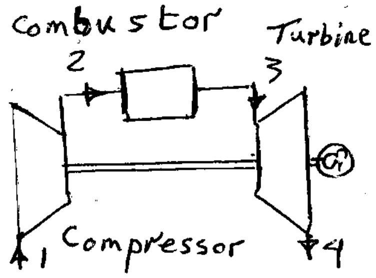
1-a) The network of the cycle per unit mass flow is



$$\frac{W_{cycle}}{\dot{m}} = w_{net} = (h_3 - h_4) - (h_2 - h_1)$$

$$= c_p\left[(T_3 - T_4) - (T_2 - T_1)\right]$$

$$= c_p T_1\left[\frac{T_3}{T_1} - \left(\frac{T_4}{T_3} \times \frac{T_3}{T_1}\right) - \frac{T_2}{T_1} + 1\right]$$

Replacing the temperature ratio $\frac{T_2}{T_1}$ and $\frac{T_4}{T_3}$, by using $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$, $\frac{T_4}{T_3} = \left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}}$

$$W_{net} = c_p T_1\left[\frac{T_3}{T_1} - \frac{T_3}{T_1}\left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}} - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} + 1\right]$$

$$\frac{\partial W_{net}}{\partial\left(\frac{P_2}{P_1}\right)} = \frac{\partial}{\partial\left(\frac{P_2}{P_1}\right)}\left\{c_p T_1\left[\frac{T_3}{T_1} - \frac{T_3}{T_1}\left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}} - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} + 1\right]\right\}$$

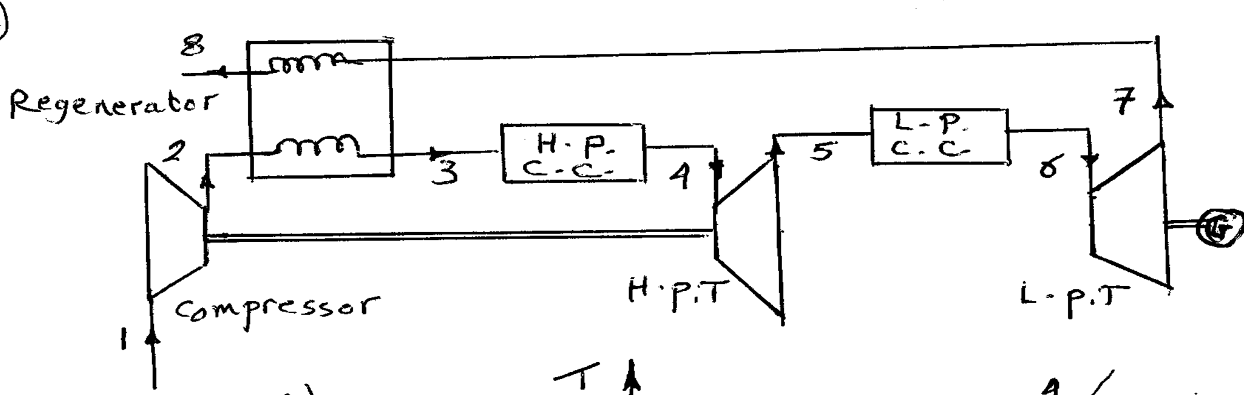
$$= c_p T_1\left(\frac{\gamma-1}{\gamma}\right)\left[\frac{T_3}{T_1}\left(\frac{P_1}{P_2}\right)^{-\frac{1}{\gamma}}\left(\frac{P_1}{P_2}\right)^{2} - \left(\frac{P_2}{P_1}\right)^{-\frac{1}{\gamma}}\right]$$

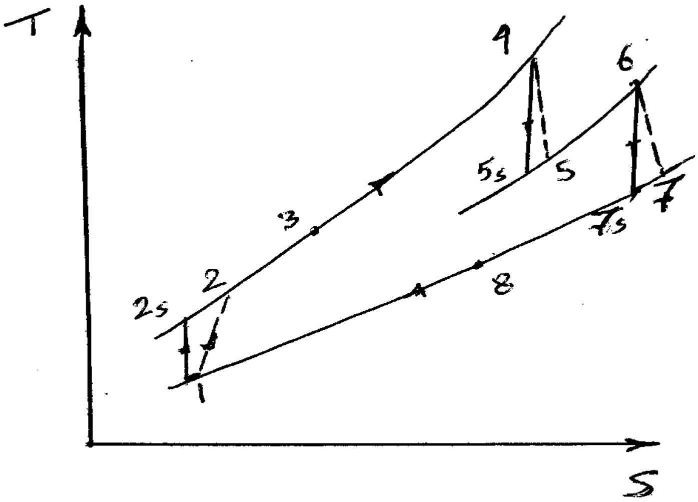
$$= c_p T_1\left(\frac{\gamma-1}{\gamma}\right)\left[\frac{T_3}{T_1}\left(\frac{P_1}{P_2}\right)^{\frac{2\gamma-1}{\gamma}} - \left(\frac{P_2}{P_1}\right)^{-\frac{1}{\gamma}}\right]$$

When the partial derivative is set to zero, the following relationship is obtained

$$\frac{P_2}{P_1} = \left(\frac{T_3}{T_1}\right)^{\frac{\gamma}{2(\gamma-1)}}$$

b)





$$\frac{T_{2s}}{T_1} = (r_{p_c})^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T_{2s}}{288} = (4)^{\frac{1.4-1}{1.4}}$$

$$T_{2s} = 427.966\,K$$

$$\eta_c = \frac{T_{2s} - T_1}{T_2 - T_1}$$

$$0.86 = \frac{427.966 - 288}{T_2 - 288}$$

$$T_2 = 450.75\,K$$

$$W_c = c_{p_{air}} (T_2 - T_1)$$

$$= 1.005\,(450.75 - 288) = 163.565\ \text{kJ/kg}$$

$$W_c = W_{H.P.T} = c_{p_{gas}} (T_4 - T_5)$$

$$163.565 = 1.15\,(933 - T_5)$$

$$T_5 = 790.77\,K$$

$$\eta_{H.P.T} = \frac{T_4 - T_5}{T_4 - T_{5s}}$$

$$0.84 = \frac{933 - 790.77}{933 - T_{5s}} \longrightarrow T_{5s} = 763.677\,K$$

$$\frac{T_4}{T_{5s}} = \left(\frac{P_4}{P_5}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{933}{763.677} = \left(\frac{4}{P_5}\right)^{\frac{1.333-1}{1.333}}$$

$$P_5 = 1.794 \text{ bar}$$

$$\frac{T_6}{T_{7s}} = \left(\frac{P_6}{P_7}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{898}{T_{7s}} = \left(\frac{1.795}{1}\right)^{\frac{1.333-1}{1.333}}$$

$$T_{7s} = 775.969 \text{ K}$$

$$\eta_{L.P.T} = \frac{T_6 - T_7}{T_6 - T_{7s}}$$

$$0.80 = \frac{898 - T_7}{898 - 775.969}$$

$$T_7 = 800.375 \text{ K}$$

$$W_{L.P.T} = Cp_{gas}(T_6 - T_7)$$

$$= 1.15(898 - 800.375)$$

$$= 112.268 \text{ kJ/kg}$$

$$\eta_{reg} = \frac{T_3 - T_2}{T_7 - T_2}$$

$$0.90 = \frac{T_3 - 450.75}{800.375 - 450.75}$$

$$T_3 = 765.413 \text{ K}$$

$$q_{in} = Cp_g\left[(T_4 - T_3) + (T_6 - T_5)\right]$$

$$= 1.15\left[(933 - 765.413) + (898 - 790.77)\right]$$

3,

$$q_{in} = 316.039 \text{ kJ/kg}$$

$$\eta_{th} = \frac{W_{L.P.T}}{q_{in}}$$

$$= \frac{112.268}{316.039}$$

$$= 35.5\%$$

$$\text{Power} = \dot{m}_{air} \times \text{net w.D} \times \eta_{mech} \times \eta_{gen}$$

$$= 1\,\frac{\text{kg}}{\text{sec}} \times 112.268 \times 0.92 \times 1$$

$$= 103.286 \text{ KW/kg}_{air}$$

2-a)

Back work ratio

Back work ratio defined as the ratio of the pump work input to the work developed by the turbine

$$b.w.r. = \frac{W_{pump}}{W_{turbine}}$$

Specific fuel consumption

The specific fuel consumption is the mass of fuel required at the steam generator to produced one kW·hr of electrical energy.

$$\text{Specific fuel consumption} = \frac{3600}{H.C.V \times \eta_{boiler} \times \eta_{mech.} \times \eta_{gen.} \times \eta_{th}} \; kg_{fuel}/kWhr$$

Specific steam Consumption

Specific steam Consumption is the mass of steam required to produce one kW·hr of electrical energy.

$$\text{Specific steam Consumption} = \frac{3600 \; kJ/kWhr}{W_{net} \times \eta_{mech.} \times \eta_{gen} \; kJ/kg\,st.}$$

$$= kg_{steam} / kW.hr$$

b)-

$$\Delta T = \frac{172 - 38.6}{2}$$

$$= 66.7\ ^\circ C$$

$$t_{H_2} = 38.6 + 66.7$$

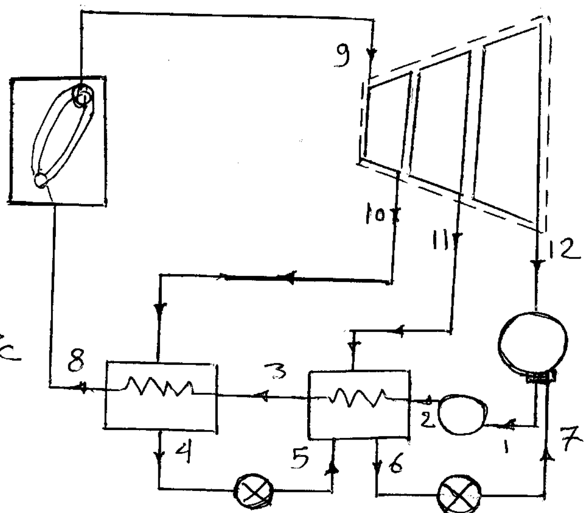
$$= 105.3\ ^\circ C$$

$$t_{H_1} = 105.3 + 66.7$$

$$= 172\ ^\circ C$$

$$t_{sat_6} = 105.3 + 5 = 110.3\ ^\circ C$$

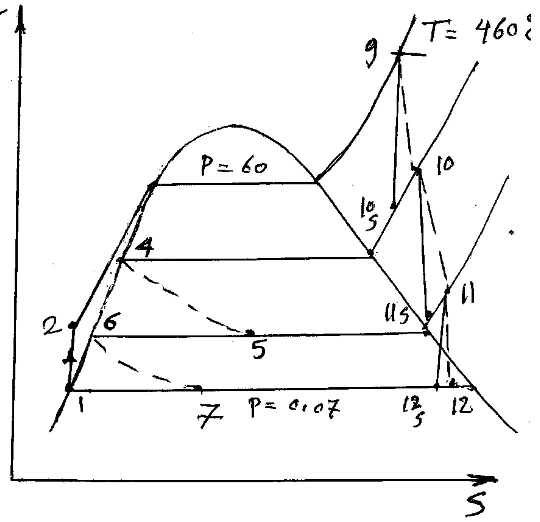
$$t_{sat_4} = 172 + 5 = 177\ ^\circ C$$



From table

at $t_{sat_6} = 110.3 \longrightarrow P \approx 1.5$ bar

at $t_{sat_4} = 177 \longrightarrow P \approx 9.5$ bar



$$h_1 = h_{f\ at\ P=0.07} = 163.4\ kJ/kg$$

$$v_1 = v_{f\ at\ P=0.07} = 0.0010074\ m^3/kg$$

$$w_p = v\left(P_{60} - P_{0.07}\right)100$$

$$= 0.0010074(60 - 0.07)100$$

$$= 6\ kJ/kg$$

$$h_2 = h_1 + w_p$$

$$= 163.4 + 6 = 169.4\ kJ/kg$$

$h_6 = h_{f\ at\ p = 1.5\ bar} = 467.1\ kJ/kg$ $\quad t_{sat_6} = 111.37\ ^\circ C$

$h_4 = h_{f\ at\ p = 9.5\ bar} = 752.8\ kJ/kg$ $\quad t_{sat_4} = 177.66\ ^\circ C$

$$t_{sat_3} = 111.37 - 5 = 106.37\ ^\circ C$$

$$t_{sat_8} = 177.66 - 5 = 172.66\ ^\circ C$$

$$h_5 = h_4$$

$$h_7 = h_6$$

$$h_3\ at\ t = 106.37,\ P = 60 = 450\ kJ/kg$$

h_8 at $t = 172.66$, $P = 60$ $= 733$ kJ/kg

h_9 at $P = 60$, $t = 460°C$ $= 3327.4$ kJ/kg

h_{10s} at $S_9 = S_{10s}$, $P = 9.5$ $= 2840$ kJ/kg

$$\eta_t = \frac{h_9 - h_{10}}{h_9 - h_{10s}}$$

$$0.83 = \frac{3327.4 - h_{10}}{3327.4 - 2840} \longrightarrow h_{10} = 2923 \text{ kJ/kg}$$

h_{11s} at $S_{10} = S_{11s}$, $P = 1.5$ $= 2570$ kJ/kg

$$\eta_t = \frac{h_{10} - h_{11}}{h_{10} - h_{11s}}$$

$$0.82 = \frac{2923 - h_{11}}{2923 - 2570} \longrightarrow h_{11} = 2633.5 \text{ kJ/kg}$$

h_{12s} at $S_{11} = S_{12s}$, $P = 0.07$ $= 2188$ kJ/kg

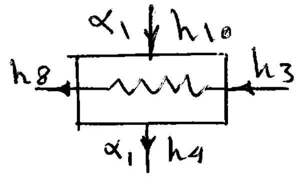
$$\eta_t = \frac{h_{11} - h_{12}}{h_{11} - h_{12s}}$$

$$0.81 = \frac{2633.5 - h_{12}}{2633.5 - 2188} \longrightarrow h_{12} = 2272.6 \text{ kJ/kg}$$

$\alpha_1 h_{10} + h_3 = \alpha_1 h_4 + h_8$

$\alpha_1 (2923) + 450 = \alpha_1 (752.8) + 733$

$\alpha_1 = 0.13$ $kg_{st.} / kg_{st}$ from boiler

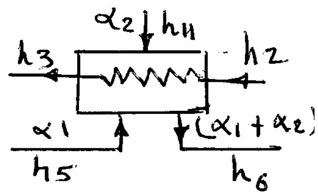


$\alpha_2 h_{11} + h_2 + \alpha_1 h_5 = h_3 + (\alpha_1 + \alpha_2) h_6$

$\alpha_2 (2633.5) + 169.4 + (0.13 \times 452.8) =$

$450 + (0.13 + \alpha_2)\, 467.1$

$\alpha_2 = 0.112$ kg_{st} / kg st from boiler



$$W_t = (h_9 - h_{10}) + (1-\alpha_1)(h_{10} - h_{11}) + (1-\alpha_1-\alpha_2)(h_{11} - h_{12})$$

$$= (3327.4 - 2923) + (1 - 0.13)(2923 - 2633.5) +$$

$$(1 - 0.13 - 0.112)(2633.5 - 2272.6)$$

$$= 929.827$$

$$\text{net w.D} = W_t - W_p$$

$$= 929.827 - 6 = 923.827 \quad \text{KJ/kg}$$

$$q_{add} = h_9 - h_8$$

$$= 3327.9 - 733 = 2594.4 \quad \text{KJ/kg}$$

$$\eta_{th} = \frac{\text{net w.D}}{q_{add}}$$

$$= \frac{923.827}{2594.4} = 0.356 = 35.6\ \%$$

$$\text{power} = \dot{m}_{st} \times \text{net w.D} \times \eta_{mech.} \times \eta_{gen.}$$

$$50000 = \dot{m}_{st} \times 923.827 \times 1 \times 1$$

$$\dot{m}_{st} = 54.1227 \quad \text{kg/sec}$$

$$= 194.8416 \quad \text{ton/hr}$$

3-a) $\eta_{th} = 1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}$

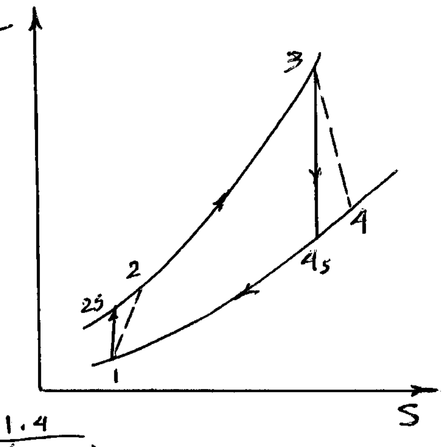
$0.32 = 1 - \frac{1}{(r_p)^{\frac{1.4-1}{1.4}}}$

$r_p = 3.8567$

$r_p = \left[\frac{T_3}{T_1}\eta_t \eta_c\right]^{\frac{\gamma}{2(\gamma-1)}}$

$3.8567 = \left[\frac{T_3}{300} \times 0.85 \times 0.8\right]^{\frac{1.4}{2(1.4-1)}}$

$T_3 = 954 \text{ K}$



b- pump work input : ≈ remain the same

Turbine work output : increases

Heat added : increases

Heat rejected : decreases

Cycle efficiency : increases

Moisture content at exit the turbine increases

4-a)

1- Load Factor. It is defined as the ratio of average load to maximum demand. Load factors is always less than unity.

2- Diversity Factor. It is defined as the ratio of sum of individual maximum demand to the simultaneous maximum demand of a system. Divesity factor is more than unity.

3- Capacity Factor. It is defined as the ratio of actual energy produced in kilowatt hours (kWh) to the maximum possible energy that could have been produced during the same period.

$$\text{Plant Capacity Factor} = \frac{E}{C \cdot t} = \frac{L_{av}}{R.c.} < 1$$

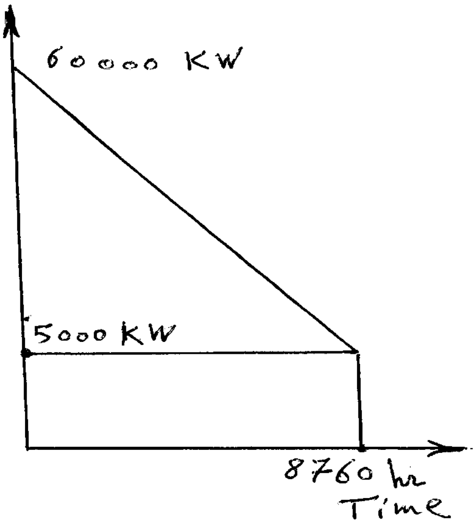
where. E = Energy produced (kWh) in a given period
C = Capacity of the plant in kW
t = total number of hours in the given period

4- Plant use Factor. It is defined as the ratio of energy produced in given time to the maximum possible energy that could have been produced during the actual number of hours the plant was in operation

$$\text{Plant use Factor} = \frac{E}{C \cdot t_1}$$

where t_1 = actual number of hours the plant has been operation.

b - The energy generated per year by the plant = Area under the Load curve



$$E = 8760\left[\frac{1}{2}(60000 - 5000) + 5000\right]$$

$$= 8760 \times 32500 \text{ KW hr}$$

$$\text{Average Load} = \frac{E}{h}$$

$$= \frac{8760 \times 32500}{8760}$$

$$= 32500 \text{ KW}$$

$$\text{Load Factor} = \frac{L_{av}}{L_{max}}$$

$$= \frac{32500}{60000} = 0.5416$$

$$\text{Capacity of plant} = 2 \times 25000 + 15000$$

$$= 65000 \text{ KW}$$

$$\text{Capacity Factor} = \frac{\text{Energy produced}}{\text{Capacity of plant} \times \text{Time}}$$

$$= \frac{8760 \times 32500}{65000 \times 8760}$$

$$= 0.5 = 50\%$$