{net} = \frac{Q_3}{5} = \frac{1000}{5} = 200\ kJ.$$

$$\eta_{HE} = \frac{W_{net}}{Q_1}$$

$$\therefore Q_1 = \frac{W_{net}}{\eta_{HE}} = \frac{200}{0.3} = 666.67\ kJ.$$

6 a) Establish the inequality of Clausius.

Let us consider a cycle ABCD. Let AB be a general process (reversible or irreversible), and the other processes in the cycle are reversible. Let the cycle be divided into a number of elementary cycles, as shown in fig.



For one of the elementary cycles

$$\eta = 1 - \frac{dQ_2}{dQ}$$

where dQ is the heat supplied at T and dQ_2 is the heat rejected at T_2.

Now the efficiency of a general cycle will be equal to or less than the efficiency of a reversible cycle.

$$1 - \frac{dQ_2}{dQ} \le \left(1 - \frac{dQ_2}{dQ}\right)_{rev} \rightarrow \left(\frac{dQ_2}{dQ}\right) \ge \left(\frac{dQ_2}{dQ}\right)_{rev}.$$

$$\rightarrow \left(\frac{dQ}{dQ_2}\right) \le \left(\frac{dQ}{dQ_2}\right)_{rev} \qquad \text{But } \left(\frac{dQ}{dQ_2}\right)_{rev} = \frac{T}{T_2}$$

$$\therefore \left(\frac{dQ}{dQ_2}\right) \le \frac{T}{T_2} \Rightarrow \left(\frac{dQ}{T}\right) \le \left(\frac{dQ_2}{T_2}\right)$$ — for any process AB reversible or irreversible.

For a reversible process.

$$ds = \frac{dQ_{rev}}{T} = \frac{dQ_2}{T_2}$$

Hence for any process AB. $\frac{dQ}{T} \le ds$.

Then for a cycle $\oint \frac{dQ}{T} \le \oint ds$

Since entropy is a property and cyclic integral of any property is zero,

$$\therefore \underline{\oint \frac{dQ}{T} \le 0.} \longrightarrow \text{Inequality of Clausius.}$$

[It provides the criterion of the reversibility of a cycle].

If $\oint \frac{dQ}{T} = 0$, the cycle is reversible.

$\oint \frac{dQ}{T} < 0$, the cycle is irreversible and possible.

$\oint \frac{dQ}{T} > 0$, the cycle is impossible, since it violates the second law of T.D.

6b) $m_i = 100\ kg$; $m_w = 50\ kg$

$T_i = 100°C = 373K$; $T_w = 20°C = 293K$

$C_i = 0.45\ kJ/kgK$; $C_w = 4.18\ kJ/kgK$

Heat lost by iron = Heat gain by water

Let the final temp of water and iron is T_f

$\therefore m_i c_i (T_i - T_f) = m_w \cdot c_w (T_f - T_w)$

$100 \times 0.45 (373 - T_f) = 50 \times 4.18 (T_f - 293)$

$\therefore \underline{T_f = 307.17K}$

$(ds)_{iron} = m \times C_i \times \ln \frac{T_f}{T_i} = 100 \times 0.45 \ln\left(\frac{307.17}{373}\right)$

$= -8.7386\ kJ/K$.

$(ds)_{water} = m \times C_w \times \ln\left(\frac{T_f}{T_w}\right) = 50 \times 4.18 \times \ln\left(\frac{307.17}{293}\right)$

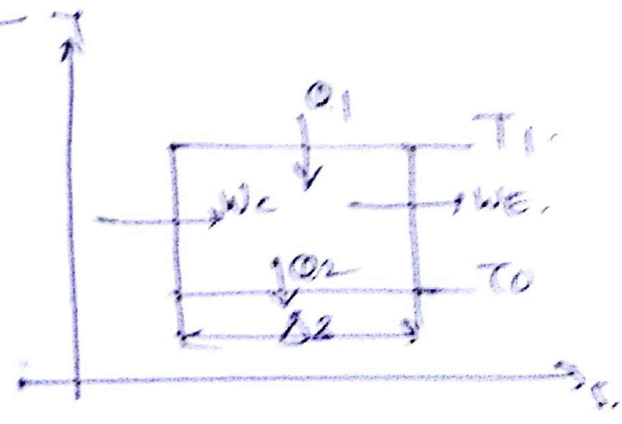
$= 9.87\ kJ/K$.

$(ds)_{universe} = ds_i + ds_w = -8.7386 + 9.87 = \underline{1.1314\ kJ/K}$

(OR)

7a) <u>HT through a finite temp. difference</u>

Let us consider a reversible heat engine operating between T_1 and T_0.



Then

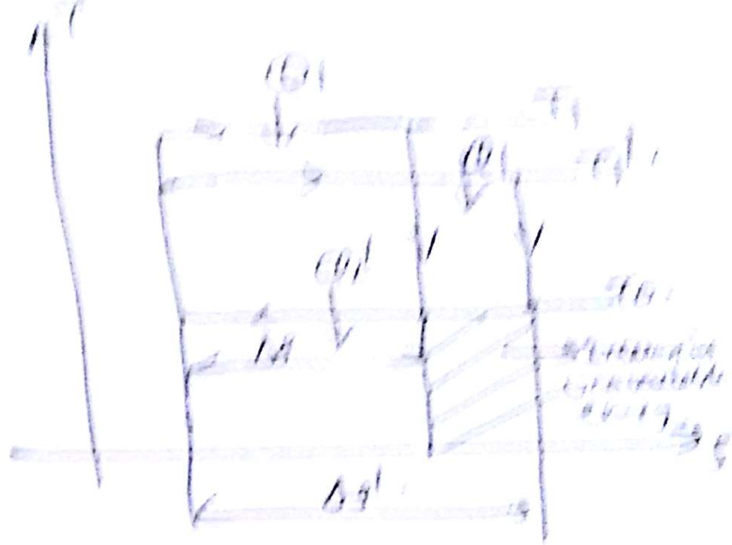
$Q_1 = T_1 \cdot \Delta s$ and $Q_2 = T_0 \cdot \Delta s$

and W = Available energy = AE.

$= (T_1 - T_0)\ \Delta s$.

Let us now assume that heat Q_1 is transferred through a finite temperature difference from the reservoir or source at T_1 to the engine absorbing heat at T_1', lower than T_1.

The availability of Q_1 as received by the engine at T_1' can be found by allowing the engine to operate reversibly in a cycle between T_1' and T_0 receiving Q_1 and rejecting Q_2'.



Now $Q_1 = T_1 \Delta s = T_1' \Delta s'$

Since $T_1 > T_1'$, $\therefore \Delta s' > \Delta s$

$Q_2 = T_0 \Delta s$

$Q_2' = T_0 \Delta s'$

Since $\Delta s' > \Delta s$, $\therefore Q_2' > Q_2$

$\therefore W' = Q_1 - Q_2' = T_1' \Delta s' - T_0 \Delta s'$

and $W = Q_1 - Q_2 = T_1 \Delta s - T_0 \Delta s$

$\therefore W' < W$, because $Q_2' > Q_2$

Available energy lost due to irreversible HT through finite temperature difference between the source and the working fluid during the heat addition process is given by

$W - W' = Q_2' - Q_2 = T_0(\Delta s' - \Delta s)$

i.e., Decrease in available energy $= T_0(\Delta s' - \Delta s)$

Note:- The decrease in AE of energy is thus the product of the lowest feasible temp. of heat rejection and the additional entropy change in the system while receiving heat irreversibly, compared to the case of reversible heat transfer from the same source.

7 b)

Temp. of source, $T_1 = 1000$ K.

Temp. of ~~sink~~ system, $T_2 = 500$ K.

Temp. of atmosphere : $T_0 = 300$ K.

Heat received by the system, $Q = 7200$ kJ/min

(i) Entropy produced during heat transfer

Change in entropy of the source during heat transfer $= \frac{-Q}{T_1}$

$= \frac{-7200}{1000} = -7.2$ kJ/min·K.

Change in entropy of system during heat transfer $= \frac{Q}{T_2}$

$= \frac{7200}{500} = 14.4$ kJ/min-K.

Net change in entropy, $\Delta S = -7.2 + 14.4 = 7.2$ kJ/min-K.

(ii) Decrease in available energy after heat transfer

Available energy with source $= (1000-300) \times 7.2 = 5040$ kJ.

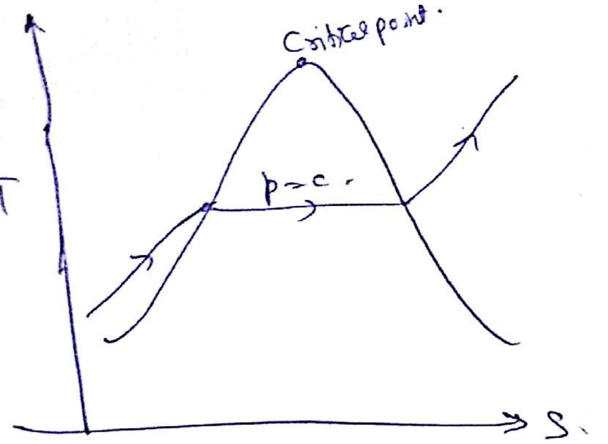
Available energy with the system $= (500-300) \times 14.4$

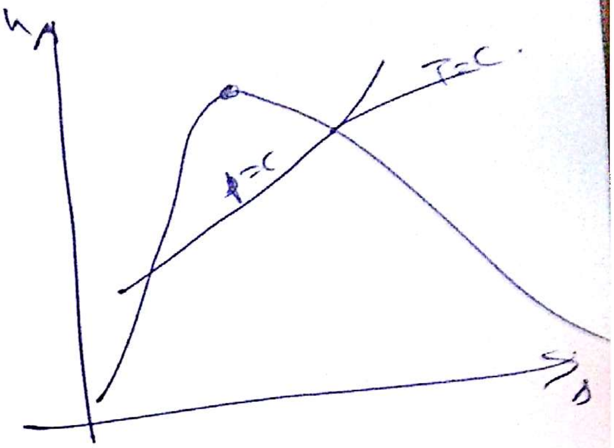
$= 2880$ kJ.

$\therefore$ Decrease in available energy $= 5040 - 2880$

$= 2160$ kJ

8a)





8b) from steam tables at 250°c

$v_f = 0.001251$ m³/kg; $v_g = 0.0501$ m³/kg.

$h_f = 1085.4$ kJ/kg; $h_{fg} = 1716.2$ kJ/kg; $h_g = 2801.6$ kJ/kg.

$m_f = 10$ kg

(i) To find mass of mixture

Volume of liquid, $V_f = m_f \cdot v_f = 10 \times 0.001251 = 0.01251$ m³.

∴ Volume of vapour, $V_g = 0.05 - 0.01251 = 0.03749$ m³.

∴ Mass of vapour, $m_g = \frac{V_g}{v_g} = \frac{0.03749}{0.0501} = 0.7483$ kg.

∴ Total mass of mixture, $m = m_f + m_g = \underline{10.7483}$ kg.

(ii) Specific volume of mixture

Let x = dryness fraction $= \frac{m_g}{m_g + m_f} = \frac{0.7483}{10.7483} = \underline{0.06962}$

∴ $v = v_f + x v_{fg}$ where $v_{fg} = v_g - v_f$.

$= 0.001251 + 0.06962(0.0501 - 0.001251)$

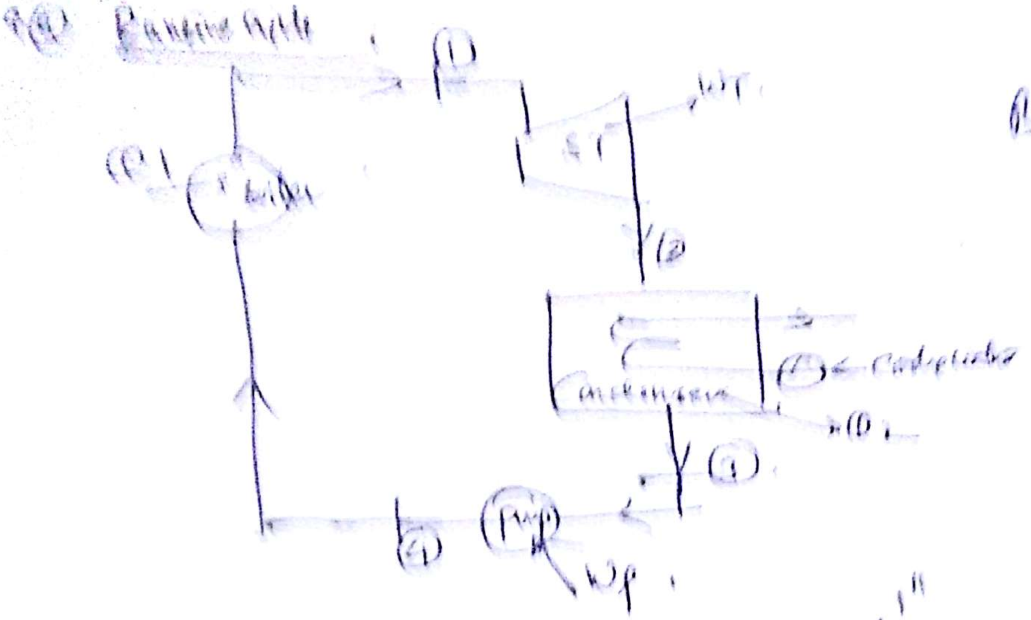
$= \underline{0.004652}$ m³/kg.

(iii) Specific enthalpy of mixture

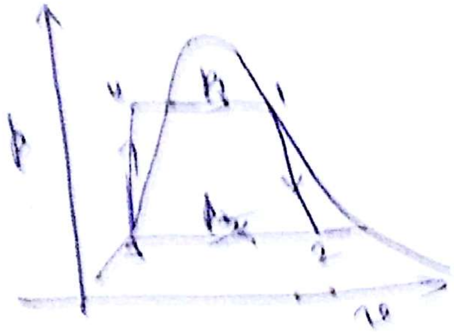
$h = h_f + x \cdot h_{fg} = 1085.4 + 0.06962(1716.2)$

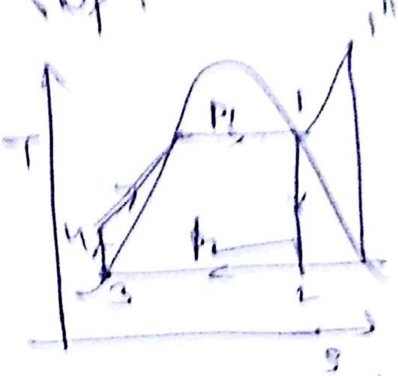
$= \underline{1204.9}$ kJ/kg.

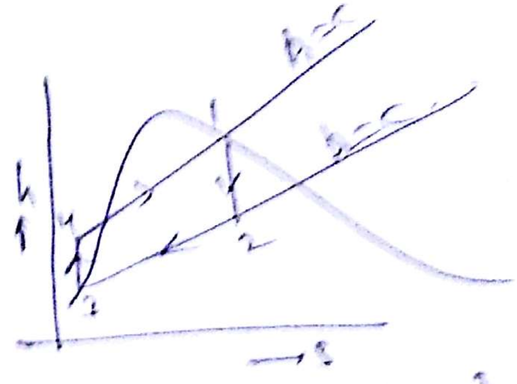
9(a) Rankine cycle



Brief explanation about working of Rankine cycle







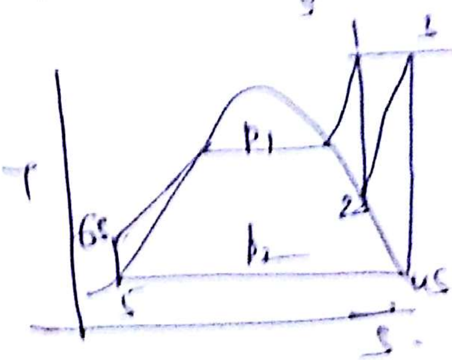
9(b)

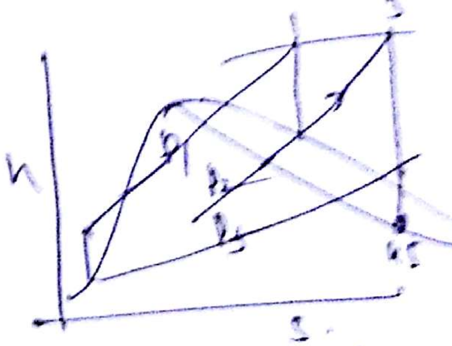
Given

$p_1 = 150$ bar

$p_2 = 0.1$ bar

$p_3 = 40$ bar





from mollier chart

$h_1 = 3465$, $h_{2s} = 3065$

$h_3 = 3565$ kJ/kg

$h_{4s} = 2300$ kJ/kg, $x_{4s} = 0.88$, h_5 (from steam tables) $= 191.83$ kJ/kg

$h_{6s} = 206.83$ kJ/kg

$W_p = v\,\Delta P = 10^{-3} \times 150 \times 10^{2} = 15$ kJ/kg

$Q_1 = (h_1 - h_{6s}) + (h_3 - h_{2s}) = 3758.17$ kJ/kg

$W_T = (h_1 - h_{2s}) + (h_3 - h_{4s}) = 1665$ kJ/kg

$W_{net} = W_T - W_p = 1665 - 15 = 1650$ kJ/kg

$\eta_{cycle} = \dfrac{W_{net}}{Q_s = Q_1} = \dfrac{1650}{3758.17} = 43.9\,\%$

Steam rate $= \dfrac{3600}{W_{net}} = \dfrac{3600}{1650} = 2.18$ kg/kW-hr