Problem (5.3): A steam power plant operates on an ideal regenerative Rankine cycle. Steam enters the turbine at 6 MPa and 450°C and is condensed in the condenser at 20 kPa. Steam is extracted from the turbine at 0.4 MPa to heat the feedwater in an open feedwater heater. Water leaves the feedwater heater as a saturated liquid. Show the cycle on a (*T-S*) diagram, and determine (a) the net work output per kilogram of steam flowing through the boiler (b) the thermal efficiency of the cycle.

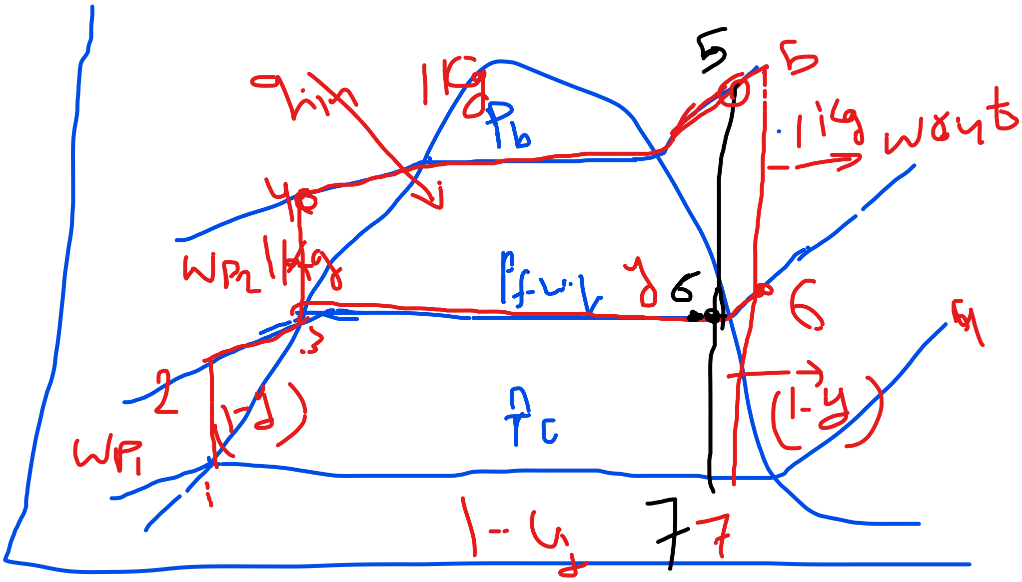
Ans. (1017 kJ/kg, 37.8%)

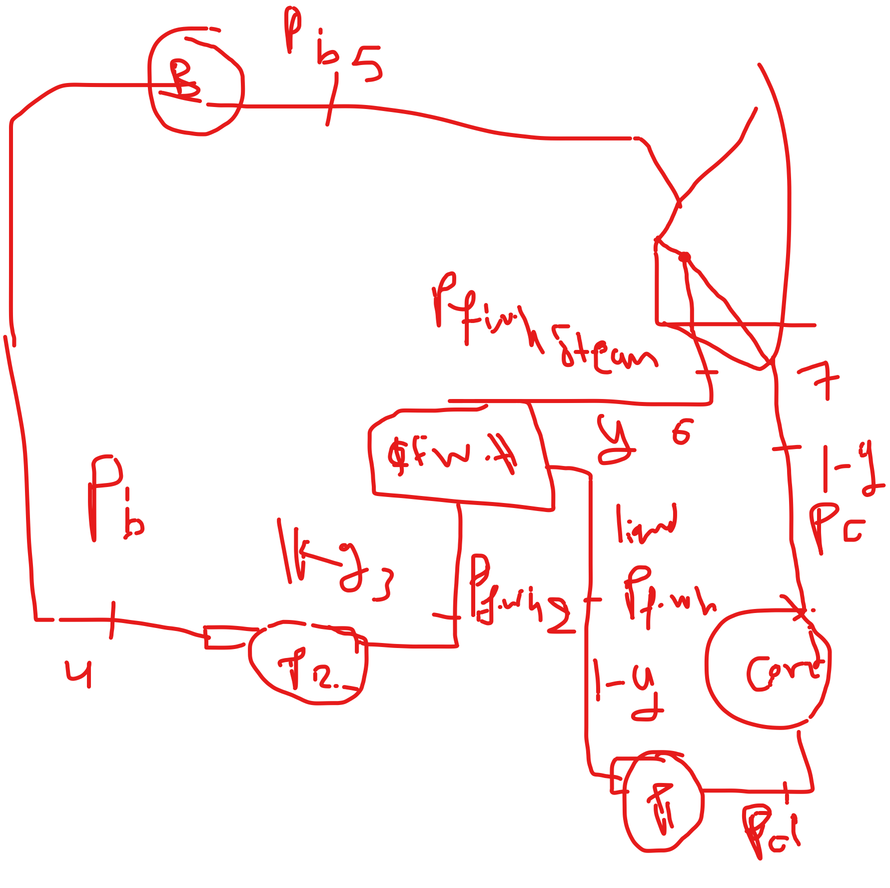
$P_b = P_4 = P_5$

$T_5 = 450°C$

$P_c = P_1 = P_7$

$P_{f.w.h} = P_3 = P_2 = P_6$





State 1 $P_1 = 20$ kPa $\rightarrow$ A-5, $h_f = h_1 = 251.42$ kJ/kg
$v_f = v_1 = 0.001017$ m³/kg

State 2 $P_2 = 0.4$ MPa $= 400$ kPa

$$h_2 = h_1 + w_{p_1} \Rightarrow h_2 = h_1 + v_1(P_2 - P_1)$$

$$h_2 = 251.42 + 0.001017(400 - 20) = 251.8 \text{ kJ/kg}$$

State 3 $P_3 = 0.4$ MPa $= 400$ kPa

$h_3 = h_f = 604.66$ kJ/kg, $V_3 = v_f = 0.001084$ m³/kg

State 4 $P_4 = 6$ MPa $= 6000$ kPa

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

$$h_4 = 604.66 + 0.001084 \times (6000 - 400)$$

5600

$$h_4 = 610.8 \text{ kJ/kg}$$

State 5 $\rightarrow$ A-6 at $P_5 = 6$ MPa, $T_5 = 450°C$

$h_5 = 3302.9$ kJ/kg, $S_5 = 6.7219$ kJ/kg·K

State 6 $P_6 = 0.4$ MPa $= 400$ kPa

$S_6 = S_5 = 6.7219$ kJ/kg·K $\rightarrow$ A-5

at $P_6 = 400$ kPa, $S_g = 6.8955 > S_6 \rightarrow$ mix

$S_f = 1.7765$ kJ/kg·K, $S_{fg} = 5.1191$, $h_f = 604.66$, $h_{fg} = 2133.4$

$$x_6 = \frac{S_6 - S_f}{S_{fg}} \Rightarrow x_6 = \frac{6.7219 - 1.7765}{5.1191} = 0.966$$

$h_6 = h_f + x_6 h_{fg}$

$= 604.66 + 0.966 (2133.4)$

$h_6 = 2665.52$ kJ/kg

State-7 $P_7 = 20$ kPa, $s_7 = s_6 = 6.7219$ kJ/kg·K

→ A-5 $s_f = 0.8302$, $s_{fg} = 7.0752$

$h_f = 251.42$, $h_{fg} = 2357.5$

$$x_7 = \frac{s_7 - s_f}{s_{fg}} = \frac{6.7219 - 0.8302}{7.0752} = 0.832$$

$h_7 = h_f + x_7 h_{fg}$

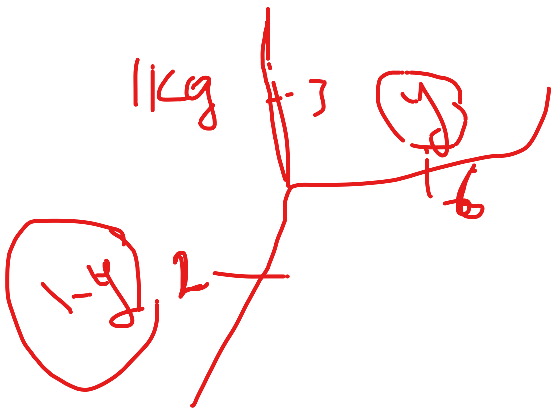
$= 251.42 + 0.8324 \times 2357.5$

$h_7 = 2213.97$ kJ/kg

$q_{in} = h_5 - h_4$

$= 3302.9 - 610.8$

$q_{in} = 2692.1$ kJ/kg



$h_3 = y h_6 + (1-y) h_2 \Rightarrow h_3 = y h_6 + h_2 - y h_2$

$h_3 - h_2 = y (h_6 - h_2)$

$$y = \frac{h_3 - h_2}{h_6 - h_2} \Rightarrow y = \frac{604.66 - 251.8}{2665.52 - 251.8}$$

$$y = 0.1462$$

$$q_{out} = (1-y)(h_7 - h_1)$$

$$= (1 - 0.1462)(2213.97 - 251.8)$$

$$= 1675.62 \text{ kJ/kg}$$

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

$$= 2692.1 - 1675.62$$

$$= 1016.5 \text{ kJ/kg}$$

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

$$= 1 - \frac{1675.62}{2692.1} = 0.3776 \times 100\%$$

$$\eta_{th} = 37.8$$

$$W_t = h_5 - h_6 + (1-y)(h_6 - h_7)$$