HW 2.2 Thermal applications

CM 10: 57, 69, 72

* review all states *

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 fraction of 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 the data provided in the tables given 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 the 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.

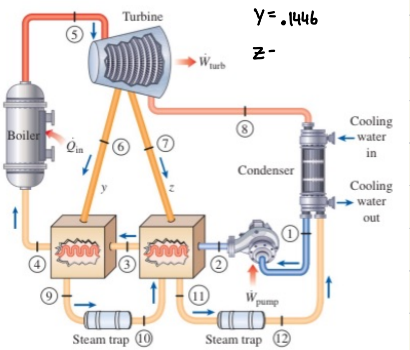
(*d*) Determine the net power output and the thermal efficiency of the plant.

Process states and selected data

State	*P*, kPa	*T*, °C	*h*, kJ/kg	*s*, kJ/kg·K
1	20			
2	5000			
3	5000			
4	5000			
5	5000	700	3900	7.512
6	1400		3406	7.512
7	245		2918	7.512
8	20		2477	7.512

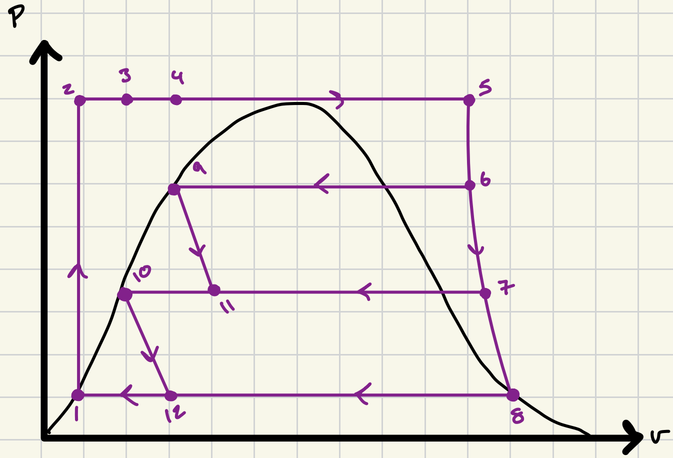
Saturation data

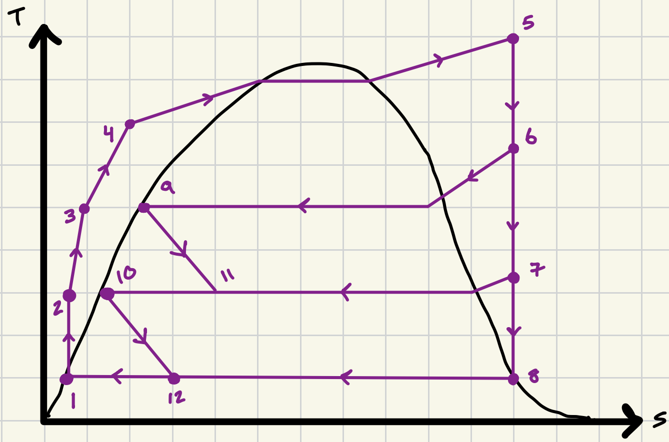
P, kPa	v_f, m³/kg	h_f, kJ/kg	s_g, kJ/kg·K
20	0.00102	251	7.907
245		533	7.060
1400		830	6.468
5000	0.00129	1154	5.973

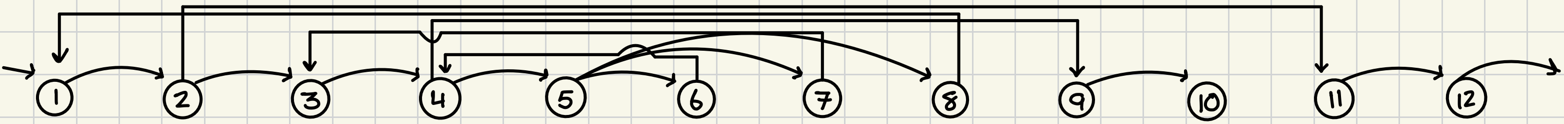


y = .1446

z -







$P_1 = 20\,kPa$	$P_2 = 5000\,kPa$	$P_3 = 5000\,kPa$	$P_4 = 5000\,kPa$	$P_5 = 5000\,kPa$	$P_6 = 1400\,kPa$	$P_7 = 245\,kPa$	$P_8 = 20\,kPa$	$P_9 = 1400\,kPa$	$P_{10} = 1400\,kPa$	$P_{11} = 245\,kPa$	$P_{12} = 245\,kPa$
$h_1 = 251\,kJ/kg$	$h_2 = 256.1\,kJ/kg$	$h_3 = 533\,kJ/kg$	$h_4 = 830\,kJ/kg$	$h_5 = 3900\,kJ/kg$	$h_6 = 3406\,kJ/kg$	$h_7 = 2918\,kJ/kg$	$h_8 = 2477\,kJ/kg$	$h_9 = 830\,kJ/kg$	$h_{10} = 830\,kJ/kg$	$h_{11} = 533\,kJ/kg$	$h_{12} = 533\,kJ/kg$
$v_1 = .00102\,m^3/kg$				$T_5 = 700°C$							

$\uparrow$
$h_2 = h_1 + v_S(P_2 - P_1)$

$$z = \frac{(h_3 - h_2) + y(h_{11} - h_{10})}{h_7 - h_{11}} \rightarrow \frac{(533 - 256.1) + .1446(533 - 830)}{(2918 - 533)} \Rightarrow z = .0981$$

$$m_w = \frac{m_s\left[(1-y-z)h_8 + (y+z)h_{12} - h_1\right]}{c_{pw}\Delta T} \rightarrow \frac{50\left[(1-.1446-.0981)\times 2477 + (.1446 + .0981)\times 533 - 251\right.}{4.18 \quad 10} \Rightarrow m_w = 3,147.5\,kg/s$$

$$w_T = h_5 - yh_6 - zh_7 - (1-y-z)h_8 \longrightarrow 3900 - .1446 \times 3406 - .0981 \times 2918 - (1 - .1446 - .0981) \times 2477 \Rightarrow w_T = 1245.5\,kJ/kg$$

$\rightarrow w_{net} = 1245 - (.00102(5000 - 20)) = 1240.3\,kJ/kg$

$\rightarrow W_{net} = m \cdot w_{net} \rightarrow 75 \times 1240.3 \Rightarrow 93\,MW$

$\rightarrow \eta = \frac{w_{net}}{Q_{in}} \rightarrow \frac{93}{230} \Rightarrow \eta = 40.4\%$

$Q_{in} = m(h_5 - h_4) \rightarrow 75 \cdot 3900 - 830 \Rightarrow 230\,MW$

b) $z = .0981$
c) $m_w = 3,147.5\,kg/s$
d) $\eta = 40.4\%$

10–69 Steam enters the turbine of a cogeneration plant at 4 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 the mixture is pumped to the boiler pressure of 7 MPa. The mass flow rate of steam through the boiler is 55 kg/s. Disregarding any pressure drops and heat losses in the piping, and assuming the turbine and the pump to be isentropic, determine the net power produced and the utilization factor of the plant.

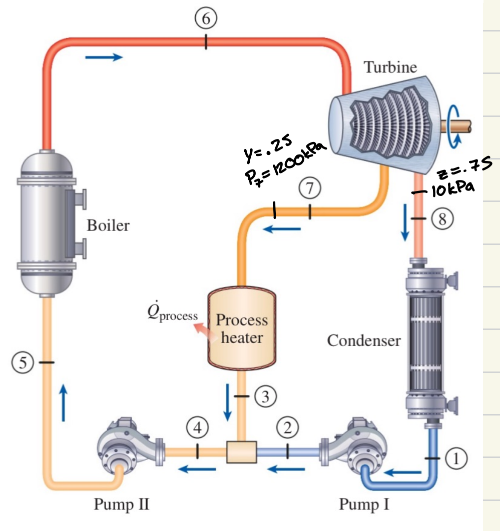
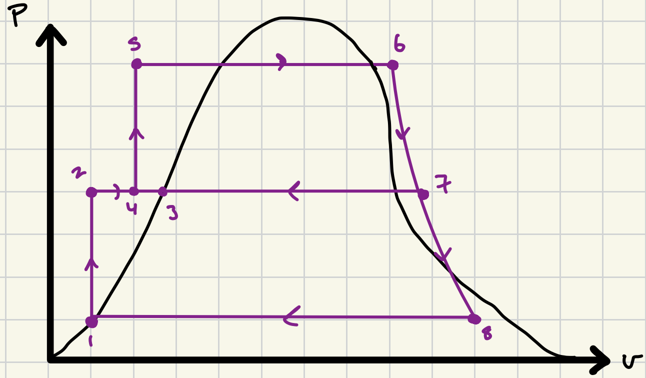
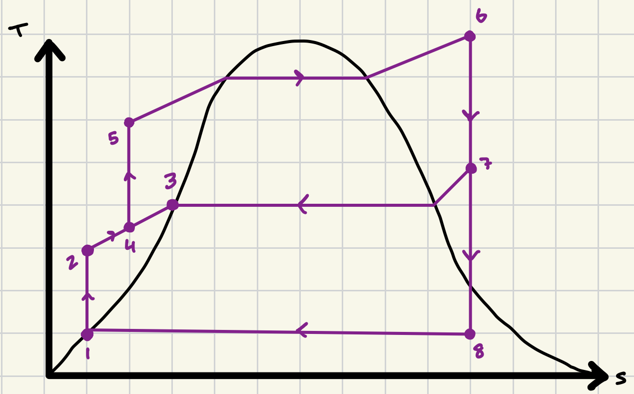


FIGURE P10–69





1 → 2 → 3 → 4 → 5 → 6 → 7 → 8

1	2	3	4	5	6	7	8
$P_1 = 10\,kPa$	$P_2 = 1200\,kPa$	$P_3 = 1200\,kPa$	$P_4 = 1200\,kPa$	$P_5 = 7\,MPa$	$P_6 = 4\,MPa$	$P_7 = 1200\,kPa$	$P_8 = 10\,kPa$
$h_1 = 191.81\ kJ/kg$	$h_2 = 193.01\ kJ/kg$	$h_3 = 798.6\ kJ/kg$	$h_4 = 344.41\ kJ/kg$	$h_5 = 347.21\ kJ/kg$	$T_6 = 500°C$	$h_7 = 3079.7\ kJ/kg$	$h_8 = 2246\ kJ/kg$
$v_1 = .00101\ m^3/kg$			$v_4 = .001\ m^3/kg$		$h_6 = 3445.4\ kJ/kg$		
					$s_6 = 7.1\ kJ/kg\cdot K$		

$w_{pump} = v_1(P_2 - P_1)$
$\Rightarrow 1.202\ kJ/kg$

$w_p = h_1 - h_2$

$m_3 h_3 + m_2 h_2 = m_4 h_4$

$w_{PII} = v_4(P_5 - P_4)$
$\Rightarrow 2.8\ kJ/kg$

$h_5 = h_4 + w_{PII}$

$m_6 = 4m_7 \rightarrow 55 = 4m_7$
$m_7 = 13.75\ kg/s$

$W_{TURB} = m_7(h_6 - h_7) + m_8(h_6 - h_8) \rightarrow 13.75(3445.4 - 3079.7) + (55 - 13.75)(3445.4 - 2246) \rightarrow W_{TURB} = 54{,}503.63\ kW$

$W_{net} = 54{,}503.63 - 203.58 \Rightarrow 54{,}300\ kW$

$Q_{in} = m_5(h_6 - h_5) \rightarrow 55(3445.4 - 347.21) \Rightarrow 170{,}400.51\ kW$

$Q_p = m_7(h_7 - h_3) \rightarrow 13.75(3079.7 - 798.6) \Rightarrow 31{,}365.13\ kW$

$\varepsilon_u = \frac{W_{net} + Q_p}{Q_{in}} = \frac{54{,}503 + 31365.13}{170{,}400.51} \Rightarrow \varepsilon_u = .502$

$\boxed{\text{a) } 54{,}503.6\ kW \quad \text{b) } \varepsilon_u = .502}$

10–72 Consider a cogeneration 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 percent of the steam is extracted from the turbine, and the remainder expands to 10 kPa. Part of the extracted steam is used to heat the feedwater in 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 the boiler pressure. Assuming the turbines and the pumps to be isentropic, show the cycle on a *T-s* diagram with respect to saturation lines, and determine the mass flow rate of steam through the boiler for a net power output of 25 MW. *Answer: 29.1 kg/s*

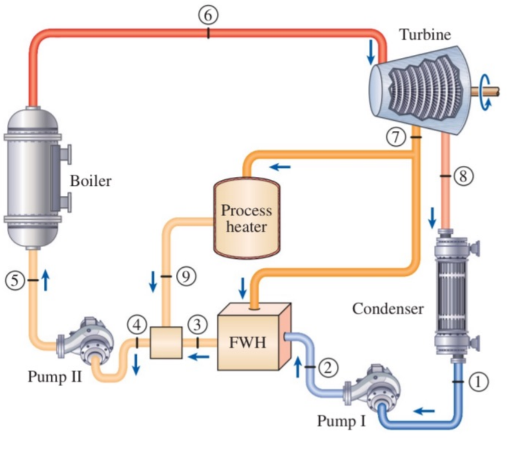
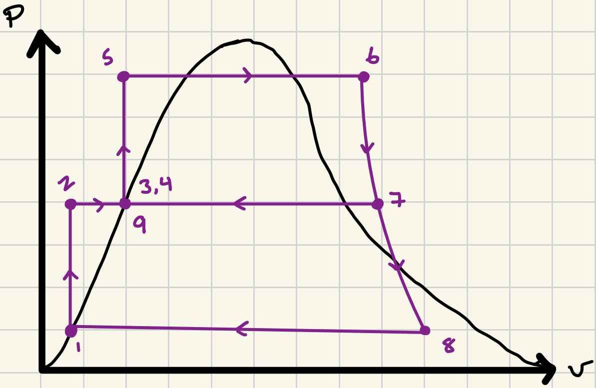
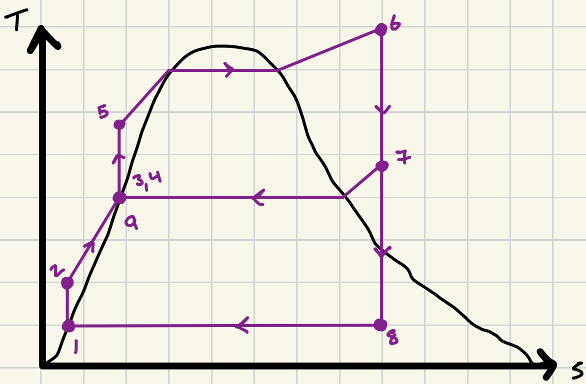
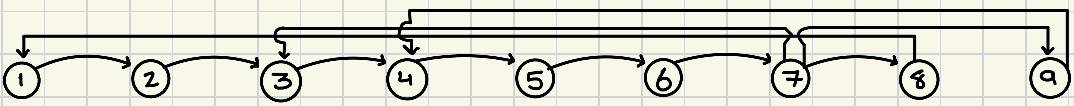


FIGURE P10–72







1	2	3	4	5	6	7	8	9
$P_1 = 10\,kPa$	$P_2 = 1.6\,MPa$	$P_3 = 1.6\,MPa$	$P_4 = 1.6\,MPa$	$P_5 = 9\,MPa$	$P_6 = 9\,MPa$	$P_7 = 1.6\,MPa$	$P_8 = 10\,kPa$	$P_9 = 1.6\,MPa$
$T_1 = 45.81\,°C$	$h_2 = 193.42\,kJ/kg$	$h_3 = 857.99\,kJ/kg$	$h_4 = 857.99\,kJ/kg$	$h_5 = 866.57\,kJ/kg$	$T_6 = 400\,°C$	$h_7 = 2729.44\,kJ/kg$	$s_8 = 6.29\,kJ/kg\cdot K$	$h_9 = 857.99\,kJ/kg$
$h_1 = 191.81\,kJ/kg$			$v_4 = .001159\,m^3/kg$		$h_6 = 3118.8\,kJ/kg$		$h_8 = 1990.3\,kJ/kg$	$T_9 = 201.3\,°C$
$v_1 = .00101\,m^3/kg$					$s_6 = 6.29\,kJ/kg\cdot K$			

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

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

$x_7 = \dfrac{s_7 - s_{f7}}{s_{fg7}}$

$h_7 = h_{f7} + x_7 h_{fg7}$

$h_8 = h_{f8} + x_8 h_{fg8}$

2500kW

$$W_{net} = \dot m_T\left[(h_6 - h_7) + (1-y)(h_7 - h_8) - (1-y)(h_2 - h_1) - (h_5 - h_4)\right] \rightarrow \dot m_T\left[389.36 + .65 \times 739.17 - .65 \times 1.61 - 858\right] \Rightarrow \boxed{\dot m_T = 29.063\,kg/s}$$