Homework 5-1

Imports

[1]:
```
from thermostate import Q_, State
```

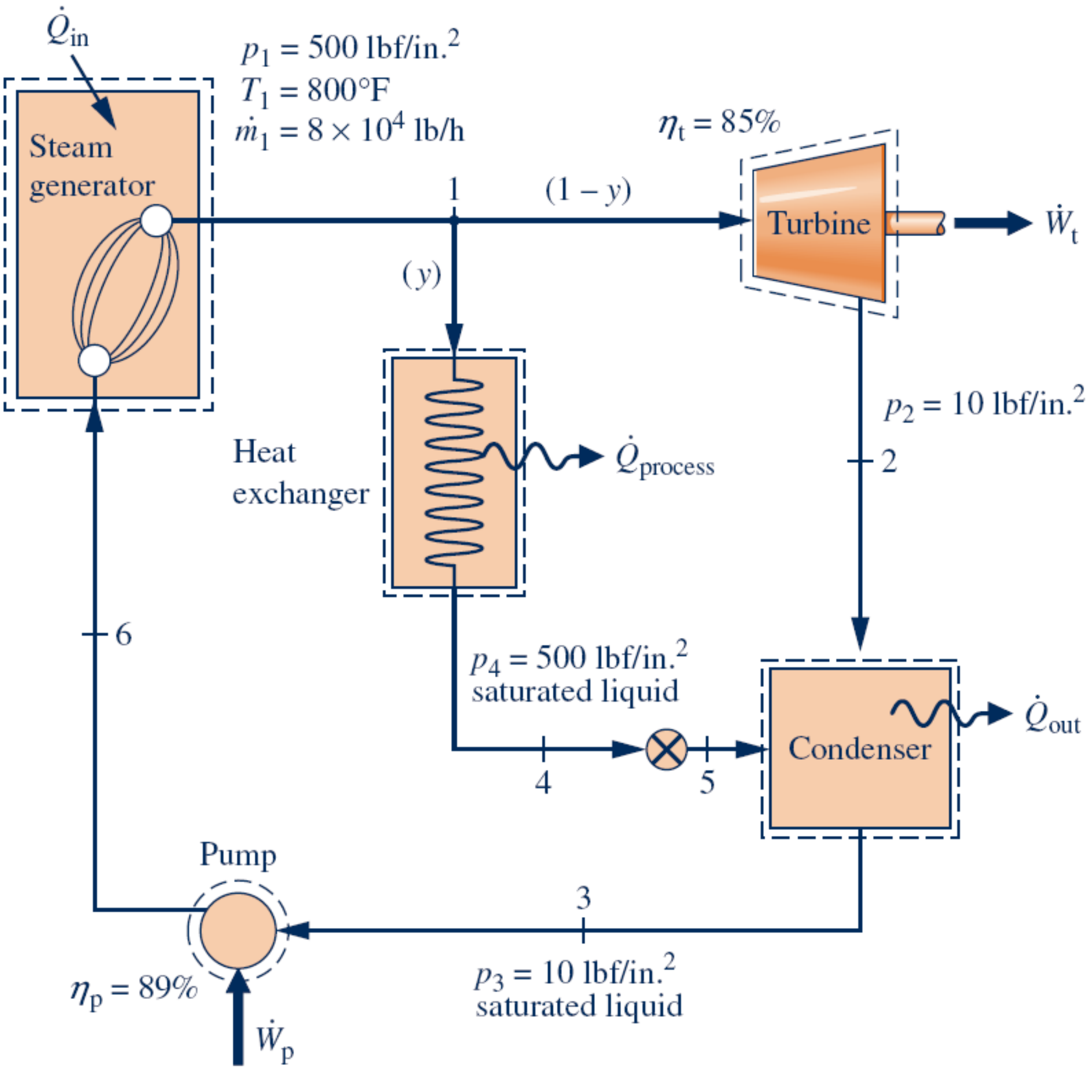
Definitions

[2]:
```
substance = 'water'

mdot_1 = Q_(8e4, 'lb/hr')
y = Q_(0.12, 'dimensionless')

p_1 = Q_(500, 'psi')  # note: psi == lbf/in**2
T_1 = Q_(800, 'degF')

p_2 = Q_(10, 'psi')

p_3 = p_2
x_3 = Q_(0.0, 'dimensionless')

p_4 = Q_(500, 'psi')
x_4 = Q_(0.0, 'dimensionless')

eta_t = Q_(0.85, 'dimensionless')
eta_p = Q_(0.89, 'dimensionless')
```

Problem Statement

The figure below shows a vapor power cycle that provides process heat and produces water. The steam generator produces vapor at 500 psi, 800 °F, at a rate of 8×10^4 lbm/hr. 88% of the steam expands through the turbine to 10 psi, and the remainder is directed to the heat exchanger. Saturated liquid exits the heat exchanger at 500 psi and passes through a trap before entering the condenser at 10 psi. It is then pumped to 500 psi before entering the steam generator. The turbine and pump have isentropic efficiencies of 85% and 89%, respectively.

1. Find the rate of heat transfer out in the central heat exchanger ($\dot{Q}_{process}$ in the figure below), in Btu/hr.
2. Find the thermal efficiency of the cycle.



Solution

Defining states:

State	1	2
1	p_1	T_1
2s	p_2	$s_{2s} = s_1$
2	p_2	h_2
3	$p_3 = p_2$	x_3
4	p_4	x_4
5	$p_5 = p_2$	$h_5 = h_4$
6s	$p_6 = p_1$	$s_6 = s_3$
6	$p_6 = p_1$	h_6

Important Equations:

1. $\eta_t = \frac{h_1 - h_2}{h_1 - h_{2s}} \Rightarrow h_2 = (h_{2s} - h_1) \cdot \eta_t + h_1$
2. $\eta_p = \frac{h_{6s} - h_3}{h_6 - h_3} \Rightarrow h_6 = \frac{h_{6s} - h_3}{\eta_p} + h_3$

[3]:
```
st_1 = State(substance,p=p_1,T=T_1)
st_2s = State(substance,p=p_2,s=st_1.s)
h_2 = (st_2s.h-st_1.h)*eta_t + st_1.h
st_2 = State(substance,p=p_2,h=h_2)
st_3 = State(substance,p=st_2.p,x=x_3)
st_4 = State(substance,p=p_4,x=x_4)
st_5 = State(substance,p=st_2.p,h=st_4.h)
st_6s = State(substance,p=st_1.p,s=st_3.s)
h_6 = (st_6s.h-st_3.h)/eta_p + st_3.h
st_6 = State(substance,p=st_1.p,h=h_6)
```

Mass Relations:

1. $\dot{m}_1 = \dot{m}_3 = \dot{m}_6$
2. $\dot{m}_4 = \dot{m}_5$ and $y = \frac{\dot{m}_4}{\dot{m}_1}$
3. $\dot{m}_2$ and $(1 - y) = \frac{\dot{m}_2}{\dot{m}_1}$

[4]:
```
mdot_4 = mdot_1 * y
mdot_2 = mdot_1 * (1-y)
```

Part 1: $\dot{Q}_{process}$, in Btu/hr

Important Equations:

1. $\dot{Q}_{process} = \dot{m}_4(h_4 - h_1)$

[5]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Qdot_process = mdot_4*(st_4.h-st_1.h)
print(Qdot_process.to("Btu/hr"))
```

```
-9244451.760722741 btu / hour
```

Answer: -9244451.76 Btu/hr

Part 2: Thermal Efficiency

Important Equations:

1. $\eta = \frac{\dot{W}_{cycle} + |\dot{Q}_{process}|}{\dot{Q}_{in}}$
2. $\dot{W}_{cycle} = \dot{W}_{out} + \dot{W}_{in}$
3. $\dot{W}_{out} = \dot{m}_2(h_1 - h_2)$

4. $\dot{W}_{in} = \dot{m}_6(h_3 - h_6)$
5. $\dot{Q}_{in} = \dot{m}_1(h_1 - h_6)$

[6]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Qdot_in = mdot_1*(st_1.h-st_6.h)
Wdot_out = mdot_2*(st_1.h-st_2.h)
Wdot_in = mdot_1*(st_3.h-st_6.h)
eta = (Wdot_out + Wdot_in - Qdot_process)/(Qdot_in)
print(eta)
```

```
0.30317841902454923 dimensionless
```

Answer: 30.32%

Homework 5-2

Imports

[1]:
```
from thermostate import Q_, State
```

Definitions

[2]:
```
substance = 'water'

mdot_1 = Q_(1.0, 'kg/s')
y = Q_(0.15, 'dimensionless')

p_1 = Q_(1.5, 'MPa')
T_1 = Q_(280.0, 'degC')

p_2 = Q_(0.2, 'MPa')

p_3 = Q_(0.1, 'bar')

p_4 = p_3
x_4 = Q_(0.0, 'dimensionless')

p_6 = Q_(0.1, 'MPa')
T_6 = Q_(60.0, 'degC')
```

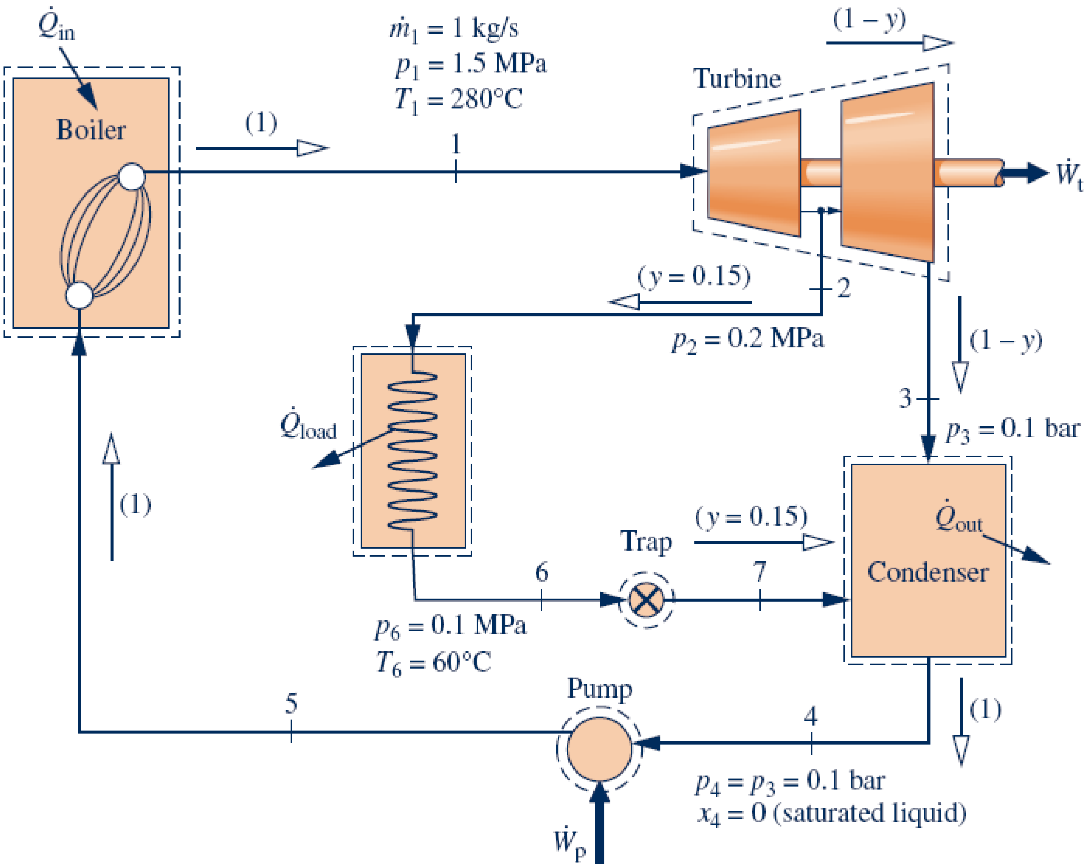
Problem Statement

The figure below shows a cogeneration power plant that generates electricity and provides heat for campus buildings (very much like UConn's own Cogen Plant!)

Steam at 1.5 MPa, 280 °C enters a two-stage turbine with a mass flow rate of 1 kg/s. 15% of the total flow is extracted between the two turbine stages at 0.2 MPa to provide for building heating, and the remainder expands through the second stage to the condenser pressure of 0.1 bar. Condensate returns from the campus buildings at 0.1 MPa, 60 °C and passes through a trap into the condenser, where it is reunited with the main feedwater flow. Saturated liquid leaves the condenser at 0.1 bar.

Determine

1. the rate of heat transfer to the working fluid passing through the boiler, in kW,
2. the net power developed, in kW,
3. the rate of heat transfer for the building heating, in kW,
4. the rate of heat transfer to the cooling water passing through the condenser, in kW.
5. Show that there is no net energy exchange with the surroundings.



Solution

Defining states:

	State	1	2
1		p_1	T_1
2		p_2	$s_2 = s_1$
3		p_3	$s_3 = s_2$
4		p_4	x_4
5		$p_5 = p_1$	$s_5 = s_4$
6		p_6	T_6
7		$p_7 = p_3$	$h_7 = h_6$

[3]:
```
st_1 = State(substance,p=p_1,T=T_1)
st_2 = State(substance,p=p_2,s=st_1.s)
st_3 = State(substance,p=p_3,s=st_2.s)
st_4 = State(substance,p=p_4,x=x_4)
st_5 = State(substance,p=st_1.p,s=st_4.s)
st_6 = State(substance,p=p_6,T=T_6)
st_7 = State(substance,p=st_3.p,h=st_6.h)
```

Mass relations:

1. $\dot{m}_1 = \dot{m}_4 = \dot{m}_5$
2. $\dot{m}_2 = \dot{m}_6 = \dot{m}_7$ and $y = \frac{\dot{m}_2}{\dot{m}_1}$
3. $\dot{m}_3$ and $(1-y) = \frac{\dot{m}_3}{\dot{m}_1}$

[4]:
```
mdot_2 = mdot_1 * y
mdot_3 = mdot_1 * (1-y)
```

Part 1: Rate of Heat Transfer Input in the Boiler, in kW

Important Equations:

1. $\dot{Q}_{in} = \dot{m}_1(h_1 - h_5)$

[11]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Qdot_in = mdot_1 * (st_1.h-st_5.h)
print(st_5.h)
print(Qdot_in.to("kW"))
```

```
193310.76997420558 joule / kilogram
2799.9694251720016 kilowatt
```

Answer: 2799.97 kW

Part 2: Net Power Developed, in kW

Important Equations:

1. $\dot{W}_{net} = \sum \dot{W}$
2. $\sum W = \dot{W}_{out} + \dot{W}_{in}$
3. $\dot{W}_{out1-2} = \dot{m}_1(h_1 - h_2)$
4. $\dot{W}_{out2-3} = \dot{m}_3(h_2 - h_3)$
5. $\dot{W}_{in} = \dot{m}_4(h_4 - h_5)$

[6]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Wdot_out1_2 = mdot_1 * (st_1.h-st_2.h)
Wdot_out2_3 = mdot_3 * (st_2.h-st_3.h)
Wdot_in = mdot_1 * (st_4.h-st_5.h)
Wdot_net = Wdot_out1_2 + Wdot_out2_3 + Wdot_in
print(Wdot_net.to("kW"))
```

```
761.3184843560886 kilowatt
```

Answer: 761.32 kW

Part 3: Rate of Heat Transfer for the Buildings ($\dot{Q}_{load}$), in KW

Important Equations:

1. $\dot{Q}_{load} = \dot{m}_2(h_6 - h_2)$

[7]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Qdot_load = mdot_2 * (st_6.h-st_2.h)
print(Qdot_load.to("kW"))
```

```
-351.3210255956621 kilowatt
```

Answer: 351.32 kW to campus buildings

Part 4: Rate of Heat Transfer to the Cooling Water, in kW

Important Equations:

1. $\dot{Q}_{out} = \dot{m}_4 h_4 - \dot{m}_3 h_3 - \dot{m}_7 h_7$

[8]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Qdot_out = mdot_1 * st_4.h - mdot_3 * st_3.h - mdot_2 * st_7.h
print(Qdot_out.to("kW"))
```

```
-1687.3299152202508 kilowatt
```

Answer: 1687.33 to cooling system

Part 5: Show No Net Energy Exchange with Surroundings

We know net energy $\dot{E} = \sum \dot{Q} - \sum \dot{W}$. If this is zero, then there is no net energy change and therefore no exchange with the surroundings

[9]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Qdot_net = Qdot_in + Qdot_out + Qdot_load
E = Qdot_net - Wdot_net
print(E.to("kW").round(4))
```

```
0.0 kilowatt
```

Answer: Since the change in energy is 0, this means there is no net energy transfer with the surrounding

Homework 5-3

Problem Statement

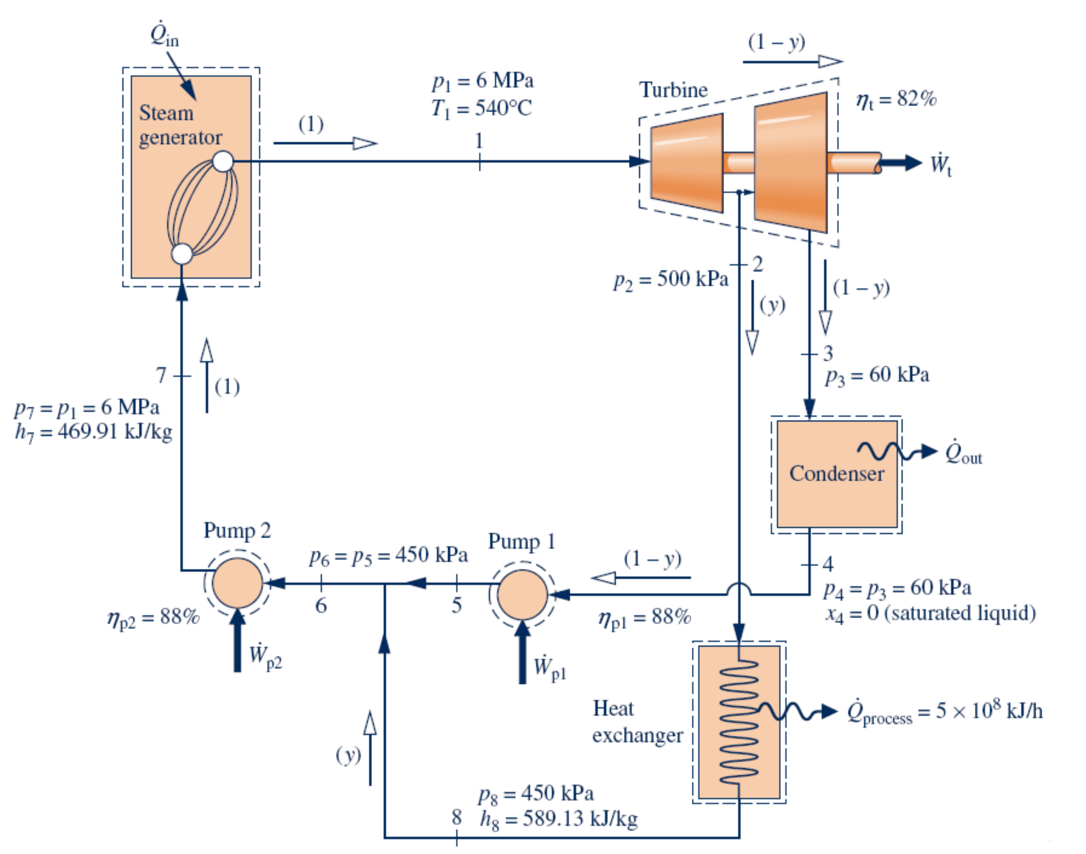
Do this problem by hand.

Consider a cogeneration system operating as shown in the figure below. Steam enters the first turbine stage at 6 MPa, 540 °C. Between the first and second stages, 45% of the steam is extracted at 500 kPa and diverted to a process heating load of 5×10^8 kJ/hr. Condensate exits the process heat exchanger at 450 kPa with a specific enthalpy of 589.13 kJ/kg. It is then mixed with liquid exiting the lower-pressure pump at 450 kPa. The entire flow is then pumped to the steam generator pressure.

At the inlet to the steam generator, the specific enthalpy is 469.19 kJ/kg. Saturated liquid at 60 kPa leaves the condenser. The turbine stages operate with isentropic efficiencies of 82%. The pumps operate with isentropic efficiencies of 88%.

Determine

1. the mass flow rate of steam entering the first turbine stage, in kg/s,
2. the net power developed by the cycle, in MW,
3. the rate of entropy production in the turbine, in kW/K.



Solution

Defining states:

State	1	2
1	p_1	T_1
2s	p_2	$s_{2s} = s_1$
2	p_2	h_2
3s	p_3	$s_{3s} = s_2$
3	p_3	h_3
4	p_4	x_4
5s	p_5	$s_{5s} = s_4$
5	p_5	h_5
6	p_6	h_6
7s	p_7	$s_{7s} = s_6$
7	p_7	h_7
8	p_8	h_8

Needed Properties:

State	$p(bar)$	$T(^oC)$	x	$h(kJ/kg)$	$s(kJ/(kgK))$	v
1	p_1	T_1		h_1	s_1	
2s	p_2			h_{2s}	s_{2s}	
2	p_2			h_2	s_2	
3s	p_3		x_{3s}	h_{3s}	s_{3s}	
3	p_3		x_3	h_3	s_3	
4	p_4		x_4	h_4	s_4	v_4
5s	p_5			h_{5s}	s_{5s}	
5	p_5			h_5	s_5	
6	p_6			h_6		
7s	p_7					
7	p_7			h_7		
8	p_8			h_8		

Completed Table:

State 2s:

$h_{2s} = \frac{h_b - h_a}{s_b - s_a}(s_{2s} - s_a) + h_a = \frac{2855.4 - 2812.0}{7.0592 - 6.9656}(6.9999 - 6.9656) + 2812.0$

State 2:

$h_2 = (h_{2s} - h_1) \cdot \eta_t + h_1 = (2827.9 - 3517.0)0.82 + 3517$

$s_2 = \frac{s_b - s_a}{h_b - h_a}(h_2 - h_a) + s_a = \frac{7.3865 - 7.2307}{3022.9 - 2939.9}(2951.9 - 2939.9) + 7.2307$

State 3s:

$x_{3s} = \frac{s_{3s} - s_f}{s_g - s_f} = \frac{7.2532 - 1.1453}{7.532 - 1.1453}$

$h_{3s} = h_f + x_{3s}(h_{fg}) = 359.86 + 0.9563(2293.6)$

State 3:

$h_3 = (h_{3s} - h_2) \cdot \eta_t + h_2 = (2553.2 - 2951.9)0.82 + 2951.9$

$x_3 = \frac{h_3 - h_f}{h_{fg}} = \frac{2625 - 359.86}{2293.6}$

$s_3 = s_f + x_3(s_g - s_f) = 1.1453 + 0.9876(7.5320 - 1.1453)$

State 5s:

all properties are a function of s and $x = 0$

State 5:

$h_5 = \frac{h_{5s} - h_4}{\eta_p} + h_4 = \frac{359.86 - 359.86}{0.88} + 359.86$

State 6:

$y = \frac{h_6 - h_5}{h_8 - h_5} = 0.45$

State	$p(bar)$	$T(^oC)$	x	$h(kJ/kg)$	$s(kJ/(kgK))$	v
1	60	540		3517.0	6.9999	
2s	5			2827.9	6.9999	
2	5			2951.9	7.2532	
3s	0.6		0.9563	2553.2	7.2532	
3	0.6		0.9876	2625.0	7.4528	
4	0.6		0	359.86	1.1453	$1.0331 * 10^{-3}$
5s	4.5		0	359.86	1.1453	
5	4.5			359.86		
6	4.5			463.03		
7s	60					
7	60			469.91		
8	4.5			589.13		

Part 1: Mass Flow Rate Entering First Turbine Stage, in kg/s

Important Equations:

1. $y = \frac{\dot{m}_2}{\dot{m}_1}$
2. $\dot{Q}_{process} = \dot{m}_2(h_8 - h_2) = 5 \times 10^8 kJ/h$

Using equation 2 we can find that $\dot{m}_2 = 211616.027$ kg/h which is 58.78 kg/s

Now we use equation 1, and knowing from the problem statement that $y = 0.45$ to find that $\dot{m}_1 = 130.627$ kg/s

Part 2: Net Power Developed, in MW

Important Equations:

1. $\dot{W}_{net} = \sum \dot{W}$

2. $\dot{W}_{1-2} = \dot{m}_1(h_1 - h_2)$
3. $\dot{W}_{2-3} = \dot{m}_3(h_2 - h_3)$
4. $\dot{W}_{4-5} = v_4 \Delta p$
5. $\dot{W}_{6-7} = \dot{m}_1(h_6 - h_7)$

note $\dot{m}_3 = \dot{m}_1(1-y)$ therfore $\dot{m}_3 = 71.84$ kg/s

$\dot{W}_{1-2} = \dot{m}_1(h_1 - h_2) = 130.627(3517 - 2951.9) = 73,817.32$ kW

$\dot{W}_{2-3} = \dot{m}_3(h_2 - h_3) = 71.84(2951.9 - 2625) = 23,484.5$ kW

$\dot{W}_{4-5} = v_4(\Delta p) = 1.0331 \times 10^{-3}(390) = -0.4029$ kW

$\dot{W}_{6-7} = \dot{m}_1(h_6 - h_7) = 130.627(463.03 - 469.91) = -898.71$ kW

$\dot{W}_{net} = 95.93$ MW

Part 3: Rate of Entropy Production in the Turbine, in kW/K

Important Equations:

1. $0 = \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \dot{\sigma} \Rightarrow \dot{\sigma} = m_2 s_2 + m_3 s_3 - m_1 s_1$

Plugging into this equation yields

$$\dot{\sigma} = 58.75(7.2532) + 71.84(7.4528) - 130.627(6.9999) = 47.159 kJ/K$$

Homework 5-4

Imports

[1]:
```
from thermostate import Q_, State
```

Definitions

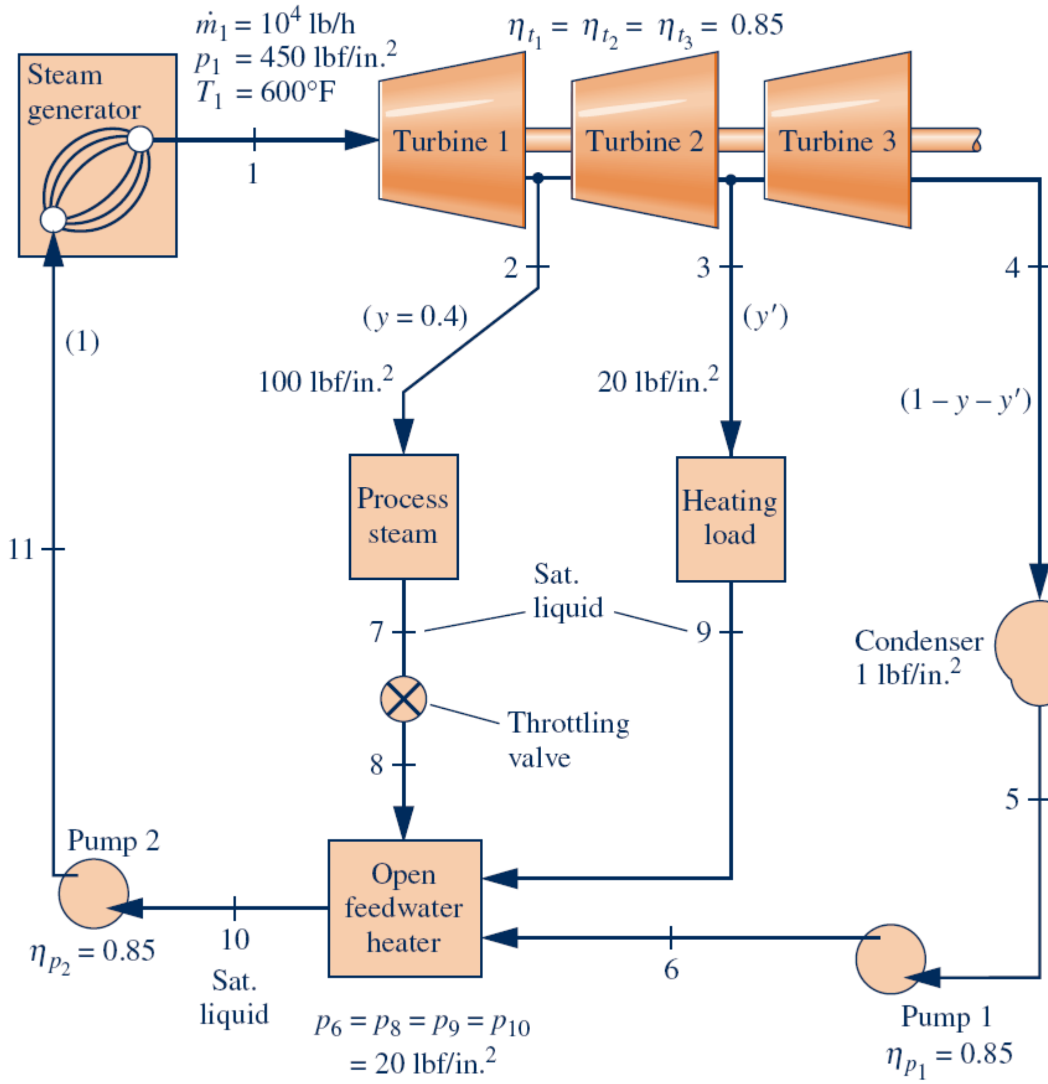
[2]:
```
substance = 'water'

mdot_1 = Q_(10.0**4, 'lb/hr')
y = Q_(0.4, 'dimensionless')

p_1 = Q_(450.0, 'psi')
T_1 = Q_(600.0, 'degF')

p_2 = Q_(100.0, 'psi')

p_3 = Q_(20.0, 'psi')

p_4 = Q_(1.0, 'psi')

p_5 = p_4
x_5 = Q_(0.0, 'dimensionless')

p_6 = Q_(20.0, 'psi')

p_7 = p_2
x_7 = Q_(0.0, 'dimensionless')

p_8 = p_6

p_9 = p_6
x_9 = Q_(0.0, 'dimensionless')

p_10 = p_6
x_10 = Q_(0.0, 'dimensionless')

eta_t1 = eta_t2 = eta_t3 = Q_(0.85, 'dimensionless')
eta_p1 = eta_p2 = Q_(0.85, 'dimensionless')
```

Problem Statement

Commander Jordan Forge is probably trying to escape some planet somewhere. I don't know, this universe needs more characters, so he's not in this assignment. Ensign Westley Blusher of the USS Enterskies is devising a new combined heat and power (CHP) system for the ship. The system provides turbine power for the ship's residential floors, process steam for cleaning, uh, space… dirt, yeah space dirt off of shuttle engines, and steam for pre-heating the warp core.

Operating data are given at key states in the cycle. Determine

1. the rates that steam is extracted as process steam in lbm/hr,
2. the rates of heat transfer for the process steam in Btu/hr,
3. the rate that steam is extracted for the heating load, in lbm/hr,
4. the rate of heat transfer for the heating load, in Btu/hr,
5. the net power developed, in Btu/hr.
6. Devise and evaluate an overall energy-based efficiency for the combined heat and power system.



Solution

Defining states:

State	1	2
1	p_1	T_1
2s	p_2	$s_{2s} = s_1$
2	p_2	h_2
3s	p_3	$s_{3s} = s_2$
3	p_3	h_3
4s	p_4	$s_{4s} = s_3$
4	p_4	h_4
5	p_5	x_5
6s	p_6	$s_{6s} = s_5$
6	p_6	h_6
7	p_7	x_7
8	p_8	$h_8 = h_7$
9	p_9	x_9
10	p_{10}	x_{10}
11s	$p_{11} = p_1$	$s_{11s} = s_{10}$
11	$p_{11} = p_1$	h_{11}

$$h_2 = (h_{2s} - h_1) \cdot \eta_{t1} + h_1$$

$$h_3 = (h_{3s} - h_2) \cdot \eta_{t2} + h_2$$

$$h_4 = (h_{4s} - h_3) \cdot \eta_{t3} + h_3$$

$$h_6 = \frac{h_{6s} - h_5}{\eta_{p1}} + h_5$$

$$h_{11} = \frac{h_{11s} - h_{10}}{\eta_{p2}} + h_{10}$$

[3]:
```
st_1   = State(substance, p=p_1,T=T_1)
st_2s  = State(substance, p=p_2,s=st_1.s)

h_2 = (st_2s.h-st_1.h)*eta_t1 + st_1.h
st_2   = State(substance, p=p_2,h=h_2)
st_3s  = State(substance, p=p_3,s=st_2.s)

h_3 = (st_3s.h-st_2.h)*eta_t2 + st_2.h
st_3   = State(substance, p=p_3,h=h_3)
st_4s  = State(substance, p=p_4,s=st_3.s)

h_4 = (st_4s.h-st_3.h)*eta_t3 + st_3.h
st_4   = State(substance, p=p_4,h=h_4)
```

```
st_5   = State(substance, p=p_5,x=x_5)
st_6s  = State(substance, p=p_6,s=st_5.s)

h_6 = (st_6s.h-st_5.h)/eta_p1 + st_5.h
st_6   = State(substance, p=p_6,h=h_6)
st_7   = State(substance, p=p_7,x=x_7)
st_8   = State(substance, p=p_8,h=st_7.h)
st_9   = State(substance, p=p_9,x=x_9)
st_10  = State(substance, p=p_10,x=x_10)
st_11s = State(substance, p=st_1.p,s=st_10.s)

h_11 = (st_11s.h-st_10.h)/eta_p2 + st_10.h
st_11  = State(substance, p=st_1.p,h=h_11)
```

Mass Flow Relations:

$\dot{m}_1 = \dot{m}_{10} = \dot{m}_{11}$

$\dot{m}_2 = \dot{m}_7 = \dot{m}_8$ and $y = \frac{\dot{m}_2}{\dot{m}_1}$

$\dot{m}_3 = \dot{m}_9$ and $y' = \frac{\dot{m}_3}{\dot{m}_1}$

$\dot{m}_4 = \dot{m}_5 = \dot{m}_6$ and $(1 - y - y') = \frac{\dot{m}_4}{\dot{m}_1}$

For the Open Feedwater Heater:

$$(\sum \dot{m}_i h_i = \sum \dot{m}_e h_e) \Rightarrow (\dot{m}_6 h_6 + \dot{m}_8 h_8 + \dot{m}_9 h_9 = \dot{m}_{10} h_{10}) \Rightarrow (\dot{m}_4 h_6 + \dot{m}_2 h_8 + \dot{m}_3 h_9 = \dot{m}_1 h_{10})$$

$$(\dot{m}_1(1 - y - y')h_6 + \dot{m}_1(y)h_8 + \dot{m}_1(y')h_9 = \dot{m}_1 h_{10}) \Rightarrow (h_6(1 - y) - h_6(y') + h_8(y) + h_9(y') = h_{10})$$

$$y' = \frac{h_{10} - h_6(1 - y) - h_8(y)}{h_9 - h_6}$$

[4]:

```
mdot_11 = mdot_10 = mdot_1
mdot_2 = mdot_7 = mdot_8 = mdot_1 * y
y_p = (st_10.h-st_6.h*(1-y)-st_8.h*y)/(st_9.h-st_6.h)
print(y_p)
mdot_3 = mdot_9 = mdot_1 * y_p
mdot_4 = mdot_5 = mdot_6 = mdot_1 * (1-y-y_p)
```

```
0.2766435909928248 dimensionless
```

Part 1: Rate of Steam Extraction for Process Steam, in lb/hr

[5]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
print(mdot_2.to("lb/hr").round(2))
```

```
4000.0 pound / hour
```

Answer: $4,000.0$ lb/hr

Part 2: Rate of Heat Transfer for the Process Steam, in Btu/hr

Important Equation:

$\dot{Q}_{process} = \dot{m}_2(h_7 - h_2)$

[6]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Qdot_process = mdot_2 * (st_7.h-st_2.h)
print(Qdot_process.to("Btu/hr").round(2))
```

```
-3546282.13 btu / hour
```

Answer: $3,546,282.13$ Btu/hr

Part 3: Rate of Steam Extraction for the Heating Load, in lb/hr

[7]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
print(mdot_3.to("lb/hr").round(2))
```

```
2766.44 pound / hour
```

Answer: $2,766.44$ lb/hr

Part 4: Rate of Heat Transfer for the Heating Load, in Btu/hr

Important Equation:

$\dot{Q}_{load} = \dot{m}_3(h_9 - h_3)$

[8]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Qdot_load = mdot_3 * (st_9.h-st_3.h)
print(Qdot_load.to("Btu/hr").round(2))
```

```
-2454486.4 btu / hour
```

Answer: $2,454,486.4$ Btu/hr

Part 5: Net Power Developed, in Btu/hr

Important Equations:

1. $\sum \dot{W}_{net} = \sum \dot{W}$
2. $\dot{W}_{t1} = \dot{m}_1(h_1 - h_2)$
3. $\dot{W}_{t2} = \dot{m}_3(h_2 - h_3)$
4. $\dot{W}_{t3} = \dot{m}_4(h_3 - h_4)$
5. $\dot{W}_{p1} = \dot{m}_6(h_5 - h_6)$
6. $\dot{W}_{p2} = \dot{m}_{11}(h_{10} - h_{11})$

[9]:

```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Wdot_t1 = mdot_1 * (st_1.h-st_2.h)
Wdot_t2 = mdot_1 * (1-y) * (st_2.h-st_3.h)
Wdot_t3 = mdot_4 * (st_3.h-st_4.h)
Wdot_p1 = mdot_6 * (st_5.h-st_6.h)
Wdot_p2 = mdot_11 * (st_11.h-st_10.h)
Wdot_net = Wdot_t1 + Wdot_t2 + Wdot_t3 + Wdot_p1 + Wdot_p2
print(Wdot_net.to("Btu/hr").round(2))
```

```
2284407.78 btu / hour
```

Answer: $2,284,407.78$ Btu/hr

Part 6: Devise and Evaluate Efficiency

What we get out over what we put in:

1. $\eta = \frac{\dot{W}_{net}+|\dot{Q}_{process}|+|\dot{Q}_{load}|}{Q_{in}}$
2. $\dot{Q}_{in} = \dot{m}_{11}(h_1 - h_{11})$

[10]:

```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Qdot_in = mdot_11 * (st_1.h-st_11.h)
eta = (Wdot_net - Qdot_process - Qdot_load)/(Qdot_in)
print(eta)
```

```
0.7497984869038016 dimensionless
```

Answer: 75%