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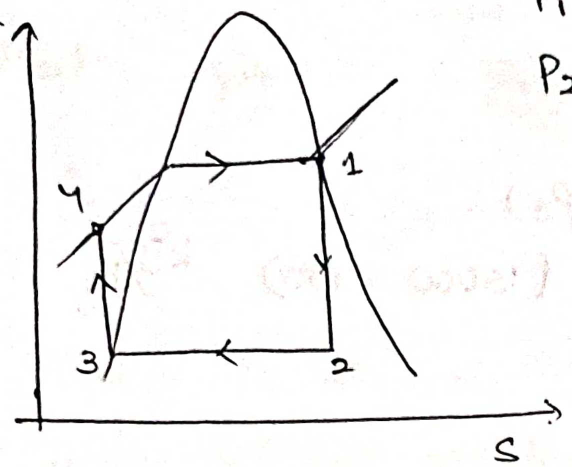
TUTORIAL - 9.

1.



$P_1 = 15\ MPa = P_4$

$P_2 = P_3 = 100\ KPa$

State 1 ⇒ saturated steam

$T_1 = 342.24\ °C$

$T_1 = 615.24\ K.$

$s_1 = s_g$ @ 15MPa

$s_1 = 5.3181\ KJ/kgK$

Now $s_1 = s_2$

⇒ $s_2 = 5.3181\ KJ/kgK$

$h_1 = h_g$ @ 15MPa

$h_1 = 2615.3\ KJ/kg.$

Also $s_2 = s_f + x\, s_{fg}$ @ 100KPa

$5.3181 = 1.3038 + x \times 6.0539$

⇒ $x = 0.663$

⇒ $h_2 = h_f + x\, h_{fg}$ @ 100 KPa

$h_2 = \cancel{419} + 418 + 0.663 \times 2257.4.$

$h_2 = 1914.65\ KJ/kg$

$h_3 = h_f$ @ 100 KPa

$h_3 = 418\ KJ/kg.$

Now $h_4 - h_3 = v_3 (P_4 - P_3)$ //

Because in open system

$W = \int v\, dp$

And ~~v remains~~ we can assume v remains constant for liquids as they are incompressibl.

$v_3 = v_f$ @ 100 kPa

$v_3 = 0.001043 \ m^3/kg$.

$h_4 - h_3 = v_3 (p_4 - p_3)$

$h_4 \cancel{h_3} = h_3 + v_3 (p_4 - p_3)$

$h_4 = 418 + 0.001043 \ (15000 - 100) \ KJ/kg$

$h_4 = 418 + 15.54$

$h_4 = 433.54 \ kJ/kg$.

Now work done by turbine

$W_T = h_1 - h_2$ (By first law)

$W_T = 2615.3 - 1914.65$

$W_T = 700.65 \ KJ/kg$

Heat transfered to boiler

$q_H = h_1 - h_4$

$= 2615.3 - 433.54$

$q_H = \cancel{2181k} \ 2181.76 \ KJ/kg$.

Work consumed by pump.

$w_p = \cancel{h_3 - h_4} \ h_4 - h_3$

$= 433.54 - 418$

$w_p = 15.54 \ KJ/kg$

Now efficiency $\eta = \dfrac{w_T - w_p}{q_H}$

$= \dfrac{700.65 - 15.54}{2181.76}$

$= 0.314$

$= 31.4\%$

electric Power 300 MW.

$\Rightarrow$ Cycle $\xrightarrow{\dot{W}_{net}}$ Generator $\xrightarrow{300\ MW.}$ $\eta_{gene} = 0.96$

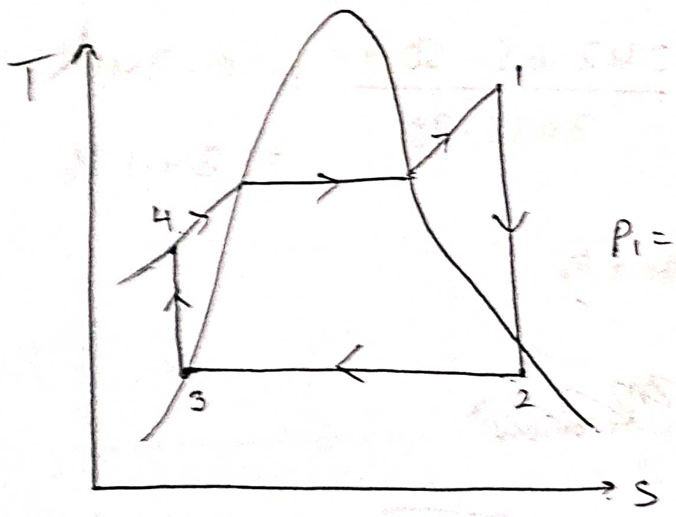
Heat is given to boiler by burning coal.

Coal $\longrightarrow \dot{q}_H \longrightarrow$ cycle $\eta_{com} = 0.75$

There is also a thermal efficiency within the cycle which relates $\dot{q}_H$ & $\dot{w}_{net}$ $\Rightarrow \eta_{Therm}$:

$\eta_{Thermal}$: Given State 1 : 5 MPa, 450°C $\Rightarrow$ superheated state.

$P_2 = P_3 = 25\ KPa$.



$P_1 = P_4$

$S_1 = 6.8185\ KJ/kg\,K$

$\Rightarrow S_2 = 6.8185\ KJ/kg\,K$

At 25 KPa

$S = 6.8185\ KJ/kg.K$

State 2. $\Rightarrow$ L–V mix state

$h_1 = 3316.15\ KJ/kg$ (superheated table)

$S_2 = S_f + x\,S_{fg}$ @ 25 kPa.

$6.8185 = 0.8934 + x \times 6.9383$

$x = 0.853$

$h_2 = h_f + x\,h_{fg}$ @ 25 kPa

$h_2 = 272.1 + 0.853 \times 2346.3$

$h_2 = 2273.5\ KJ/kg$.

New, $h_3 = h_f$ @ 25 KPa.

$h_3 = 272.1\ KJ/kg$.

$v_3 = v_f$ @ 25 KPa

$v_3 = 0.001020\ m^3/kg$.

Also, $h_4 - h_3 = v_3(P_4 - P_3)$

$h_4 = h_3 + v_3(P_4 - P_3)$

$= 272.1 + 0.001020(5000 - 25)$

Work done by turbine

$$w_T = h_1 - h_2$$
$$= 3316.15 - 2273.5$$
$$w_T = 1042.65 \text{ KJ/kg}$$

work consumed by pum

$$w_p = h_4 - h_3$$
$$= 277.17 - 272.1$$
$$w_p = 5.07 \text{ KJ/kg}$$

Heat absorbed by boiler

$$q_H = h_1 - h_4$$
$$= 3316.15 - 277.17$$
$$q_H = \cancel{3038} \; 3038.98 \text{ KJ/kg}$$

$$\eta_{Thermal} = \frac{w_T - w_p}{q_H} = \frac{1042.65 - 5.07}{3038.98} = 0.341$$
$$= 34.1\%$$

$$\eta_{Thermal} = 34.1\%$$

Overall plant efficiency: $\cancel{= \eta_{combus}}$

Coal → q_H → cycle → w_{net} → $\boxed{\text{Gen}}$ → 300 MW (W_{elec})

($\dot{m}_c \times CV$) η_{com} η_{Therm} η_{gen}

$$\eta_{overall} = \frac{W_{elec}}{\dot{m}_c \times CV} = \eta_{com} \times \eta_{Therm} \times \eta_{gen}$$
$$= 0.75 \times 0.341 \times 0.96$$
$$= 0.245$$
$$= 24.5\% \text{ efficiency.}$$

$$\frac{W_{elec}}{\dot{m}_c \times CV} = 0.245$$

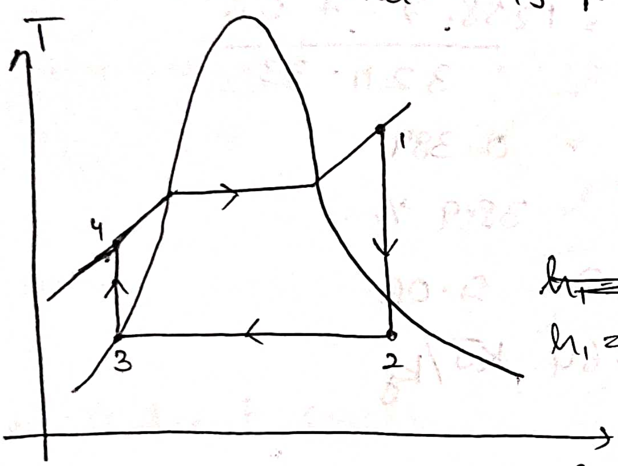
$$\dot{m}_c = \frac{300 \times 10^3 \text{ kW}}{0.245 \times 29300 \text{ kJ}} \text{ kg}$$

$$\dot{m}_c = 41.8 \text{ kg/s} \times 3600 \frac{\text{s}}{\text{hr}}$$

$$\dot{m}_c = 150449.25 \frac{\text{kg}}{\text{hr}}$$

$$\approx 150 \text{ t/hr.}$$

3. Given $\dot{W}_{net} = 45 \text{ MW}$



State 1: $P_1 = 7 \text{ MPa} = P_4$ ⇒ super heated vapour

$T_1 = 500°C$

$P_2 = P_3 = 10 \text{ kPa}$.

~~$h_1 = h_g$ @ 7 MPa~~ $S_1 = 6.7974$ kJ/kgK

$h_1 = 3410.29$ kJ/kg $S_2 = S_1 = 6.7974$ kJ/kgK

@ 10 kPa $s = 6.7974$ kJ/kgK

State 2 ⇒ L-V mix state.

$S_2 = S_f + x S_{fg}$ @ 10 kPa

$6.7974 = 0.6494 + x \times 7.5013$

$x = 0.819$

$h_2 = h_f + x h_{fg}$ @ 10 kPa

$= 191.9 + 0.819 \times 2392.8$

$h_2 = 2151.6$ kJ/kg.

$h_3 = h_f$ @ 10 kPa

$h_3 = 191.9$ kJ/kg.

$v_3 = v_f$ @ 10 kPa

$v_3 = 0.001010 \text{ m}^3/\text{kg}$.

$h_4 = h_3 + v_3(P_4 - P_3)$

$= 191.9 + 0.001010 (7000 - 10)$

$h_4 = 198.96$ kJ/kg

Work consumed by pump

$w_p = h_4 - h_3$

$= 198.96 - 191.9$

$w_p = 7.06$ KJ/kg.

Work done by turbine

$w_T = h_1 - h_2$

$= 3410.29 - 2151.6$

$w_T = 1258.7$ KJ/kg.

Heat absorbed by boiler

$q_H = h_1 - h_4$

$= 3410.29 - 198.96$

$q_H = 3211.33$ KJ/kg

1251.64

$$\eta_{Therm} = \frac{w_T - w_p}{q_H} = \frac{1258.7 - 7.06}{3211.33}$$

$= 0.389$

$= 38.9\%$

$w_{net} = w_T - w_p = 1258.7 - 7.06$

$= 1251.64$ KJ/kg.

Now $\dot{W}_{net} = \dot{m}_s w_{net}$

$$\dot{m}_s = \frac{\dot{W}_{net}}{w_{net}}$$

$$= \frac{45 \times 10^3 \text{ KJ/s}}{1251.64 \text{ KJ/kg}}$$

$\dot{m}_s = 35.9$ kg/s

≈ 36 kg/s

Heat lost in the condensor is the heat taken by the cooling water

Heat lost in condenser.

$q_L = h_2 - h_9$

$= 2151.6 - 191.9$

$q_L = 1959.7 \text{ KJ/kg}$

$\dot{q}_L = \dot{m}_s q_L$

$= \cancel{36}\, 35.9 \times 1959.7$

$\dot{q}_L = 70353.2 \text{ KJ/s} \longrightarrow$ Cause for temperature rise in water

$\dot{m}_{water} C_{water} (\Delta T) = \dot{q}_L$

$2000 \frac{\cancel{kg}}{\cancel{s}} \times 4.18 \frac{\cancel{KJ}}{\cancel{kg}\,°C} (\Delta T) = 70353.2 \text{ KJ}/\cancel{s}$

$\Delta T = 8.415°C$

$\boxed{\Delta T = 8.4°C}$

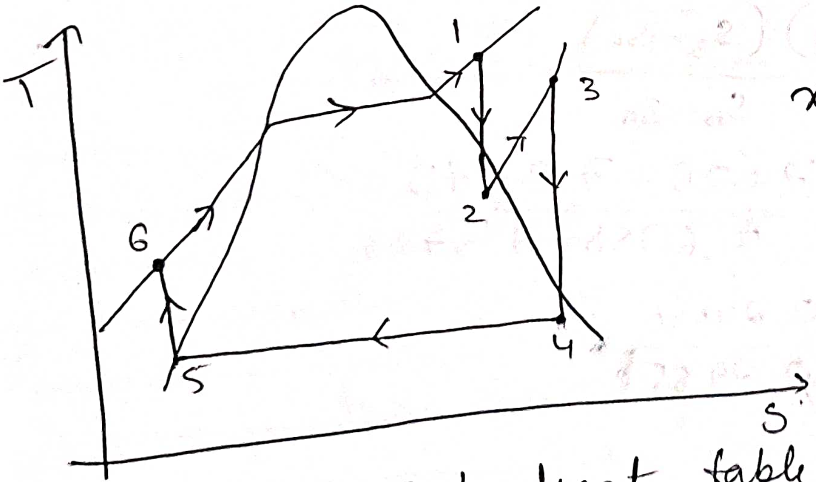
4. Reheat cycle

Given $P_1 = 5000 \text{ KPa} = P_6$

$P_3 = 1200 \text{ KPa} = P_2$

$P_4 = P_5 = 20 \text{ KPa}$

$x_2 = 0.96 \quad x_4 = 0.96$



$S_2 = S_f + x_2 S_{fg}$ @ 1200 kPa

$S_2 = 2.2163 + 0.96 \times 4.3024$

$S_2 = 6.34 \text{ KJ/kgK} = S_1$

From superheat table at 50 bar we find temperature for $S = 6.34$ KJ/kg K.

$\Downarrow$

lies b/w 300°C to 350°C

$$\cancel{T_b = T_a + (T - T_a)\frac{(S_b - S_a)}{(S - S_a)}}$$ ~~[in the ta~~

$$\cancel{300\ T_b = 300 + (T-300)}$$

$$T_1 = T_a + (T_b - T_a)\frac{(S_1 - S_a)}{(S_b - S_a)}$$

$$T_1 = 300 + 50 \times \frac{(6.34 - 6.2083)}{(6.4492 - 6.2083)}$$

$$T_1 = 300 + 50 \times \frac{0.1317}{0.2409}$$

$$T_1 = 327.33^\circ C$$

@ State 4 : $S_4 = S_f + x\, S_{fg}$ @ 20kPa

$$S_4 = 0.8322 + 0.96 \times 7.0774$$

$$S_4 = 7.626\ KJ/kgK$$

$$S_3 = S_4 = 7.626\ KJ/kgK.$$

Again in superheat table @ 12 bar lies b/w 400°C-500°C

$$T_3 = T_a + (T_b - T_a)\frac{(S_3 - S_a)}{S_b - S_a}$$

$$T_3 = 400 + 100 \times \frac{7.626 - 7.3773}{7.6758 - 7.3773}$$

$$= 400 + 100 \times \frac{0.2487}{0.2985}$$

$$T_3 = 483.3^\circ C$$

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$$h_1 = h_a + (h_b - h_a)\frac{(T_1 - T_a)}{T_b - T_a} \quad @\ 50\ bar$$

$h_1 = \cancel{3145.64}$

$$= 2924.53 + (3068.39 - 2924.53)\frac{(327.33 - 300)}{(350 - 300)}$$

$$= 2924.53 + 143.86 \times \frac{27.33}{50}$$

$$h_1 = 3002.21\ kJ/kg$$

$$h_3 = h_a + (h_b - h_a)\frac{(T_3 - T_a)}{T_b - T_a} \quad @\ 12\ bar$$

$$h_3 = 3260.66 + (3476.28 - 3260.66)\frac{(483.3 - 400)}{500 - 400}$$

$$= 3260.66 + 215.62 \times \frac{83.3}{100}$$

$$h_3 = 3440.27\ kJ/kg$$

$$h_2 = h_f + x_2 h_{fg} \quad @\ 1200\ kPa$$

$$h_2 = 798.7 + 0.96 \times 2014.9$$

$$h_2 = 2733.004\ kJ/kg$$

$$h_4 = h_f + x_4 h_{fg} \quad @\ 20\ kPa$$

$$= 251.5 + 0.96 \times 2358.4$$

$$h_4 = 2515.5\ kJ/kg$$

$$h_5 = h_f \quad @\ 20\ kPa$$

$$= 251.5\ kJ/kg$$

$$v_5 = v_f \quad @\ 20\ kPa$$

$$= 0.001017\ m^3/kg$$

$$h_6 - h_5 = v_5 (P_6 - P_5)$$

$$h_6 = 251.5 + 0.001017\,(5000 - 20)$$

$$h_6 = 256.56\ kJ/kg.$$

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$w_{net} = w_{LT} + w_{HT} - w_p$

$w_{LT} = h_3 - h_4$ (Work done by low press turbine

$= 3440.27 - 2515.5$

$w_{LT} = 924.77$ KJ/kg

$w_{HT} = h_1 - h_2$ (Work done by high press turbine)

$= 3002.2 - 2733.004$

$w_{HT} = 269.2$ KJ/kg

$w_p = h_6 - h_5$

$= 256.56 - 251.5$

$w_p = 5.06$

$w_{net} = 924.77 + 269.2 - 5.06$

$w_{net} = 1188.91$ KJ/kg.

$q_{in} = q_{6-1} + q_{2-3}$

$= h_1 - h_6 + h_3 - h_2$

$q_{in} = 3002.2 - 256.56 + 3440.27 - 2733.004$

$q_{in} = 3452.86$ KJ/kg

$$\eta = \frac{w_{net}}{q_{in}}$$

$$\eta = \frac{1188.91}{3452.86}$$

$= 0.344$

$\eta = 34.4\%$

Q. Reheat Cycle. $W_{net} = 80\ MW$

State 1 : $P_1 = 10MPa$ $T_1 = 500°C$ $P_{6s} = P_1 = 10MPa$

State 3 : $P_3 = 1MPa$ $T_3 = 500°C$ $P_{2s} = P_3 = 1MPa$

$P_{4s} = P_5 = 10kPa$

Superheated ~~Saturated~~ vapour

State 5 → saturated liq.

$s_1 = 6.5965\ kJ/kgK = s_{2s}$

$h_1 = 3373.63\ kJ/kg$

@ P_2 $s_2 = 6.5965\ kJ/kgK$ ⇒ superheated ~~saturated~~ vapour

Superheated ~~Saturated~~ vapour

$s_3 = 7.7621\ kJ/kgK = s_{4s}$

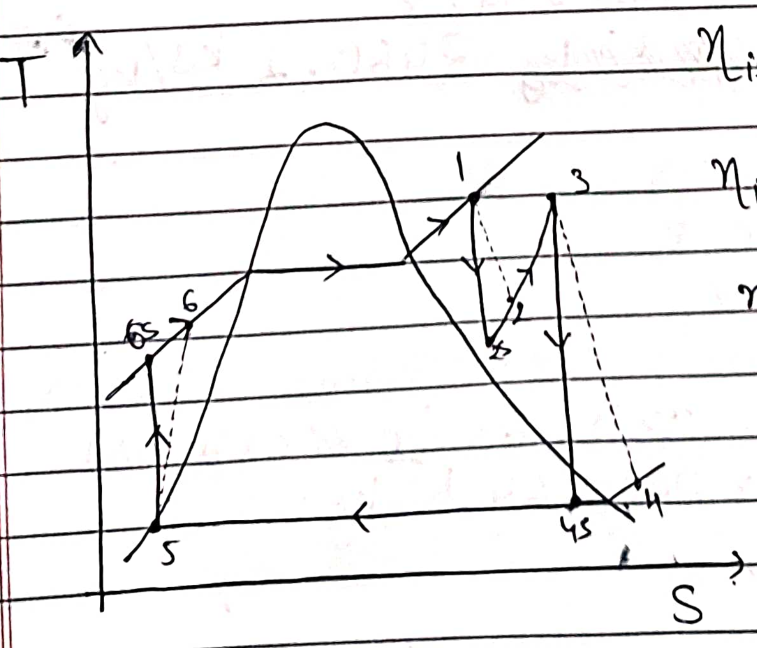
$h_3 = 3478.44\ kJ/kg$

@ P_{4s} $s_{4s} = 7.7621$ ⇒ L-V mix

$s_{4s} = s_f + x s_{fg}$ @ 10kPa

$7.7621 = 0.6494 + x\ 7.5013$

$x_{4s} = 0.948$



$\eta_{isen,1-2} = \frac{h_1 - h_2}{h_1 - h_{2s}}$ (Turbine)

$\eta_{isen,3-4} = \frac{h_3 - h_4}{h_3 - h_{4s}}$ (Turbine)

$\eta_{isen,5-6} = \frac{h_{6s} - h_5}{h_6 - h_5}$ (Pump)

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$h_5 = h_f @ 10 kPa$ $\quad v_5 = v_f @ 10 kPa$
$= 191.9 \, kJ/kg$ $\quad = 0.001010 \, m^3/kg$

$h_{6s} - h_5 = v_5 (p_6 - p_5)$
$\cancel{= 0.0010}$
$h_{6s} = h_5 + v_5 (p_6 + p_5)$
$= 191.9 + 0.001010 (10000 - 10)$
$h_{6s} = 201.99 \, kJ/kg$

$h_{2s} \rightarrow$ state 2s is superheated @ 1MPa
$s_{2s} = 6.5965 \, kJ/kgK$
$$h_{2s} = h_a + (h_b - h_a)\frac{(s_{2s} - s_a)}{s_b - s_a}$$
$$= 2779.9 + (2827.86 - 2779.9)\frac{(6.5965 - 6.5819)}{6.6939 - 6.5819}$$
$$= 2779.9 + 47.96 \times \frac{0.0146}{0.112}$$
$h_{2s} = 2786.152 \, kJ/kg$

$h_{4s} = h_f + x_{4s} h_{fg}$ @ 10kPa
$h_{4s} = 191.9 + 0.948 \times 2392.8$
$h_{4s} = 2460.2 \, kJ/kg$

$\eta_{isen,1-2} = 0.8$
$$\frac{h_1 - h_2}{h_1 - h_{2s}} = 0.8$$
$3373.63 - h_2 = 0.8 (3373.63 - 2786.15)$
$h_2 = 3373.63 - 0.8(587.48)$
$h_2 = 2903.64 \, kJ/kg.$

$\eta_{isen, 3-4} = 0.8$

$$\frac{h_3 - h_4}{h_3 - h_{4s}} = 0.8$$

2460.2

$3478.44 - h_4 = 0.8(3478.44 - \cancel{2460.2})$

$h_4 = 3478.44 - \cancel{\quad} 814.5$

$h_4 = \cancel{\quad}$ $2663.94\ kJ/kg$

$\eta_{isen\ 5-6} = 0.95$

$h_{6s} - h_5 = 0.95(h_6 - h_5)$

$$h_6 = h_5 + \frac{h_{6s} - h_5}{0.95}$$

$$= 191.9 + \frac{201.99 - 191.9}{0.95}$$

$h_6 = 202.52\ kJ/kg$

h_4 @ 10 kPa $\Rightarrow$ superheated state.

In superheated table h_4 lies b/w 50°C to 100°C

Interpolation

$$T_4 = T_a + (T_b - T_a)\frac{(h_4 - h_a)}{h_b - h_a}$$

$$\cancel{T_4 = 50 + 50 \times \frac{2648.6 - 2592.56}{2687.46 - 2592.56}}$$

$$\cancel{= 50 + 50 \times \frac{56.04}{94.9}}$$

$$T_4 = 50 + 50 \times \frac{2663.94 - 2592.56}{2687.46 - 2592.56}$$

$$= 50 + 50 \times \frac{71.38}{94.9}$$

a) $\boxed{T_4 = 87.6°C}$ $\longrightarrow$ Temp at which steam leaves turbine

$w_{net} = w_{LT} + w_{HT} - w_p$

$q_{in} = q_{6-1} + q_{2-3}$

~~w_{HT}~~ (Work done by low pressure turbine)

$w_{LT} = h_3 - h_4$

$= 3478.44 - 2663.94$

$w_{LT} = 814.5$ KJ/Kg

$w_{HT} = h_1 - h_2$ (Work done by high pressure turbine)

$w_{HT} = 3373.63 - 2903.64$

$w_{HT} = 469.99$ KJ/Kg

$w_p = h_6 - h_5$ (Work consumed by pump)

$w_p = 202.52 - 191.9$

$= 10.62$ KJ/Kg.

$w_{net} = 814.5 + 469.99 - 10.62$

$= 1273.87$ KJ/Kg

~~q_{in}~~ $q_{6-1} = h_1 - h_6$

$= 3373.63 - 202.52$

$= 3171.11$ KJ/Kg

$q_{2-3} = h_3 - h_2$

$= 3478.44 - 2903.64$

$q_{23} = 574.8$ KJ/Kg

$q_{in} = 3171.11 + 574.8$

$= 3745.91$ KJ/Kg.

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$$\eta_{Thermal} = \cancel{1273.87}\ \frac{w_{net}}{q_{in}}$$

$$= \frac{1273.87}{3745.91}$$

b) $$\boxed{\eta_{Ther} = 0.340 = 34\%}$$

Given $\dot{W}_{net} = 80MW$.

$$\dot{m}_s w_{net} = 80MW.$$

$$\dot{m}_s = \frac{80 \times 10^3 \ \frac{kJ}{s}}{1273.87 \ \frac{kJ}{kg}}$$

c) $$\boxed{\dot{m}_s = 62.8 \ \frac{kg}{s}}$$