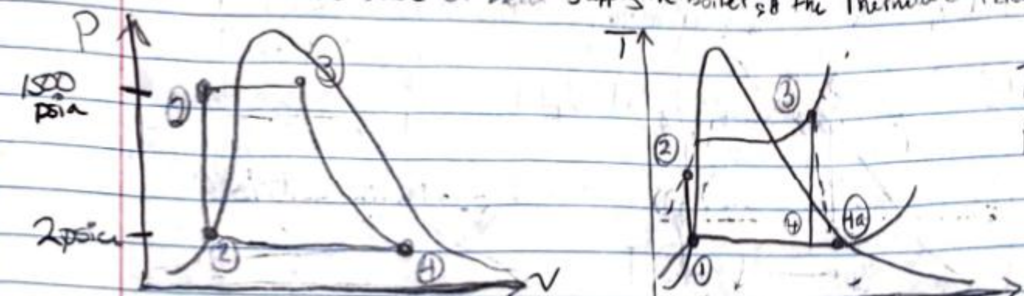
10-18E

10-18E Steam Rankine cycle operates btw/ pressure limits of 1500 psia in the boiler & 2 psia in condenser. Turbine inlet temp. is 800°F. Turbine isentropic efficiency is 90%. Ideal, cycle is sized to produce 2500 KW of power. Calculate mass flow rate through boiler, the power to produce by turbine, the rate of heat supply in boiler, & the Thermal efficiencies



$T_1 = T_4$
$P_2 = P_3$
$P_1 = P_1$
$S_1 = S_2$
$S_3 = S_4$

Isentropic → P const. → Isentropic → Isobaric

	1	2	3	4 ($\eta_T = .9$)	4a
psia	2	1500	1500	2	
°F	126.02		800	126.02	
S (Btu/lbm·R)	0.17499	0.17499	1.5064	1.5064	
X	0			0.76	
h (Btu/lbm)	94.02	118.33	1363.1	803.81	859.739

$h_1 = h_f @ P_1 \Rightarrow 94.02 \ Btu/lbm$

$S_1 = S_f @ P_1 = .17499 \ Btu/lbm\text{-}R$

$V_1 = V_f @ P_1 = 0.01623 \ ft^3/lbm$

$w_{in} = V(P_2 - P_1) = h_2 - h_1$

$h_2 = h_1 + V_1(P_2 - P_1) \Rightarrow 118.33 \ Btu/lbm$

$q_{in} = h_3 - h_2 \Rightarrow 1244.77 \ Btu/lbm$

$q_{out} = h_{4a} - h_1 \Rightarrow 859.739 - 94.02 \Rightarrow 765.716 \ Btu/lbm$

$W_{net} = q_{in} - q_{out} \Rightarrow 479.054 \ Btu/lbm$

Superheated Tables → $h_3 @ P_3 \& T_3 \Rightarrow 1363.1 \ Btu/lbm$

→ $S_3 @ P_3 \& T_3 \Rightarrow 1.5064 \ Btu/lbm\text{-}R$

$S_f @ P_4 = .17499 \quad S_{fg} @ P_4 = 1.74444$

$X_4 = \frac{S_4 - S_f}{S_{fg}} \Rightarrow \frac{1.5064 - .17499}{1.74444}$

$x_4 = 0.76$

$h_f @ P_4 = 94.02$

$h_{fg} @ P_4 = 1021.7$

$h_4 = h_f + X_4(h_{fg}) \Rightarrow h_4 = 803 \ Btu/lbm$

$\eta_T = \frac{h_3 - h_{4a}}{h_3 - h_4} \Rightarrow h_{4a} = 859.739 \ Btu/lbm$

a.) Mass Flow rate through boiler (2-3):

$\dot{m} = \frac{\dot{W}}{w_{net}} \Rightarrow \frac{2500 \ kW \ (kJ/s)}{479.054 \ Btu/lbm} \times \frac{0.947817 \ Btu}{1 \ kJ}$ $4.94 \ lbm/s$ or $5 \ lbm/s = \dot{m}$

10-18E pt2

10-18E

b.) Power produced by Turbine (3-4):

$W_T = h_3 - h_4 \Rightarrow 1368.1 - 859.739$

$W_T = 503.361$

$\dot{W}_T = \dot{m}(\Delta h_{3-4})$

Power $\frac{Btu}{s}$

$\dot{W}_T = 5 \frac{lbm}{s}(503.361)^{Btu}/_{lbm} \Rightarrow$ **$2516.805\ Btu/s = \dot{W}_T$**

$s(\dot{m})$

c.) Rate of heat supply (q_{in}) in boiler (2-3):

$\dot{Q}_{in_{2-3}} = \dot{m}(h_3 - h_2) \Rightarrow 5 \frac{lbm}{s} \times (1363.1 - 118.33)^{Btu}/_{lbm}$

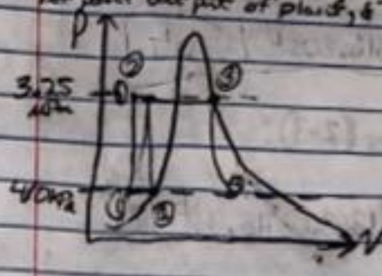
$\dot{Q}_{2-3} = 6223.85\ Btu/s$

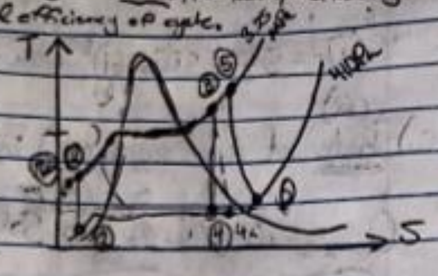
d.) Thermal Efficiency: $\eta_{th} = 1 - \frac{q_{out}}{q_{in}}$

$\eta_{th} = 1 - \frac{765.716}{1244.77} \Rightarrow$ **$.385$ or $38.5\% = \eta_{th}$**

10-25

10-25 Binary geothermal power plant uses geothermal wtr @ 160°C as heat source. Cycle operates on simple Rankine w/ isobutane as working fluid. Heat is transferred to cycle by heat exchanger, geothermal wtr enters @ 160°C @ Rate 555.9 kg/s & leaves @ 90°C. Isobutane enters turbine @ 3.25 MPa & 147°C @ rate 305.6 kg/s, & leaves 79.5°C & 410 kPa. Assume pump isentropic efficiency of 90%. Find isentropic efficiency of turbine, net power output of plant, & Thermal efficiency of cycle.





	1 η_P=.9	2 2a	3	4 4a	5	6
°C	160	90	147	79.5	160	90
KPa	410 kPa	3.25 MPa	3.25 MPa	410 kPa		
$\dot{m}$ (kg/s)	555.9	555.9	305.6			

Interpolate $s_1 = s_2$ | $h_4 @ P_4 = 608.356 \frac{kJ}{kg}$ Interpolate

$h_1 = 608.36 \frac{kJ}{kg}$ | $S_2 = 1.785 \, kJ/kg \cdot K$ | $S_4 @ P_4 = 1.785 \, kJ/kg \cdot K$ | $P_6 @ T_6 = 70.183$

$S_1 = 1.785 \frac{kJ}{kg \cdot K}$ | $h_2 - h_1 = v_1(P_2 - P_1)$ | $X_{4a} = \frac{S_{4a} - S_{fa}}{S_{fga}}$ | $h_6 @ T_6 = 377.04$

$v_1 = .002 \frac{m^3}{kg}$ | $h_2 = 611.2 \, kJ/kg$ | $S_6 @ T_6 = 1.1929$

$\eta_P = \frac{h_2 - h_1}{h_{2a} - h_1} \Rightarrow h_{2a} = 611.55 \frac{kJ}{kg}$ → $X_{4a} = 0.436$

η_T

$h_3 @ P_3 \, \& \, T_3 = 761.54 \, kJ/kg$

$S_3 = S_4 \Rightarrow S_3 = 2.5467$

$h_{4a} = h_{fa} + X_{4a}(h_{fga})$

$h_{4a} = 1537.297$

$h_{fa} @ S_{4a} = 608.226$

$h_{fg} @ S_{4a} = 2130.847$

a.) Isentropic efficiency of turbine: $w_T = \dot{m}_3(h_3 - h_4)$

$\eta_T = \frac{h_3 - h_{4a}}{h_3 - h_4}$ | $w_T = 305.6 \frac{kg}{s}(761.54 - 608.356) \, kJ/kg$

$\eta_T = -5.0642$ I don't know where went wrong. | $w_T = 46813.03 \, kJ/s$

b.) Net power of plant:

$w_{net} = W_{turb,out} - W_{pump,in}$

$\dot{W} = \dot{m}_3 (w_{net})$ | $w_{net} = (h_3 - h_4) - (h_2 - h_1)$

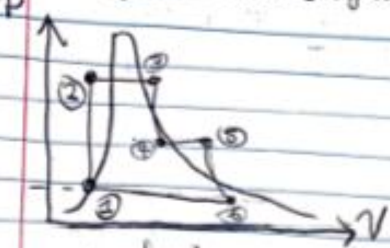
$\dot{W}_{net} = 45945.13 \frac{kJ}{s}$ | $w_{net} = 150.344 \, kJ/kg$

≈ 46 MW

Not ideal

c) Thermal efficiency: $\eta_{th} = \frac{150.344 \, kJ/kg}{150.34 \frac{kJ}{kg}} = 1.0$ or 100% | $q_{in} = h_3 - h_2$, $q_{in} = 150.34$

10-34 Steam Power plant operating as ideal reheat rankine cycle. Boiler @ 5,000 kPa, reheat section @ 1200 kPa & Condensor 20 kPa. Mixture quality at exit of both turbines is 96%. Find temperature inlet of each turbine & cycle thermal efficiency.



1 —Isentropic→ 2 —Isobaric→ 3 ($\eta_T = .964$) —Isentropic→ —Isobaric→ —Isentropic→ ($S\ \eta_T = .96$) —Isobaric→ 6

	1	2	3	4	5	6
kPa	100	5,000	5000	1200	1200	100
°C				187.96		94.61
X	0			0.96		0.96
h (kJ/kg)	419.17	424.28	3027.325	2777.014	3071.643	2584.806
s kJ/kg·K	1.3072	1.3072	6.3813	6.3813	7.116752	7.116752

$P_1 = P_6$ $S_1 = S_2$ $P_2 = P_3$ $S_3 = S_4$ $P_4 = P_5$ $S_5 = S_6$ $T_6 @ P_6 = 94.61°C$

$h_1 @ P_1 = 419.17\ kJ/kg$ $P_3 = 5000\ kPa$ (A-5) $S_3 = 6.3813\ kJ/kg\cdot K$ $T_4 @ P_4 = 187.96$ $S_f @ P_6 = 6.0562$, $S_{fg} @ P_6 = 1.3026$

$S_1 @ P_1 = 1.3072\ kJ/kg$ → $h_3 = 3027.325\ kJ/kg$ (Interpolate) $S_4 = S_f + X_4 (S_{fg})$ $h_{fg} @ P_6 = 2254$ $h_f @ P_6 = 417.51\ kJ/kg$

$v_1 @ P_1 = 0.001043\ m^3/kg$ → $T_3 = 335.285°C$ → $S_4 = 6.38126\ kJ/kg\cdot K$ $S_6 = S_f + X_6 (S_{fg6})$

$X_1 = 0$ $S_f @ P_4 = 2.2159$ $S_{fg} @ P_4 = 4.2058$ → $7.116752\ kJ/kg\cdot K = S_4$

$h_2 = v_1 (P_2 - P_1) + h_1$ $h_f = 781.03\ kJ/kg$ $h_{fg} @ P_4 = 1985.4\ kJ/kg$ $h_6 = h_{f6} + X_6 (h_{fg6})$

→ $h_2 = 424.28$ $h_4 = h_f + X_4 (h_{fg})$ → $2584.806 = h_6$

@5000 kPa → $h_4 = 2777.014\ kJ/kg$

6.2111 300

6.4516 350 $P_5 = 1200\ kPa$ (A-5)

6.3813 Interpolate $S_5 = 7.116752\ kJ/kg\cdot K$ → $h_5 = 3071.643\ kJ/kg$

a) Temperature inlet of each turbine (4) / (6): → $T_5 = 323.074°$

→ $T_3 = 335.285°C$ → $T_5 = 323.074°C$

b) Thermal efficiency: $W_{net} = W_{out,3-4} + W_{out,5-6} - W_{in,1-2}$

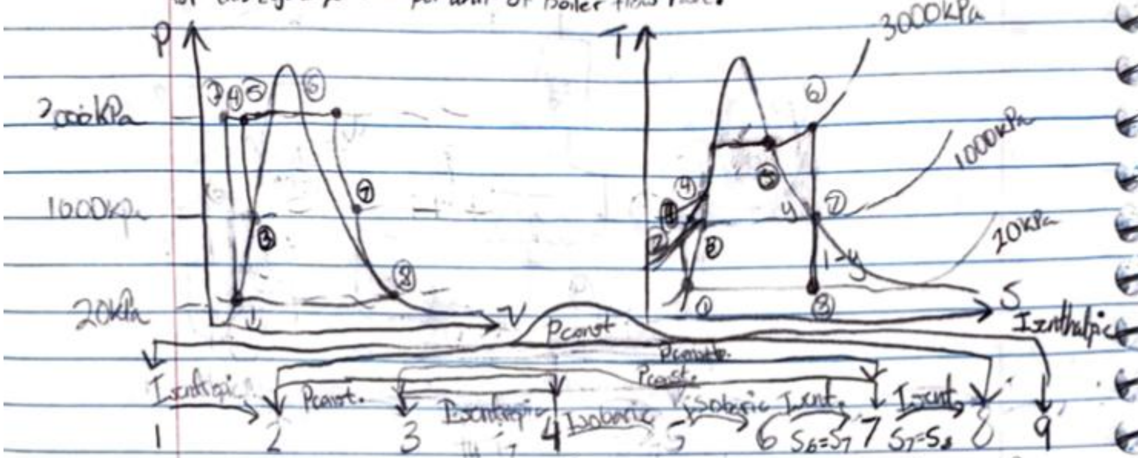
$\eta_{th} = \dfrac{W_{net}}{q_{in}} \Rightarrow 0.253$ or 25.3% $\quad (h_3 - h_4) + (h_5 - h_6) - (h_2 - h_1) \Rightarrow 732.038$

$q_{in} = q_{in,2-3} + q_{in,4-5}$

→ $(h_3 - h_2) + (h_5 - h_4) \Rightarrow 2897.105$

10-48

10-48: Steam plant operates on ideal regenerative rankine w/ closed feedwtr heater. Plant turbines inlet @3,000KPa & 350°C, condenser operation is 20KPa. Steam extracted @ 1000KPa, serve closed feedwater heater, discharges to condenser after being throttled to condenser pressure. Find work produce @ turb., work consumed by pump ($W_{in,p}$) & heat supply in boiler for this cycle per unit per unit of boiler flow rate.



1	2	3	4	5	6	7	8	9
20kPa	3000kPa	$X_3=0$	3000kPa	3000kPa	3000kPa	1000KPa	20KPa	

1-2:

$h_1 @ P_1 = 251.42 \frac{kJ}{kg}$

$s_1 @ P_1 = 0.8320 \, kJ/kg \cdot K$

$T_1 @ P_1 = 60.06°C$

$V_1 @ P_1 = 0.001017 \, m^3/kg$

$X_1 = 0$

$s_2 = s_1$

$h_2 - h_1 = V_1(P_2 - P_1)$

$h_2 = 254.42 \frac{kJ}{kg}$

$T_2 @ h_2 =$ ← Interpolate

$V_2 @ h_2 =$

$P_3 = 1000KPa$

$h_5 @ P_5$ 350°C $S_7 = 6.7456 \frac{kJ}{kg \cdot K}$ $S_8 = 6.7456 \frac{kJ}{kg \cdot K}$

$h_5 = 1008.3 \frac{kJ}{kg}$ A-6 → $h_6 @ P_6 | T_6 = 3116.1 \frac{kJ}{kg}$

$S_6 @ P_6 | T_6 = 6.7456 \frac{kJ}{kg \cdot K}$

$h_9 = 254.52 \frac{kJ}{kg}$

$X_8 = \frac{S_8 - S_{f8}}{S_{fg8}}$

$X_8 = .836$

3-4:

$T_3 @ P_3 = 179.88°C$

$h_3 @ P_3 = 762.51 \, kJ/kg$

$S_3 @ P_3 = 2.1381 \, kJ/kg \cdot K$

$V_3 @ P_3 = 0.001127 \, m^3/kg$

$h_4 - h_3 = V_3(P_4 - P_3)$

$h_4 = 764.76 \, kJ/kg$

$T_4 = 179.88°C$ ← Interpolate

$V_4 = 0.001127 \, m^3/kg$

$h_8 = h_{f2} + X_8(h_{fg})$

$h_8 = 2221.27 \frac{kJ}{kg}$

$P_7 = 1MPa$

$S_7 = 6.7456 \, kJ/kg \cdot K$

A-6: $T_7 @ P_7 \, \& \, S_7 = 210.827°C$

Interpolate → $h_7 @ P_7 \, \& \, S_7 = 2,853.159 \, kJ/kg$

a.) Work produced by turbine: $W_{T(6-7)+(6-8)}$

$W_T = (h_6 - h_7) + (h_6 - h_8)(1 - y)$

$(3116.1 - 2853.159) + (3116.1 - 2221.27)(1 - .3605)$

$W_T = 834.8 \, kJ/kg$

$y = \frac{h_5 - h_9}{h_7 - h_3} \Rightarrow \frac{1008.3 \frac{kJ}{kg} - 254.52 \frac{kJ}{kg}}{2853.159 - 762.51}$

$y = .3605$

b.) Work consumed by pump: $(W_p = h_2 - h_1) \Rightarrow 254.42 - 251.42 \Rightarrow$

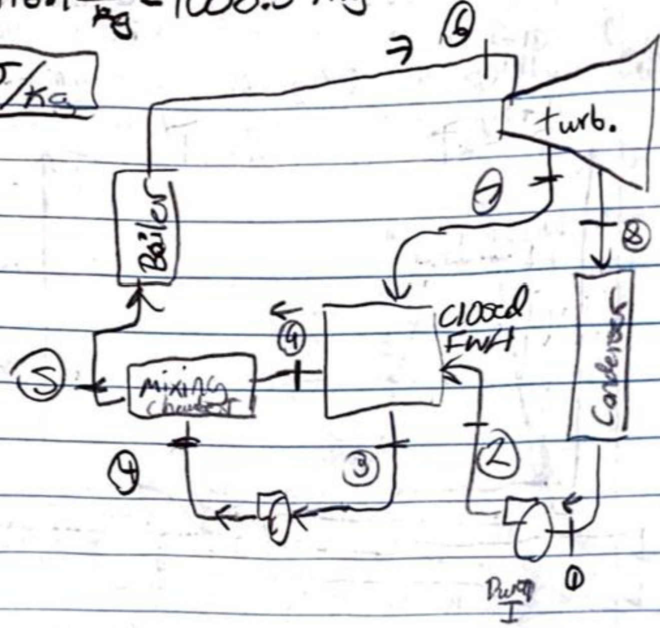
$W_p = 3 \, kJ/kg$

10-48 pt2:

3.) Heat supply in boiler for this cycle per unit of boiler flow rate:

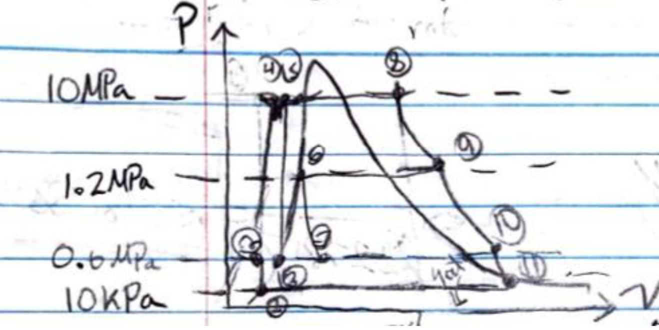
$Q_{in} = h_6 - h_5 \Rightarrow 3116.1 \, kJ/kg - 1008.3 \, kJ/kg$

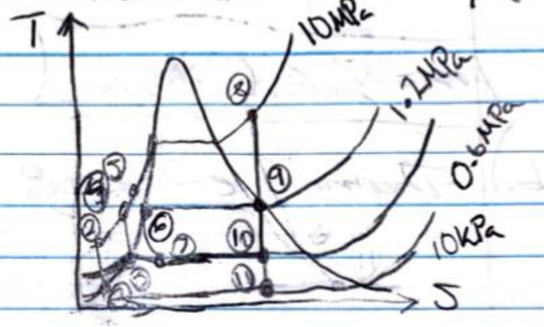
$Q_{in} = 2107.8 \, kJ/kg$



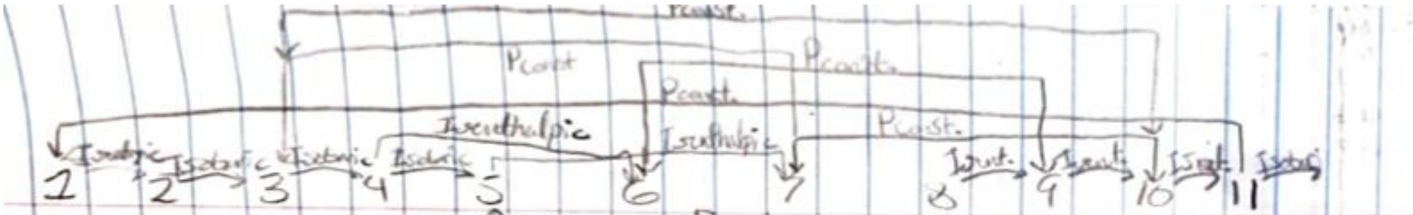
10-53

10-53: Ideal steam regen Rankine cycle w/ two FWH's, one closed & one open. Steam enters turb. @ 10 MPa @ 600°C & exhausts to condenser @ 10KPa. Steam extracted @ 1.2MPa to FWH closed & 0.6MPa to FWH open. FWH is heated to condensation temp. of extracted @ closed FWH. Leaves extracted as Sat. liquid.





10-53 pt2



$P_1 = 10 kPa$
$T_1 = 45.81°C$
$h_1 = 191.81 \frac{kJ}{kg}$
$s_1 = 0.6492 \frac{kJ}{kg \cdot K}$
$v_1 = 0.00101 \frac{m^3}{kg}$

$P_2 = 0.6 MPa$
$h_2 - h_1 = v_1 (P_2 - P_1)$
$h_2 = 191.8 \frac{kJ}{kg}$

$P_3 = 0.6 MPa$ $P_4 = 10 MPa$
$h_3 = 670.38 \frac{kJ}{kg}$
$v_3 = .00101 \frac{m^3}{kg}$
$h_4 - h_3 = v_3 (P_4 - P_3)$
$h_4 = 671.33 \frac{kJ}{kg}$

$P_5 = 10 MPa$
$T_5 = T_6$
$T_5 = 187.96°C$
$h_5 = 798.33 \frac{kJ}{kg}$

$P_6 = 1.2 MPa$
$T_6 = 187.96°C$
$h_6 = 798.33 \frac{kJ}{kg}$
$s_6 = 2.2159 \frac{kJ}{kg \cdot K}$

$P_7 = 0.6 MPa$
$P_7 = 0.6 MPa$
$h_5 = h_7 = 798.33 \frac{kJ}{kg}$

$P_8 = 10 MPa$
$T_8 = 600°C$
A-6: $h_8 = 3625.8 \frac{kJ}{kg}$
$s_8 = 6.9045 \frac{kJ}{kg \cdot K}$

$s_8 = s_9$
$P_9 = 1.2 MPa$
$s_9 = 6.9045 \frac{kJ}{kg \cdot K}$
$h_9 = 2974.1 \frac{kJ}{kg}$

$P_{10} = 0.6 MPa$
$s_{10} = 6.9045$
$h_{10} = 2186.$

$P_{11} = 10 kPa$
$s_8 = s_{11}$
$s_{11} = 6.9045 \frac{kJ}{kg \cdot K}$
$x_{11} = \frac{s_{11} - s_f @ 10 kPa}{s_{fg} @ 10 kPa}$
$x_{11} = .834$
$h_{11} = h_f + x_{11}(h_{fg})$
$h_{11} = 2186.82 \frac{kJ}{kg}$

$y: y \times h_9 - y \times h_6 = h_5 - h_4 = y(h_9 - h_6) = (h_5 - h_4) \Rightarrow y = 0.0526$

$z: y(h_7) + z(h_{10}) = h_3 \Rightarrow z = \frac{h_3 - y(h_7)}{h_{10}} \Rightarrow z = 0.285$

$(1 - y - z) \Rightarrow q_{out}$ Condenser

$q_{in} = h_8 - h_5 \Rightarrow q_{in} = 2827.47 \frac{kJ}{kg}$

$q_{out} = (1 - y - z)(h_{11} - h_1)$

$q_{out} = 1310 \ kJ/kg$

10-53 pt3

a.) Mass flow rate of steam, net power output 400MW:

$$\dot{m} = \frac{400MW}{w_{net}} \leftarrow 400000$$

$w_{net} = q_{in} - q_{out} \Rightarrow 1517.47 \frac{kJ}{kg}$

$\dot{m} = 263.6 \ kg/s$

b.) Thermal efficiency:

$$\eta_{th} = \frac{w_{net}}{q_{in}} \Rightarrow \frac{1517.47}{2827.47} = .537 \text{ or } 53.7\%$$