SOLUTIONS

VAPOUR POWER CYCLE

Sol:1 (D)

$\eta_{overall} = \eta_g \times \eta_b \times \eta_t \times \eta_{auxill} \times \eta_c$

$\eta_{auxill} = 0.9268$

$\therefore$% electricity generated is consumed in running auxiliaries $= (1 - 0.9268) \times 100$

$= 7.32\%$

Sol:2 (B)

Sol:3 (C)

Sol:4 (B)

$\eta_{overall} = \eta_1 + \eta_2 - \eta_1 \times \eta_2$

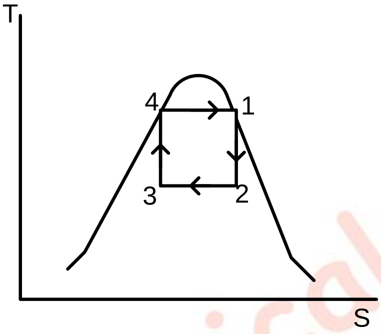
Sol:5 (D)

Sol:6 (A)

Sol: 7 & 8

$h_1 = 2724.7$ KJ/kg

$S_1 = 5.6141\ kJ/kgk = S_2$



$5.6141 = 0.4764 + x(8.3911 - 0.4764)$

$x_2 = 0.65$

$h_2 = h_f + x(h_g - h_f)$

$h_2 = 1713.22$ KJ/kg

$h_4 = 1407.56$ KJ/kg

$S_4 = 3.3596$ KJ/kg K

$S_4 = S_3$

$\therefore 3.3596 = 0.4764 + x(3.3911 - 0.4764)$

$x_3 = 0.364$

$h_3 = 1020.73$ KJ/kg

$W_{net} = h_1 - h_2 - h_4 + h_3$

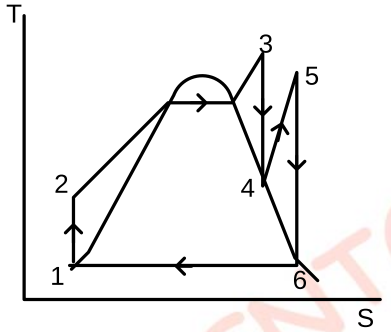
$W_{net} = 624.65\ kJ/kgk$

$\therefore SSC = \frac{3600}{W_{net}} = 5.74$ kg/kWh

$W_T = h_1 - h_2 = 1011.48$ KJ/kg

$work$ ratio $= \frac{W_{net}}{W_T} = 0.617$

Sol: 9 & 10



$W_{HPt} = h_3 - h_4$

$= 486$ KJ/kg

$W_{CPT} = h_5 - h_6$

$= 1005$ KJ/kg

$h_3 = 3095$ KJ/kg $h_4 = 2609$ KJ/kg

$h_5 = 3170$ KJ/kg $h_6 = 2165$ KJ/kg

$h_1 = 29.3$ KJ/kg

Assuming $h_1 \approx h_2$

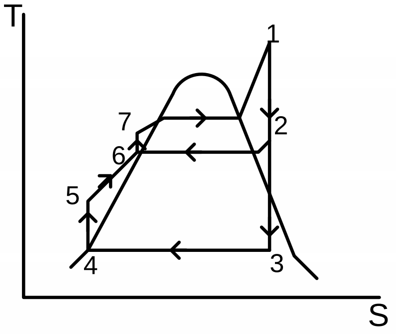
$\therefore Q_s = h_3 - h_1 + h_5 - h_4$

$= 3626.7$ KJ/kg

$\eta = \frac{W_{net}}{Q_S} = \frac{W_{HPT} + W_{LPT}}{Q_S} \times 10$

$\eta = 41.11\%$

Sol: 11 & 12



$h_1 = 3675.3$ KJ/kg

$S_1 = S_2 = 6.6582$ KJ/kg K $\&S_2 = S_g = 6.6628$ KJ/kg K

$\therefore x \approx 1$

$h_2 = h_g = 2761.11$ KJ/kg

$S_1 = S_3 = 6.6582$ KJ/kg K

$6.6582 = 0.4764 + x7.9187$

$x = 0.78$

$h_3 = 2028.306$ KJ/kg $\quad h_4 = 137.82$ KJ/kg

$h_5 = h_4 + v_4 dp = 138.01$ KJ/kg

$h_6 = 721.11$ KJ/kg

$h_7 = h_6 + v_6 dp$

$= 721.8$ KJ/kg

$Q_S = h_1 - h_7 \qquad W_{net} = (h_1 - h_2) + (1-m)(h_2 - h_3)$

$\eta = \dfrac{W_{net}}{Q_S}$ (Neglecting pump work)

Sol:13 (A)

Sol:14 (B)

Sol:15 (D)

Sol:16 (D)

Sol:17 (A)

Sol:18 (C)

Sol: 19

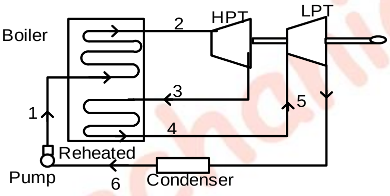
From steam table at 15MPa & 550^{0}C

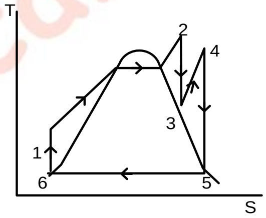
$h_2 = 3445.2$ KJ/kg

$S_2 = 6.5125$ KJ/kg K

From mollier diagram (at P = 3MPa & S = 6.5125 KJ/kg K)

(A)





(B) State 3 is in superheated region

$\therefore h_3 = 2990$ KJ/kg K

$h_4 = 3344.35$ KJ/kg (from ST at 3MPa & 550^{0}C)

$S_4 = 7.3715$ KJ/kg K

Process 4-5 is isentropic

$\therefore S_4 = S_5 = 7.3715$ KJ/kg K

$7.3715 = S_f + xS_{fg}$

(from ST, at 54^{0}C)

$7.3715 = 0.755 + 7.254x$

$x = 0.912$

$\therefore h_5 = 2390.64$ KJ/kg

$h_6 = 226$ KJ/kg

$h_1 = h_6 + v_6(P_1 - P_6) = 226 + 0.1014(150 - 15.002)$

$h_1 = 239.69$ KJ/kg

$W_T = W_{HPT} + W_{LPT} = h_2 - h_3 + h_4 - h_5 = 1408.9$ KJ/kg

$W_P = h_1 - h_6 = 13.69$ KJ/kg

$W_{net} = W_T - W_P = 1395.22$ KJ/kg

$Q_S = h_2 - h_1 + h_4 - h_3 = 3559.86$

(C) $\therefore \eta = \dfrac{W_{net}}{Q_s} = 39.19\%$

(D) $210 \times 10^3 = m_s(h_2 - h_3) = 455.2 m_s$

Steam flow rate (m_s) = 461.33 kg/s

(E) $m_s(h_5 - h_6) = m_w C_{p_w} \Delta T$

$m_w = 34128.96$ Kg/s

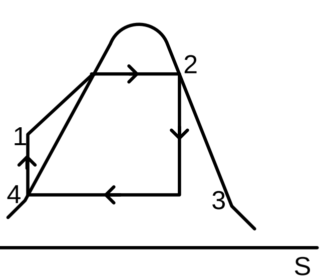
Heat transfer rate in condenser $= m_s(h_5 - h_6) =$ 998.6MW

(F) $Q_s = m_s(h_2 - h_1) = m_f \times C_v$

$m_f = 73.94$ Kg/s

Sol: 20

When boiler pressure is 3MPa



$h_2 = 2802.3$ KJ/kg (from ST, at 30 bar x = 1)

$S_2 = 6.184$ KJ/kg K

$S_2 = S_3$

$\therefore 6.184 = 0.649 + 7.502x$ (at 0.1 bar)

$x = 0.738$

$\therefore h_3 = 191.8 + 0.738 \times 2392.9 = 1957.76$ KJ/kg

$h_4 = 191.8$ KJ/kg

$h_1 = h_4 + vdp$

$= 191.8 + 0.101(30 - 0.1)$

$h_1 = 194.82$ KJ/kg

$\eta_3 = \dfrac{W_{net}}{Q_s} = \dfrac{h_2 - h_3 - h_1 + h_4}{h_2 - h_1} = 32.27\%$

For boiler pressure 6MPa

$h_2 = 2785$ KJ/kg (from ST, at 60 bar)

$S_2 = 5.89$ KJ/kg K

$S_2 = S_3$

$5.89 = 0.649 + 7.502x$ (from ST, at 0.1 bar)

$x = 0.698$

$h_3 = 1862.04$ KJ/kg

$h_4 = 191.8$ KJ/kg

$h_1 = 191.8 + 0.101(60 - 0.1)$

$h_1 = 197.85$ KJ/kg

$\eta_6 = 35.44\%$

For boiler pressure 9MPa.

$h_2 = 2744.6$ KJ/kg

$S_2 = 5.682$ KJ/kgk

$5.682 = 0.649 + 7.502x$

$x = 0.67$

$h_3 = 1795.04$ KJ/kg

$h_4 = 191.8$ KJ/kg

$h_1 = 200.88$ KJ/kg

$\eta_9 = 36.97\%$

For pressure = 12MPa

$h_2 = 2698.2$ KJ/kg

$S_2 = 5.5$ KJ/kg K

$5.5 = 0.649 + 7.502x$

$x = 0.646$

$h_3 = 1737.6$ KJ/kg

$h_4 = 191.8$ KJ/kg

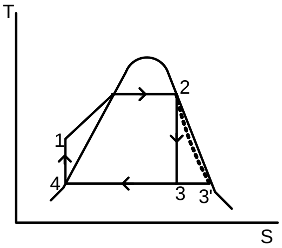
$h_1 = 203.91$ KJ/kg

$\eta_{12} = 38.02\%$

From the solution, we conclude that as the boiler pressure increases while keeping the condenser pressure constant, the quality of steam decreases at the turbine outlet & the efficiency of the plant increases.

Sol: 21

From ST at 2 bar



$h_2 = h_g = 2706.3$ KJ/kg

$S_2 = 7.127$ KJ/kg K

$S_2 = S_3$

$\therefore 7.127 = S_f + xS_{fg}\left(at\ 40^0C\right)$

$7.127 = 0.572 + 7.686x$

$x = 0.853$

$h_3 = h_f + xh_{fg} = 2220.22$ KJ/kg

$h_4 = 167.5 kJ/kg$

$h_3 = 2333.71$ KJ/kg (from ST, at 40^0C & x = 0.9)

$h_1 = h_4 + vdp = 167.7$ KJ/kg

(A) $\therefore \eta_{isen} = \dfrac{h_2 - h_3'}{h_2 - h_3} = 76.65\%$

(B) $W_{net} = W_{turb} - W_{Pump}$

$= h_2 - h'_3 - (h_1 - h_4)$

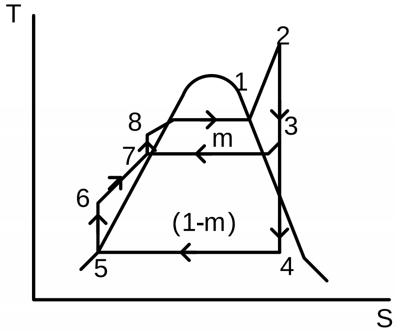
$W_{net} = 372.4$ KJ/kg

(C) $0.58 \times A = \dfrac{150}{3600} \times (h_2 - h_1) = \dfrac{150}{3600}(2706.3 - 167.7)$

$A = 182.37 m^2$

Sol: 22

For ST, at 55 bar .



$h_1 = h_g = 2789.9$ KJ/kg

$h_2 = 3777.6$ KJ/kg (at 55 bar , 650^0C)

$S_2 = 7.337$ KJ/kg K $= S_3 = S_4$

$h_3 = 2950$ KJ/kg (From Mollier diagram at 4 bar , 7.337 KJ/kg K)

At point 4

$S_4 = S_f + xS_{fg} \Rightarrow 7.337 = 0.572 + 7.686x$

$x = 0.88$

$\therefore h_4 = 2285.57$ KJ/kg

$h_5 = 167.5$ KJ/kg ($h_5 = h_f$ at 40^0C)

$h_6 = h_5 + v_5 dp = 167.9$ KJ/kg

$h_7 = 604.7$ KJ/kg$\left(h_f \text{ at 4 bar}\right)$

$h_8 = h_7 + v_7 dp = 610.23$ KJ/kg

Now balancing energy at the feed water heater

$mh_3 + (1-m)h_6 = h_7$

Substituting values & solving , we get

$m = 0.157$

$\therefore W_T = \left[(h_2 - h_3) + (1-m)(h_3 - h_4)\right] \times 0.75$

$W_T = 1040.78$ KJ/kg

$W_{P_{5-6}} = (1-m)(h_6 - h_5) = 0.334$ KJ/kg

$W_{P_{7-8}} = h_8 - h_4 = 5.53$ KJ/kg

$\therefore W_{net} = W_T - W_{P_{5-6}} - W_{P_{7-8}}$

$= 1034.91$ KJ/kg

Steam flow rate $(\dot{m}) = \dfrac{80 \times 10^3}{1034.91} = 77.3 kg / \text{s}$

Heat transfer in reacter

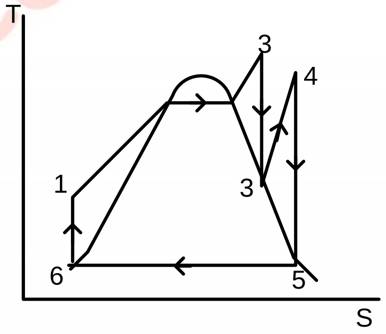
$\dot{m}(h_1 - h_8) = 168.49 MW$

Heat transfer in superheater $= \dot{m}(h_2 - h_1) = 76.35 MW$

Sol: 23

At state 5

From ST at 40^0C & x = 0.85



$h_5 = 167.5 + 2406.9 \times 0.85$

$h_5 = 2213.36$ KJ/kg

$S_5 = 0.572 + 7.686 \times 0.85$

$S_5 = 7.105$ KJ/kg K

$S_4 = S_5$

$h_4 = 3250$ KJ/kg (from Mollier diagram at 400^0C & 7.105 KJ/kg K)

$P_4 = 19 bar = P_3$

$h_3 = 2796.1$ KJ/kg (from ST h_g at 19 bar)

$S_3 = 6.356$ KJ/kg K

$S_3 = S_2$

$\therefore h_2 = 3320$ KJ/kg $\left(at \text{ S}_3 \text{ \& } 500^0 C\right)$

$P_2 = 145 bar$

$h_6 = h_f \, at \, 40^0 C = 167.5$ KJ/kg

$h_1 = h_6 + v_6 dp = 182.1$ KJ/kg

$W_T = h_2 - h_3 + h_4 - h_5 = 1560.54$ KJ/kg

$W_P = h_1 - h_6 = 14.6$ KJ/kg

$W_{net} = W_T - W_P = 1545.94$ KJ/kg

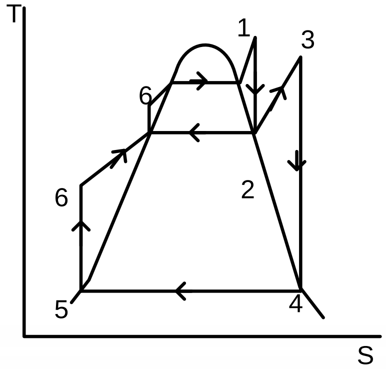
$Q_S = h_2 - h_1 = 3137.9$ KJ/kg

¦ $= \dfrac{W_{net}}{Q_S} = 49.26\%$

$SSC = \dfrac{3600}{W_{net}} = 2.33$ kg/kwh

Sol: 24

From ST at 90 bar , 550^0C



$h_1 = 3508.95$ KJ/kg

$S_1 = 6.8085$ KJ/kg

$S_1 = S_2 = 6.8085$ KJ/kg K

$\therefore h_2 = 2825$ KJ/kg (from mollier diagram at S_1 & 7 bar)

$h_3 = 3269$ KJ/kg (from ST at 7 bar , 400^0C)

$S_3 = 7.636$ KJ/kg K

$S_3 = S_4$

$7.636 = 0.559 + 7.718x$ (from ST at 0.07 bar)

$x = 0.917$

$\therefore v_4 = (1-x)v_f + xv_g \quad {}^{3}{}_{4} = 18.83 m^3 / kg$

$h_5 = 163.4$ KJ/kg $\left(h_f \text{ at 0.07 bar}\right)$

$h_6 = h_5 + {}^{3}{}_{5}dp = 170.38$ KJ/kg

$h_7 = 697.1$ KJ/kg $\left(h_f at7bar\right)$

$h_8 = 706.3$ KJ/kg

Energy balance in open heater

$$\therefore m = \frac{h_7 - h_6}{h_2 - h_6} = 0.198$$

$W_T = h_1 - h_2 + (1-m)(h_3 - h_4) = 1402.46$ KJ/kg

Now

(a) $\dot{m} = \frac{100\times10^3}{1402.46} = 71.3$ Kg/s $\quad (\dot{m} = steam \text{ flow rate})$

(b) $W_P = (1-m)(h_6 - h_5) + h_8 - h_7 = 14.8$ KJ/kg

$Q_s = h_1 - h_8 = 2802.65$ KJ/kg

(c) $¦ = \frac{W_{net}}{Q_s} = \frac{W_T - W_P}{Q_s} = 49.51\%$

(d) Balancing energy in condenser

$\dot{m}_w C_p \Delta T = \dot{m}(1-m)(h_4 - h_5)$

$$\dot{m}_w = \frac{71.3\times(1-0.198)(2372.63-163.4)}{4.18\times10}$$

$\dot{m}_w = 3022.24$ Kg/s

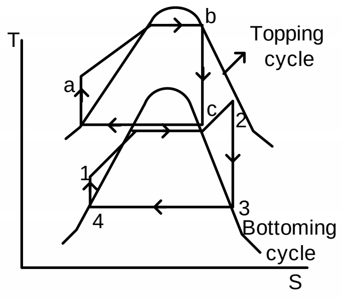
(e) $\dot{m} = \frac{AV}{{}^{3}} \Rightarrow 71.3(1-0.198) = \frac{A\times130}{18.83}$

$A = 8.28m^2$ & d = 3.25m

Sol: 25

At Topping cycle

From table at 10 bar .



$h_g = h_b = 363$ KJ/kg

$S_b = S_c = 0.5167$ KJ/kg K

$0.5167 = 0.0967 + x(0.6385 - 0.0967)$

$x_c = 0.775$

$h_c = h_f + x\left(hg - h_f\right)\left(at0.2bar\right)$

$h_c = 269.455$ KJ/kg

$h_d = 38.35$ KJ/kg

$h_a = h_d + v_d dp$

$h_a = 38.42$ KJ/kg

At Bottoming cycle

From steam table at 40 bar, 400^0C

$h_2 = 3215.7$ KJ/kg

$S_2 = 6.773$ KJ/kg K

$S_2 = S_3 \Rightarrow 6.773 = 0.572 + 7.686x_3 \quad \left(at 40^0 C\right)$

$x_3 = 0.806$

$h_3 = h_f + x_3 h_{fg} \Rightarrow h_3 = 2107.46$ KJ/kg

$h_4 = 167.5$ KJ/kg (from ST at 40^0C h_f)

$h_1 = h_4 + v_4 dp$

$h_1 = 171.52$ KJ/kg

(a) Now, heat rejected by Topping cycle = heat gained by bottoming cycle

$m_m (h_c - h_d) = m_s (h_2 - h_1)$

$$\therefore \frac{m_m}{m_S} = 13.17 \frac{Kg \text{ of mercury}}{\text{Kg of water}}$$

(b) $Q_S = m_m (h_b - h_a) = 4274.72 m_S$ KJ/kg

$W_T = m_m (h_b - h_c) + m_S (h_2 - h_3)$

$= 13.17 m_S (363 - 269.455) + m_S (3215.7 - 2107.46)$

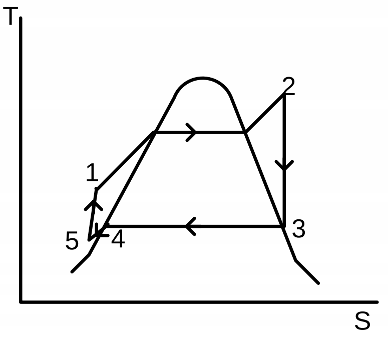
$W_T = 2340.24 m_s$ KJ / kg

$¦_{Overall} = \frac{W_{Total}}{Q_S}$ (neglecting pump work)

$= 54.74\%$

Sol: 26

(a) from ST at 20 bar & 400^0C



$h_2 = 3248.4$ KJ/kg

$S_2 = 7.13$ KJ/kg K

$S_2 = S_3$

Which shows state 3 is in saturated vapour condition

$h_3 = 2706.3$ KJ/kg (from ST at 2 bar)

$h_4 = 504.7$ KJ/kg $\left(T_{sat} = 120.2^0 C\right)$

$h_5 = h_4 - C_p \Delta T = 504.7 - 4.18(120.2 - 65)$

$h_5 = 273.6$ KJ/kg

$h_1 = h_5 + vdp = 275.4$ KJ/kg

Now, $W_T = (h_2 - h_3)\text{¦}$

$= (3248.7 - 2706.3)0.7$

$= 378.9$ KJ/kg

$Q_1 = h_2 - h_1 = 2972.2$ KJ/kg

Heat rejection that utilised $(Q_o) = \text{¦}\,(h_3 - h_5)$

$= (2706.3 - 273.6) \times 0.9$

$Q_o = 2189.4$ KJ/kg

$W_P = h_1 - h_5 = 1.8$ KJ/kg

$W_{net} = W_T - W_P = 377.1$ KJ/kg

$\therefore$ fraction at energy supplied utilised

$= \dfrac{W_{net} + Q_o}{Q_1}$

$= 86.35\%$

(b) when condenser pressure is 0.07 bar

$\therefore S_2 = S_3 = 7.13$ KJ/kg K

$7.13 = 0.559 + x7.717 \Rightarrow x = 0.851$

$\therefore h_3 = 163.4 + 0.851 \times 2409.1$

$h_3 = 2214.4$ KJ/kg

$h_4 = 163.4$ KJ/kg

$h_1 = h_4 + vdp$

$h_1 = 165.4 KJ/kg$

$W_T = (h_2 - h_3) \times 0.7$

$W_T = 723.24$ KJ/kg $\qquad W_P = 2$ KJ/kg

$W_{net} = W_T - W_P \quad = 721.24$ KJ/kg

$Q_1 = h_1 - h_1 = 3082.2$ KJ/kg

For same power of 377.1 KJ/kg

The amount of water needed $= \dfrac{721.24}{377.1}$

$= 0.5228$ kg

$\therefore$ heat input $(Q_1) = 3082.2 \times 0.5228$

$= 1611.5$ KJ

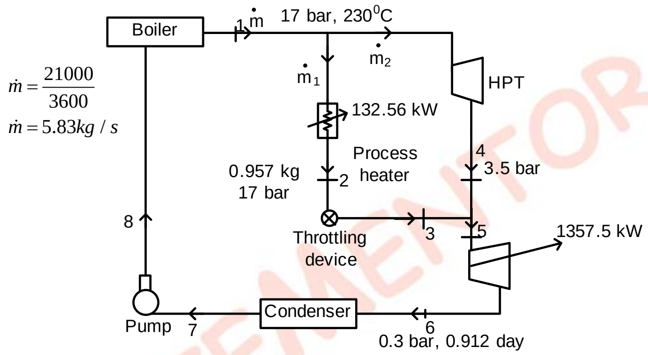
Heat input for heating $= \dfrac{2189.4}{0.9}$

$= 2432.7$ KJ

$\therefore$ fraction of energy used $= \dfrac{377.1 + 2189.4}{1611.5 + 2432.7}$

$= 63.46\%$

Sol: 27



From ST at 17 bar , 230^{0}C

$h_1 = 2862.2$ KJ/kg $\qquad S_1 = 6.538$ KJ/kg K

$h_2 = 871.8 + 0.957 \times 1921.5 = 2710.77$ KJ/kg

Mass flow through process heater $(\dot{m}_1) = \dfrac{132.56}{h_1 - h_2}$

$\dot{m}_1 = 0.875$ kg/s

Mass flow through $HPT = 5.83 - 0.875$

$\dot{m}_2 = 4.96$ kg/s

$h_2 = h_3$ (since the process is throttling)

$= 2710.77$ KJ/kg

Considering ideal expansion in HPT

$\therefore S_1 = S_4 = 6.538$ KJ/kg K

$6.538 = 1.727 + 5.212x$ (from ST, at 3.5 bar)

$x = 0.923$

$h_4' = 584.3 + 0.923 \times 2147.4$

$h_4' = 2566.4$ KJ/kg

Now,

$h_6 = 289.3 + 0.912 \times 2336.1$ (from ST, at 0.3 bar)

$h_6 = 2419.8 KJ/kg$

At LPT

$1337.5 = \dot{m}(h_5 - h_6) = 5.83(h_5 - 2419.8)$

$h_5 = 2649.1$ KJ/kg

Now,

Balancing energy

$\dot{m}_1 h_3 + \dot{m}_2 h_4 = \dot{m} h_5$

$0.875 \times 2710.77 + 4.96 \times h_4 = 5.83 \times 2649.1$

$h_4 = 2636.7$ KJ/kg

(a) from ST at 3.5 bar

$2636.7 = 584.3 + 2147.4x$

$x = 0.956$

(b) $W_{HPT} = \dot{m}_2 (h_1 - h_4) = 4.96(2862.2 - 2636.7)$

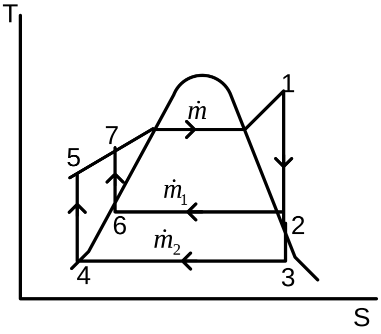
$W_{HPT} = 1118.48$ KW

(c) $\eta_{isentropic} = \dfrac{h_1 - h_4}{h_1 - h_4'} = \dfrac{2862.2 - 2636.7}{2862.2 - 2566.4} \times 100$

$= 76.24\%$

Sol: 28

From ST at 40 bar , 500^0C



$h_1 = 3445$ KJ/kg

$S_1 = 7.091$ KJ/kg K

$S_1 = S_2$

$\therefore 7.091 = 1.53 + 5.597x_2$ (From ST at 2 bar)

$x_2 = 0.9935$

$h_2 = 504.7 + 0.9935 \times 2201.6$

$h_2 = 2692.14$ KJ/kg

$S_1 = S_3$

$\therefore 7.091 = 0.521 + x_3 \Rightarrow x_3 = 0.84$ (from ST at 0.06 bar)

$h_3 = 2183.9$ KJ/kg

$h_4 = 151.5$ KJ/kg $\quad h_6 = 504.7$ KJ/kg

$h_5 = h_4 + v_4 dp \quad h_7 = h_6 + v_6 dp$

$h_5 = 155.51$ KJ/kg $\quad h_7 = 508.73$ KJ/kg

Now, heating load is 1.163 MW

$\therefore 1.163 \times 10^3 = \dot{m}_1 (h_2 - h_6)$

$\dot{m}_1 = 0.5316$ kg/s

Power load is 5.6 MW

$\therefore 5600 = (\dot{m}_1 + \dot{m}_2)(h_1 - h_2) + \dot{m}_2 (h_2 - h_3)$

$5600 = 752.86 \times 0.5316 + 752.86\dot{m}_2 + 508.24\dot{m}_2$

$\dot{m}_2 = 4.1232$ kg/s

(A) $\dot{m} = \dot{m}_1 + \dot{m}_2$

$\dot{m} = 4.6548$ kg/s

$= 4.6548 \times \dfrac{3600}{1000}$

$\dot{m} = 16.757$ tonnes /hr

(B) heat input to the boiler $= \dot{m}(h_1 - h_7) + \dot{m}_2 (h_7 - h_s)$

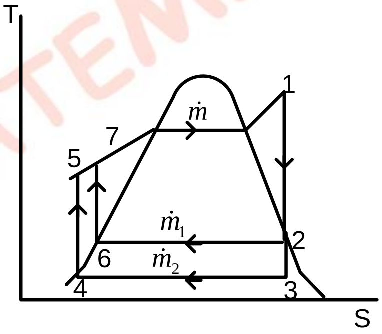
$= 15.124$ MW

(C) heat rejected to the condenser $= \dot{m}_2 (h_3 - h_4)$

$= 8.38$ MW

Sol: 29

From ST at 35 bar, 350^0C



$h_1 = 3106.45$ KJ/kg

$S_1 = 6.663$ KJ/kg K

$S_1 = S_2 = 6.663$ KJ/kg K

$\therefore 6.663 = 1.727 + 5.212x_2$ (from ST at 3.5 bar)

$x_2 = 0.947$

$h_2 = 584.3 + 0.947 \times 2147.3 \quad h_2 = 2617.9$ KJ/kg

$h_6 = 584.3$ KJ/kg

$h_7 = h_6 + v_6 dp = 587.7$ KJ/kg

Similarly,

$S_1 = S_3$

$6.663 = 0.559 + 7.718x_3$ (from ST at 0.07 bar)

$x_3 = 0.79$

$h_3 = 2068.8$ KJ/kg

$\text{h}_4 = 163.4$ KJ/kg

$h_5 = h_4 + v_4 dp = 163.4 + 0.1007 \times 34.93$

$h_5 = 166.91$ KJ/kg

Now,

Process load is 1.4 MW

$$\therefore 1400 = \dot{m}_1\left(h_2 - h_6\right)$$

$$\dot{m}_1 = 0.688 \text{ Kg/s}$$

Work done by turbine is 1 MW

$$1000 = \left(\dot{m}_1 + \dot{m}_2\right)\left(h_1 - h_2\right) + \dot{m}_2\left(h_2 - h_3\right)$$

$$= 0.688 \times 488.55 - 488.55\dot{m}_2 + 549.1\dot{m}_2$$

$$\dot{m}_2 = 0.64 \text{ Kg/s}$$

$\because$ Maximum steam flow through $LPT\ is\ \dot{m}_2 = 0.64$ kg/s

Maximum steam flow through $HPT = \dot{m}_1 + \dot{m}_2$

$$= 1.328 \text{ kg/s}$$

Sol: 30

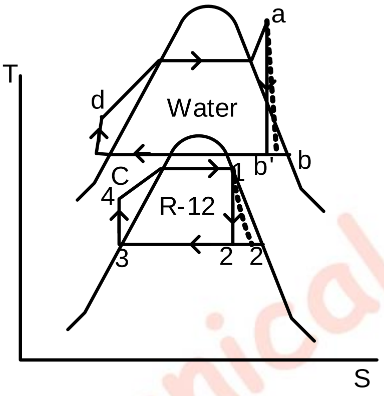
Water is working fluid in the topping cycle

$\therefore$ from ST at 80 bar, 500^0C

$h_a = 3398.8$ KJ/kg $S_a = 6.726$ KJ/kg K

$$S_a = S_b'$$

$\therefore 6.726 = 0.521 + 7.21x_b$ (from ST at 0.06 bar)



$$x_b = 0.794$$

$$h_b' = 2069.8 \text{ KJ/kg}$$

$$\eta_{isentropic} = 0.81 = \frac{h_a - h_b}{h_a - h_b'}$$

$$h_b = 2322.31 \text{ KJ/kg}$$

$$h_c = 151.8 KJ/kg$$

$$h_d = h_c + v_c dp = 159.84 \text{ KJ/kg}$$

$$\eta_1 = \frac{h_a - h_b - h_d + h_c}{h_a - h_d}$$

$$\eta_1 = 32.98\%$$

R-12 is working fluid in the Bottoming cycle

$h_1 = 199.6$ KJ/kg (from table , at h_g in 30^0C)

$$P_1 = 7.45 \text{ bar}$$

$$S_1 = 0.6854 \text{ KJ/kg K}$$

$$S_1 = S_2'$$

$$0.6854 = 0 + 0.7274x_2 \Rightarrow x_2 = 0.94226$$

$$h_2' = 169 \times 0.94226 \Rightarrow h_2' = 159.24 \text{ KJ/kg} \quad P_2 = 0.647bar$$

$$\eta_{isen} = 0.83 = \frac{199.6 - h_2}{199.6 - 159.24} \Rightarrow h_2 = 166.1 \text{ KJ/kg}$$

$$h_3 = 0 \qquad h_4 = h_3 + vdp$$

$$h_4 = 0 + 0.075\left(7.45 - 0.647\right)$$

$$h_4 = 0.487 \text{ KJ/kg}$$

$$\eta_2 = \frac{h_1 - h_2 - h_4 + h_3}{h_1 - h_4} \times 100 = 16.58\%$$

$$\eta_2 = 16.58\%$$

$$\eta_{cycle} = \eta_1 + \eta_2 - \eta_1\eta_2$$

$$= 44.09\%$$

Now,

Heat rejected by condenser in topping cycle = heat absorbed in bottoming cycle.

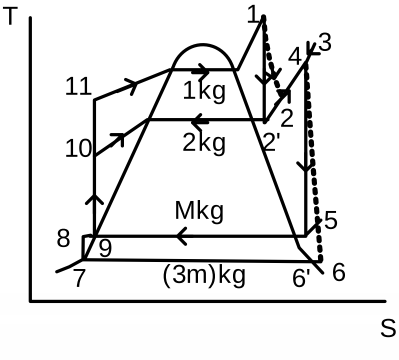
$$m_w\left(h_b - h_c\right) = m_{R-12}\left(h_1 - h_4\right)$$

Substituting values$_1$ we get

$$\frac{m_{R-12}}{m_w} = 10.9$$

Sol: 31

From ST at 70 bar , 500^0C



$$h_1 = 3410.6 \text{ KJ/kg}$$

$$S_1 = 6.18 \text{ KJ/kg K}$$

$$S_1 = S_2'$$

$\therefore h_2' = 3170$ KJ/kg (from ST at 30 bar S_2')

$$\eta_{isen} = \frac{h_1 - h_2}{h_1 - h_2'}$$

$$0.77 = \frac{3410.6 - h_2}{3410.6 - 3170}$$

$$h_2 = 3225.34 \text{ KJ/kg}$$

$h_3 = 3232.5$ KJ/kg (from ST at 30 bar , 400^0C)

Now,

Balancing energy

$M_2 = 1$ kg $\;M_2 h_2 + M_3 h_3 = M_4 h_4 \quad M_3 = 2kg$

$\therefore M_4 = M_2 + M_3 = 3$ Kg

$$\frac{1\times 3225.34 + 2\times 3232.5}{3} = h_4$$

$h_4 = 3230.11$ KJ/kg $\quad S_4 = 6.9 KJ/kgK$ (From Mollier diagram at 30 bar , h_4)

Now,

$S_4 = S_5{}'$ (pt. 5' is in superheated states) (from ST, at 5 bar & $S_5{}'$)

$\therefore h_s{}' = 2800$ KJ/kg

$$\eta_{isen} = \frac{h_4 - h_5}{h_4 - h_5{}'} \Rightarrow 0.8 = \frac{323011 - h_5}{3230.11 - 2800} \Rightarrow h_5 = 2886.02 \text{ KJ/kg}$$

Similarly

$S_4 = S_6{}'$

$6.9 = 0.521 + 7.81x \Rightarrow x = 0.817$

$\therefore h_6{}' = 2124.82$ KJ/kg

$$\eta_{isen} = \frac{h_4 - h_6}{h_4 - h_6{}'} \Rightarrow 0.8 = \frac{3230.11 - h_6}{3230.11 - 2124.82} \Rightarrow h_6 = 2345.88 \text{ KJ/kg}$$

$h_4 = 151.5$ KJ/kg$\left(h_f \text{ at } 0.06 \text{ bar}\right)$

$h_8 = 151.5 + v_7 dp = 152 KJ/kg$

$h_9 = 640.1$ KJ/kg $\quad \left(h_f at 5 bar\right)$

$h_{10} = 640.1 + v_9\left(30 - s\right) = 642.83$ KJ/kg

$h_{11} = h_9 + v_9\left(70 - 5\right) = 640.1 + 0.1093\left(70 - 5\right)$

$h_{11} = 647.2$ KJ/kg

From heat balance & condenser

$mh_S + \left(3 - m\right)h_8 = 3h_9$

Substituting valves we get

$m = 0.535$ kg

Now,

$W_{HPT} = h_1 - h_2 = 185.26$ KJ/kg

$W_{LPT} = 3\left(h_4 - h_5\right) + \left(3 - m\right)\left(h_5 - h_6\right) = 1032.27 + 1331.44$

$W_{LPT} = 2363.71$ KJ/kg

$W_P = \left(3 - m\right)\left(h_8 - h_7\right) + 3\left(h_{10} - h_9\right) + \left(h_{11} - h_{10}\right)$

Substituting values , we get

$W_p = 13.8$ KJ/kg

$W_{net} = W_{HPT} + W_{LPT} - W_P$

$= 2535.17$ KJ/kg

$Q_S = \left(h_1 - h_{11}\right) + 2\left(h_3 - h_9\right)$

$Q_s = 7948.2$ KJ/kg

$$\eta_{cycle} = \frac{W_{net}}{Q_S}\times 100$$

$\eta_{cycle} = 31.89\%$

Sol: 32

From ST at $40^0 C, 14.67\%$ moisture

$i.e.\; x = 1 - 0.1467$

$x = 0.8533$

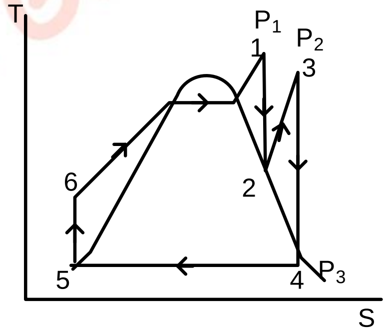
$P_3 = 0.0738 bar \quad h_4 = 167.6 + 0.8533\times 2406.7$

$h_4 = 2221.2$ KJ/kg

$S_4 = 0.573 + 0.8533\times 7.685$

$S_4 = 7.1306$ KJ/kg K

$\therefore$ at 400^0C and $S_4 = 7.1306$, from steam table



(A) $P_2 = 20 bar$

$h_3 = 3247.6$ KJ/kg

At 20 bar saturation

$h_2 = 2797.2$ KJ/kg

$S_2 = 6.336$ KJ/kg K

(B) at 550^0C & 6.3366 KJ / kg K

From ST, we get

$P_1 = 200 bar$

$h_1 = 3393.5$ KJ/kg

$h_5 = 167.6$ KJ/kg

$h_6 = 167.6 + 0.1\left(200 - 0.0738\right)$

$h_6 = 187.6$ KJ/kg

(C) $W_{net} = h_1 - h_2 + h_3 - h_4 - h_6 + h_5$

$W_{net} = 1602.7$ KJ/kg

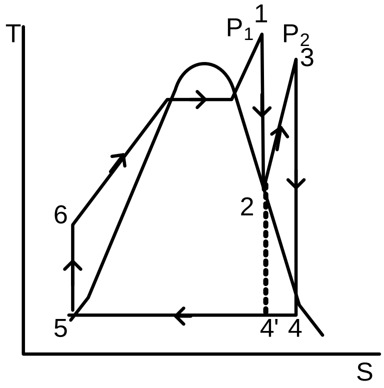
$Q_1 = h_1 - h_6 + h_3 - h_2$

$Q_1 = 3656.3$ KJ/kg

(D) $¦ = \frac{W_{net}}{Q_1} \times 100$

$¦ = 43.83\%$

Sol: 33



From ST at 0.1 bar

$h_4' = 191.8 + 0.7592 \times 2392.9$

$h_4' = 2008.5 KJ / kg$

$S_4' = 0.649 + 0.7592 \times 7.501$

$S_4' = 6.344$ KJ/kg K

(A) $h_4 = 191.8 + 0.8778 \times 2392.9$

$h_4 = 2292.3$ KJ/kg

$S_4 = 0.649 + 0.8778 \times 7.501$

$S_4 = 7.234$ KJ/kg K

From Mollier diagram at S_4 & 500^0C

$P_2 = 30 bar$

$h_3 = 3456.5$ KJ/kg

$h_2 = 2802.3$ KJ/kg

$h_5 = 191.8$ KJ/kg

$h_6 = h_5 + v_6 dp \quad = 191.8 + 0.101(150 - 0.1)$

$h_6 = 206.94$ KJ/kg

$W_p = 15.14$ KJ/kg

$W_T = (h_1 - h_2) + (h_3 - h_4) = 1672.5$ KJ/kg

$W_{net} = W_T - W_P$

$= 1657.36$ KJ/kg

$Q_1 = h_1 - h_6 + h_3 - h_2 = 3757.86$ KJ/kg

(B) From Mollier diagram

At $6.344 KJ / kgK \ \& \ 500^0 C$

$P_1 = 150 bar \qquad h_1 = 3310.6$ KJ/kg

(C) $¦ = \frac{W_{net}}{Q_1} \times 100$

$¦ = 44.1\%$

(D) Steam rate $= \frac{3600}{W_{net}} = 2.172$ Kg/Kwh