Thermodynamics: Homework A – Set 7 -Answers
Jennifer West (2004)

Problem 1
Answer 1 of 4:
B. 50.9%
After fixing the states, use the formula for thermal efficieny given in the text to find the answer.
Fixing any two properties fixes the state of the system. In this problem we know the following:
1. State 1 is saturated vapor at 180 bar. Hence it is completely specified and h1 and s1 can be determined.
2. State 2 pressure is known. Also, the turbine is isentropic. Hnce s2 = s1. Thus state 2 is completely specified.
3. State 4 is known (satrated liquid at 180 bar).
4. State 3 pressure is given and s3 = s4 since the pump is isentropic. Thus the state is completely specified.
Hence all states are known and the following table can be generated:
(Note: s2 and s3 lie between sf2 and sg2 and sf3 and sg3, respectively. Thus they indicate saturated liquid-vapor mixtures, and indicate that x values must be found)

State 1	**State 2**	**State 3**	**State 4**
P1 = 180 bar	P2 = 0.06 bar	P3 = 0.06 bar	P4 = 180 bar
Saturated vapor	s2 = s1 s2 = 5.1044 kJ/(kg*K)	s3 = s4 s3 = 3.8715 kJ/(kg*K)	Saturated Liquid
h1 = 2509.1 kJ/kg	x2 = (s2 – sf2)/sfg2 x2 = 0.5869	x3 = (s2 – sf3)/sfg3 x3 = 0.429	s4 = s3 s4 = 3.8715 kJ/(kg*K)
s1 = 5.1044 kJ/(kg*K)	h2 = 1569.4 kJ/kg	h3 = 1188.0 kJ/kg	h4 = 1732.0 kJ/kg

For the thermal efficiency, the given formula is:
$n_{max} = 1 = T_C/T_H$
$T_C|_{sat., 180\ bar} = 309.3$ K
$T_H|_{sat., 0.06}$ bar = 630.25 K
$n_{max} = 1 – (309.3 \text{ K} / 630.25 \text{ K})$
$n_{max} = 0.509$
$n_{max} = 50.9$ %

Answer 2 of 4:
57.9 %
Using the formula:
bwr = (Wp/m) / (Wt/m) = (h4 – h3) / (h1 – h2)
Substitution of the known values yields:

bwr = (1732.0 kJ/kg – 1188.0 kJ/kg) / (2509.1 kJ/kg – 1569.4 kJ/kg)
bwr = 0.579
bwr = 57.9 %

Answer 3 of 4:
Using the formula:
395.7 kW
(along with the fixed property values found for previous questions)
W_{cycle}/m = Wt/m – Wp/m = (h1 – h2) – (h4 – h3)
W_{cycle}/m = (2509.1 kJ/kg – 1569.4 kJ/kg) – (1732.0 kJ/kg – 1188.0 kJ/kg)
W_{cycle}/m = 939.7 kJ/kg – 544 kJ/kg
W_{cycle}/m = 395.7 kJ/kg
Assuming a mass flow rate of 1 kg/s:
W_{cycle} = 395.7 kJ/kg * 1 kg/s
W_{cycle} = 395.7 kJ/s
Since 1 kJ/s = 1 kW...
W_{cycle} = 395.7 kW

Answer 4 of 4:
381.4 kJ/s
Using the formula:
(along with the fixed property values found for previous problems)
Q_{out}/m = (h2 – h3) = 15694 kJ/kg – 1188.0 kJ/kg
Q_{out}/m = 381.4 kJ/kg
Using a mass flow rate of 1 kg/s:
Q_{out} = 381.4 kJ/kg * 1 kg/s
Q_{out} = 381.4 kJ/s

Problem 2
Answer 1 of 5:
B. 6.30%
The equation that relates the temperatures of the reservoirs to the efficiency is:
$n_{max} = 1 – T_C/T_H$
where T_C and T_H are in either Rankine or Kelvin
TC = 46 °F = 506 °R
TH = 80 °F = 540 °R
n_{max} = 1 – (506/540)
n_{max} = 0.0630
n_{max} = 6.30 %

Answer 2 of 5:

Given the range of seawater temperatures in the boiler, an assumption of an evaporation temperature for the ammonia of 75 °F would not be

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unreasonable. Additionally, given the range of seawater temperatures in the condenser, a condensing temperature of 50 °F for the ammonia could be assumed. A realistic efficiency for the turbine would be assumed to be about 80 %. After making these assumptions it is possible to fix and thus specify all of the principal states of the system.

Fixing any two properties fixes the state of the system. In this problem we know the following:

1. State 1 temperature and quality is known. Hence it is completely specified and h1 and s1 can be determined.
2. State 2 cna be assumed to have a temperature of 50 F and would be saturated liquid. Thus the state would be completely specified.
3. State 3 pressure is equal to that of state 2 and is saturated liquid; thus the state is specified.
4. State 4 pressure is known and enthalpy can be found using a relationship between the enthalpy, pressure, and specific volume of state three and the pressure of state 4.

Hence all states are known and the following table can be generated:

State 1	State 2	State 3	State 4
T1 = 75 F	T2 = 50 F	Saturated Liquid	P4 = P1 P4 = 140.60 psia
x1 = 1.0	P2 = Psat|$_{50\ F}$ P2 = 89.242 psia	P3 = P2 P3 = 89.242 psia	h4s = h3 + v3*(P4-P3) h4s = 97.893 Btu/lb
P1 = 140.60 psia	s2s = s1	h3 = 97.55 Btu/lb	
h1 = 629.20 Btu/lb	x2s = 0.9625		
s1 = 1.2048 Btu/(lb*R)	h2s = 604.8 Btu/lb		
	h2 = h1 – nt*(h1 – h2s) h2 = 609.7 Btu/lb		

The thermal efficiency is given by the equation:

n = 1 – (Qout/m)/(Qin/m)

Qout/m ~ heat transfer from the seawater to the ammonia passing through the condenser

Qout/m = h2 – h3 = 609.7 – 97.55 = 512.2 Btu/lb

Qin/m ~ heat transfer from the seawater to the ammonia passing through the boiler

Qin/m = h1 – h4 = 629.20 – 97.893 = 531 Btu/lb

n = 1 – (512.2 / 531)

n = 0.0359

n = 3.59 %

Answer 3 of 5:
In order to find the power input required for the pumps, it is necessary to know the mass flow rate of the ammonia. The net power output of the plant will need to take into account the required power input of the heat exchangers, the power output of the turbine, and the power input required for the pumps.
For the mass flow rate of ammonia:
(using a turbine work of 8.2 x 10^8 Btu/h)
m = Wt/(h1 – h2)
m = (8.2 x 10^8 Btu/h) / (629.2 Btu/lb – 609.7 Btu/lb)
m = 4.205 x 10^7 lb/h
Using this mass flow rate to find the pump work input required:
Wp = m*(h3 – h4)
Wp = 1.38 x 10^7 Btu/h
For the net work for the process:
W_{Net} = Wt – Wp – $W_{s.w.pumps}$
W_{net} = 5.512 x 10^8 Btu/h

Answer 4 of 5:
1.267 x 10^6 lb/h
Using the mass flow rate of ammonia found in the previous problem (in the case of the example, m = 4.205 x 10^7 lb/h
Energy gained by seawater = Energy given up by ammonia condensing
$m_{s.w.condenser}$ * c * (Tw_{out} – Tw_{in}) = m * (h2 - h3)
$m_{s.w.condenser}$ = m*(h2-h3) / (c*(Tw_{out} – Tw_{in})
$m_{s.w.condenser}$ = (4.205 x 10^7 lb/h)*(512.2 Btu/lb) / (1.0 Btu/(lbm*R) * (47.7 F – 46 F))
$m_{s.w.condenser}$ = 1.267 x 10^6 lb/h

Answer 5 of 5:
8.94 x 10^9 lb/h
Using the mass flow rate of ammonia found in the previous problem (in the case of the example, m = 4.205 x 10^7 lb/h
Energy given up by seawater through boiler = Energy gained by ammonia in boiler
$m_{s.w.boiler}$ * c * (Tw_{in} – Tw_{out}) = m * (h1 - h4)
$m_{s.w.boiler}$ = m*(h1-h4) / (c*(Tw_{in} – Tw_{out}))
$m_{s.w.boiler}$ = (4.205 x 10^7 lb/h)*(531.3 Btu/lb) / (1.0 Btu/(lbm*R) * (80 F – 77.5 F))
$m_{s.w.boiler}$ = 8.94 x 10^9 lb/h

Problem 3
Answer 1 of 3:
A. 161.59 kJ/(kg*K)
Begin by fixing and listing the properties of each state. Look for a relationship between specific enthalpy, specific volume, and pressure.
Upon fixing two properties of a system, the entire system is fixed.
We know the following things about the system:

1. States 1, 4, and 5 are completely specified.
2. State 3 can thus be calculated because s3 = s4 and T3 is given.
3. State 2 can then be calculated because s2 = s1 and P2 = P3.
4. State 6 can be calculated bacause P6 is given and h6 can be calculated from the pump equation.

Once the values are calculated, the following table can be generated:

State 1	State 2	State 3	State 4	State 5	State 6
P1 = 10 MPa	s2 = s1 s2 = 6.9029 kJ/(kg*K)	s3 = s4 s3 = 7.5495 kJ/(kg*K)	P4 = 6 kPa	P5 = 6 kPa	h6 = h5 + v5*(P6 - P5) h6 = 161.59 kJ/(kg*K)
T1 = 600 C	P2 = P3 P2 = 15.735 bars	T3 = 500 C	x4 = 0.9	Saturated Liquid	vs = 1.0064 x 10-3 m3/kg
h1 = 3625.3 kJ/kg	h2 = 3040.5 kJ/kg	P3 = 15.735 bars	h4 = 2325.8 kJ/kg	h5 = 151.53 kJ/kg	P6 = 100 bar
s1 = 6.9029 kJ/(kg*K)		h3 = 3472.3 kJ/kg	s4 = 7.5495 kJ/(kg*K)		

Thus, the specific enthalpy of the stream at state 6 is:
161.59 kJ/(kg*K)

Answer 2 of 3:
<u>44.2 %</u>
After fixing the principle states, the thermal efficiency can be found using the relationship between the net work per unit mass of stem flow and the total heat transfer for the boiling per unit mass of steam flow.
Using the properties found for the previous question:
The net work per unit mass of stem flow is:
$W_{cycle}/m = Wt/m – Wp/m$
$W_{cycle}/m = (h1 – h2) + (h3 – h4) – (h6 – h5)$
$W_{cycle}/m = (3625.3-3040.5)+(3472.3-2325.8)-(10.06)$
$W_{cycle}/m = 1721.2$ kJ/kg
The total heat transfer for the boiling per unit mass of steam flow:
$Q_{in}/m = (h1 – h6) + (h3 – h2)$
$Q_{in}/m = (3625.3-161.59)+(3472.3-3040.5)$
$Q_{in}/m = 3895.5$ kJ/kg
The thermal efficiency is:
$n = \underline{W_{cycle}/m} = \underline{1721.2} = 0.442$

Q_{in}/m 3895.5

n = 44.2 %

Problem 4

Answer 1 of 4:

Fixing 2 properties of a system allows the state to be completely specified.

The following things are known about this system:

1. State 1 is given.
2. State 2 can be calculated since P2 = 7 bar and s2 = s1.
3. State 3 is known.
4. State 4 can be calculated from P4 = 0.08 bar and saturated liquid.
5. State 5 can be calculated since the pressure is known, and using the pump equation to find the enthalpy.
6. State 6 is fixed by P6 = 7 bar and saturated liquid.
7. State 7 can be determined from the given pressure and the pump equation.

Once all the properties are specified, the following table can be generated:

State 1	**State 2**	**State 3**	**State 4**
s1 = 6.6586 kJ/(kg*K)	P2 = 7 bar	h3 = 2082.9 kJ/kg	h4 = 173.88 kJ/kg
h1 = 3348.4 kJ/kg	s2 = s1		P4 = 0.08 bars
T1 = 480 C	x2 = 0.9895		v4 = 0.0010084 m3/kg
P1 = 8 MPa = 80 bar	h2 = 2741.8 kJ/kg		
State 5	**State 6**	**State 7**	
h5 = h4 + v4*(P5-P4) h5 = 174.58 kJ/kg	P6 = 7 bar Saturated Liquid	h7 = h6 + v6*(P7–P6) h7 = 705.31 bars	
	h6 = 697.22 kJ/kg	P7 = 80 bars	
	v6 = 0.001108 m3/kg		

Next, finding the fraction of flow extracted at location 2 by applying mass and energy balances to the open heater control volume:

$$y = \frac{(h6 - h5)}{(h2 - h5)} = \frac{(697.22 - 174.58)\ \text{kJ/kg}}{(2741.8 - 174.58)\ \text{kJ/kg}} = 0.2036$$

Answer 2 of 4:

<u>235000 kW</u>

Using the properties found in the previous question, along with the fraction of flow extracted, it is necessary to find the mass transfer rate to achieve a solution. Once a

mass transfer rate has been determined, the heat transfer rate may be found using an energy balance.
In order to find the heat transfer rate, the mass transfer rates must first be determined. Using the specific enthalpy values and the fraction of flow extracted found for the previous problem:
Wt/m = energy change in turbine 1 + energy change in turbine 2
Wt/m = (h1 - h2) + fraction of flow going to turbine 2 * (h2 - h3)
Wt/m = (h1 – h2) + (1 – y)*(h2 – h3) = 1131.3 kJ/kg
An energy balance on the pumps yields:
Wp1/m = h7 - h6
Wp2/m = (1-y)*(h5 - h4)
Thus the total pump work is:
Wp/m = Wp2/m + Wp1/m
Wp/m = (1 – y)*(h5 – h4) + (h7 – h6) = 8.65 kJ/kg
Using a net power output of 100 MW:
m = Wcycle/(Wt/m – Wp/m) = (100000 kW)/(1131.3 kJ/kg – 8.65 kJ/kW) = 89.07 kg/s
The heat transfer rate can then be determined:
Qin = m*(h1 – h7) = (89.07 kg/s)*(3348.4 – 705.31)(kJ/kg)*(1 kW / 1 kJ/s) = 235000 kW

Answer 3 of 4:
42.5 %
Use the equation for thermal efficiency that relates the net power output of the cycle to the heat transfer. All needed information for the formula should have been found in order to answer the two previous questions.
Using a net power output of 100 MW (given in the problem statement) and a heat transfer rate of 235000 (found in the previous question):

$$n = \frac{Wcycle/m}{Qin/m} = \frac{100000}{235000} = 0.425$$

n = 42.5 %

Answer 4 of 4:
5825000 kg/h
Note that the cooling water only cools the mass that is not extracted from the flow at point 2. Also, note that the cooling water will be saturated water at all points throughout the process.
The mass of the cooling water can be determined by:

$$m_{cw} = (1-y)^* \frac{m * (h3 - h4)}{(h_{cwout} - h_{cwin})}$$

Because the cooling water is saturated water at all points during the process, the specific enthalpy or the cooling water is the saturated liquid enthalpy at the respective temperature values.
$h_{cwout} = h|_{35\ C} = 146.68$ kJ/kg
$h_{cwin} = h|_{15\ C} = 62.99$ kJ/kg
Using the mass flow rate found in the previous question (89.07 kg/s):

m_{cw} = (0.7964)*(89.07 kg/s)*(2082.9-173.88 kJ/kg)*(3600 s / 1 h) / (146.68-62.99 kJ/kg)

m_{cw} = 5825000 kg/h

Problem 5

Answer 1 of 4

B. 1002.5 kJ/kg

Begin by fixing and listing the properties for all of the principle states. Note the relationship that exists between the specific enthalpy of a stream with that of the stream before it, as well as the pressure and specific volume.

Fixing two properties of a system fixes the system as a whole.

The following things are known about the system:

1. State 1 is completely specified by the pressure and temperature.
2. State 2 is fixed by the given pressure and by s2s = s1. Also note that the phase of the system will be a saturated liquid-vapor mixture.
3. State 3 is also specified by the pressure and is saturated vapor.
4. State 4 is completely specified by the pressure and temperature.
5. State 5 is specified by the givn pressure and s5s = s4.

Upon calculating a ll necessary values, the following table can be generated:

State 1	**State 2**	**State 3**	**State 4**
P1 = 1000 psi	P2 = 100 psi	P3 = 100 psi	P4 = 100 psi
T1 = 800 F	s2s = s1	Saturated Vapor	T4 = 530 F
h1 = 1388.5 Btu/lb	x2s = 0.9673	h3 = 1187.8 Btu/lb	h4 = 1294.2 Btu/lb
s1 = 1.5665 Btu/(lb*R)	h2s = 1158.7 Btu/lb		s4 = 1.7234 Btu/(lb/R)
	h2 = h1 – nt1*(h1–h2s) h2 = 1186.3 Btu/lb		
State 5			
P5 = 1 psi			
s5s = s4			
x5s = 0.8620			
nt2 = 0.88			
h5s = 962.77 Btu/lb			
h5 = h4 – nt2*(h4-h5) h5 = 1002.5 Btu/lb			

Note that h5 = h4 – nt2*(h4 – h5)

Thus: h5 = 1002.5 Btu/lb

Answer 2 of 4:
In addition to the fixing and listing of the properties of the principle states, it is also crucial to know the mass flow ratios, y' and y", which may be found using mass rate balances on the flash chamber and the heat exchanger.
Fixing and listing all of the properties of the remaining principle states:

State 1	State 2	State 3	State 4
P1 = 1000 psi	P2 = 100 psi	P3 = 100 psi	P4 = 100 psi
T1 = 800 F	s2s = s1	Saturated Vapor	T4 = 530 F
h1 = 1388.5 Btu/lb	x2s = 0.9673	h3 = 1187.8 Btu/lb	h4 = 1294.2 Btu/lb
s1 = 1.5665 Btu/(lb*R)	h2s = 1158.7 Btu/lb		s4 = 1.7234 Btu/(lb/R)
	h2 = h1 – nt1*(h1 – h2s) h2 = 1186.3 Btu/lb		
State 5	**State 6**	**State 7**	**State 8**
P5 = 1 psi	P6 = 1 psi	P7 = 100 psi	P8 = 100 psi
s5s = s4	Saturated Vapor	h7 = h6 + v6*(P7-P6) h7 = 70.04 Btu/lb	Saturated Liquid
x5s = 0.8620	v6 = 0.01614 ft3/lb		h8 = 542.4 Btu/lb
nt2 = 0.88	h6 = 69.74 Btu/lb		
h5s = 962.77 Btu/lb			
h5 = h4 – nt2*(h4-h5) h5 = 1002.5 Btu/lb			
State 9	**State 10**	**State 11**	
Throttling Process	P10 = 100 psi	To be Determined in Analysis	
h9 = h8 h9 = 542.4 Btu/lb	Saturated Liquid		
	h10 = 298.6 Btu/lb		

The mass flow ratios (y' and y") are found using mass rate balances on the flash chamber and heat exchanger:
(1 – y')*h2 = y" * h3 + (1 – y' – y")*h10
y' * (h1 – h8) + y" * (h3 – h4) = 0
Solving this set of simultaneous equations using substitution and using the specific enthalpy values listed above:
y' = 0.8866
y" = 7.952
The power outputs and requirements of the turbines and pumps, respectively, are:
Wt1/m1 = (1 – y") * (h1 – h2)   and   Wt2/m2 = y" * (h4 – h5)
Wp1/m1 = y" * (h7 – h6)   and   Wp2/m2 = (h12 – h11)

where h11 is found by the energy balance on the open feedwater heater:
(1 – y' – y")*h10 + y'*h9 + y"*h7 = h11 = 123.1 Btu/lb
Thus, it can be found that T11 = 155 F and v11 = 0.01637 ft3/lb.
This information, along with specific enthalpy and pressures already found, can be used to find h12
h12 = h11 + v11*(P12 – P11)
h12 = 125.83 Btu/lb
Thus the mass flow rate can be found:
m1 = Wcycle/(Wt1/m1 + Wt2/m2 – Wp1/m1 – Wp2/m2)
Inserting the relevant values yields:
m1 = 1.148 x 10^7 lb/h

Answer 3 of 4:
34.5 %
In addition to using the formula for the thermal efficiency of a cycle, note the relationship between the total heat input, mass, and specific enthalpy.
Using the properties of the principle states, as found for the previous two questions, and a net power output of 5 x 109 Btu/h, the thermal efficiency is:
n = Wcycle/Qin
n = Wcycle/[m1*(h1 – h12)]
n = (5 x 10^9 Btu/h)/[1.148 x 10^7 lb/h * (1388.5 – 125.83 Btu/lb)
n = 0.345
n = 34.5 %

Answer 4 of 4:
9.494 x 10^9 Btu/h
In addition to the properties of the principle streams, mass ratio for the condenser is required. Then use energy balances.
The heat transfer rate may be found using the relationship:
Qin = m1*y"*(h5 – h6)
Using the mass found in the previous question:
Qin = (1.148 x 10^7 lb/h)*(0.8866)*(1002.5 – 69.74 Btu/lb)
Qin = 9.494 x 10^9 Btu/h

Problem 6
C. 5.75
Answer 1 of 3:
After listing the properties of each stream, use the relevant stream properties with the formula for the coefficient of performance.
Fixing and listing the properties of the principle streams:

State 1	**State 2**	**State 3**	**State 4**
T1 = - 10 C	P2 = Psat@28 C *****	T2 = 28 C	Throttling Process
Saturated Vapor	P2 = 7.2675 bar	Saturated Liquid	h4 = h3

h1 = 241.35 kJ/kg	s2 = s1 **	h3 = 88.61 kJ/kg	h4 = 88.61 kJ/kg
s1 = 0.9253 kJ/(kg*K)	h2 = 267.9 kJ/kg		

* = P2 = P3; P3 is saturated liquid at 28 C; hence P2 = Psat@28 C
** = s2 = s1 since compressor is isentropic
The coefficient of performance is:
Beta = (h1 – h4) / (h2 = h1)
Substituting the relevant specific enthalpies, the result is:
Beta = 5.75

Answer 2 of 3:
<u>2.212 kW</u>
Begin by fixing and listing the properties of each state. Then construct an energy balance to determine the power fo the compressor. Recall the relationship between power and work.
The compressor power is found by:
Wc = m*(h2 – h1)
Using a mass flow rate of 5 kg/min:
Wc = (5 kg/min)*(1 min/60s)*(267.9 kJ/kg – 241.35 kJ/kg)*(1 kW / 1 kJ/s)
Wc = 2.212 kW

Answer 3 of 3:
3.62 tons
A conversion factor from kJ/min to tons will need to be found and used.
The refrigeration capacity can be found by:
Qin = m*(h1 – h4)
Using a mass of 5 kg/min:
Qin = (5 kg/min)*(241.35 kJ/kg – 88.61 kJ/kg)*(1 ton / 211 kJ/min)
Qin = 3.62 tons

Problem 7
Answer 1 of 3:
<u>D. 3.212</u>
Begin by fixing and listing the properties of the principle streams for the process. Then use the formula for the coefficient of performance.
Calculating the properties of the principal states:
Since P1 = 1.6 bar and is saturated vaopr, the other properties may be determined:
h1 = 237.97 kJ/kg
s1 = 0.9295 kJ/(kg*K)
h2s can be found to be:
h2s = 273.73 kJ/kg
Since we know the efficiency, we can find h2:
h2 = h1 + (h2s – h1)/n
h2 = 282.67 kJ/kg

Then, knowing h2, we can find s2.
s2 = 0.9576 kJ/(kg*K)
Additionally, state 3 is completely specified by the temperature and pressure, and state 4 can be determined as it is a throttling process so h3 = h4 and it is a saturated liquid-vapor mixture, it can be found that for states three and four:

State 3:	State 4:
P3 = 9 bar	Throttling process
T3 = 32 C	h4 = h3
h3 = 94.39 kJ/kg	h4 = 94.39 kJ/kg
s3 = 0.3490 kJ/(kg*K)	x4 = 0.31034
	s4 = 0.37198 kJ/(kg*K)

The coefficient of performance is found by:
Beta = (h1 – h4) / (h2 – h1)
Beta = 3.212

Answer 2 of 3:
<u>3.725 kW</u>
Begin by fixing and listing the properties of the principle streams for the process. Use the properties of the principle states in the energy balance, along with the necessary conversion factors, to find the compressor power.
The compressor power can be found by:
Wc = m*(h2 – h1)
Substituting the relevant specific enthalpy values and using a mass of 5 kg/min:
Wc = 3.725 kW

Answer 3 of 3:
<u>3.402 tons</u>
Use the properties of the principle states in and energy balance to find the refrigeration capacity. A conversion factor from kJ/min to tons will need to be found and used.
The refrigeration capacity can be found by:
Qin = m*(h1 – h4)
Using a mass of 5 kg/min:
Qin = (5 kg/min)*(237.97 kJ/kg – 94.39 kJ/kg)*(1 ton / 211 kJ/min)
Qin = 3.402 tons

Problem 8
Answer 1 of 3:
<u>A. 118.64 Btu/lb</u>
Fixing and listing the properties of the principle streams:

State 1	**State 2**	**State 3**	**State 4**
T = -20 F	P2 = 180 psi	P3 = 180 psi	P4 = 180 psi
Saturated Vapor	s2 = s1	Saturated liquid	T = 40 F
h1 = 102.50 Btu/lb	h2 = 124.23 Btu/lb	h3 = 35.95 Btu/lb	Subcooled liquid

s1 = 0.2334 Btu/(lb*R)			h4 = 21.66 Btu/h
State 5	**State 6**	**State 7**	**State 8**
Throttling process	Throttling process	T7 = 20 F	P8 = 180 psi
h5 = h4	h6 = h3	Saturated vapor	s8 = s7
h5 = 21.66 Btu/h	h6 = 35.95 Btu/lb	h7 = 106.45 Btu/lb	h8 = 118.64 Btu/lb
		s7 = 0.2240 Btu/lb	

Thus the specific enthalpy of stream 8 is 118.64 Btu/lb.

Answer 2 of 3:
26.452 lb/min
Begin by listing the properties of the each stream. Then construct mass balances on the system (also, possibly energy balances). In order to define the mass flow rate of stream 7, you will first need to determine the mass flow rate into the other compressor, of stream 1.
To begin with, determine the mass flow rate of stream 1, entering the main compressor, by using the evaporator capacity (for this example: 50 tons) and the enthalpy values obtained for the previous question:
Qin = m1*(h1 – h5)
m1 = Qin/(h1 – h5)

$$m1 = \frac{50 \text{ tons}}{(102.5 - 21.66 \text{ Btu/lb})} * (211 \text{ Btu/min} / 1 \text{ ton})$$

m1 = 130.50 lb/min

The mass flow rate of stream 7 is found by analyzing the counterflow heat exchanger:
0 = m1*(h3 – h4) + m7*(h6 – h7)

$$m7 = m1 * \frac{(h4 - h3)}{(h6 - h7)}$$

$$m7 = (130.53 \text{ lb/min}) * \frac{(21.66 - 35.95 \text{ Btu/lb})}{(35.95 - 106.45 \text{ Btu/lb})}$$

m7 = 26.452 lb/min

Answer 3 of 3:
3.34
In order to find the coefficient of performance, use the formula provided in the text. Note that the formula in the text requires, among other things, that you know the total work input to the compressors. Thus you will need to find the work requirement for each compressor.
The coefficient of performance for this process may be found using the relationship:
Beta = Qin/(Wc1 + Wc2)
The work input required for the first compressor, Wc1, using the mass flow rate found in the previous question:

Wc1 = m1*(h2 – h1)
Wc1 = (130.50 lb/min)*(124.23 – 102.50 Btu/lb)
Wc1 = 2835.765 Btu/min
The work input required for the second compressor, Wc2, using the mass flow rate found in the previous question:
Wc2 = m7*(h8 – h7)
Wc2 = (26.452 lb/min)*(118.64 – 106.45 Btu/lb)
Wc2 = 322.450 Btu/min
Thus, the coefficient of performance is:

$$\text{Beta} = \frac{50 \text{ tons}}{(2835.765 + 322.450 \text{ Btu/min})} * (211 \text{ Btu/min} / 1 \text{ ton})$$

Beta = 3.34