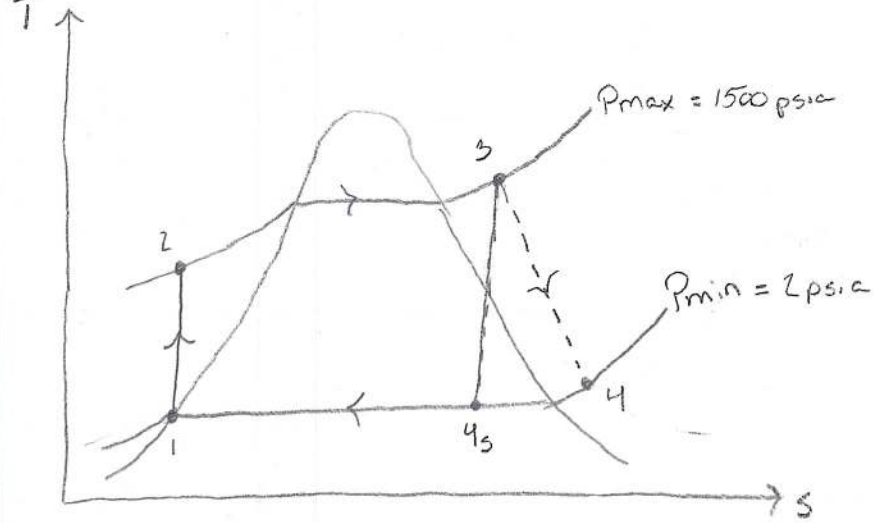
Rhiley Silvis | HW 2.1 | MET 350

Problem 10-18

A Steam Rankine cycle operates between the pressure limits of 1500 psia in the boiler and 2 psia in the condenser. The turbine inlet temperature is 800 °F. The Turbine Isentropic efficiency is 90%, The pump losses are negligable, and the cycle is sized to produce 2500 kW of power. Calculate the mass flow rate through the boiler, the power produced by the turbine, the rate of heat supply to the boiler, and the thermal efficiency.



Given:

$P_{max} = 1500$ psia

$P_{min} = 2$ psia

$T_3 = 800$ °F

$\eta_T = 0.9$

$\dot{W}_{net} = 2500$ kW

State 1) $P_1 = 2$ psia, Sat Liquid

$T_1 = 126.02$ °F

$h_1 = 94.02$ BTu/lbm

$s_1 = 0.17499$ BTu/lbm·R

$v_1 = 0.01623$ ft³/lbm

State 2) $P_2 = 1500$ psia, compressed liquid, $s_1 = s_2$

$h_2 = 98.53$ BTu/lbm

$$h_2 = h_1 + v_1 (P_2 - P_1)$$

$$= 94.02 \left(\frac{BTu}{lbm}\right) + 0.01623 \frac{ft^3}{lbm} (1500 + 2) \text{ Psia} \left(\frac{1 \text{ BTu}}{5.403 \text{ Psia} \cdot ft^3}\right)$$

$$h_2 = 98.53 \text{ BTu/lbm}$$

State 3) $P_3 = 1500$ psia, $T_3 = 800$ °F

T @ 1600 psia < 800 Superheated

$h_3 = 1363.1$ Btu/lbm

$s_3 = 1.5064$ Btu/lbm·R

— State 4) $\left.\begin{matrix} P_4 = 2\,\text{psia} \\ s_{4s} = s_3 \end{matrix}\right\}$ @ 2 psia $s_f < 1.5064 < s_{fg}$
Sat Mixture
$h_{4s} = 873.78$ Btu/lbm
$h_4 = 922.71$ Btu/lbm

$$x_{4s} = \frac{s_{4s} - s_f}{s_{fg}} = \frac{1.5064 - 0.17499}{1.74444} = 0.7632$$

$$h_{4s} = h_f + x_{4s} \cdot h_{fg} = 94.02 + 0.7632(1021.7)$$

$$h_{4s} = 873.78 \text{ Btu/lbm}$$

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} \quad h_4 = h_3 - (\eta_T (h_3 - h_{4s}))$$

$$h_4 = 1363.1 - (0.9(1363.1 - 873.78))$$

$$h_4 = 922.71 \text{ Btu/lbm}$$

— Solving Questions

$$\dot{M} = \frac{\dot{W}}{q_{in} - q_{out}}$$

$$\dot{M} = \frac{2500 \cancel{kW} \left(\frac{1 \cancel{kJ/s}}{1 \cancel{kW}}\right)\left(\frac{0.94782 \text{ Btu}}{1 \cancel{kJ}}\right)}{(h_3 - h_2) - (h_4 - h_1)\left(\frac{\text{Btu}}{\text{lbm}}\right)}$$

$$= \frac{2369.55 \text{ Btu/s}}{(1363.1 - 98.53) - (922.71 - 94.02)\ (\text{Btu/lbm})}$$

$$\dot{M} = \boxed{5.436 \text{ lbm/s}}$$

$$P_T = \dot{M}(h_3 - h_4)$$

$$= 5.436 \frac{\cancel{\text{lbm}}}{\text{s}}(1363.1 - 922.71) \text{ Btu}/\cancel{\text{lbm}}$$

$$P_T = \boxed{2393.96 \text{ Btu/s}}$$

$$\dot{Q}_{in} = \dot{M}\,(h_3 - h_2)$$

$$= 5.436\ \frac{lbm}{s}\ (1363.1 - 98.53)\ \frac{Btu}{lbm}$$

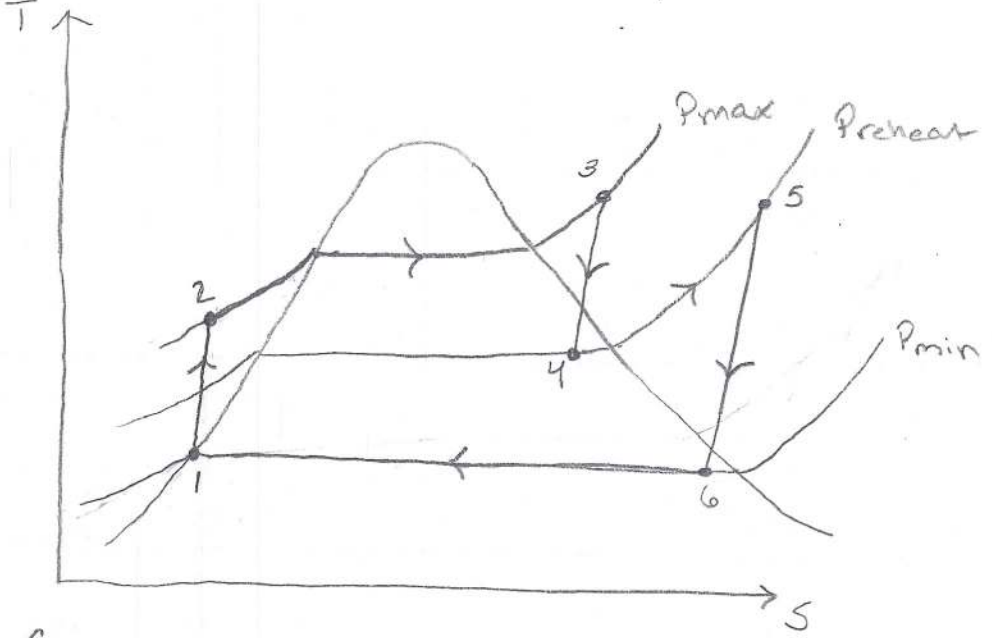
$$\dot{Q}_{in} = \boxed{6874.2\ Btu/s}$$

$$\eta_{Th} = \frac{\dot{W}}{\dot{Q}_{in}} = \frac{2369.55\ Btu/s}{6874.2\ Btu/s} = \boxed{0.345}$$

Rhiley Silvis | HW 2.1 | MET 350

Problem 10-34

Consider a steam power plant that operates on the Ideal Reheat Rankine cycle. The plant maintains the boiler at 5000 kpa, the reheat section at 1200 kpa, and the condenser at 20kpa. The mixture quality at the exit of both turbines is 96 %. Determine the temperature at the inlet of each turbine and the cycles thermal efficiency.



Given:

$P_{max} = 5000$ kpa $\qquad x_T = 0.96$

$P_{reheat} = 1200$ kpa

$P_{min} = 20$ kpa

State 1) $P_1 = 20$ kpa, Saturated liquid $\Big\}$ $v_1 = 0.001017\ m^3/kg$, $h_1 = 251.42\ kJ/kg$, $T_1 = 60.06\ °C$

State 2) $P_2 = 5000$ kpa $\Big\}$ $h_2 = 256.48\ kJ/kg$

$$h_2 = h_1 + v_1 (P_2 - P_1)$$

$$= 251.42\ \frac{kJ}{kg} + 0.001017\ \frac{m^3}{kg}\ (5000 - 20)\ kpa$$

$$h_2 = 256.48\ kJ/kg$$

— State 4) $P_4 = 1200$ kpa, $X = 0.96$ } $h_4 = 2704.31$ kJ/kg, $s_4 = 6.3495 \frac{kJ}{kg \cdot K}$

$h_4 = h_f + x\, h_{fg}$

$= 798.33 + 0.96 \cdot 1985.4$

$h_4 = 2704.31$ kJ/kg

$s_4 = s_f + x\, s_{fg}$

$= 2.2159 + 0.96 \cdot 4.3058$

$s_4 = 6.3495 \frac{kJ}{kg \cdot K}$

— State 3) $P_3 = 5000$ kpa, $s_3 = s_4$ } s_3 @ 5000 kpa = Superheated, $h_3 = 3008.34$ kJ/kg

s	h
6.2111	2925.7
6.3495	h_3
6.4516	3069.3

$$\frac{6.3495 - 6.2111}{6.4516 - 6.2111} = \frac{h_3 - 2925.7}{3069.3 - 2925.7}$$

$h_3 = 3008.34$ kJ/kg

— State 6) $P_6 = 20$ kpa, $x = 0.96$ } $h_6 = 2514.62$ kJ/kg, $s_6 = 7.6242 \frac{kJ}{kg \cdot K}$

$h_6 = h_f + x\, h_{fg}$

$= 251.42 + 0.96 \cdot 2357.5$

$h_6 = 2514.62$ kJ/kg

$s_6 = s_f + x\, s_{fg}$

$= 0.8320 + 0.96 \cdot 7.0752$

$s_6 = 7.6242 \frac{kJ}{kg \cdot K}$

— State 5) $P_5 = 1200\ kpa$, $s_6 = s_5$ $\Big\}$ s_5 @ 1200 kpa = Super heated , $h_5 = 3438.21\ KJ/kg$

S	h
7.3793	3261.3
7.6242	h_5
7.6779	3477.0

$$\frac{7.6242 - 7.3793}{7.6779 - 7.3793} = \frac{h_5 - 3261.3}{3477.0 - 3261.3}$$

$$h_5 = 3438.21\ KJ/kg$$

— Solving Questions

Determine the temp at Inlet of each turbine

h	T
2925.7	300
3008.34	T_3
3069.3	350

$$\frac{3008.34 - 2925.7}{3069.3 - 2925.7} = \frac{T_3 - 300}{350 - 300}$$

$$\boxed{T_3 = 328.77\ °C}$$

h	T
3261.3	400
3438.21	T_5
3477.0	500

$$\frac{3438.21 - 3261.3}{3477.0 - 3261.3} = \frac{T_5 - 400}{500 - 400}$$

$$\boxed{T_5 = 482.02\ °C}$$

$$\eta_{Th} = 1 - \frac{q_{out}}{q_{in}}$$

$$q_{in} = (h_3 - h_2) + (h_5 - h_4)$$
$$= (3008.34 - 256.48) + (3438.21 - 2704.31)$$
$$q_{in} = 3485.76$$

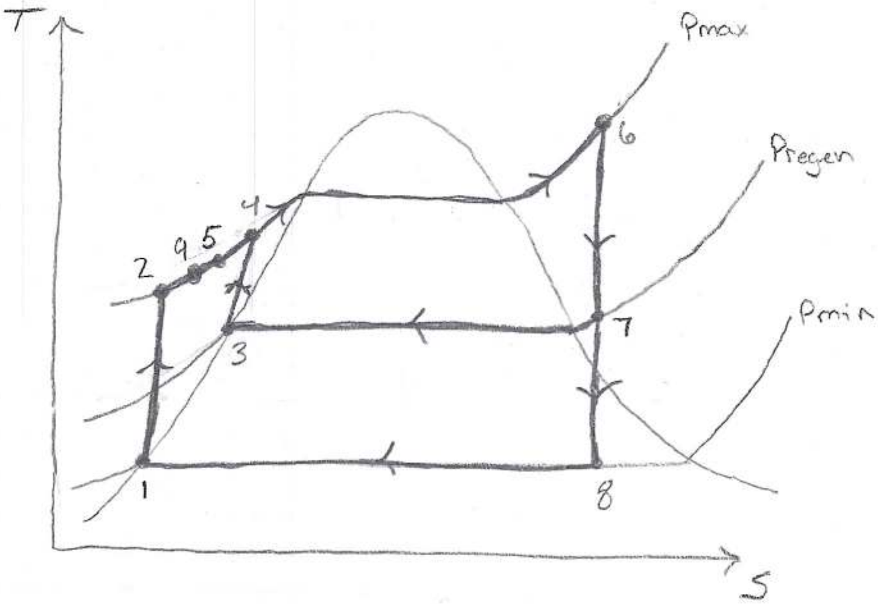
$$q_{out} = (h_6 - h_1)$$
$$= (2514.62 - 251.42)$$
$$q_{out} = 2263.2$$

$$\eta_{Th} = 1 - \frac{2263.2}{3485.76}$$
$$= \boxed{0.35}$$

Rhiley silvis | HW 2.1 | MET 350

Problem 10-48

Consider a steam power plant that operates on the Ideal regenerative Rankine cycle with a closed feedwater heater as shown in the figure. The plant maintains the Turbine inlet at 3000 kpa and 350 °c ; and operates the condenser at 20 kpa. Steam is extracted at 1000 kpa to serve the closed feedwater heater, which discharges into the condenser after being throttled to condenser pressure. Calculate the work produced by the Turbine, The work consumed by the pump, and the heat supply in the boiler for this cycle per unit of boiler flow rate.



Given:

$P_{max} = 3000$ Kpa

$T_6 = 350$ °c

$P_{min} = 20$ Kpa

$P_{regen} = 1000$ Kpa

State 1) $P_1 = 20$ Kpa } $T_1 = 60.06$ °c, $h_1 = 251.42$ KJ/kg, $V_1 = 0.001017$ m³/kg

State 2) $P_2 = 3000$ kpa, $s_2 = s_1$ } $h_2 = 254.45$ KJ/kg

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

$$= 251.42 \text{ KJ/kg} + 0.001017 \frac{m^3}{kg} (3000 - 20) \text{ Kpa}$$

$$h_2 = 254.45 \text{ KJ/kg}$$

— State 6) $P_6 = 3000$ kPa, $T_6 = 350$ °C $\Bigg\}$ 350 °C @ 3000 kPa = Superheated
$h_6 = 3116.1$ kJ/kg
$s_6 = 6.7450$ kJ/kg·K

— State 7) $P_7 = 1000$ kPa, $s_6 = s_7$ $\Bigg\}$ s_7 @ 1000 kPa = Superheated
$h_7 = 2848.93$ kJ/kg

s	h
6.6956	2823.3
6.7450	h_7
6.9265	2943.1

$$\frac{6.7450 - 6.6956}{6.9265 - 6.6956} = \frac{h_7 - 2823.3}{2943.1 - 2823.3}$$

$$h_7 = 2848.93 \text{ kJ/kg}$$

— State 8) $P_8 = 20$ kPa, $s_7 = s_8$ $\Bigg\}$ s_8 @ 20 kPa = Sat mixture
$h_8 = 2222.29$ kJ/kg

$$s_8 = s_f + x\, s_{fg}$$

$$x = \frac{s_8 - s_f}{s_{fg}} = \frac{6.7450 - 0.8320}{7.0752}$$

$$x = 0.836$$

$$h_8 = h_f + x\, h_{fg} = 251.42 + 0.836 \cdot 2357.5$$

$$h_8 = 2222.29 \text{ kJ/kg}$$

— State 3) $P_3 = 1000$ kPa, Saturated liquid $\Bigg\}$
$h_3 = 762.51$ kJ/kg
$T_3 = 179.88$
$v_3 = 0.00127$ m³/kg
$s_3 = 2.1381$ kJ/kg·K

— State 4) $P_4 = 3000$ kpa, $s_3 = s_4$ } s_4 @ 3000 kpa = compressed liquid, $h_4 = 764.76$ KJ/kg

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

$$= 762.51 \text{ KJ/kg} + 0.001127 \text{ m}^3\text{/kg} (3000 - 1000) \text{ kpa}$$

$$h_4 = 764.76 \text{ KJ/kg}$$

— State 9) $T_3 = T_9$, $P_9 = 3000$ kpa } $h_9 = 763.53$

Obtained 3MPa Table from google

T	h
175	742.13
179.88	h_9
180	764.06

$$\frac{179.88 - 175}{180 - 175} = \frac{h_9 - 742.13}{764.06 - 742.13}$$

$$h_9 = 763.53 \text{ KJ/kg}$$

Solving Questions

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

$$y(h_7 - h_3) = (1 - y)(h_9 - h_2)$$

$$y(2848.93 - 762.51) = (1 - y)(763.53 - 254.45)$$

$$y(2086.42) = (1 - y)(509.08)$$

$$4.098\, y = 1 - y$$

$$5.098\, y = 1$$

$$y = \frac{1}{5.098} = 0.196$$

$$W_T = (3116.1 - 2848.93) + (1 - 0.196)(2848.93 - 2222.29)$$

$$W_T = 267.17 + 0.804\,(626.64)$$

$$\boxed{W_T = 770.99 \text{ kJ/kg}}$$

$$W_P = (1-y)(h_2 - h_1) + y(h_4 - h_3)$$

$$= (1 - 0.196)(254.45 - 251.42) + 0.196(764.76 - 762.51)$$

$$= 0.804\,(3.03) + 0.196\,(2.25)$$

$$\boxed{W_P = 2.877 \text{ kJ/kg}}$$

$$Q_{in} = h_6 - h_5$$

$$h_5 = y h_4 + (1-y) h_9$$

$$= 0.196\,(764.76) + (1 - 0.196)\,763.53$$

$$= 149.89 + 613.878$$

$$h_5 = 763.77$$

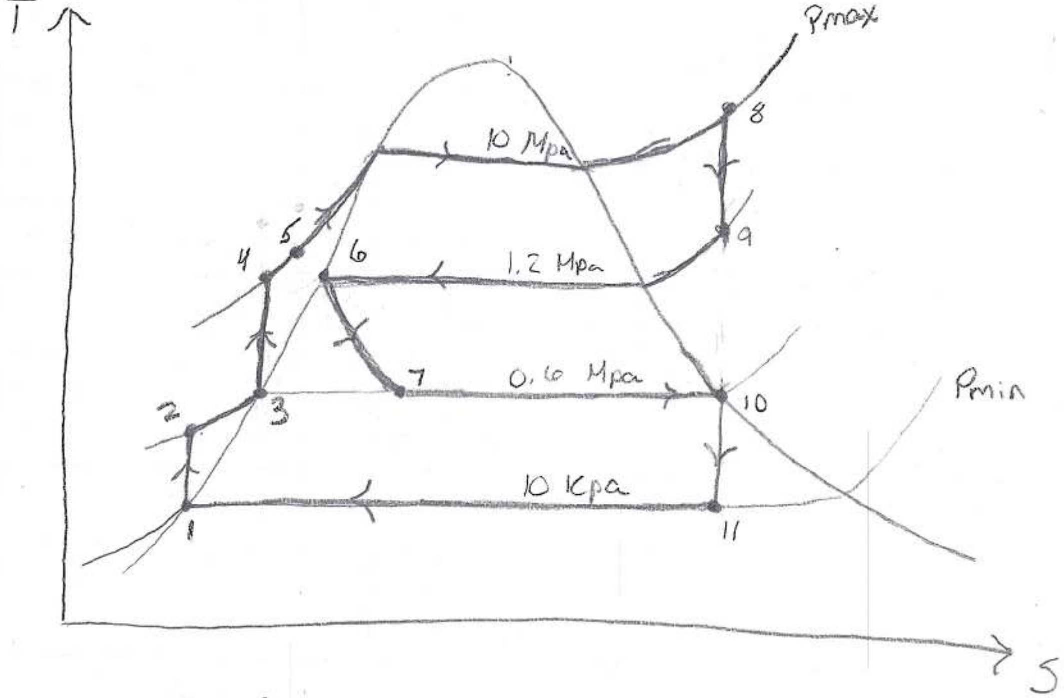
$$Q_{in} = 3116.1 - 763.77$$

$$\boxed{Q_{in} = 2352.33 \text{ kJ/kg}}$$

Rhiley Silvis | HW 2.1 | MET 350

Problem 10-53

Consider an Ideal Steam Regenerative Rankine cycle with two feedwater heaters, One Close and one open, steam enters the turbine at 10 MPa and 600 °c and exhausts to the condenser at 10 kPa. Steam is extracted from the turbine at 1.2 MPa for the closed feedwater heater and at 0.6 MPa for the open one. The feedwater is heated to the condensation temperature of the extracted steam in the closed feedwater heater. The extracted steam leaves the closed feedwater heater as a saturated liquid, which is subsequentually throttled to the open feedwater heater. Show the cycle on a T/s Diagram and determine (a) the mass flow rate of steam to the boiler for a net power output of 400 MW and (b) the thermal efficiency of the cycle.



Given: $P_{max} = 10\ Mpa$

$T_8 = 600°c$

$P_{min} = 10\ kpa$

$P_9 = P_6 = 1.2\ Mpa$

$P_7 = P_{10} = P_3 = 0.6\ Mpa$

— State 1) $P_1 = 10$ kpa, Sat liquid $\}$ $h_1 = 191.81$ KJ/kg, $V_1 = 0.001010$ m³/kg

— State 2) $P_2 = 0.6$ Mpa, $S_2 = S_1$ $\}$ $h_2 = 192.41$ KJ/kg

$$h_2 = h_1 + V_1(P_2 - P_1)$$
$$= 191.81 + 0.001010(600 - 10) \text{ kpa}$$
$$= 192.41 \text{ KJ/kg}$$

— State 3) $P_3 = 0.6$ Mpa, Sat liquid $\}$ $h_3 = 670.38$ KJ/kg, $V_3 = 0.001101$ m³/kg

— State 4) $P_4 = 10$ Mpa, $S_3 = S_4$ $\}$ $h_4 = 680.73$ KJ/kg

$$h_4 = h_3 + V_3(P_4 - P_3)$$
$$= 670.38 + 0.001101(10000 - 600)$$
$$h_4 = 680.73 \text{ KJ/kg}$$

— State 8) $P_8 = 10$ Mpa, $T_8 = 600°C$ $\}$ 600°C @ 10 Mpa = Superheated, $h_8 = 3625.8$ KJ/kg, $S_8 = 6.9045$

— State 9) $P_9 = 1.2$ Mpa, $S_8 = S_9$ $\}$ S_8 @ 1.2 Mpa = Superheated, $h_9 = 2975.68$ KJ/kg

S	h
6.8313	2935.6
6.9045	h_9
7.0335	3046.3

$$\frac{6.9045 - 6.8313}{7.0335 - 6.8313} = \frac{h_9 - 2935.6}{3046.3 - 2935.6}$$

$$h_9 = 2975.68 \text{ KJ/kg}$$

- State 6) $P_6 = 1.2$ Mpa, Sat liquid $\Big\}$ $h_6 = 798.33$ KJ/kg, $T_6 = 187.96$ °C

- State 10) $P_{10} = 0.6$ Mpa, $S_{10} = S_8$ $\Big\}$ $S_{10} = 6.9045$

S_{10} @ 0.6 Mpa = Super heated

$h_{10} = 2821.78$ KJ/kg

S	h
6.7593	2756.2
6.9045	h_{10}
6.9683	2850.6

$$\frac{6.9045 - 6.7593}{6.9683 - 6.7593} = \frac{h_{10} - 2756.2}{2850.6 - 2756.2}$$

$h_{10} = 2821.78$ KJ/kg

- State 11) $P_{11} = 10$ kpa, $S_{10} = S_{11}$ $\Big\}$ S_{11} @ 10 kpa = Sat Mixture

$h_{11} = 2186.82$ KJ/kg

$$X = \frac{S_{11} - S_f}{S_{fg}} = \frac{6.9045 - 0.6492}{7.4996} = 0.834$$

$h_{11} = h_f + X \cdot h_{fg} = 191.81 + 0.834 \cdot 2392.1$

$h_{11} = 2186.82$ KJ/kg

- State 5) $P_5 = 10$ Mpa, $T_5 = T_6 = 187.96$ °C $\Big\}$ 187.96°C @ 10 Mpa = Compressed

$h_5 = 802.75$ KJ/kg

T	h
180	767.68
187.96	h_5
200	855.80

$$\frac{187.96 - 180}{200 - 180} = \frac{h_5 - 767.68}{855.80 - 767.68}$$

$h_5 = 802.75$ KJ/kg

- State 7) $h_7 = h_6$

— Calculating Questions

$m_9 (h_9 - h_6) = m_5 (h_5 - h_4)$

$y(2975.68 - 798.33) = 1(802.75 - 680.73)$

$2177.55\, y = 122.02$

$y = 0.056$

$m_7 h_7 + m_2 h_2 + m_{10} h_{10} = m_3 h_3$

$y h_7 + (1-y-z) h_2 + z h_{10} = h_3$

$y(798.33) + (1-y-z)\,192.41 + z(2821.78) = 670.38$

$798.33 y + 192.41 - 192.41 y - 192.41 z + 2821.78 z$

$605.92(0.056) + 192.41 + 2629.37 z = 670.38$

$2629.37 z + 33.932 + 192.41 = 670.38$

$2629.37 z = 444.038$

$z = 0.169$

$q_{in} = h_8 - h_5$

$= 3625.8 - 802.75$

$= 2823.05 \text{ kJ/kg}$

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

$= (1 - 0.056 - 0.169)(2186.82 - 191.81)$

$= 1546.13 \text{ kJ/kg}$

$W_{net} = q_{in} - q_{out}$

$= 2823.05 - 1546.13$

$= 1276.92 \text{ kJ/kg}$

$$\dot{m} = \frac{400{,}000 \text{ W}}{W_{net}} = \frac{400{,}000 \text{ kJ/s}}{1276.92 \text{ kJ/kg}}$$

$$\dot{m} = \boxed{313.25 \text{ kg/s}}$$

$$\eta_{Th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{1546.13}{2823.05} = \boxed{0.452}$$