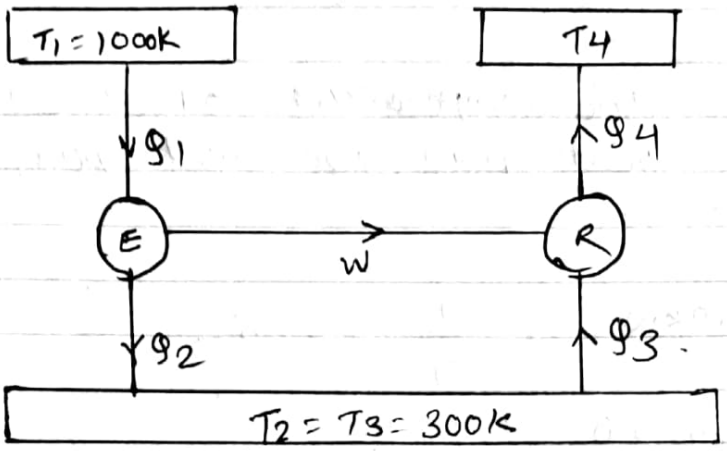
Thermodynamics (CBSGS)

Q.2 (b) – soln



For engine: $\eta_{max} = \frac{T_1 - T_2}{T_1}$

$= \frac{1000 - 300}{1000} = 0.7$

$\eta_{actual} = 0.4 \times 0.7 = 0.28$

$\therefore \frac{W}{Q_1} = 0.28$

But $Q_1 = W + Q_2$ (first law)

$\therefore \frac{W}{W + Q_2} = 0.28$

or $\frac{W}{W + \frac{Q_3}{2}} = 0.28$ $(\because Q_3 = 2Q_2$ given)

That gives $\therefore Q_3 = 5.14\, W$

For Heat pump:

$(COP)_{max} = \frac{T_4}{T_4 - T_3} = \frac{T_4}{T_4 - 300}$

$(COP)_{actual} = 0.5 \times \frac{T_4}{T_4 - 300}$

solution gives :

$T_4 = 326.6\ K$

Therefore, the temperature of the reservoir receiving heat from the heat pump is 326.6 k.

(b) $Q_1 = 50kw$; $\frac{W}{Q_1} = 0.28$

$\therefore W = 0.28 \times 50 = 14\ kw$

$Q_2 = 50 - 14 = 36\ kw$

$Q_3 = 2Q_2 = 2 \times 36 = 72kw$

$\therefore$ Rate of heat rejection from the heat pump

$Q_4 = W + Q_3$

$= 14 + 72$

$\boxed{Q_4 = 86\ kw}$

Q.3 (a) - Soln

Let suffix f & 0 represent the forging & oil respectively. From the principle of energy conservation,

heat lost by forging = heat gained by oil

$m_f c_f (T_{f_1} - T_m) = m_0 c_0 (T_m - T_{0_1})$

where T_m is the common temperature of the composite system.

$T_{f_1} = 500 + 273 = 773K$

$T_{0_1} = 25 + 273 = 298K$

$30 \times 0.5 (773 - T_m) = 200 \times 2.5 (T_m - 298)$

soln gives: $T_m = 311.83\ K$

(i) Entropy change of forging

$$= m_f c_f \log_e \frac{T_m}{T_{f_1}}$$

$$= 30 \times 0.5 \log_e \frac{311.83}{773}$$

$$= -13.617\ kJ/K$$

(ii) Entropy change of oil

$$= m_o c_o \log_e \frac{T_m}{T_{O_1}}$$

$$= 200 \times 2.5 \log_e \frac{311.83}{298}$$

$$= 22.682\ kJ/K$$

(iii) change in entropy of the system is

$$(ds)_{system} = (ds)_{forging} + (ds)_{oil}$$

$$= -13.617 + 22.682$$

$$= 9.065\ kJ/K \text{ (increase)}$$

Q.3 (b)

Soln -> - The surroundings work is the work done by or against the surroundings during a process. Consider for example, a gas enclosed in a cylinder - piston assembly expand pushing the piston up against the contacting atmospheric air.

- This work is surroundings work, which cannot be recovered and utilized for any useful purpose & is equal to the atmospheric pressure P_0 time the volume change of the system.

$$W_{surr} = P_0 \Delta V$$

- The difference between the actual work 'W' & the surroundings work is the useful work.

$$W_u = W - W_{surr}$$

- when the gas expands, a part of the work done by the gas is expended to overcome the atmospheric pressure. & thus W_{surr} here stands for a loss.
- However if the gas is compressed the atm pr. helps in compression, & thus W_{surr} represents a gain.

Q.3 (c)

Ans -> Boiling converts a liquid into vapour under an isobaric & isothermal condition. and this change of phase take place with the absorption of latent heat L.

we can apply the clapeyron equation to determine the change of temp. with pressure.

$$\frac{dp}{dT} = \frac{L}{T(V_2 - V_1)}$$

Q.3 (c)

In the conversion of liquid into a vapour state ($f \rightarrow fg$), $v_2 > v_1$, and as both T & L are positive quantities, the ratio

$\left[\frac{dp}{dT}\right]$ must be positive

And therefore, with the increase of pressure there must be a commensurate increase of temperature in order to keep the ratio dp/dT fixed. This is known as elevation of boiling point.

Q.4 (a)

Soln →

Let Q_r be the rate of heat release and Q_a the rate of heat absorption.

Then:

$$\eta_I = \frac{Q_a}{Q_r} \quad \& \quad \eta_{II} = \frac{\left(1 - \frac{T_a}{T_0}\right)}{\left(1 - \frac{T_0}{T_r}\right)}$$

(a) Furnace. $\eta_I = \frac{480}{500} \times 100 = 96\%$

$$\eta_{II} = \eta_I \times \frac{\left(1 - \frac{T_0}{T_a}\right)}{\left(1 - \frac{T_0}{T_r}\right)} = 0.96 \times \frac{\left(1 - \frac{300}{1000}\right)}{\left(1 - \frac{300}{2000}\right)}$$

$= \underline{79\%}$

(b) ~~Steam~~ generation chemical processes:

$$\eta_I = \frac{300}{500} \times 100 = 60\%$$

$$\eta_{II} = 0.60 \times \frac{\left(1 - \frac{300}{320}\right)}{\left(1 - \frac{300}{2000}\right)} \times 100 = \underline{4.409\%}$$

(ii) steam generation

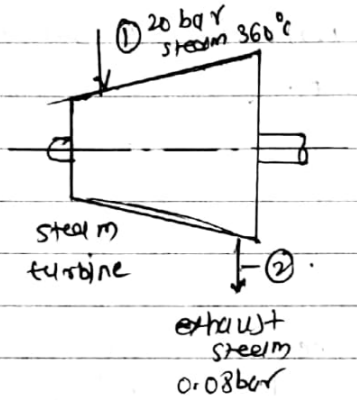
$$\eta_I = \frac{450}{500} \times 100 = 90\%$$

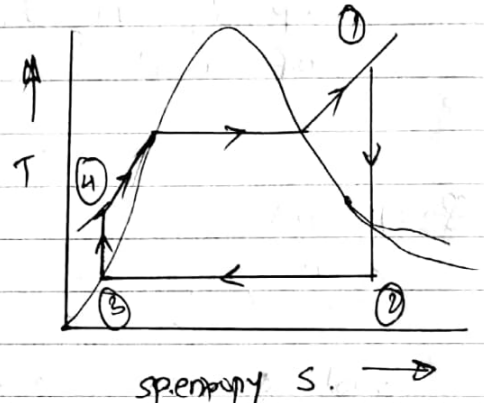
$$\eta_{II} = 0.90 \times \frac{\left(1 - \frac{300}{500}\right)}{\left(1 - \frac{300}{2000}\right)} \times 100$$

$$= 42.29\ \%$$

Q.4 (b)

Soln ->





T-s diagram of a Rankine cycle with superheat.

Steam 20 bar / 360°C

$T_{sat(1)} = 198°C$

$h_1 = 3159\ KJ\ kg^{-1}$

$s_1 = 6.99\ KJ\ kg^{-1}\ K^{-1}$

Exhaust steam 0.08 bar.

$h_3 = h_{f3} = 174\ KJ\ kg^{-1}$

$h_{fg3} = 2403\ kg/log$

$s_{f3} = 0.593\ KJ/log\ K$

$s_{fg3} = 7.636\ KJ/log\ K$

$v_{f3} = 0.001\ m^3/log$.

Calculation :- The expansion of steam in the ST is isentropic.

quality of steam

$$s_1 = s_2 = s_{f3} + x\, s_{fg3}$$

or

$6.99 \text{ KJ/kg K} = 0.593 \text{ KJ/kg K} + x(7.636 \text{ KJ/kg K})$

$x = 0.8377$.

Steam at state 2

$\therefore h_2 = hf_3 + x\,hfg_3$

$= 174 \text{ KJ/kg} + 0.8377 (2403 \text{ KJ/kg})$

$= \underline{2187 \text{ KJ/kg}}$.

pump work w_p

$w_p = hf_4 - hf_3$

$= vf_3 (P_1 - P_2)$

$= (0.001 \text{ m}^3/\text{kg})(20 - 0.08) \text{ bar} \times 10^2 \text{ KN/bar}$

$= 1.992 \text{ KJ/kg}$.

Turbine work w_T

$w_T = h_1 - h_2$

$= 3159 - 2187 \text{ KJ/kg}$.

$= 972 \text{ KJ/kg}$.

cycle efficiency η_{cycle}

$Q_{ip} = h_1 - h_4$

$= 3159 - (174 + 1.99) \text{ KJ/kg}$.

$= \underline{2983.01 \text{ KJ/kg}}$.

$w_{net} = w_T - w_p = (972 - 1.992) \text{ KJ/kg}$.

$= \underline{970 \text{ KJ/kg}}$

$\therefore \eta_{cycle} = Q_{input} / w_{net}$

$= \frac{970 \text{ KJ/kg}}{2983.01 \text{ KJ/kg}} = 0.325$

i.e $= \underline{32.57\ \%}$

Q.4 (c)

Ans :-

① Dryness fraction:

The ratio of mass of dry saturated steam in a given mass of wet steam is defined as dryness fraction. & it denoted by 'x'

$$x = \frac{m_s}{m_s + m}$$

② Enthalpy -

$$H = U + p \cdot V$$

The above equation U, p & V are point function i.e. they represent the property of the system. Therefore H so defined property of the system. this property H is called enthalpy.

For unit mass of gas we can write

$$h = u + p \cdot v$$

h = sp. enthalpy.

u = sp. internal energy.

③ Internal energy:

The internal energy is present in a system due to molecular motion, arrangement of atomic structure and chemical composition

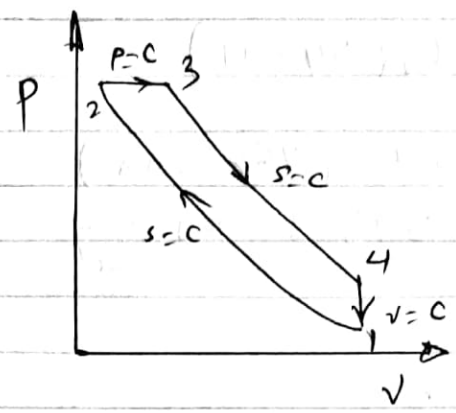
Various types of internal energy.

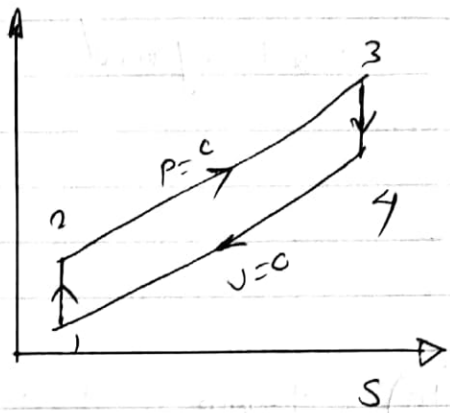
a) chemical energy b) Atomic energy c) Molecular internal energy.

4) Entropy - with the help of clausius inequality equation. we can derive as a consequence of second law of thermodynamics a significant property called entropy.

Q.5 (a).

Soln :-





$T_1 = 273 + 15 = 288\ K$

$P_1 = 0.1\ MPa = 100\ kN/m^2$

$T_3 = 1480 + 273 = 1753\ K$

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{n-1} = (16)^{0.4} = 3.03$$

$$T_2 = 288 \times 3.03 = 873\ K$$

Now, for process (2-3) $\frac{P_2 v_2}{T_2} = \frac{P_3 v_3}{T_3}$

but here since $P_2 = P_3$.

(i) cut off ration $= \frac{v_3}{v_2} = \frac{T_3}{T_2}$

$$= \frac{1753}{873} = 2.01$$

(ii) Heat supplied : $c_p (T_3 - T_2) = 1.005 (1753 - 873)$

$= 884.4\ kJ/kg$

$$\frac{T_3}{T_4} = \left(\frac{v_4}{v_3}\right)^{n-1} = \left(\frac{v_4}{v_2} \times \frac{v_2}{v_3}\right)^{n-1}$$

$$= \left[\frac{v_1}{v_2} \times \frac{v_2}{v_3}\right)^{n-1} = \left(\frac{16}{2.01}\right)^{n-1}$$

$= 2.29$.

$$T_4 = \frac{1753}{2.29} = 766\ K$$

Heat rejected : $q_2 = C_v(T_4 - T_1)$

$= 0.718(766 - 288)$

$= 343.2 \text{ kJ/kg}$.

iii) $\eta_{cycle} = 1 - \frac{q_2}{q_1} =$

$= 1 - \frac{343.2}{884.4}$

$= 61.2\%$

$v_1 = \frac{RT_1}{P_1} = \frac{0.287 \times 288}{100}$

$v_1 = 0.827 \text{ m}^3/\text{kg}$

$v_2 = \frac{0.827}{16} = 0.052 \text{ m}^3/\text{kg}$.

$v_1 - v_2 = 0.827 - 0.052$

$= 0.775 \text{ m}^3/\text{kg}$.

iv) Mean effective pressure :

$w_{net} = q_1 - q_2 = 541.2 \text{ kJ/kg}$

$mep = \frac{w_{net}}{v_1 - v_2} = \frac{541.2}{0.775}$

$= 698.45 \text{ kPa}$.