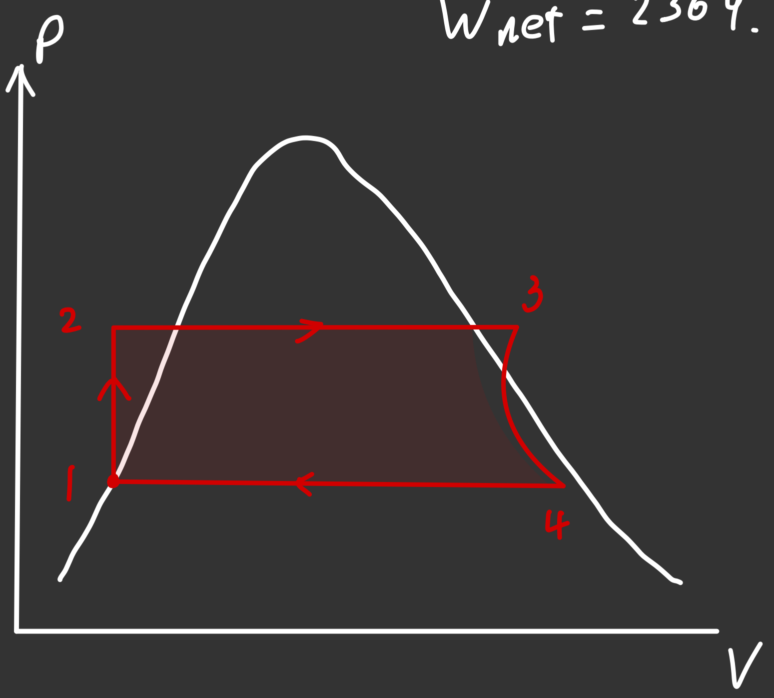
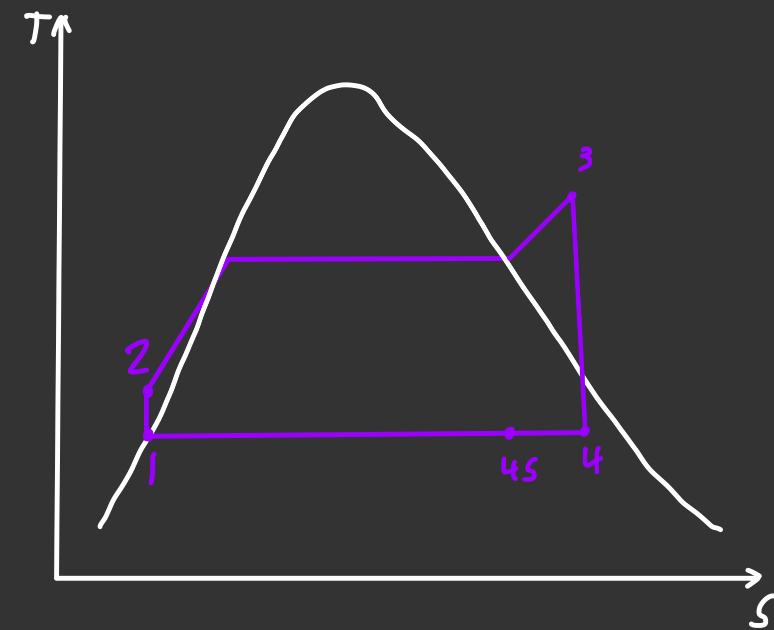
10–18E A steam Rankine cycle operates between the pressure limits of 1500 psia in the boiler and 2 psia in the condenser. The turbine inlet temperature is 800°F. The turbine isentropic efficiency is 90 percent, the pump losses are negligible, and the cycle is sized to produce 2500 kW of power. Calculate the mass flow rate through the boiler, the power produced by the turbine, the rate of heat supply in the boiler, and the thermal efficiency.

$\dot{W}_{net} = 2369.5$ Btu/s





$$1 \xrightarrow{\text{Isentropic}} 2 \xrightarrow{\text{Const P}} 3 \xrightarrow{\text{Isentropic}} 4 \xrightarrow{\text{Const P}} \qquad 4s$$

1

$P_1 = 2$ psi

$h_1 = 94.02$

$V_1 = 0.01623$

$S_1 = 0.175$

Table A-5E

2

$P_2 = 1500$ psi

$h_2 = 99$

$V_2 =$

$S_2 = S_1$

Table A-7E

Interpolate

3

$P_3 = 1500$ psi

$h_3 = 1363$

$V_3 = 0.4355$

$T_3 = 800\,°F$

$S_3 = 1.5064$

Table A-6E

4

$P_4 = 2$ psi

$h_4 = 922.7$

$S_4 = S_3$

4s

$$x_{4s} = \frac{S_4 - S_f}{S_{fg}}$$

$$x_{4s} = \frac{1.5064 - 0.175}{1.744}$$

$$x_{4s} = 0.763$$

$$h_{4s} = h_f + x_{4s} \cdot h_{fg}$$

$$h_{4s} = 94 + (0.763 \cdot 1021.7)$$

$$h_{4s} = 873.8$$

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

$$h_4 = 1363 - 0.9(1363 - 873.8)$$

$$h_4 = 922.7$$

$$q_{in} = h_3 - h_2$$

$$q_{in} = 1363 - 99 = 1264 \text{ Btu/lbm}$$

$$q_{out} = h_4 - h_1$$

$$q_{out} = 922.7 - 94.02 = 828.7 \text{ Btu/lbm}$$

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

$$W_{net} = 1264 - 828.7 = 435.3 \text{ Btu/lbm}$$

$$\dot{m} = \frac{\dot{W}_{net}}{W_{net}}$$

$$\dot{m} = \frac{2369.55 \ \text{Btu/s}}{435.3 \ \text{Btu/lbm}} = \boxed{5.44 \ \text{lbm/s}}$$

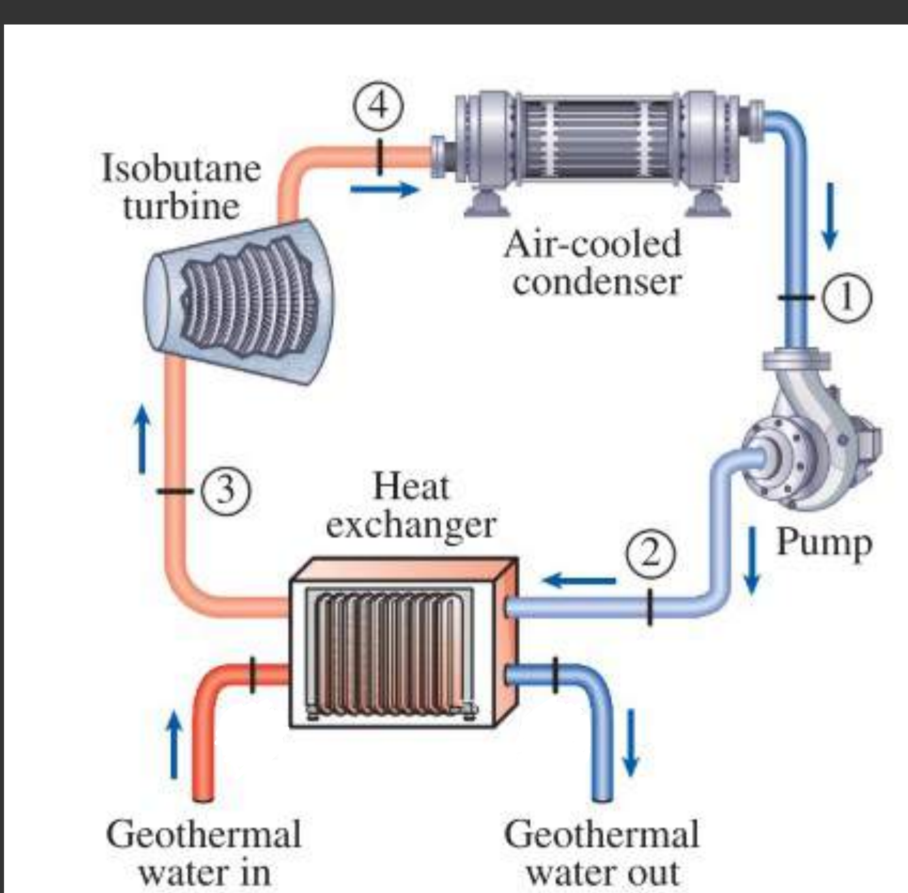
$$\dot{W}_t = \dot{m}(h_3 - h_4)$$

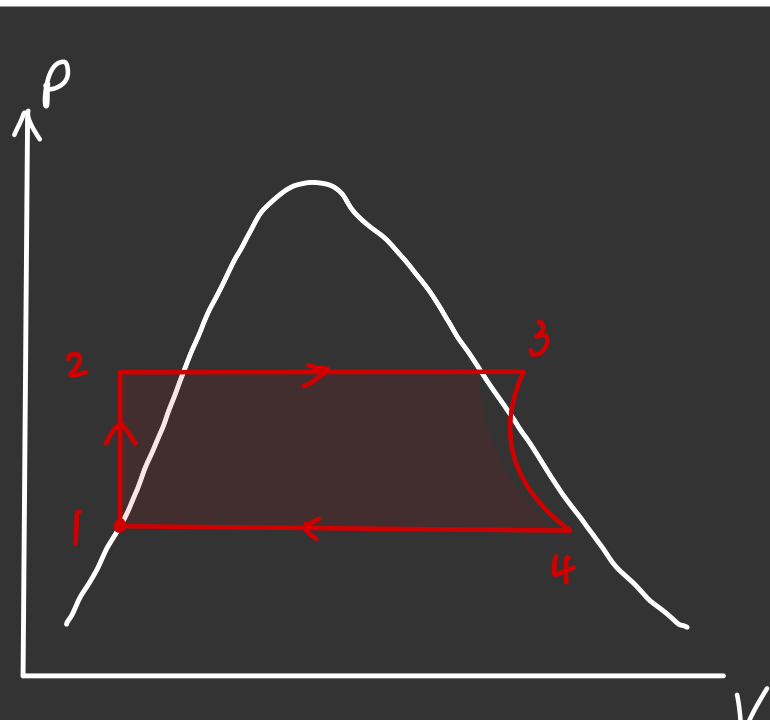
$$\dot{W}_t = 5.44(1363 - 922.7) = \boxed{2396.8 \ \text{Btu/s}}$$

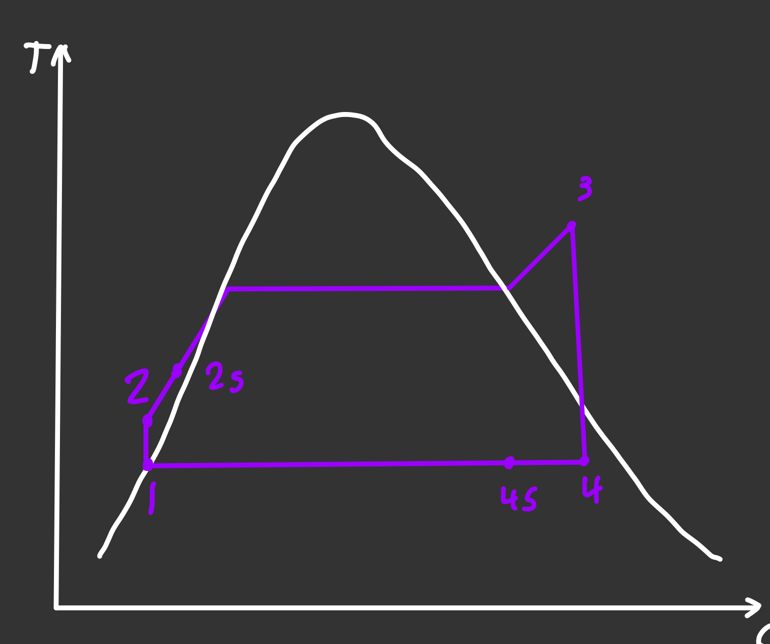
$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{in}}$$

$$\eta_{th} = \frac{2369.55 \ \text{Btu/s}}{5.44 \cdot 1264} = 34.4\%$$

10–25 A binary geothermal power plant uses geothermal water at 160°C as the heat source. The cycle operates on the simple Rankine cycle with isobutane as the working fluid. Heat is transferred to the cycle by a heat exchanger in which geothermal liquid water enters at 160°C at a rate of 555.9 kg/s and leaves at 90°C. Isobutane enters the turbine at 3.25 MPa and 147°C at a rate of 305.6 kg/s, and leaves at 79.5°C and 410 kPa. Isobutane is condensed in an air-cooled condenser and pumped to the heat exchanger pressure. Assuming the pump to have an isentropic efficiency of 90 percent, determine (a) the isentropic efficiency of the turbine, (b) the net power output of the plant, and (c) the thermal efficiency of the cycle.







$$1 \xrightarrow{\text{Isentropic}} 2 \xrightarrow{\text{Const } P} 3 \xrightarrow{\text{Isentropic}} 4 \xrightarrow{\text{Const } P}$$

Pump

1	2	3	4	4s
$P_1 = 410\ kPa$	$P_2 = 3250\ kPa$	$P_3 = 3250\ kPa$	$P_4 = 410\ kPa$	$P_4 = 410\ kPa$
$h_1 = 273$	$h_2 = 278.68$	$h_3 = 761.5$	$h_4 = 689.7$	$h_{4s} = 670.4$
$v_1 = 0.0018$		$v_3 =$	$S_4 = S_3$	
		$T_3 = 147\ ^\circ C$	$T_4 = 179.5$	
		$S_3 = 2.5457$		

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

$$\eta_T = \frac{761.5 - 689.7}{761.5 - 670.4} = \boxed{78.8\%}$$

$$h_2 = (v_1 (P_2 - P_1)/\eta_p) + h_1$$

$$h_2 = (0.0018 \cdot (3250 - 410)/0.9) + 273$$

$$h_2 = 278.68$$

$$\dot{W}_{net} = W_T - W_P = \dot{m}(h_3 - h_4) - \dot{m}(h_2 - h_1)$$

$$W_{net} = 305.6\,((761.5 - 689.7) - (278.68 - 273))$$

$$\boxed{W_{net} = 20{,}206\ kW}$$

$$\dot{Q}_{in} = \dot{m} \cdot C \cdot (T_{in} - T_{out})$$

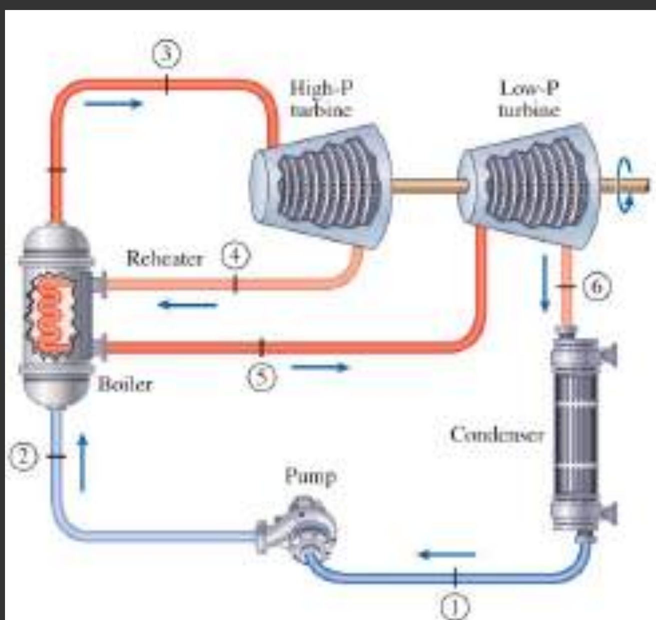
$$Q_{in} = 555.9 \cdot 4.18 \cdot (160 - 90)$$

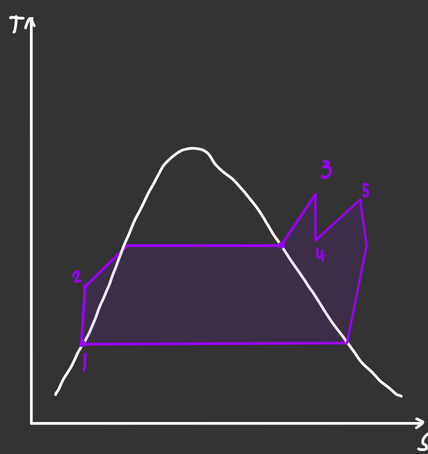
$$Q_{in} = 162{,}656\ kW$$

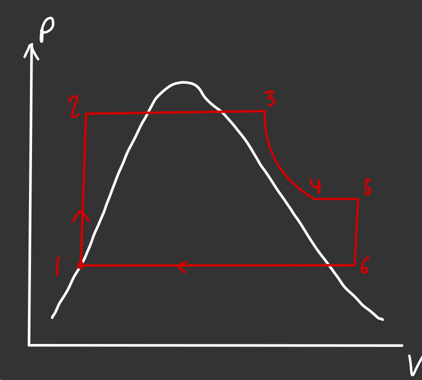
$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{in}}$$

$$\eta_{th} = \frac{20{,}206}{162{,}656} = \boxed{12.4\%}$$

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 20 kPa. The mixture quality at the exit of both turbines is 96 percent. Determine the temperature at the inlet of each turbine and the cycle's thermal efficiency.







Isentropic (Pump) ①→②, const P ②→③, Isentropic ③→④, const. P ④→⑤, Isent ⑤→⑥, const. P

1	2	3	4	5	6
$T_1 = 99.61\ °C$	$T_2 =$	$T_3 = 450\ °C$	$T_4 = 212\ °C$	$T_5 = 450\ °C$	$T_6 = 99.6\ °C$
$P_1 = 100\ kPa$	$P_2 = 15000\ kPa$	$P_3 = 15000\ kPa$	$P_4 = 2000\ kPa$	$P_5 = 2000\ kPa$	$P_6 = 100\ kPa$
$h_1 = 417.51\ kJ/kg$	$h_2 = 433\ kJ/kg$	$h_3 = 3157.9\ kJ/kg$	$h_4 = 2703.3$	$h_5 = 3358$	$h_6 = 2646.1\ kJ/kg$
$s_1 = 1.30$	$\boxed{s_2 = s_1}$ (Isentropic)	$s_3 = 6.1434$	$\boxed{s_4 = s_3}$ (Isentropic)	$s_5 = 7.28$	$\boxed{s_6 = s_5}$ (Isentropic)
$v_1 = 0.001043$					

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

$$h_2 = 0.001043\,(15000 - 100) + 417.51$$

$$h_2 = 433\ kJ/kg$$

$$x_4 = \frac{s_4 - s_f}{s_{fg}}$$

$$x_4 = \frac{6.1434 - 2.44}{3.892}$$

$$x_4 = 0.9497$$

$$h_4 = h_f + x_4 \cdot h_{fg}$$

$$h_4 = 908.47 + 0.9497 \cdot 1889.8$$

$$h_4 = 2703.3\ kJ/kg$$

$$x_6 = \frac{s_4 - s_f}{s_{fg}}$$

$$x_6 = \frac{7.28 - 1.303}{6.056}$$

$$x_6 = 0.987$$

$$h_6 = h_f + x_6 \cdot h_{fg}$$

$$h_6 = 417.5 + 0.987 \cdot 2257$$

$$h_6 = 2646.1\ kJ/kg$$

$$\dot{W}_P = \dot{m}(h_2 - h_1)$$

$$\dot{W}_P = 1.74(433 - 417.5)$$

$$\boxed{\dot{W}_P = 26.97 \text{ kW}}$$

$$W_{net} = \dot{m}\left((h_3 - h_4) + (h_5 - h_6) - (h_2 - h_1)\right)$$

$$\dot{W}_{net} = 1.74\,(3157.9 - 2703.3) + (3358 - 2646) - (433 - 417.5))$$

$$\boxed{\dot{W}_{net} = 2003 \text{ kW}}$$

$$Q_R = \dot{m}\, q_{in} = \dot{m}(h_5 - h_4)$$

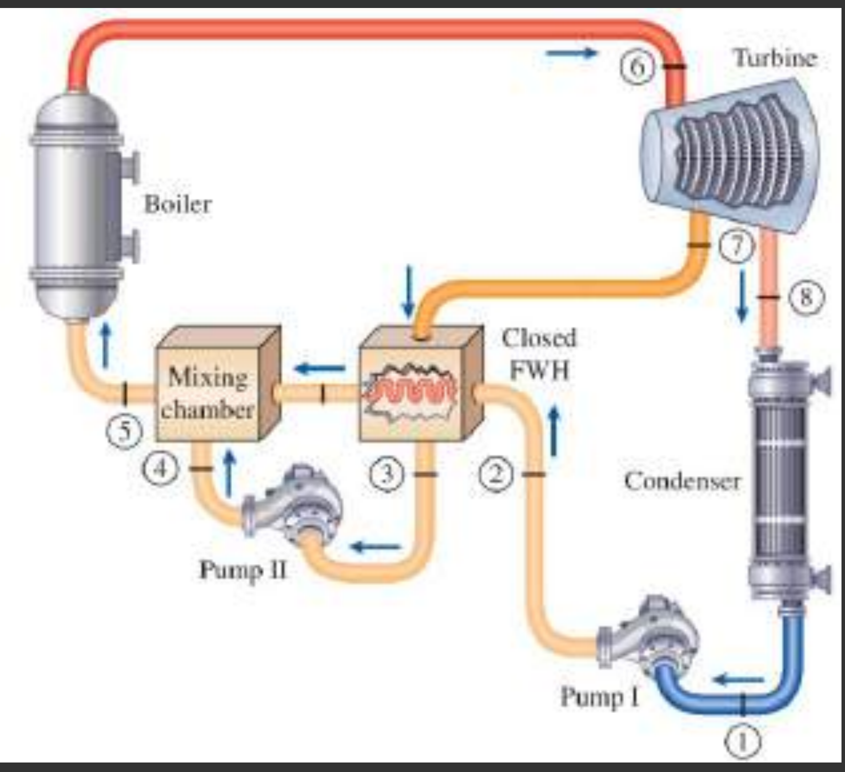
$$Q_R = 1.74(3358 - 2703.3)$$

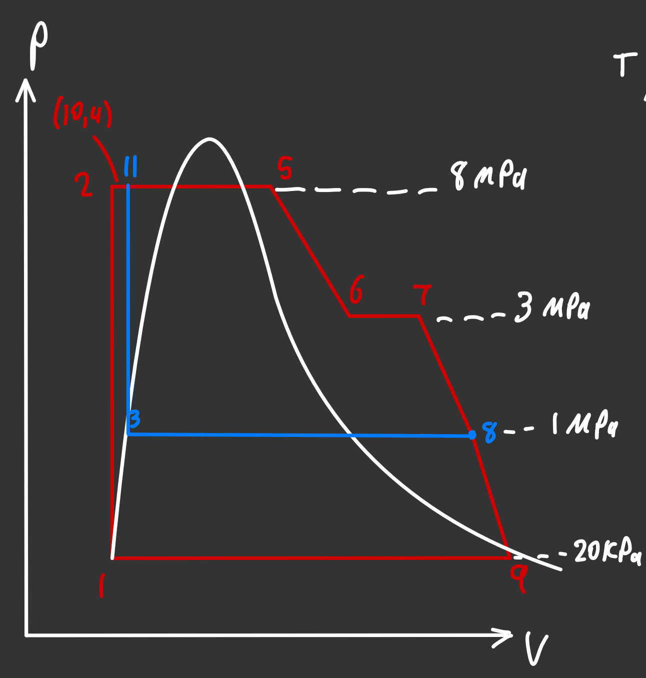
$$\boxed{Q_R = 1140 \text{ kW}}$$

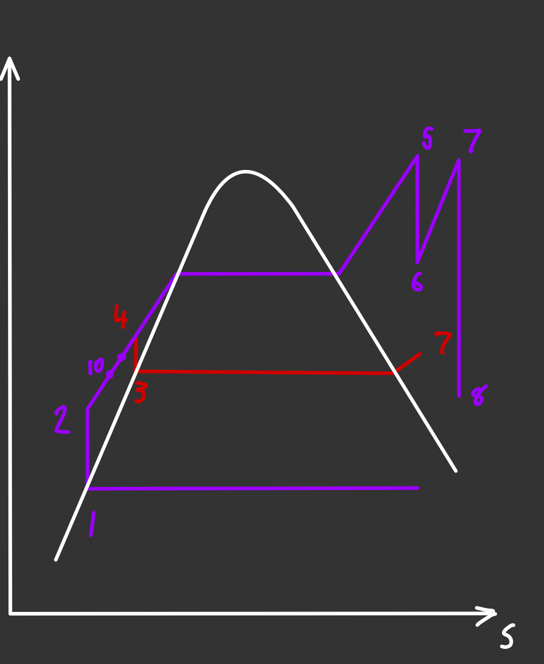
$$\eta_{th} = \frac{W_{net}}{Q_{in}}$$

$$\eta_{th} = \frac{1151}{3375} = \boxed{34\,\%}$$

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.







Iscntropic (5 → 6) P const. (6 → 7) Iscntropic (7 → 8)

1	2	3	4	5	6	7	8
$P_1 = 20$ kPa	$P_2 = 8$ MPa	$P_3 = 1$ MPa	$P_4 = 3$ MPa	$P_5 = 1$ MPa	$P_6 = 20$ kPa	$P_7 = 1$ MPa	$P_8 = 20$ kPa
$x = 0$		$x_3 = 0$	$T_4 = 350$			$T_5 = 209$ °C	
$h_1 = 251.42$	$h_2 = 254.5$	$h_3 = 762.51$	$h_4 = 3116$	$h_5 = 2852$	$h_6 = 2221.7$	$h_7 = 762.5$	$h_8 = 762.5$
$s_1 = 0.832$	$s_2 =$	$s_3 = 2.138$	$s_4 = 6.745$	$s_5 = s_4$	$s_6 = s_4$	$s_7 = 7.2359$	$s_8 = 7.2359$
$v_1 = .001017$	$v_2 =$	$v_3 = .001127$					

$w_p = h_2 - h_1$

$w_p = v_1 (P_2 - P_1)$

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

$h_2 = 0.001043 (15000 - 100) + 417.51$

$h_2 = 433$ kJ/kg

$$x_4 = \frac{s_4 - s_f}{s_{fg}}$$

$$x_4 = \frac{6.1434 - 2.44}{3.892}$$

$x_4 = 0.9497$

$h_4 = h_f + x_4 \cdot h_{fg}$

$h_4 = 908.47 + 0.9497 \cdot 1889.8$

$u = 2703.3$ kJ/kg

$$x_6 = \frac{s_4 - s_f}{s_{fg}}$$

$$x_6 = \frac{7.28 - 1.303}{6.056}$$

$x_6 = 0.987$

$h_6 = h_f + x_6 \cdot h_{fg}$

$h_6 = 417.5 + 0.987 \cdot 2257$

$h_6 = 2646.1$ kJ/kg

$$y = \frac{h_3 - h_2}{h_5 - h_7}$$

$$y = \frac{762.5 - 254.5}{2852 - 762.5} = 0.2437$$

$W_T = (h_4 - h_5) + (1 - y)(h_5 - h_6)$

$W_T = (3116 - 2852) + (1 - 0.2437)(2852 - 2221.7)$

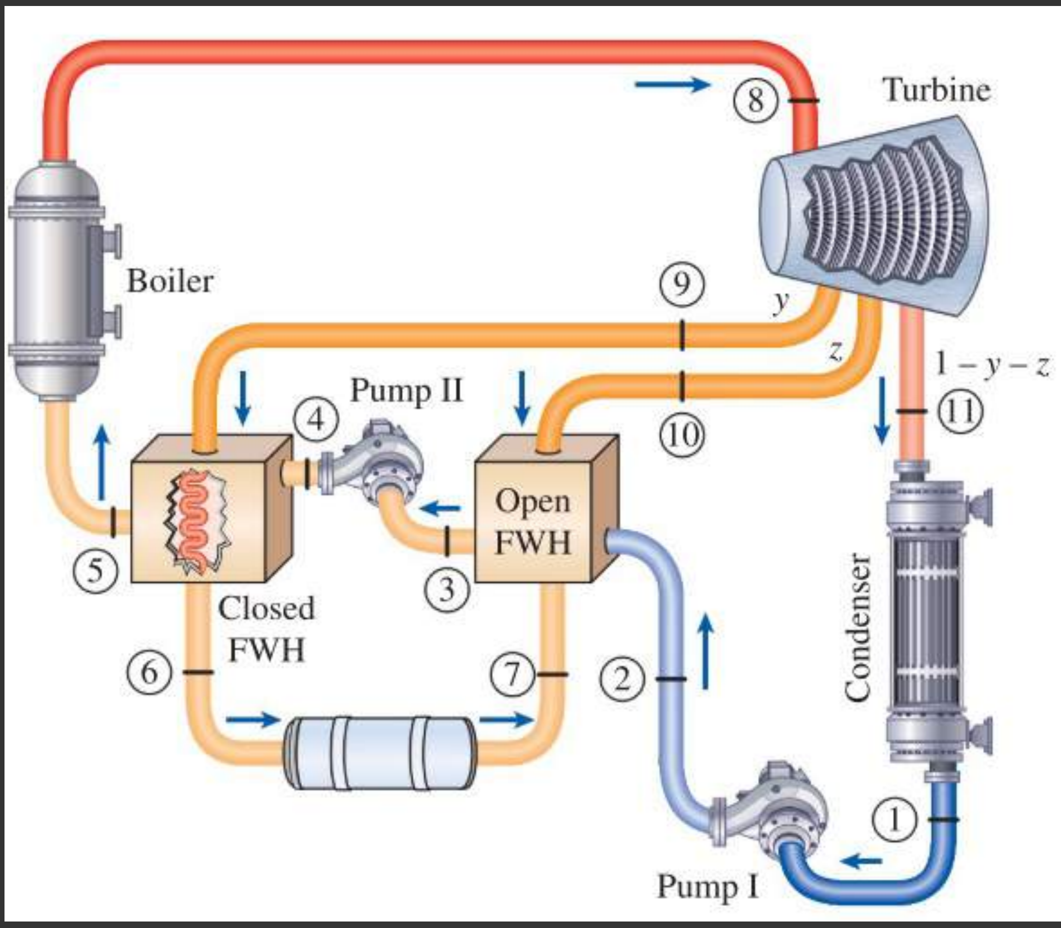
$\boxed{W_T = 741 \text{ kJ/kg}}$

$q_{in} = h_4 - h_3$

$q_{in} = (3116 - 762.5) = \boxed{2353.5 \text{ kJ/kg}}$

10–53

Consider an ideal steam regenerative Rankine cycle with two feedwater heaters, one closed 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 subsequently throttled to the open feedwater heater. Show the cycle on a T-s diagram with respect to saturation lines, and determine (a) the mass flow rate of steam through the boiler for a net power output of 400 MW and (b) the thermal efficiency of the cycle.



did not finish this problem