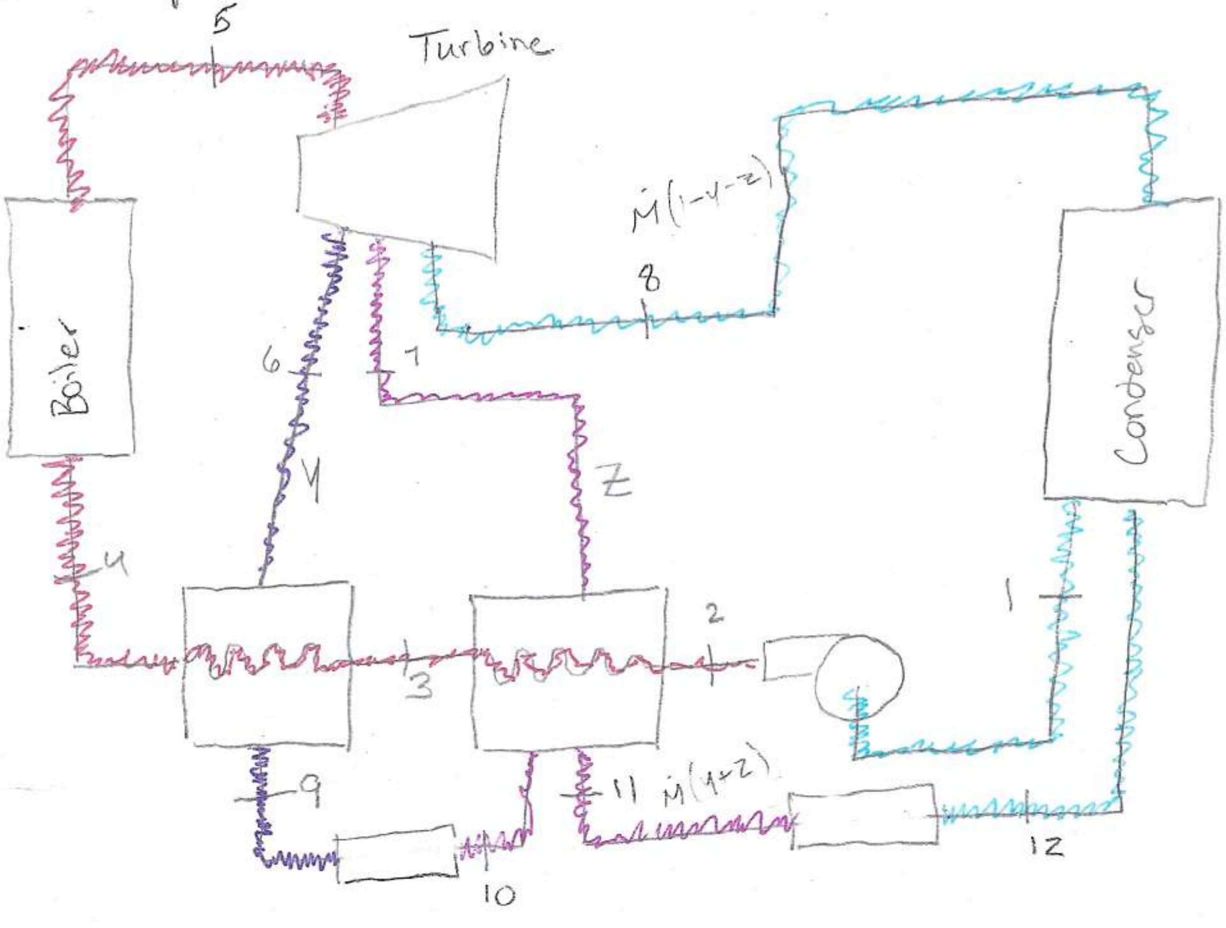
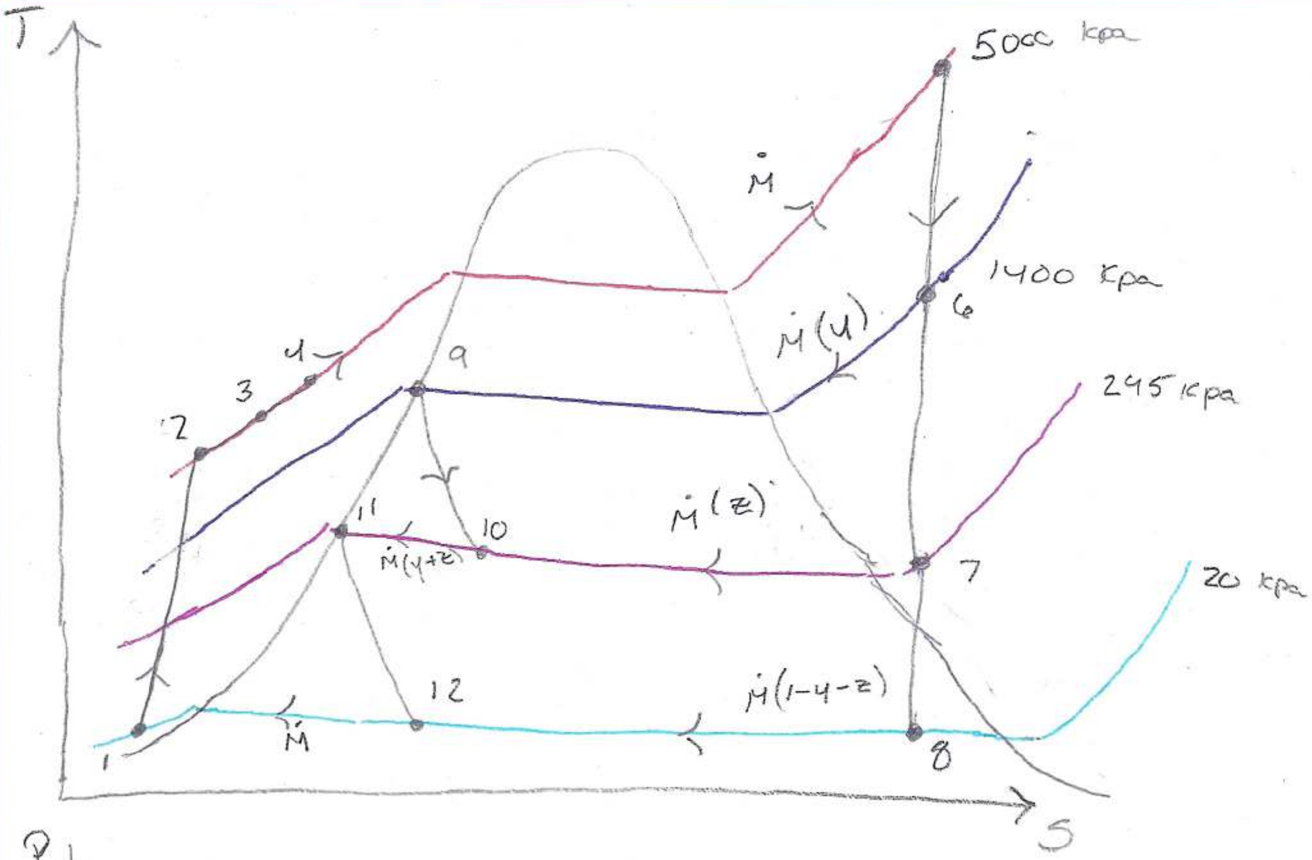
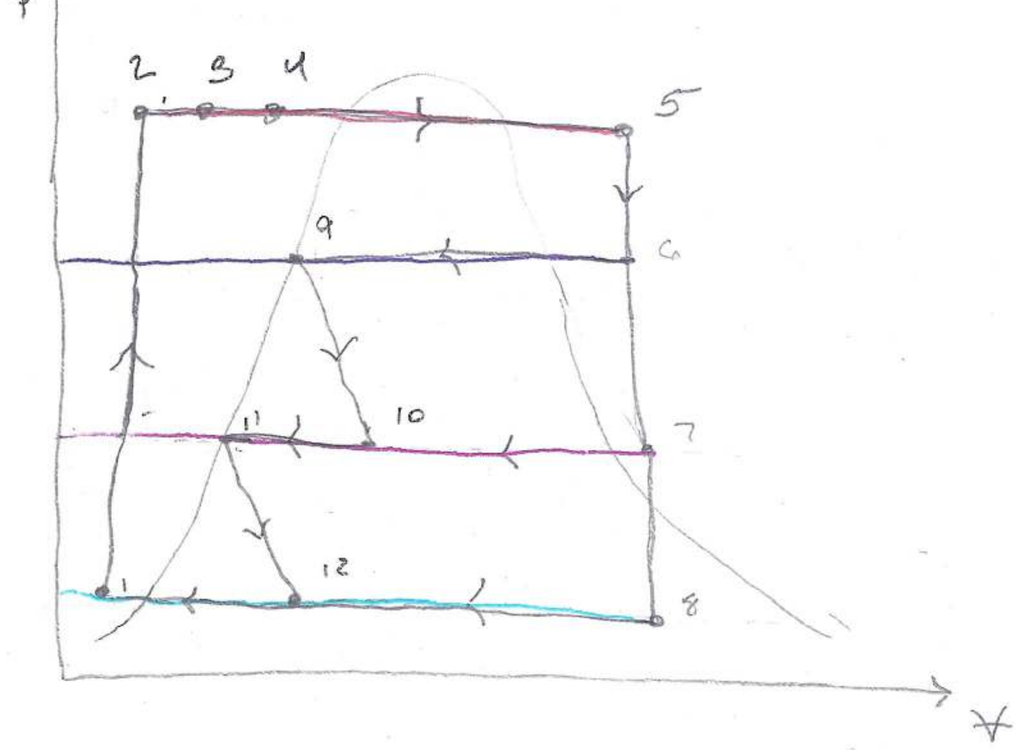
Rhiley Silvis | HW 2.2 | MET 350

Problem 10-57

An Ideal Rankine steam cycle modified with two closed feedwater heaters is shown below. The power cycle receives 75 kg/s of steam at the high pressure inlet to the turbine. The feedwater heater exit states for the boiler feedwater and the condensed steam are the normally assumed Ideal States. The mass entering the high pressure turbine at state 5 that is extracted for the feedwater heater operating at 1400 kpa is $y = 0.1446$. Use data provided in tables below to (a) sketch the T-s diagram for the Ideal Cycle. (b) determine the fraction of mass, z, that is extracted for the closed feedwater heater operating at 245 kpa extraction pressure. (c) determine the required cooling water flow rate, in kg/s to keep the cooling water temperature rise in the condenser to 10°C. Assume $C_p = 4.18$ KJ/kg-k for cooling water. (d) determine the net power output and thermal efficiency of the plant




T
5000 kpa
1400 kpa
245 kpa
20 kpa
Ṁ
Ṁ(y)
Ṁ(z)
Ṁ(y+z)
Ṁ(1-y-z)
Ṁ
1
2
3
4
5
6
7
8
9
10
11
12
S


P
2
3
4
5
6
9
10
11
7
12
1
8
v

- State 1) $P_1 = 20$ kpa, Saturated liquid $\}$ $v_1 = 0.00102$ m³/kg, $h_1 = 251$ kJ/kg, $s_1 = 0.8320$ kJ/kg·k

- State 2) $P_2 = 5000$ kpa, $s_1 = s_2$ $\}$ $s_2 = 0.8320$ kJ/kg·k, $h_2 = 256.08$ kJ/kg

$$h_2 = h_1 + v_1 (P_2 - P_1) = 251 + 0.00102(5000 - 20)$$

$$h_2 = 256.08 \text{ kJ/kg}$$

- State 11) $P_{11} = 245$ kpa, Saturated liquid $\}$ $h_{11} = 532.42$ kJ/kg

P	h_f
225	520.71
245	h_{11}
250	535.35

$$\frac{245 - 225}{250 - 225} = \frac{h_{11} - 520.71}{535.35 - 520.71}$$

$$h_{11} = 532.42 \text{ kJ/kg}$$

- State 9) $P_9 = 1400$ kpa, Saturated liquid $\}$ $h_9 = 829.96$ kJ/kg

- State 3) $h_{11} = h_3$, $P_3 = 5000$ kpa $\}$ $h_3 = 532.42$ kJ/kg

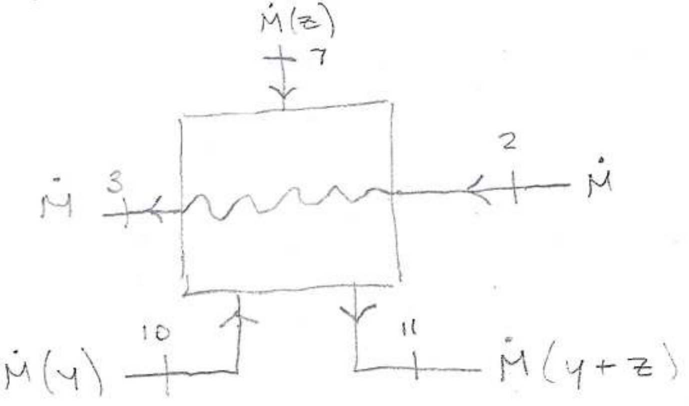
- State 12) $h_{11} = h_{12}$, $P_{12} = 20$ kpa $\}$ $h_{12} = 532.42$ kJ/kg

- State 4) $h_4 = h_9$, $P_4 = 5000$ kpa $\}$ $h_4 = 829.96$ kJ/kg

- State 5) $h_5 = 3900$ kJ/kg
- State 6) $h_6 = 3406$ kJ/kg
- State 7) $h_7 = 2918$ kJ/kg
- State 8) $h_8 = 2477$ kJ/kg

b) Determine Z

y = 0.1446



$$\cancel{\dot{M}} h_2 + \cancel{\dot{M}}(z) h_7 + \cancel{\dot{M}}(y) h_{10} = \cancel{\dot{M}} h_3 + \cancel{\dot{M}}(y+z) h_{11}$$

$$h_2 + (z)h_7 + (y)h_{10} = h_3 + (y+z)h_{11}$$

$$(z)h_7 - (y+z)h_{11} + (y)h_{10} = h_3 - h_2$$

$$(z)h_7 - (y)h_{11} - (z)h_{11} + (y)h_{10} = h_3 - h_2$$

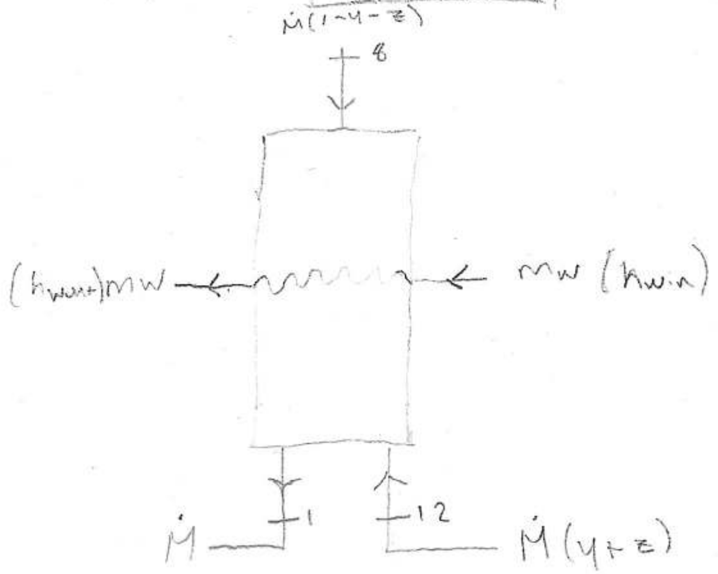
$$z(h_7 - h_{11}) = h_3 - h_2 + y(h_{11} - h_{10})$$

$$z = \frac{h_3 - h_2 + y(h_{11} - h_{10})}{h_7 - h_{11}}$$

$$z = \frac{(532.42 - 256.08) + 0.1446(532.42 - 829.96)}{2918 - 532.42}$$

$$= \frac{276.34 - 43.02}{2385.58} = \boxed{0.0978}$$

c)



$$\dot{M}_w h_{win} + \dot{M}(1-y-z)h_8 + \dot{M}(y+z)h_{12} = \dot{M}h_1 + \dot{M}_w h_{wout}$$

$$\dot{M}_w(h_{wout} - h_{win}) = \dot{M}((1-y-z)h_8 + (y+z)h_{12} - h_1)$$

$$\dot{M}_w = \frac{\dot{M}((1-y-z)h_8 + (y+z)h_{12} - h_1)}{C_p \Delta T}$$

$$= \frac{75((1-0.1446-0.0978)2477 + (0.1446-0.0978)532.42 - 251}{4.18(10)}$$

$$= \frac{75(1876.575 + 24.917 - 251)}{41.8}$$

$$\boxed{\dot{M}_w = 2961.41 \ kg/s}$$

d) determine $\dot{W}_{net}$ an η_{Th}

$$W_{net} = h_5 - (y)h_6 - (z)h_7 - (1-y-z)h_8$$

$$= 3900 - (0.1446)3406 - (0.0978)2918 - (1-0.1446-0.0978)2477$$

$$= 3900 - 492.51 - 285.38 - 1876.58$$

$$= 1245.53 \ kJ/kg$$

$$\dot{W}_{net} = \dot{M} \cdot w_{net}$$

$$= 75 \ kg/s \cdot 1245.5 \ kJ/kg$$

$$\boxed{= 93.41 \ MW}$$

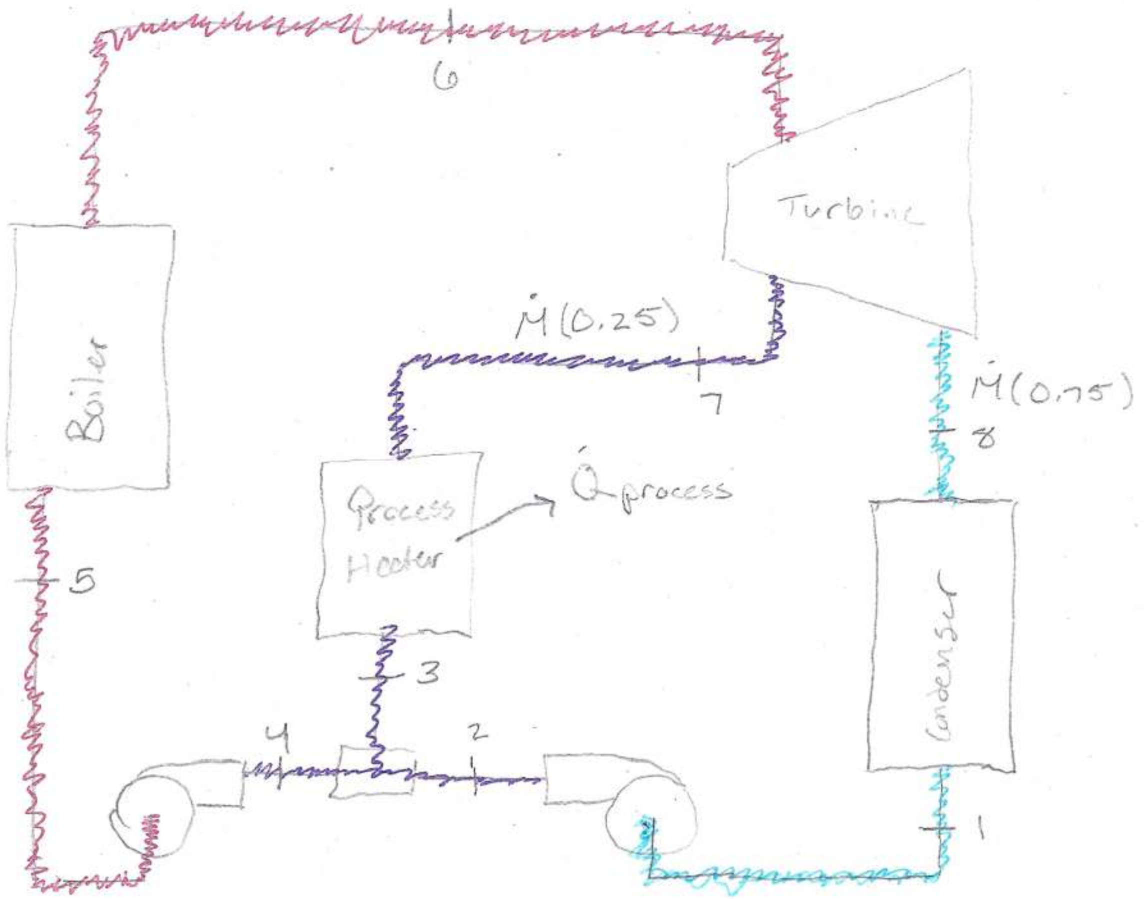
$$\dot{Q}_{in} = \dot{M}(h_5 - h_4) = 75 \ kg/s \ (3900 - 829.96) \ kJ/kg$$

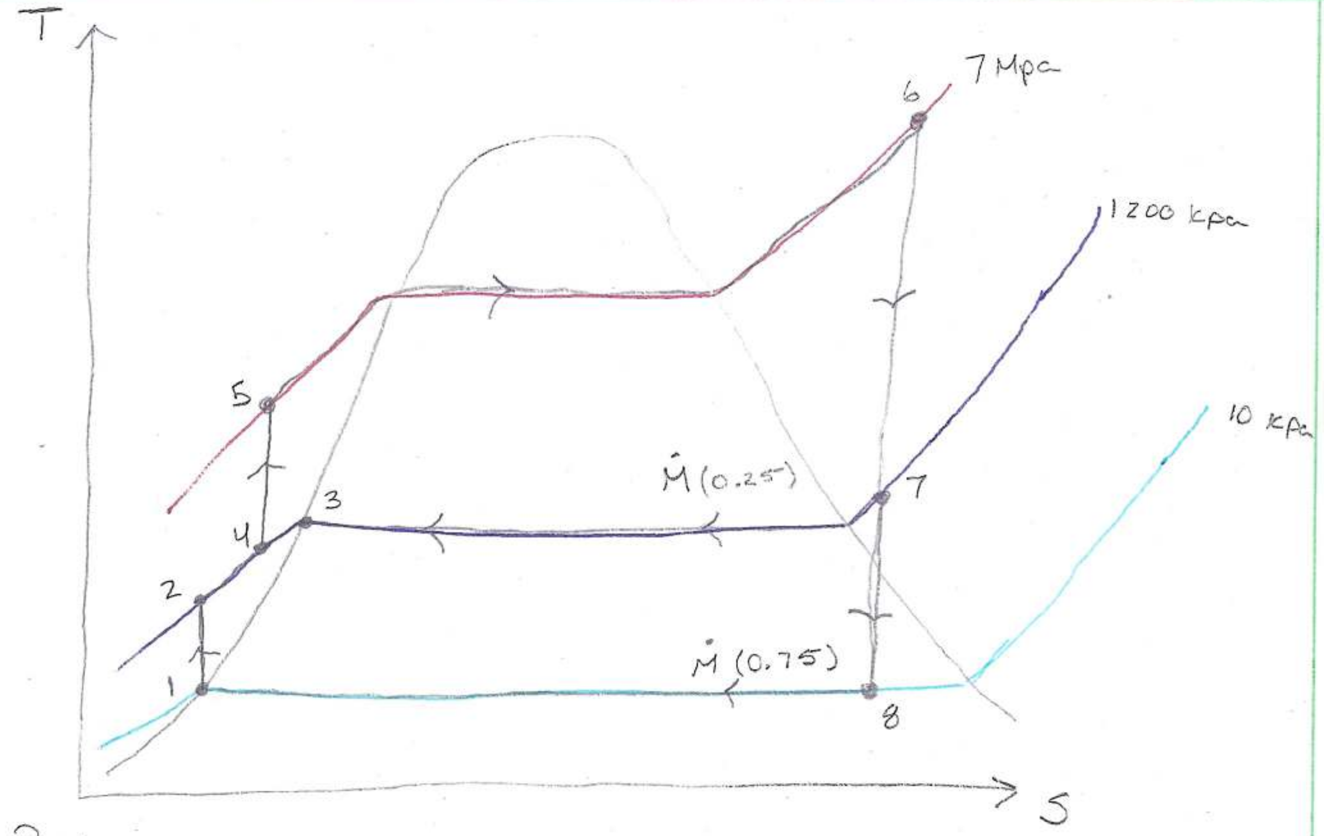
$$= 230.25 \ MW$$

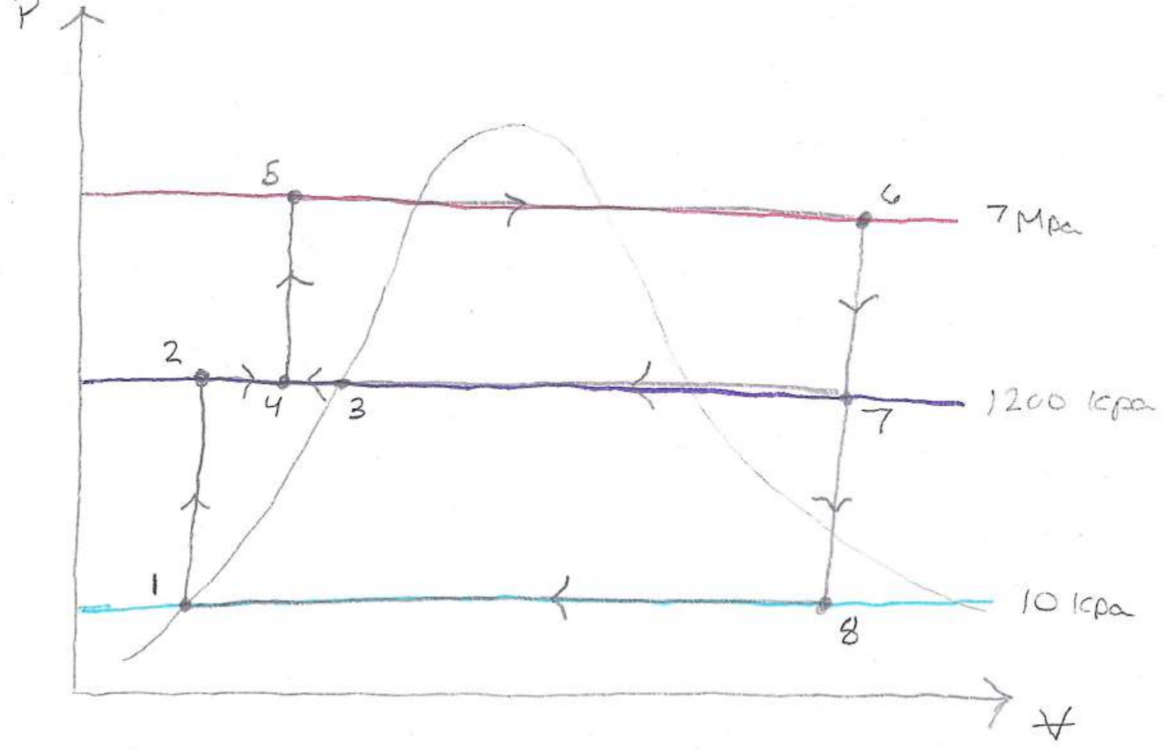
$$\eta_{Th} = \frac{93.41}{230.25} = \boxed{40.57 \ \%}$$

Problem 10-69

Steam enters the turbine of a cogeneration plant at 7 Mpa and 500 °c. One fourth of the steam is extracted from the turbine at 1200 kpa pressure for process heating. The remaining steam continues to expand to 10 kpa. The extracted steam is then condensed and mixed with feedwater at constant pressure and mixture is pumped to the boiler pressure of 7 MPa. The mass flow rate of steam through the boiler is 65 kg/s. Disregarding and pressure drops and heat losses in piping, and assuming turbine and pump to be Isentropic, determine Net power to be produced and the utilization factor of the plant




T
S
7 Mpa
1200 kpa
10 kpa
1
2
3
4
5
6
7
8
$\dot{M}(0.25)$
$\dot{M}(0.75)$


P
$\forall$
7 Mpa
1200 kpa
10 kpa
1
2
3
4
5
6
7
8

— State 1) $P_1 = 10$ kpa, Saturated liquid } $h_1 = 191.81$ KJ/kg

$V_1 = 0.001010$ m³/kg

— State 2) $P_2 = 1200$ kpa, $s_1 = s_2$ } $h_2 = 193.01$ KJ/kg

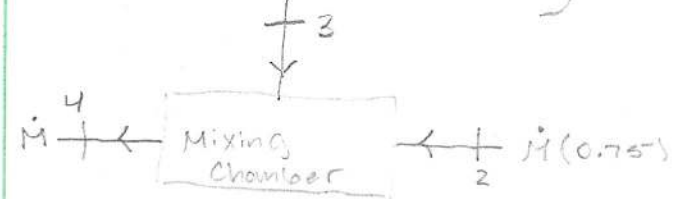
$$h_2 = h_1 + V_1(P_2 - P_1) = 191.81 + 0.001010(1200 - 10)$$

$$h_2 = 193.01 \text{ KJ/kg}$$

— State 3) $P_3 = 1200$ kpa, Saturated liquid } $h_3 = 798.33$ KJ/kg

— State 4) $P_4 = 1200$ kpa } $h_4 = 344.34$ KJ/kg

$\dot{M}(0.25)$ } $V_4 = 0.0010306$ m³/kg



$$\cancel{\dot{M}}(0.25)h_3 + \cancel{\dot{M}}(0.75)h_2 = \cancel{\dot{M}}h_4$$

$$(0.25)798.33 + (0.75)193.01 = h_4$$

$$h_4 = 344.34 \text{ KJ/kg}$$

$V_4 = V_F$ @ h_F $\quad h_f = 344.34$

h	V
340.54	0.001030
344.34	V_4
384.44	0.001037

$$\frac{344.34 - 340.54}{384.44 - 340.54} = \frac{V_4 - 0.001030}{0.001037 - 0.001030}$$

$$V_4 = 0.0010306$$

- State 5) $P_5 = 7$ Mpa, $s_4 = s_5$ $\}$ $h_5 = 350.32$ KJ/kg

$h_5 = h_4 + v_4(P_5 - P_4) = 344.34 + 0.0010306(7000 - 1200)$

$h_5 = 350.32$ KJ/kg

- State 6) $T_6 = 500°C$, $P_6 = 7$ MPa $\}$ 7Mpa @ 500°C = Superheated
  $h_6 = 3411.4$ KJ/kg
  $s_6 = 6.800$

State 7) $P_7 = 1200$ kpa, $s_6 = s_7$ $\}$ s_7 @ 1200 kpa = Superheated
$h_7 = 2920.04$ KJ/kg

s	h
6.5909	2816.1
6.8000	h_7
6.8313	2935.6

$$\frac{6.800 - 6.5909}{6.8313 - 6.5909} = \frac{h_7 - 2816.1}{2935.6 - 2816.1}$$

$h_7 = 2920.04$ KJ/kg

State 8) $P_8 = 10$ Kpa, $s_6 = s_8$ $\}$ s_8 @ 10 kpa = Saturated Mixture
$h_8 = 2153.33$

$s_8 = s_f + x_8 s_{fg}$

$$x_8 = \frac{s_8 - s_f}{s_{fg}} = \frac{6.800 - 0.6492}{7.4996} = 0.820$$

$h_8 = h_f + x_8 h_{fg} = 191.81 + 0.820(2392.1)$

$h_8 = 2153.33$

Solving Questions)

Net power to be produced , $\dot{W}_{net}$

$\dot{W}_{net} = \dot{W}_T - \dot{W}_P$

$\dot{W}_T = \dot{M} h_6 - [\dot{M}(0.25) h_7 + \dot{M}(0.75) h_8]$

$= 55(3411.4) - [55(0.25)2920.04 + 55(0.75)2153.33]$

$\dot{W}_T = 58651.59$ kW

$\dot{W}_P = \dot{W}_{PI} + \dot{W}_{PII}$

$= \dot{M}(0.75)(h_2 - h_1) + \dot{M}(h_5 - h_4)$

$= 55(0.75)(193.01 - 191.81) + 55(350.32 - 344.34)$

$\dot{W}_P = 378.4$ kW

$\dot{W}_{net} = 58651.59 - 378.4 = \boxed{58.27 \text{ MW}}$

$$\varepsilon_u = \frac{\dot{W}_{net} + \dot{Q}_p}{\dot{Q}_{in}}$$

$\dot{Q}_p = \dot{M}(0.25)(h_7 - h_3) = 55(0.25)(2920.04 - 798.33)$

$\dot{Q}_p = 29173.51$ kW $= 29.17$ MW

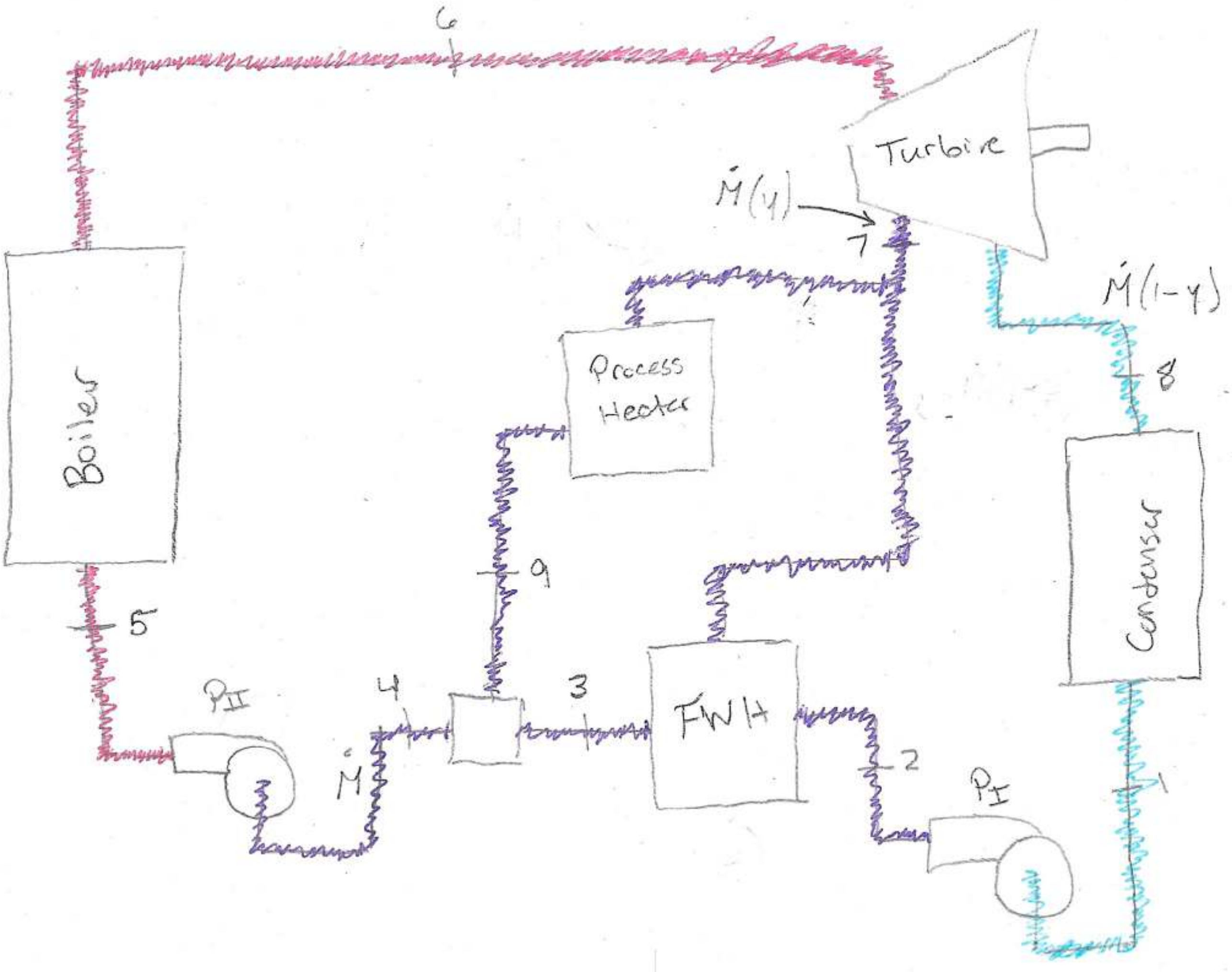
$\dot{Q}_{in} = \dot{M}(h_6 - h_5) = 55(3411.4 - 350.32)$

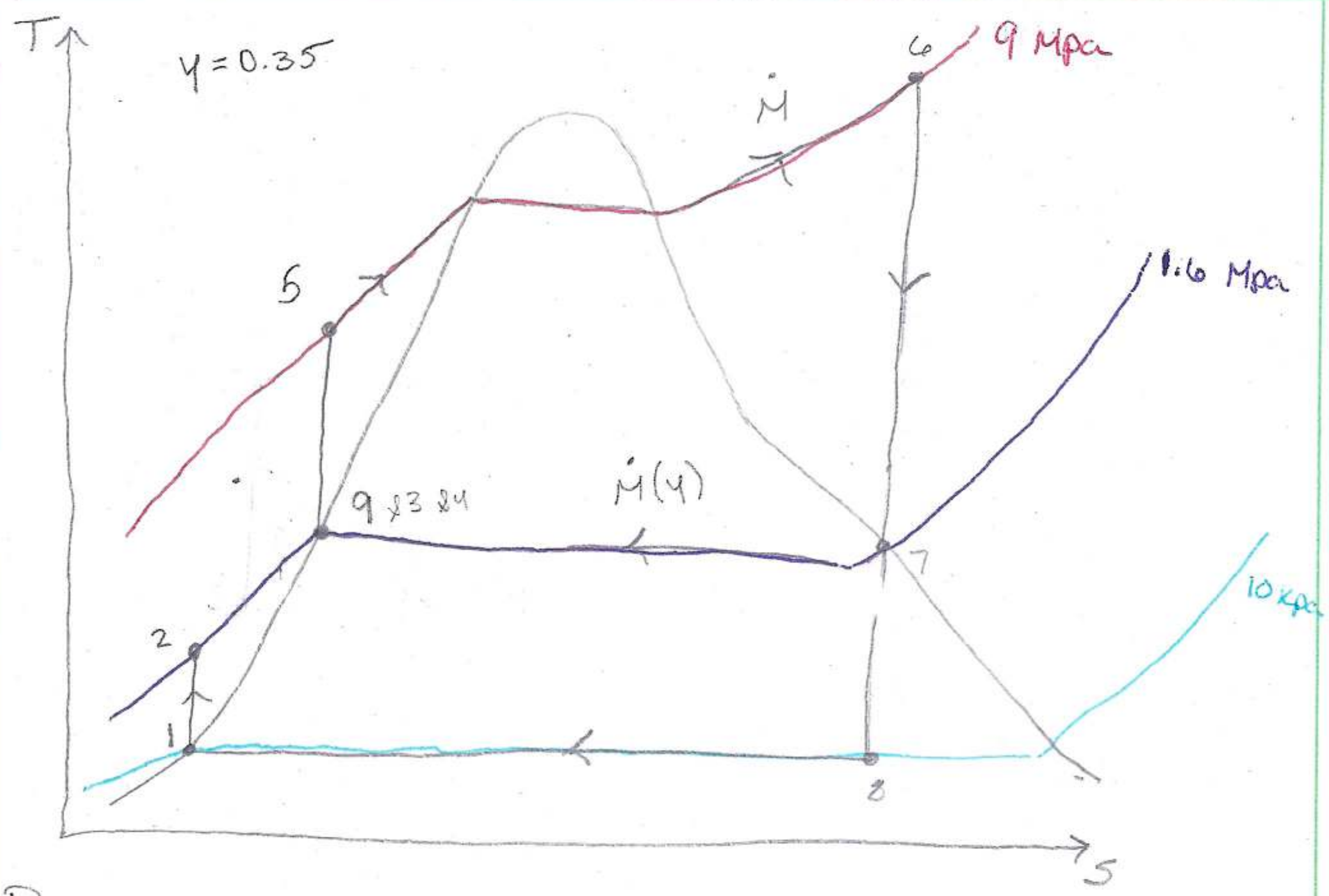
$\dot{Q}_{in} = 168.36$ MW

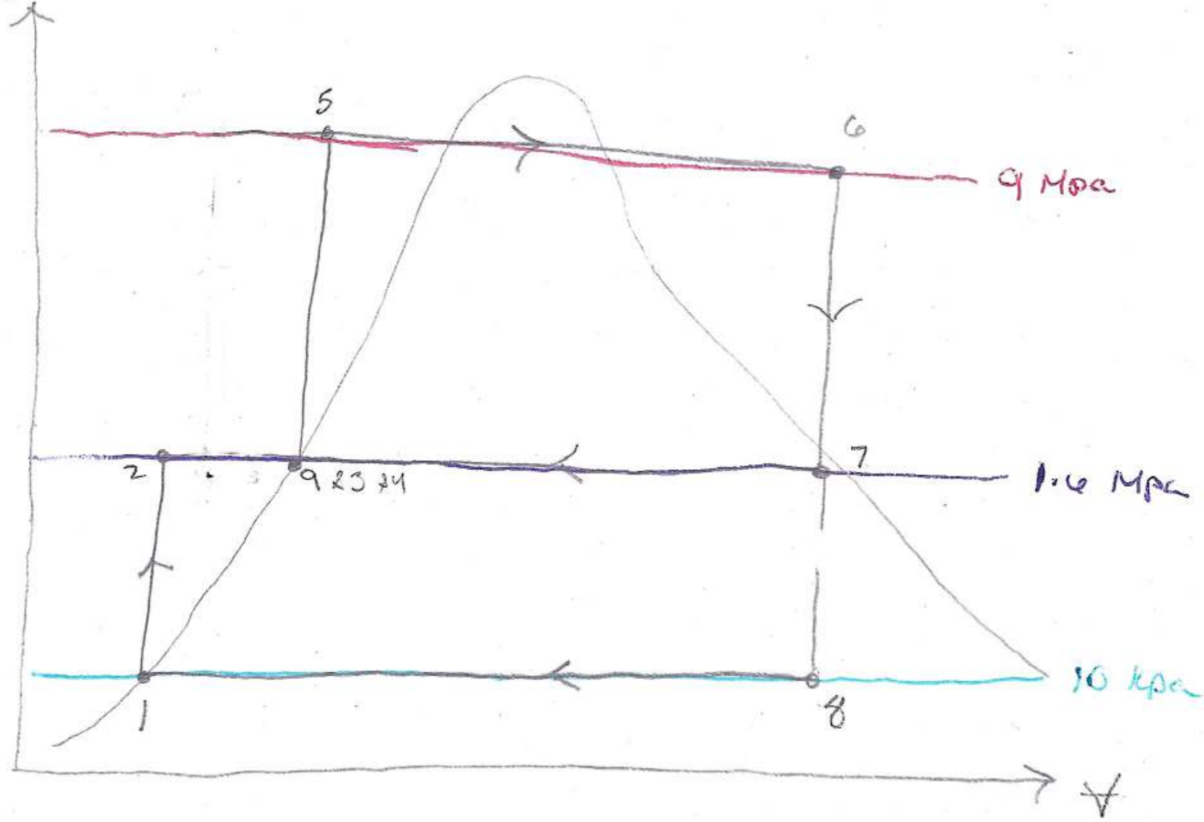
$$\varepsilon_u = \frac{58.27 + 29.17}{168.36} = \boxed{0.519}$$

10 - 72

Consider a coregeneration power plant modified with regeneration. Steam enters the turbine at 9 MPa and 400°C and expands to a pressure of 1.6 MPa. At this pressure, 35% of the steam is extracted from the turbine, and the remainder expands to 10 kPa. Part of the extracted steam is used to heat an open feedwater heater. The rest of the extracted steam is used for process heating and leaves the process heater as a saturated liquid at 1.6 Mpa. It is subsequently mixed with the feedwater leaving the feedwater heater, and the mixture is pumped to boiler pressure. Assuming the turbines and pumps to be Isentropic, show the cycle on a T-s diagram with respect to saturation lines, and determine the mass flow rate of the steam through the boiler for a Net power output of 25 MW.




T
y = 0.35
6
9 Mpa
Ṁ
5
1.6 Mpa
9 & 3 & 4
Ṁ(y)
7
10 kpa
2
1
8
s


P
5
6
9 Mpa
7
1.6 Mpa
2
9 & 3 & 4
10 kpa
1
8
V

— State 1) $P_1 = 10$ kpa, Saturated liquid $\Big\}$ $h_1 = 191.81$ KJ/kg, $v_1 = 0.001010$

— State 2) $P_2 = 1600$ kpa, $s_1 = s_2$ $\Big\}$ $h_2 = 193.42$ KJ/kg

$$h_2 = h_1 + v_1 (P_2 - P_1) = 191.81 + 0.001010 (1600 - 10)$$

$$h_2 = 193.42 \text{ KJ/kg}$$

— State 6) $P_6 = 9000$ kpa, $T_6 = 400°c$ $\Big\}$ 400°c @ 9000 kpa = Superheated, $h_6 = 3118.8$ KJ/kg, $s_6 = 6.2876$

— State 7) $P_7 = 1600$ kpa, $s_6 = s_7$ $\Big\}$ 1600 kpa @ s_7 = Saturated Mix, $h_7 = 2729.41$

$$s_7 = s_f + x_7 s_{fg} =$$

P	sf
1500	2.3143
1600	sf
1750	2,3844

$$\frac{1600 - 1500}{1750 - 1500} = \frac{s_f - 2,3143}{2,3844 - 2,3143}$$

sf @1600 = 2,3423

P	sfg
1500	4,1287
1600	sfg
1750	4,0033

$$\frac{1600 - 1500}{1750 - 1500} = \frac{s_{fg} - 4.1287}{4.0033 - 4.1287}$$

sfg @ 1600 = 4,0785

$$x_7 = \frac{s_7 - s_f}{s_{fg}} = \frac{6.2876 - 2.3423}{4.0785} = 0,9673$$

$$h_7 = h_f + x_7 h_{fg}$$

P	h_f
1500	844.55
1600	h_f
1750	878.16

$$\frac{1600-1500}{1750-1500} = \frac{h_f - 844.55}{878.16-844.55}$$

$$h_f = 857.99$$

P	h_{fg}
1500	1946.4
1600	h_{fg}
1750	1917.1

$$0.4 = \frac{h_{fg} - 1946.4}{1917.1 - 1946.4}$$

$$h_{fg}\ @1600 = 1934.68$$

$$h_7 = 857.99 + 0.9673(1934.68) = 2729.41$$

State 8) $\left.\begin{array}{l} P_8 = 10\text{ Kpa} \\ s_6 = s_8 \\ \text{Sat Mixture} \end{array}\right\}$ $h_8 = 1990.67$

$$x_8 = \frac{s_8 - s_f}{s_{fg}} = \frac{6.2876 - 0.6492}{7.4996} = 0.752$$

$$h_8 = h_f + x_8 h_{fg} = 191.81 + 0.752(2392.1)$$

$$h_8 = 1990.67$$

State 9,3,4) $\left.\begin{array}{l} P_9 = 1600\text{ kpa} \\ \text{Saturated liquid} \end{array}\right\}$ $\begin{array}{l} h_9 = 857.99 \\ v = 0.001159 \end{array}$

P	v
1500	0.001154
1600	v
1750	0.001166

$$\frac{1600-1500}{1750-1500} = \frac{v - 0.001154}{0.001166-0.001154}$$

$$v = 0.001159$$

State 5) $\left.\begin{array}{l} P_5 = 9000\text{ kpa} \\ s_5 = s_4 \end{array}\right\}$ $h_5 = 866.57$

$$h_5 = h_4 + v_4(P_5 - P_4)$$

$$= 857.99 + 0.001159(9000 - 1600) = 866.57$$

- Solving for $\dot{M}$

$\dot{W}_{net} = \dot{M} \cdot w_{net}$

$w_{net} = h_6 - y h_7 - (1-y) h_8$

$= 3118.8 - (0.35 \cdot 2729.41) - (1-0.35)\, 1990.67$

$= 3118.8 - 955.29 - 1293.94.$

$= 869.57 \ \mathrm{KJ/Kg}$

$25\ \mathrm{MW} = 25000\ \mathrm{KJ/s} = \dot{M} \cdot 869.57\ \mathrm{KJ/Kg}$

$\dfrac{25000\ \mathrm{KJ/s}}{869.57\ \mathrm{KJ/Kg}} = \boxed{28.75\ \mathrm{Kg/s}}$