Homework 4-1

Imports

[1]:
```
from thermostate import Q_, State, units
import numpy as np
import matplotlib.pyplot as plt

%matplotlib inline
#%matplotlib notebook

# this just suppresses a warning due to the plotting code
import warnings
warnings.filterwarnings('ignore')
```

Definitions

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

mdot_1 = Q_(120, 'kg/s')

T_1 = Q_(560.0, 'degC')
p_1 = Q_(16.0, 'MPa')

p_2 = Q_(1.0, 'MPa')

p_3 = Q_(8.0, 'kPa')

x_4 = Q_(0.0, 'dimensionless')

x_6 = Q_(0.0, 'dimensionless')

p_lo = 0.1  # (MPa)
p_hi = 7.5  # (MPa)
```

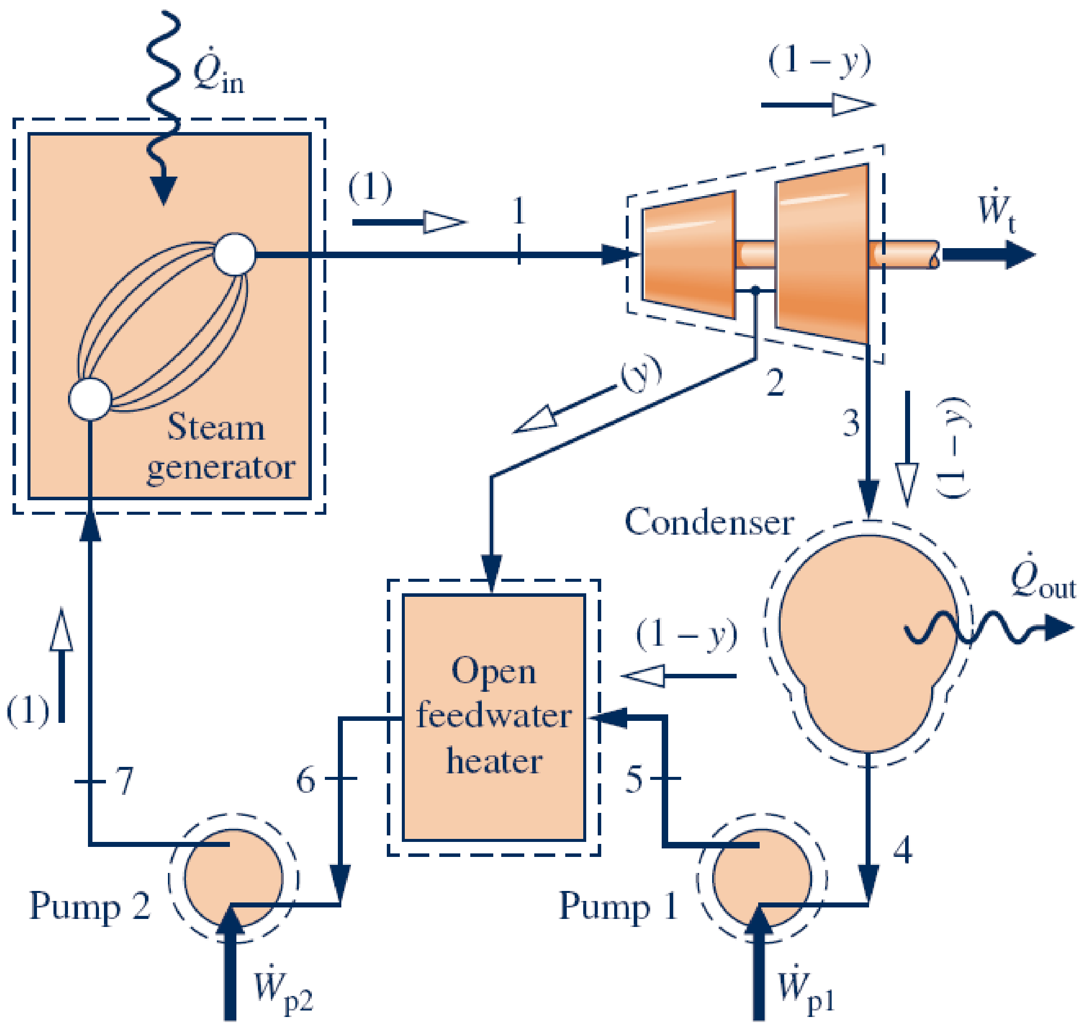
Problem Statement

Water is the working fluid in an ideal regenerative Rankine cycle with one open feedwater heater. Superheated vapor enters the first turbine stage at 16.0 MPa, 560.0 °C, with a mass flow rate of 120.0 kg/s. Steam expands through the first turbine stage at 1.0 MPa where it is extracted and diverted to the open feedwater heater. The remainder expands through the second turbine stage to the condenser pressure of 8.0 kPa. Saturated liquid exits the feedwater heater at 1.0 MPa. The processes in the turbines and pumps can be modeled as isentropic.

Determine:

1. the net power developed, in MW,
2. the rate of heat transfer to the steam passing through the steam generator, in MW,

3. the overall cycle thermal efficiency.
4. For extraction pressures (p_2) ranging from $p_{lo} = 0.1MPa$ to $p_{hi} = 7.5MPa$, calculate the extracted mass fraction y and the overall cycle thermal efficiency. Plot η on the vertical axis against y on the horizontal axis.
5. Your plot should show a concave-down curve (if it doesn't, we're happy to help debug at office hours). Why might this plot be increasing at first, then start decreasing?



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	x_4		$p_4 = p_3$

	State	1	2
5		$p_5 = p_2$	$s_5 = s_4$
6		x_6	$p_6 = p_5$
7		$p_7 = p_1$	$s_7 = s_6$

[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,x=x_4,p=st_3.p)
st_5 = State(substance,p=st_2.p,s=st_4.s)
st_6 = State(substance,x=x_6,p=st_5.p)
st_7 = State(substance,p=st_1.p,s=st_6.s)
```

Calculating mass flow rates:

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

In the open feedwater heater:

$$\sum m_i h_i = \sum m_e h_e \Rightarrow \dot{m}_5 h_5 + \dot{m}_2 h_2 = \dot{m}_6 h_6 \Rightarrow \dot{m}_3 h_5 + \dot{m}_2 h_2 = \dot{m}_1 h_6$$

$$(1-y)h_5 + y h_2 = h_6 \Rightarrow y = \frac{h_6 - h_5}{h_2 - h_5}$$

Lastly rearranging the final equation with eq.4 yields: $\dot{m}_2 = y\dot{m}_1$

[4]:
```
y = (st_6.h-st_5.h)/(st_2.h-st_5.h)
mdot_2 = mdot_1 * y
mdot_3 = mdot_1 * (1-y)
```

Part 1: Net Power Developed

Important Equations:

1. $\dot{W}_{net} = \sum \dot{W}$
2. $\dot{W}_{t,hp} = \dot{m}_1(h_1 - h_2)$
3. $\dot{W}_{t,lp} = \dot{m}_3(h_2 - h_3)$
4. $\dot{W}_{p,1} = \dot{m}_4(h_4 - h_5)$
5. $\dot{W}_{p,2} = \dot{m}_6(h_6 - h_7)$

[5]:

```python
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Wdot_thp = mdot_1 * (st_1.h-st_2.h)
Wdot_tlp = mdot_3 * (st_2.h-st_3.h)
Wdot_p1 = mdot_3 * (st_4.h-st_5.h)
Wdot_p2 = mdot_1 * (st_6.h-st_7.h)
Wdot_net = Wdot_thp + Wdot_tlp + Wdot_p1 + Wdot_p2
print(Wdot_net.to("MW"))
```

```
149.98588505011458 megawatt
```

Answer: 149.99 MW

Part 2: Rate of Heat Transfer Input

Important Equations:

1. $\dot{Q}_{in} = \dot{m}_7(h_1 - h_7)$

[6]:

```python
# 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_7.h)
print(Qdot_in.to("MW"))
```

```
322.53859595399416 megawatt
```

Answer: 322.54 MW

Part 3: Cycle Thermal Efficiency

Important Equations:

1. $\eta = \frac{\dot{W}_{net}}{\dot{Q}_{in}}$

[7]:

```python
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
eta = Wdot_net/Qdot_in
print(eta)
```

```
0.4650168597853885 dimensionless
```

Answer: 46.50%

Part 4: Plot η vs. y

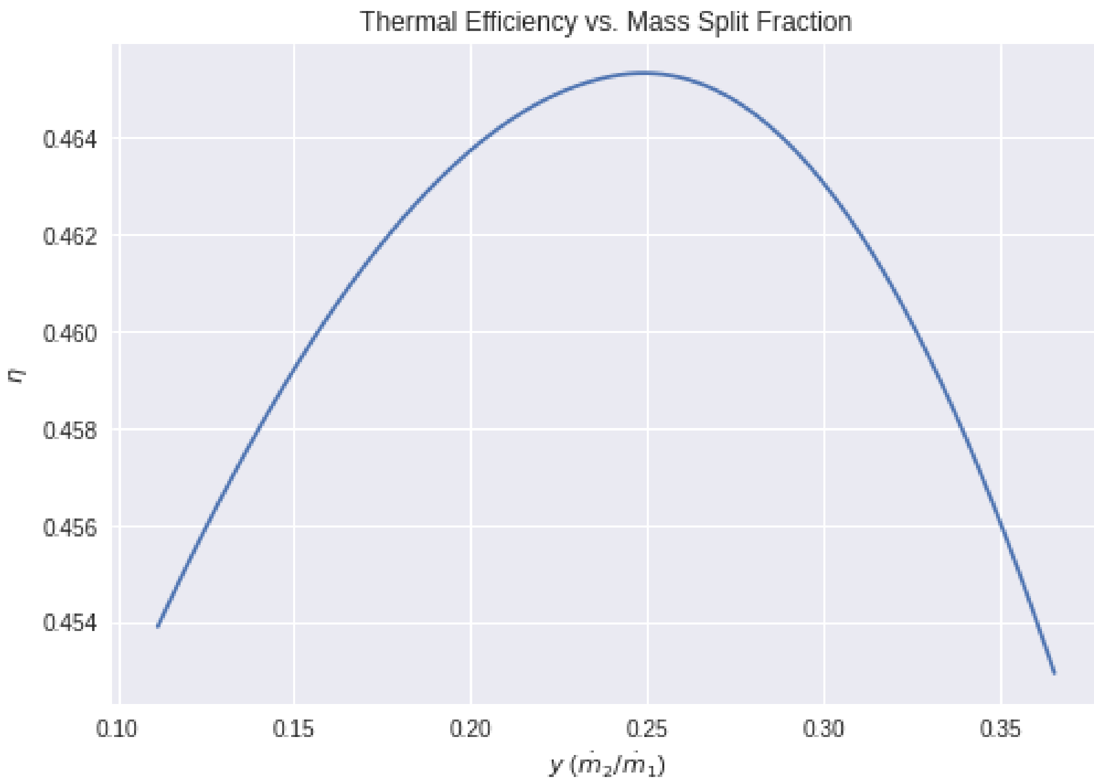
You should copy all of your code above (except any `print` statements) into the given function (it should be indented underneath the `def calc_eta` line, and above the `return eta` line). You'll need to copy code here into the code cell below.

```
def calc_eta_and_y(p_2):
    '''Calculate the cycle thermal efficiency given the
    pressure at State 2.'''

    # SET STATES


    # CALCULATE y (variable name must be "y")


    # CALCULATE WORK OUTPUT FROM TURBINES


    # CALCULATE WORK INPUT TO PUMPS


    # CALCULATE NET WORK


    # CALCULATE HEAT TRANSFER IN


    # CALCULATE ETA (variable name must be "eta")


    return eta, y

p_2_values = np.linspace(p_lo, p_hi)*units.MPa
eta_values = np.zeros_like(p_2_values)
y_values = np.zeros_like(p_2_values)

for i, p_2 in enumerate(p_2_values):
    eta_values[i], y_values[i] = calc_eta_and_y(p_2)

plt.style.use('seaborn')
plt.title('Thermal Efficiency vs. Mass Split Fraction')
plt.xlabel('$y$ ($\dot{m}_2/\dot{m}_1$)')
plt.ylabel('$\eta$')
plt.plot(y_values, eta_values);
```

Write your engineering model, equations, and/or explanation of your process here.

[8]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
def calc_eta_and_y(p_2):
    '''Calculate the cycle thermal efficiency given the
```

```
    pressure at State 2.'''

    # SET STATES
    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,x=x_4,p=st_3.p)
    st_5 = State(substance,p=st_2.p,s=st_4.s)
    st_6 = State(substance,x=x_6,p=st_5.p)
    st_7 = State(substance,p=st_1.p,s=st_6.s)

    # CALCULATE y (variable name must be "y")
    y = (st_6.h-st_5.h)/(st_2.h-st_5.h)
    mdot_2 = mdot_1 * y
    mdot_3 = mdot_1 * (1-y)

    # CALCULATE WORK OUTPUT FROM TURBINES
    Wdot_thp = mdot_1 * (st_1.h-st_2.h)
    Wdot_tlp = mdot_3 * (st_2.h-st_3.h)

    # CALCULATE WORK INPUT TO PUMPS
    Wdot_p1 = mdot_3 * (st_4.h-st_5.h)
    Wdot_p2 = mdot_1 * (st_6.h-st_7.h)

    # CALCULATE NET WORK
    Wdot_net = Wdot_thp + Wdot_tlp + Wdot_p1 + Wdot_p2

    # CALCULATE HEAT TRANSFER IN
    Qdot_in = mdot_1 * (st_1.h-st_7.h)

    # CALCULATE ETA (variable name must be "eta")
    eta = Wdot_net/Qdot_in

    return eta, y

p_2_values = np.linspace(p_lo, p_hi,1000)*units.MPa
eta_values = np.zeros_like(p_2_values)
y_values = np.zeros_like(p_2_values)

for i, p_2 in enumerate(p_2_values):
    eta_values[i], y_values[i] = calc_eta_and_y(p_2)

plt.style.use('seaborn')
plt.title('Thermal Efficiency vs. Mass Split Fraction')
plt.xlabel('$y$ ($\dot{m}_2/\dot{m}_1$)')
plt.ylabel('$\eta$')
plt.plot(y_values, eta_values);
```



Answer:

Part 5: Discuss Results

Write your engineering model, equations, and/or explanation of your process here.

[9]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
```

Answer: We see that there is a maximume efficency of about 46.5% with a corrisponding bleed fraction of 0.25. Some possible reasons for this is that a higher bleed fraction would give less flow to the condenser and state 4 will have a higher entropy. It could also be because not enough of a bleed fraction and the feedwater heater won't carry enough heat with it.

Homework 4-2

Imports

[1]:
```
from thermostate import Q_, State, units
import numpy as np
import matplotlib.pyplot as plt
```

Definitions

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

mdot_1 = Q_(120.0, 'kg/s')

T_1 = Q_(560.0, 'degC')
p_1 = Q_(16.0, 'MPa')

p_2 = Q_(2.0, 'MPa')

p_3 = Q_(8.0, 'kPa')

x_4 = Q_(0.0, 'dimensionless')

x_7 = Q_(0.0, 'dimensionless')
```

Problem Statement

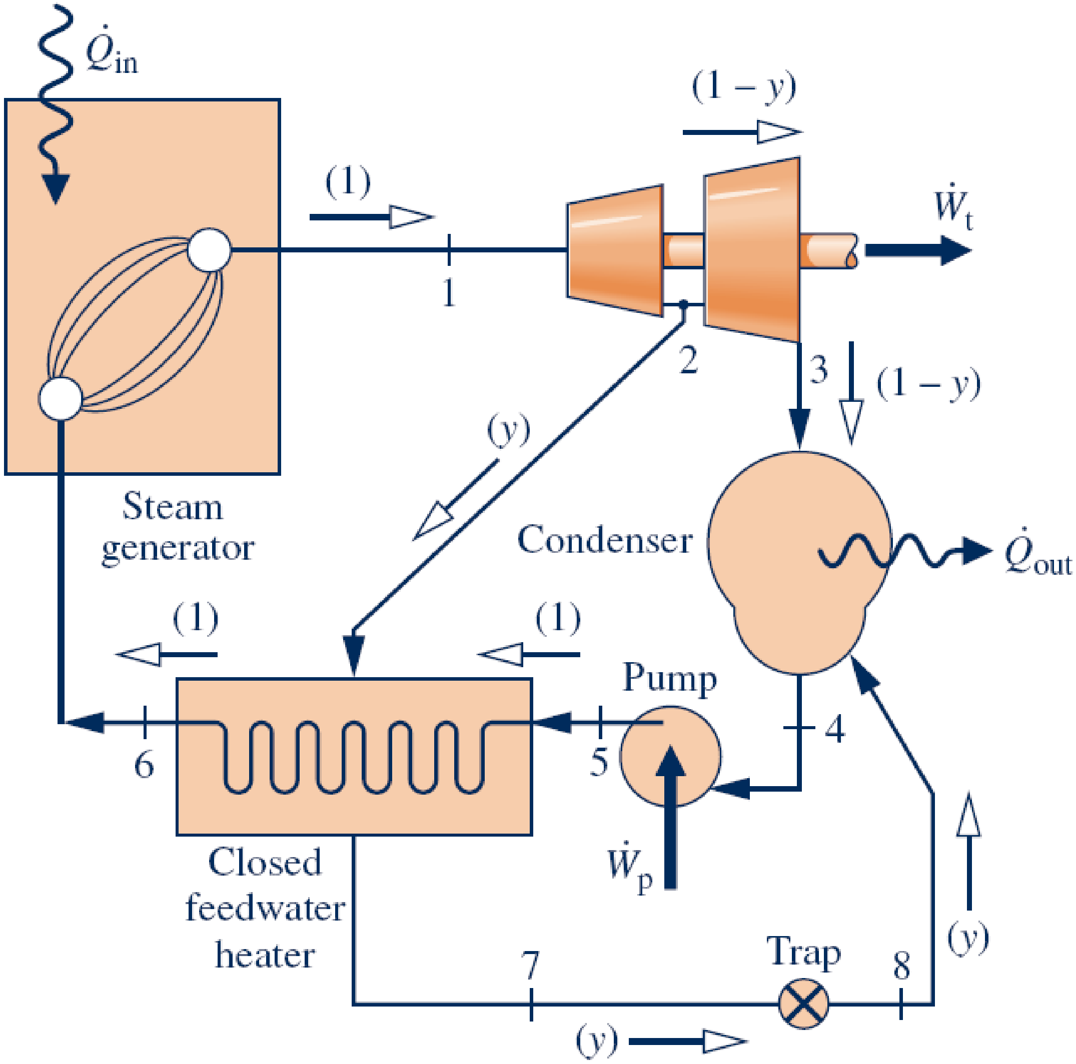
Water is the working fluid in an ideal regenerative Rankine cycle with one closed feedwater heater.

Superheated vapor enters the first-stage turbine at 16.0 MPa, 560.0 °C, with a mass flow rate of 120.0 kg/s. Steam expands through the first turbine stage to 2.0 MPa, where it is extracted and diverted to the closed feedwater heater. The remainder expands through the second turbine stage to the condenser pressure of 8.0 kPa.

Condensate drains from the feedwater heater as a saturated liquid at 2.0 MPa, and goes through a steam trap (an isenthalpic device) before entering the condenser. The feedwater leaves the heater at 16.0 MPa and a temperature equal to the saturation temperature at p_7.

Determine:

1. the net power developed, in MW,
2. the rate of heat transfer to the steam passing through the steam generator, in MW,
3. the overall cycle thermal efficiency.



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	x_4	$p_4 = p_3$
5	$p_5 = p_1$	$s_5 = s_4$
6	$p_6 = p_1$	$T_6 = T_7$
7	$p_7 = p_2$	x_7
8	$h_8 = h_7$	$p_8 = p_3$

[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,x=x_4,p=st_3.p)
st_5 = State(substance,p=st_1.p,s=st_4.s)

st_7 = State(substance,p=st_2.p,x=x_7)
st_8 = State(substance,h=st_7.h,p=st_3.p)

st_6 = State(substance,p=st_1.p,T=st_7.T)
```

Calculating mass flow rates:

Important facts:

1. $\dot{m}_1 = \dot{m}_4 = \dot{m}_5 = \dot{m}_6$
2. $\dot{m}_2 = \dot{m}_7 = \dot{m}_8$
3. $\dot{m}_3 = \dot{m}_1 - \dot{m}_2$
4. $y = \frac{\dot{m}_2}{\dot{m}_1}$
5. $(1-y) = \frac{\dot{m}_3}{\dot{m}_1}$

In the closed feedwater heater:

$$\sum m_i h_i = \sum m_e h_e \Rightarrow (\dot{m}_5 h_5 + \dot{m}_2 h_2 = \dot{m}_6 h_6 + \dot{m}_7 h_7) \Rightarrow (\dot{m}_1 h_5 + \dot{m}_2 h_2 = \dot{m}_1 h_6 + \dot{m}_2 h_7)$$

$$\dot{m}_1(h_5 - h_6) = \dot{m}_2(h_7 - h_2)$$

$$\frac{\dot{m}_2}{\dot{m}_1} = \frac{(h_5 - h_6)}{(h_7 - h_2)} = y$$

[4]:
```
y = (st_5.h-st_6.h)/(st_7.h-st_2.h)
mdot_2 = y * mdot_1
mdot_3 = mdot_1 - mdot_2
```

Part 1: Net Power Developed

Important Equations:

1. $\dot{W}_{net} = \sum \dot{W}$
2. $\dot{W}_{t,hp} = \dot{m}_1(h_1 - h_2)$
3. $\dot{W}_{t,lp} = \dot{m}_3(h_2 - h_3)$
4. $\dot{W}_p = \dot{m}_4(h_4 - h_5)$

[5]:
```python
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Wdot_thp = mdot_1 * (st_1.h-st_2.h)
Wdot_tlp = mdot_3 * (st_2.h-st_3.h)
Wdot_p1 = mdot_1 * (st_4.h-st_5.h)
Wdot_net = Wdot_thp + Wdot_tlp + Wdot_p1
print(Wdot_net.to("MW"))
```

```
132.32522548296015 megawatt
```

Answer: 132.33 MW

Part 2: Rate of Heat Transfer Input

Important Equations:

1. $\dot{Q}_{in} = \dot{m}_7(h_1 - h_7)$

[6]:
```python
# 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_7.h)
print(Qdot_in.to("MW"))
```

```
307.0410211220969 megawatt
```

Answer: 307.04 MW

Part 3: Cycle Thermal Efficiency

Important Equations:

1. $\eta = \frac{\dot{W}_{net}}{\dot{Q}_{in}}$

[7]:
```python
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
eta = Wdot_net/Qdot_in
print(eta)
```

```
0.430969207304519 dimensionless
```

Answer: 43.10 %

Homework 4-3

Imports

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

Definitions

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

Wdot_net = Q_(150, 'MW')

T_1 = Q_(480.0, 'degC')
p_1 = Q_(12.0, 'MPa')

p_2 = Q_(2.0, 'MPa')

p_3 = Q_(2.0, 'MPa')
T_3 = Q_(440.0, 'degC')

p_4 = Q_(0.3, 'MPa')

p_5 = Q_(6.0, 'kPa')

x_6 = Q_(0.0, 'dimensionless')

p_7 = Q_(0.3, 'MPa')

x_8 = Q_(0.0, 'dimensionless')
p_8 = Q_(0.3, 'MPa')

T_10 = Q_(210.0, 'degC')
p_10 = Q_(12.0, 'MPa')

x_11 = Q_(0.0, 'dimensionless')
p_11 = Q_(2.0, 'MPa')

p_12 = Q_(0.3, 'MPa')
```

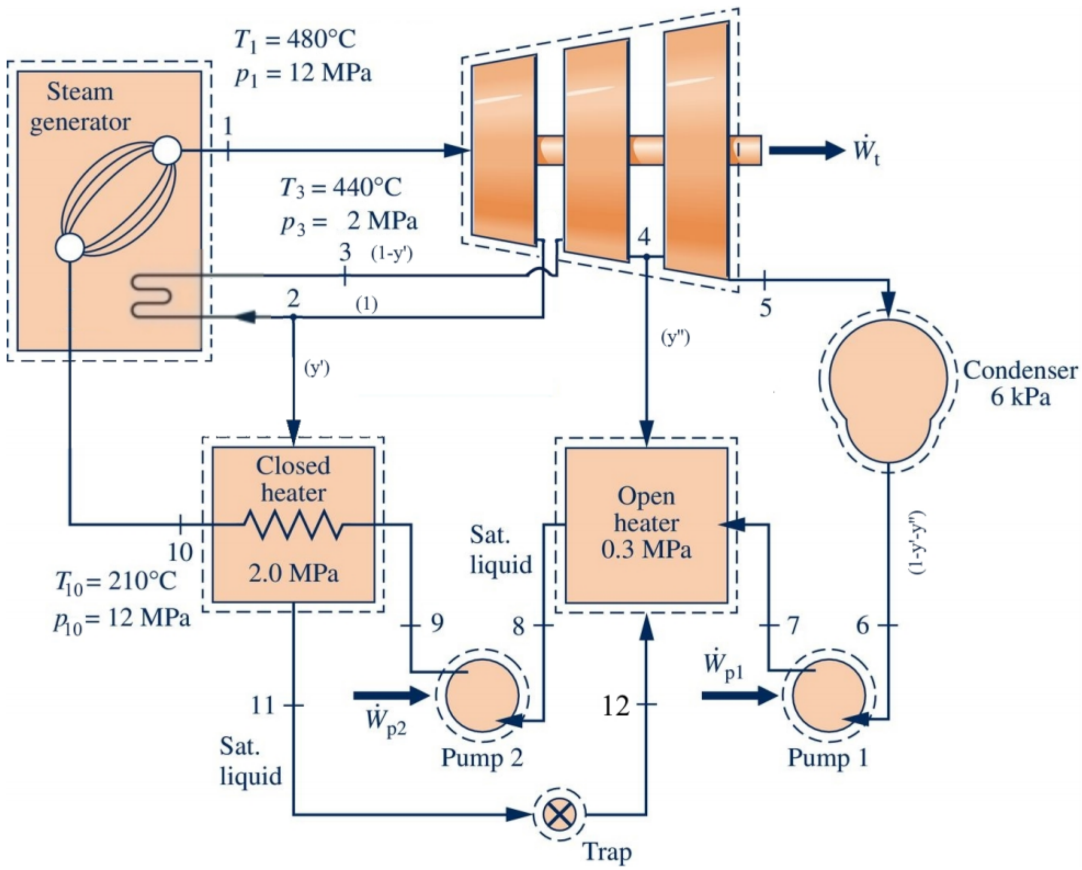
Problem Statement

Consider a regenerative vapor power cycle with two feedwater heaters, one open and one closed, and a reheater. Steam enters the first turbine stage at 12.0 MPa, 480.0 °C, and expands to 2.0 MPa. Some steam is extracted at 2.0 MPa and bled to the closed feedwater heater. The remainder is reheated at 2.0 MPa to 440.0 °C, and then expands through the second turbine to a pressure of 0.3 MPa. Some steam at 0.3 MPa is then extracted and bled into the open feedwater heater. The steam expanding through the third turbine stage exits at the condenser pressure of 6.0 kPa, and the steam exits the condenser as a saturated liquid at 6.0 kPa.

Feedwater leaves the closed heater at 210.0 °C, 12.0 MPa, and condensate exiting as a saturated liquid at 2.0 MPa is trapped into the open feedwater heater. Saturated liquid at 0.3 MPa leaves the open feedwater heater. Processes in the turbines and pumps can be modeled as isentropic.

Determine:

1. the heat transfer to the working fluid passing through the steam generator and the reheater, in kJ/kg of steam exiting the first turbine stage,
2. the overall cycle thermal efficiency,
3. the heat transfer from the working fluid passing through the condenser to the cooling water, in kJ/kg of steam entering the first turbine stage.
4. If the plant must output 150.0 MW in order to service the local suburban region, what is the mass flow rate required entering the first turbine stage (i.e. the required $\dot{m}_1$).



Solution

Defining States:

	State	1	2
1	p_1		T_1
2	p_2		$s_2 = s_1$
3	p_3		T_3

State	1	2
4	p_4	$s_4 = s_3$
5	p_5	$s_5 = s_4$
6	x_6	$p_6 = p_5$
7	p_7	$s_7 = s_6$
8	x_8	p_8
9	$p_9 = p_1$	$s_9 = s_8$
10	T_{10}	p_{10}
11	x_{11}	p_{11}
12	p_{12}	$h_{12} = h_{11}$

[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,T=T_3)
st_4 = State(substance,p=p_4,s=st_3.s)
st_5 = State(substance,p=p_5,s=st_4.s)
st_6 = State(substance,x=x_6,p=st_5.p)
st_7 = State(substance,p=p_7,s=st_6.s)
st_8 = State(substance,x=x_8,p=p_8)
st_9 = State(substance,p=st_1.p,s=st_8.s)
st_10 = State(substance,T=T_10,p=p_10)
st_11 = State(substance,x=x_11,p=p_11)
st_12 = State(substance,p=p_12,h=st_11.h)
```

Part 1: Heat Transfer per Unit Mass Flow Rate in Steam Generator & Reheater

Important equations:

1. $\frac{\dot{Q}_{10-1}}{\dot{m}_1} = (h_1 - h_{10})$
2. $\frac{\dot{Q}_{2-3}}{\dot{m}_3} = (h_3 - h_2)$

[4]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Qdot_10_1_per_mdot = st_1.h - st_10.h
Qdot_2_3_per_mdot = st_3.h - st_2.h
print(Qdot_10_1_per_mdot.to("kJ/kg"))
print(Qdot_2_3_per_mdot.to("kJ/kg"))
```

```
2393.9932946382 kilojoule / kilogram
498.8070769600435 kilojoule / kilogram
```

Answer: The heat transfer into the steam generator is 2393.99 kJ/kg and the heat transfer into the reheater is 498.81 kJ/kg

Part 2: Cycle Thermal Efficiency

Important equations:

1. $\eta = \frac{\dot{W}_{net}}{\dot{Q}_{in}}$
2. $\frac{\dot{W}_{1-2}}{\dot{m}_1} = h_1 - h_2$
3. $\frac{\dot{W}_{3-4}}{\dot{m}_3} = h_3 - h_4$
4. $\frac{\dot{W}_{4-5}}{\dot{m}_5} = h_4 - h_5$
5. $\frac{\dot{W}_{6-7}}{\dot{m}_7} = h_6 - h_7$
6. $\frac{\dot{W}_{8-9}}{\dot{m}_9} = h_8 - h_9$

Mass relations:

1. $(1) \Rightarrow (\dot{m}_1 = \dot{m}_8 = \dot{m}_9 = \dot{m}_{10})$
2. $(y') = \frac{\dot{m}_2}{\dot{m}_1} \Rightarrow (\dot{m}_2 = \dot{m}_{11} = \dot{m}_{12})$
3. $(1 - y') = \frac{m_3}{m_1} \Rightarrow (\dot{m}_3)$
4. $(y'') = \frac{\dot{m}_4}{\dot{m}_1} \Rightarrow (\dot{m}_4)$
5. $(1 - y' - y'') = \frac{\dot{m}_5}{\dot{m}_1} \Rightarrow (\dot{m}_5 = \dot{m}_6 = \dot{m}_7)$

Rearranging using mass relations:

$$\frac{\dot{W}_{1-2}}{\dot{m}_1} \qquad \frac{\dot{W}_{3-4}}{\dot{m}_1(1-y')} \qquad \frac{\dot{W}_{4-5}}{\dot{m}_1(1-y'-y'')} \qquad \frac{\dot{W}_{6-7}}{\dot{m}_1(1-y'-y'')} \qquad \frac{\dot{W}_{8-9}}{\dot{m}_1}$$

$$\frac{\dot{Q}_{10-1}}{\dot{m}_1} \qquad \frac{\dot{Q}_{2-3}}{\dot{m}_1(1-y')}$$

Plugging into the important equations from above:

2. $\dot{W}_{1-2} = \dot{m}_1(h_1 - h_2)$
3. $\dot{W}_{3-4} = \dot{m}_1(1 - y')(h_3 - h_4)$
4. $\dot{W}_{4-5} = \dot{m}_1(1 - y' - y'')(h_4 - h_5)$
5. $\dot{W}_{6-7} = \dot{m}_1(1 - y' - y'')(h_6 - h_7)$
6. $\dot{W}_{8-9} = \dot{m}_1(h_8 - h_9)$

Plugging into the important equations from part 1:

1. $\dot{Q}_{10-1} = \dot{m}_1(h_1 - h_{10})$
2. $\dot{Q}_{2-3} = \dot{m}_1(1 - y)(h_3 - h_2)$

Now plugging it into our η equations, $\dot{m}_1$ cancels and we get:

$$\eta = \frac{(h_1 - h_2) + (1 - y')(h_3 - h_4) + (1 - y' - y'')(h_4 - h_5) + (1 - y' - y'')(h_6 - h_7) + (h_8 - h_9)}{(h_1 - h_{10}) + (1 - y)(h_3 - h_2)}$$

Defining y' and y'':

We know that in both heaters: $\sum m_i h_i = \sum m_e h_e$

For the closed heater, this becomes $\dot{m}_2 h_2 + \dot{m}_9 h_9 = \dot{m}_{10} h_{10} + \dot{m}_{11} h_{11} \Rightarrow y' = \frac{\dot{m}_2}{\dot{m}_1} = \frac{(h_{10} - h_9)}{(h_2 - h_{11})}$

For the open heater, this becomes $(\dot{m}_4 h_h + \dot{m}_7 h_7 + \dot{m}_{12} h_{12} = \dot{m}_8 h_8) \Rightarrow (\dot{m}_4 h_h + \dot{m}_5 h_7 + \dot{m}_2 h_{12} = \dot{m}_1 h_8)$

$$\dot{m}_1 y'' h_4 + \dot{m}_1 (1 - y' - y'') h_7 + \dot{m}_1 y' h_{12} = \dot{m}_1 h_8$$

$$y'' = \frac{h_8 - h_7(1 - y') - h_{12} y'}{h_4 - h_7}$$

[5]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
y_prime = (st_10.h - st_9.h)/(st_2.h - st_11.h)
y_double_prime = (st_8.h - st_7.h * (1-y_prime) - st_12.h*y_prime)/(st_4.h -␣
↪st_7.h)

eta = ((st_1.h-st_2.h) + (1-y_prime)*(st_3.h-st_4.h) +␣
↪(1-y_prime-y_double_prime)*(st_4.h-st_5.h) +
      (1-y_prime-y_double_prime)*(st_6.h-st_7.h) + (st_8.h-st_9.h))/((st_1.
↪h-st_10.h) + (1-y_prime)*(st_3.h-st_2.h))
print(eta)
```

```
0.4616675501869451 dimensionless
```

Answer: 46.17%

Part 3: Heat Transfer per Unit Mass Flow Rate in Condenser

Important equations:

1. $\frac{\dot{Q}_{5-6}}{\dot{m}_5} = (h_6 - h_5)$

[6]:
```
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Qdot_5_6_per_mdot = st_6.h - st_5.h
print(Qdot_5_6_per_mdot.to("kJ/kg"))
```

```
-2083.2578784267403 kilojoule / kilogram
```

Answer: 2083.26 kJ/kg

Part 4: Mass Flow Rate Required for Desired Power Output

Important equations:

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

Refer to part 2 to get individual $\dot{W}$ equations

$$\dot{W}_{net} = \dot{m}_1(h_1 - h_2) + \dot{m}_1(1-y')(h_3 - h_4) + \dot{m}_1(1-y'-y'')(h_4 - h_5) + \dot{m}_1(1-y'-y'')(h_6 - h_7) + \dot{m}_1(h_8 - h_9)$$

$$\dot{m}_1 = \frac{\dot{W}_{net}}{(h_1 - h_2) + (1-y')(h_3 - h_4) + (1-y'-y'')(h_4 - h_5) + (1-y'-y'')(h_6 - h_7) + (h_8 - h_9)}$$

[10]:
```python
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
mdot_1 = (Wdot_net)/((st_1.h-st_2.h) + (1-y_prime)*(st_3.h-st_4.h) +
 ↪(1-y_prime-y_double_prime)*(st_4.h-st_5.h)
                        + (1-y_prime-y_double_prime)*(st_6.h-st_7.h) + (st_8.h -
 ↪st_9.h))
print(mdot_1.to("kg/s"))
```

```
115.7021104244187 kilogram / second
```

Answer: 115.7 kg/s

Homework 4-4

Imports

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

Definitions

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

Wdot_net = Q_(300, 'hp')

T_1 = Q_(120, 'degF')
x_1 = Q_(1.0, 'dimensionless')

T_2 = Q_(60, 'degF')

x_3 = Q_(0.0, 'dimensionless')
p_3 = Q_(105.0, 'lbf/in**2')

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

Problem Statement

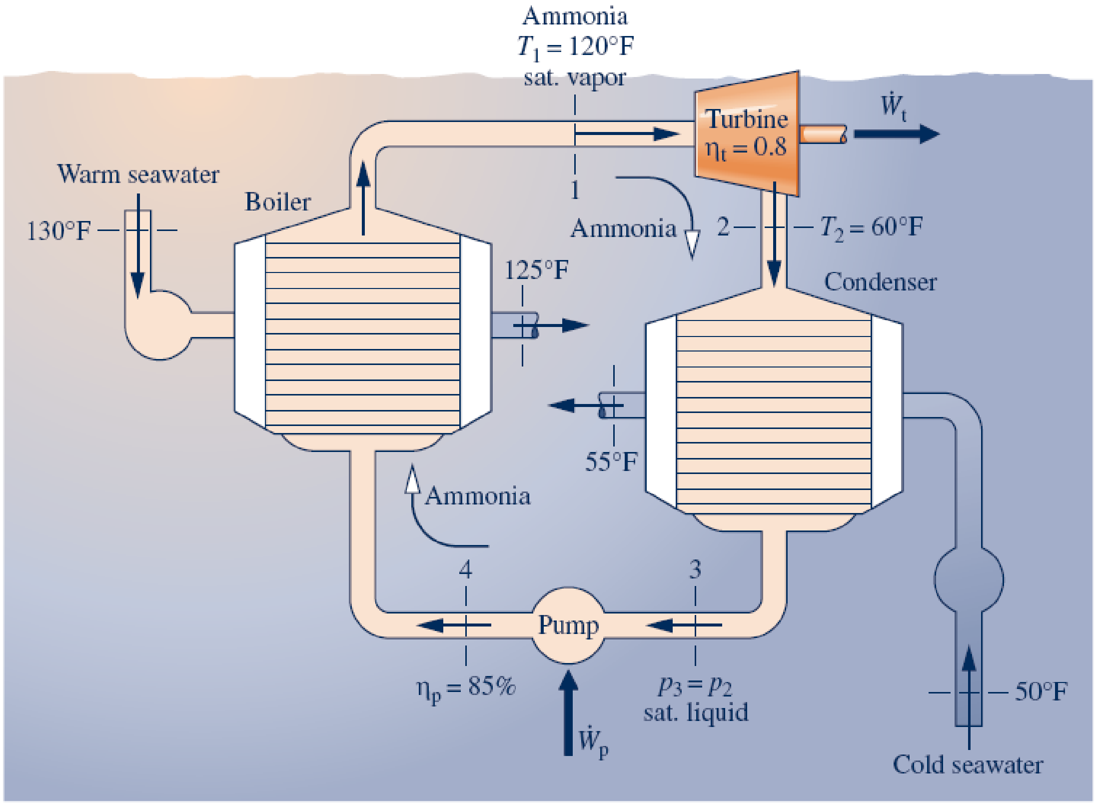
Commander Jordan Forge, having recently escaped from the volcano planet More-door, is interested in testing a design for a geothermal powerplant. More-door has never housed any life, so there are no fossil fuels available, and mining for coal is infeasible due to a thick layer of hard igneous rock on the planet's surface.

Lava flows continuously into the cold saltwater ocean. Cdr. Forge wants to anchor a floating power plant that uses ammonia as the working fluid offshow of a lava flow. The plant would exploit the temperature variation between the warm seawater near the surface at 130 °F and the deep seawater at 50 °F to produce power.

Forge's assistant, Lt. Cdr. Datum, has sketched a preliminary design, shown in the figure below.

Determine:

1. the cycle's thermal efficiency,
2. the mass flow rate of ammonia, in lb/min, for a net power output of 300 hp.
3. The thermal efficiency of this cycle is very low compared to the Rankine cycle plants in the previous problems. Why might a company decide to use this type of plant instead of the other types? What considerations should be made about maintaining the plant in its environment?



Solution

Note: due to some limitations with Thermostate, we're unable to use temperature and specific enthalpy to set state 2. This means we should use the following procedure for this problem only:

1. Use the given properties to set state 3.
2. Use $p_2 = p_3$ and the given T_2 to set state 2 using Thermostate.
3. Get h_2 using Thermostate, rather than making use of the turbine's isentropic efficiency.

Defining states:

	State 1	2
1	x_1	T_1
2	T_2	$p_2 = p_3$
3	p_3	x_3
4s	$p_{4s} = p_1$	$s_{4s} = s_3$
4	$p_4 = p_1$	h_4

$$\eta_p = \frac{h_{4s} - h_3}{h_4 - h_3} \Rightarrow h_4 = \frac{h_{4s} - h_3}{\eta_c} + h_3$$

[5]:
```python
st_1 = State(substance,x=x_1,T=T_1)
st_2 = State(substance,T=T_2,p=p_3)
st_3 = State(substance,p=p_3,x=x_3)
st_4s = State(substance,p=st_1.p,s=st_3.s)
h_4 = (st_4s.h-st_3.h)/eta_p + st_3.h
st_4 = State(substance,p=st_1.p,h=h_4)
```

Part 1: Cycle Thermal Efficiency

Important equations:

1. $\eta = \frac{\dot{W}_{net}}{\dot{Q}_{in}}$
2. $\frac{\dot{W}_{net}}{\dot{m}} = (h_1 - h_2) + (h_3 - h_4)$
3. $\frac{\dot{Q}_{in}}{\dot{m}} = (h_1 - h_4)$

[7]:
```python
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
Wdot_per_mdot = (st_1.h-st_2.h) + (st_3.h-st_4.h)
Qdot_per_mdot = (st_1.h-st_4.h)
eta = Wdot_per_mdot/Qdot_per_mdot
print(eta * 100)
```

```
0.8982755676118398 dimensionless
```

Answer: 0.9%

Part 2: Mass Flow Rate

Important equations:

1. $\frac{\dot{W}_{net}}{\dot{m}} = (h_1 - h_2) + (h_3 - h_4) \Rightarrow \dot{m} = \frac{\dot{W}_{net}}{(h_1 - h_2) + (h_3 - h_4)}$

[10]:
```python
# Write your code here to solve the problem
# Make sure to write your final answer in the cell below.
mdot = Wdot_net/((st_1.h-st_2.h) + (st_3.h-st_4.h))
print(mdot.to("kg/s"))
```

```
20.415457235825585 kilogram / second
```

Answer: 20.42 kg/s

Part 3: Why use this type of plant?

Answer: This type of plant is effective in this sinario because it requires very little input. The only manual input is the work into the pump. It takes advantage of the natural warming and cooling bodies of the different ocean layer temperatures.