Thermodynamics: Homework A – Set 6 -Answers
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Problem 1
Answer 1 of 4:
<u>D. 2676.2 kJ/kg</u>
Begin by listing the properties of the principal states. Then use that information to find the required information in the thermodynamic property tables. Note that you are given both a pressure and temperature for point 3.

Fixing and listing the properties of the principle states:

State 1	**State 2**	**State 3**
P1 = 2 MPa	P2 = 1.5 MPa	P3 = 100 kPa
T1 = 400 C	T2 = 201.76 C	T3 = 100 C
h1 = 3247.6 kJ/kg	h2 = 3247.6 kJ/kg	h3 = ?
s1 = 7.1271 kJ/(kg*K)	s2 = 7.2564 kJ/(kg*K)	

Since pressure and temperature are specified for state 3 enthalpy can simply be read from the tables.
Thus h3 = 2676.2 kJ/kg

Answer 2 of 4:
After listing the properties of the principal streams, perform a mass and energy balance on the turbine. Note the units of the answer.
Fixing and listing the properties of the principle states:

State 1	**State 2**	**State 3**
P1 = 2 MPa	P2 = 1.5 MPa	P3 = 100 kPa
T1 = 400 C	T2 = 201.76 C	T3 = 100 C
h1 = 3247.6 kJ/kg	h2 = 3247.6 kJ/kg	h3 = 2676.2 kJ/kg
s1 = 7.1271 kJ/(kg*K)	s2 = 7.2564 kJ/(kg*K)	

The energy balance on the turbine is:
m*h2 – W – m*h3 = 0
Rearranging, and using a mass flow rate of 100 kg/s:
W = m*(h2 – h3)
W = (100 kg/s)*(3247.6 – 2676.2 kJ/kg)
W = (57140 kJ/s)*(1 MW / 1000 kJ/s)
W = 57.14 MW

Answer 3 of 4:
<u>93.93 %</u>
For the isentropic analysis, the specific enthalpy of stream 3 is a function of the pressure of that stream and the entropy of the previous stream. Thus:
h3is = 2639.3 kJ/kg
Using the new h3is value in the energy balance on the turbine, along with a mass flow rate of 100 kg/s:
m*h2 – Wis – m*h3is = 0
Rearranging:
Wis = m*(h2 – h3is)
Wis = (100 kg/s)*(3247.6 – 2639.3 kJ/kg)*(1 MW/ 1000 kJ/s)
Wis = 60.83 MW
Thus the turbine efficiency is:
n = W/Wis
n = (57.14/60.83)*100%
n = 93.93 %

Answer 4 of 4:
<u>0.15 MPa</u>
Note that for an adiabatic turbine, Q = 0. Begin by constructing mass and energy balances on the turbine, assuming isentropic conditions. Then find the enthalpy by solving the energy balance. Finally, the pressure may be found by using the obtained properties and the thermodynamic property tables.
An energy balance yields:
m*h2 – W – m*h3 = 0
Solving for h3:
h3 = h2 – W/m
h3 = 3247.6 kJ/kg – (57140 kW / 100 kg/s) * (1 kJ/s / 1 kW)
h3 = 2676.2 kJ/kg
Since the turbine would be reversible it would be isentropic and thus s2 = s3. Knowing s2 and h3 the superheated thermodynamic property tables can be consulted to find:
P3 = 0.15 MPa

Problem 2
<u>E. 25.56^{o}C</u>
Answer 1 of 3:
Begin by listing the properties of each point. Note that the outlet pressure is given. Also, note that a minimum of work is done when the internal energy of the second state is at a minimum. This might be one approach to solve the problem (i.e. make an assumption).
We know that:
1. State 1 is completely specified by the Temperature and Pressure; thus it can be determined that:
u1 = 225.13 kJ/kg

h1 = 248.15 kJ/kg
s1 = 0.9330 kJ/(kg*K)

2. State 2 is partially specified by the given temperature. Assuming that the minimum work will be done if the compressor operated isentropically, s1 = s2s and thus the system can be specified for isentropic conditions.

Using the fact that s1 = s2s it is notable that the value of s2s implies that state 2 is a saturated liquid-vapor mixture.

Thus interpolation may be used to find the temperature using the entropy values of state 2:

$$\frac{0.9330 - 0.9315}{0.9448 - 0.9315} = \frac{T_{2s} - 25\ °C}{30\ °C - 25\ °C}$$

T_{2s} = 25.56 °C

Answer 2 of 3:

-13 kW

Using the property values found for the previous question, and performing the mass, energy, and entropy balances…

Mass Balance: m1 = m2 = m

Energy Balance: $-W_{is} = m*(u_{2s} - u1)$ (Note that the negative merely indicates that work must be input)

Entropy Balance: s2 – s1 $\geq$ 0

…the minimum work is achieved when the system operates isentropically, i.e. when s1 = s2s. Note that the value of s2s at the given outlet pressure indicates that the system is a saturated liquid-vapor mixture. Thus the value of u_{2s} (u2 for isentropic case) can be found by interpolation:

$$\frac{0.9330 - 0.9315}{0.9448 - 0.9315} = \frac{u_{2s} - 237.76}{241.04 - 237.76}$$

u_{2s} = 238.13 kJ/kg

Using a mass flow rate of 1 kg/s:

$-W_{is}$ = (1 kg/s)*(238.13 kJ/kg – 225.13 kJ/kg)

$-W_{is}$ = 13 kJ/s

Noting that 1 kJ/s = 1 kW

W_{is} = -13 kW

Answer 3 of 3:

50.06 %

Note that for efficiency you will need the isentropic work and the actual work. Determine h2 from the tables and then use an energy balance. Calculate the actual work using the newly given outlet conditions.

It is most convenient to use the formula for compressor efficiency of the form:

$n = [(W_{is}/m) / (W_{act}/m)] * 100\ \%$

OR

$n = (W_{is} / W_{act}) * 100\%$

You already know the isentropic work from the previous question; we will assume it to be 13 kW.
Hence the actual work is required.
At an exit pressure of 8 bar and an exit temperature of 40 C, the refrigerant is superheated. Thus h2 can be easily found from the tables:
h2 = 274.42 kJ/kg
Performing an energy balance and assuming a mass flow rate of 1 kg/s yields:
$W_{act} = m * (h1 – h2)$
W_{act} = (1 kg/s) * (248.45 kJ/kg – 274.42 kJ/kg)
W_{act} = - 25.97 kJ/s
Note that the negative only indicates that work must be input. Also note that 1 kJ/s = 1 kW.
$n = W_{is} / W_{act}$
n = 13 / 25.97
n = 50.06 %

Problem 3
Answer 1 of 3:
<u>3169.2 kJ/kg</u>
State 4 is completely specified by the given temperature of 360 C and the given pressure of 1.5 MPa. Thus the thermodynamic property tables can be consulted to find the value of specific enthalpy:
3169.2 kJ/kg

Answer 2 of 3:
<u>2873 kJ/s</u>
Fixing two properties of a system fixes all properties of the system as a whole. We know the following information for this system:
1. State 1 is completely specified by the temperature of 600 C and a pressure of 24 MPa. Thus all other properties may be determined. s1 is 6.36 kJ/(kg*S).
2. States 2 and 3 are the same (except for the mass flow rates). They are specified by the given pressure of 1.5 MPa. But states two and three are not yet completely specified.
3. State 4 is completely specified by the given pressure of 1.5 MPa and temperature of 360 C. Thus all other properties may be determined.
4. State 5 has a given pressure of 30 kPa.
In order to find the rate of heat transfer in the interstage heater, it is necessary to find the specific enthalpy of state 2 (or state 3 since they are equal). This must be done by first performing an energy balance on the first turbine under reversible (isentropic) conditions.
m1*h1 - W1is – m1*h2s = 0
s2 = s1 (Note: 2-phase region! Since s2 = s1, and at P2 s2 is between sf and sg)
s2 = (1 – x2s)*sf2s + x2s*sg2s
$x2s = \underline{s2 - sf2s} = \underline{6.36 - 2.2838} = 0.974$

sg2s – sf2s   6.4685 – 2.2838

h2s = (1 – x2s)*hf2s + x2s*hgs
h2s = (1 – 0.974)*(830.2 kJ/kg) + (0.974)*(2789.6 kJ/kg)
h2s = 2738.65 kJ/kg
-W1is = m1*(h2s – h1)
-W1is = (12 kg/s)*(2738.65 kJ/kg – 3500 kJ/kg)
W1is = 9136.13 kJ/s
Using an efficiency of 80 %:
W1act = n*W1is
W1act = (0.80)*(9136.13 kJ/s)
W1act = 7308.9 kJ/s
Actual Energy Balance:
m1*h1 - W1act – m1*h2 = 0
h2 = (h1 - W1act)/m1
h2 = 2890.9 kJ/kg
Energy Balance for interstage cooler:
m3*h2 + Q – m4*h4 = 0
Note: m3 = m4, h2 = h3, h4 is known because state 4 is completely specified.
Q = m3*(h4 – h2) = (10 kg/s)*(3169.2 kJ/kg – 2890.9 kJ/kg) = 2873 kJ/s

Answer 3 of 3:
It is already known from the previous problem that when using an efficiency of 80 %, the actual work for the first stage is -7308.9 kJ/s.
An isentropic energy balance on the second stage yields:
m4*h4 - W2is – m5*h5s = 0
m4 = m5
s4 = s5 = 7.136 kJ/(g*K)   (Note: 2-phase region!)

$$x5s = \frac{s5 - sf5s}{sg5s - sf5s} = \frac{7.136 - 0.9439}{7.7686 - 0.9439} = 0.907$$

h5s = (1 – x5s)*hf5s + x5s*hg5s
h5s = (1 – 0.907)*(289.23 kJ/kg) + (0.907)*(2625.3 kJ/kg)
h5s = 2408.05 kJ/kg
W2is = 7410 kJ/s
Using an efficiency of 80 %:
W2act = n * W2is = (0.80)*(7410 kJ/s) = 5928 kJ/s
Thus the total power for the two-stage turbine is:
W = W1act + W2act
W = 7308.9 kJ/s + 5928 kJ/s
W = 13237 kJ/s
W = 13237 kW
W = 13.237 MW

Problem 4

Answer 1 of 1:

<u>No</u>

Using the given information and values garnered from the thermodynamic property tables:

h2 = 153.9 kJ/kg h3 = 618.2 kJ/kg

s2 = 0.5285 kJ/(kg*K) s3 = 1.8085 kJ/(kg*K)

h1 = (0.1)*(720.7 kJ/kg) + (0.9)*(2768.7 kJ/kg) = 2563.9 kJ/kg

s1 = (0.1)*(2.0451 kJ/(kg*K)) + (0.9)*(6.6620 kJ/(kg*K)) = 6.2003 kJ/(kg*K)

The energy balance yields:

m1*h1 + m2*h2 – m3*h3 = 0

The mass balance provides:

m1 + m2 – m3 = 0

Substitution and solution of the simultaneous equations gives:

m1 = 1.6147 kg/s

m2 = 0.3853 kg/s

Finally, an entropy balance indicates:

m1*s1 + m2*s2 – m3*s3 + s(v) = 0

s(v) = 2*1.085 - 1.6147*0.5285 – 0.3853*6.2003 = -1.0723 kJ/(kg*K)

Thus, it IS NOT possible

Problem 5

Answer 1 of 2:

<u>A. 259.13 kJ/kg</u>

Given the temperature of 100 C and a quality of 1.0 (saturated vapor) the thermodynamic property tables indicate that the specific enthalpy of the stream at point 3 is:

h1 = 259.13 kJ/kg

Answer 2 of 2:

<u>4.247 kg/s</u>

Begin by listing the properties at each point. Then use the R-134a property tables to determine the unknown properties. Then construct isentropic energy balances on the compressor and the turbine. Using the isentropic energy balances on the compressor and turbine, use the given efficiencies to calculate the actual power outputs/inputs.

For the turbine:

Isentropic energy balance: m3*h3 - Wtis – m3*h4s = 0 , -Wtis = m1*(h4s – h3)

Isentropic implies s3 = s4 = 0.8117; Note that s4 would be a liquid-vapor mixture!

$$x4s = \frac{s4 - sf4s}{sg4s - sf4s} = \frac{0.8117 - 0.3838}{0.9043 - 0.3838} = 0.8221$$

h4s = (1-x4s)*hf4s + x4s*hg4s

h4s = (1 – 0.8221)*(105.29) + (0.8221)*(267.97) = 239.03 kJ/kg

-Wtis/m3 = (239.03 – 259.13 kJ/kg) = -20.10 kJ/kg

So Wtis/m3 = 20.10 kJ/kg

Using a turbine efficiency of 70%:
Wtact/m3 = (Wtis/m3)*n = (20.10*/0.70) = 14.07 kJ/kg
Actual energy balance: m3*h3 - Wtact – m3*h4 = 0
Rearranging: h4 = h3 - (Wtact/m3)/m3 = 259.13 - 14.07 = 245.06 kJ/kg
For the compressor:
Isentropic energy balance: m1*h1 - Wcis – m1*h2s = 0, -Wcis = m1*(h2s – h1)
Isentropic implies that s1=s2; Note that at the given pressure this is superheated vapor!
h2s can thus be found using interpolation:

$$h2s = \frac{0.9332 - 0.9066}{0.9428 - 0.9066} = \frac{h4s - 268.68}{280.19 - 268.68} = 277.14 \text{ kJ/kg}$$

-Wcis/m1 = (277.14 – 235.31) = 41.83
Using a compressor efficiency of 70%:
-Wcact/m1 = -Wcis/m1/n = 41.83/0.70 = 59.757
So Wcact/m1 = -59.757
Note that the problem statement indicated that the work needed by the compressor was exactly equal to the work output by the turbine!
Wcact/m1 + Wtact/m3 = 0
-Wcact/m1 = Wtact/m3
-Wcact/Wtact = m3/m1
m3/m1 = -(-59.757)/14.07
m3/m1 = 4.247 kg/s

Problem 6
Answer 1 of 1:
D. No, -0.6971 kJ/(kg*K)
To begin with, the initial state can be completely specified:
Ti = 100 C
xi = 0.70 (saturated liquid-vapor mixture!)
Pi = 3.97 MPa
si = (1 – xi)*sfi + xi*sgi =   (0.3*0.674)   +   (0.7*0.722) = 0.7076 kJ/(kg*K)
A general energy balance for the system yields:
Q - W = Uf - Ui
It is claimed that:
Q = 220 kJ
and
W = 80 kJ
Thus:
Uf – Ui = 220 – 80 = 140 kJ
in order for the claim to be valid.
Consulting the tables and using given information, the specific enthalpies can be obtained:
ui = 239.5
uf = 253.3

Since Pf and uf are now known, the final state is now completely specified. Thus we can find the final entropy using interpolation in the tables:
sf = 0.0105
Determining the change in entropy:
sf – si = 0.0105 – 0.7076 = -0.6971
-0.6971 < 0
Thus, the negative entropy indicates that this process may not be possible!

Problem 7
Answer 1 of 3:
D. 518.61 Btu/lbm
Begin by listing the properties of the initial and final states of the system. Note that the initial temperature and pressure are given; thus the initial state is completely specified and thus the other properties may be determined using the thermodynamic property tables.
Given the initial temperature of 1590 °F, it is necessary to change the temperature to Rankine.
Looking in the tables for a listing for 2050 °R, it is found that hi = 518.61 Btu/lbm.

Answer 2 of 3:
95.064 hp
An energy balance yields:
W = m*(h1 – h2)
Using the Ideal Gas relationship:

$$\frac{T2}{T1} = \left(\frac{P2}{P1}\right)^{\frac{k-1}{k}}$$

Assuming an isentropic process, and using a k value of 1.330 obtained from the property tables:
T2s = 2050 * $(15/40)^{(0.330/1.330)}$
T2s = 1607.17 R = 1147.5 F
T2s can then be used to find h2s by interpolation:

$$\frac{1607.17 - 1600}{1650 - 1600} = \frac{h2s - 395.74}{409.13 - 395.74}$$

h2s = 397.66 Btu/lbm
Wis = m*(h1 – h2s)
Using a mass flow rate of 2500 lbm/h:
Wis = (2500 lbm/h)*(518.614 – 397.66 Btu/lbm)
Wis = 302375 Btu/h
Converting to hp:
Wis = 302375 Btu/h * (1 hp / 2544.5 Btu/h)
Wis = 118.83 hp

Wact = n*Wis
Wact = 0.80*(118.83 hp)
Wact = 95.064 hp

Answer 3 of 3:
<u>1237.6 °F</u>
The actual energy balance yields:
Wact = m*(h1 – h2)
Rearranging:
h2 = h1 – Wact/m
Note that Wact will need to have units of Btu/h!
Wact = 95.064 * (2544.5 Btu/h / 1 hp) = 241890 Btu/h
h2 = 518.61 Btu/lbm – (241890 Btu/h)/(2500 lbm/h)
h2 = 421.854 Btu/lbm
Interpolation can then be used in the tables to find the temperature:

$$\frac{T2 - 1650}{1700 - 1650} = \frac{421.854 - 409.13}{422.59 - 409.13}$$

T2 = 1697.27 °R
T2 = 1237.6 °F

Problem 8
Answer 1 of 2:
<u>None of the above</u>
The correct pressure for the initial state of the system is given as 1 atm, which is equivalent to 14.696 psia. Thus the correct choice is: None of the above.

Answer 2 of 2:
<u>-64.7 hp</u>
Begin by listing the properties of all states for the system. Construct mass and energy balances on the system. Use the relationship between specific enthalpy and Cp. In addition to using the relationship between specific enthalpy and Cp, it is also necessary to find the isentropic work first.
An energy balance yields:
W = m*(h2 – h1)
Cp is related to specific enthalpy by:

$$h2 - h1 = \int_{T1}^{T2} Cp\,dT$$

Assuming an isentropic process (si = sf) and assuming that ethylene oxide has Ideal Gas properties at the given temperature:
s2 – s1 = s°(T2s) - s°(T1) – R*ln(P2/P1) NOTE: this formula requires absolute temperatures! But your Cp formulas are given in degrees F!

$$0 = \int_0^{T2s} (Cp/T)dT - \int_0^{T1} (Cp/T)dT - R * \ln\left(\frac{P2}{P1}\right)$$

0 = [10.03*ln(T2s) + 0.0184*T2s] – [10.03*ln(70) + 0.0184*70] – [1.98576 * ln(250/14.696)]

49.40036903 = 10.03*ln(T2s) + 0.0184*T2s But this is with temperature in degrees F!

So:

49.40036903 = 10.03*ln(T2s + 459) + 0.0184*(T2s + 459)

Using iterative solving techniques (plug a number in and see how close it is then try another based on the first result):

T2s = -346.88 F

Now, using the relationship between Cp and specific enthalpy:

h2s - h1 = (10.03)*(-346.88 - 70) + (0.0184 / 2)*[$(-346.88)^2$ - $(70)^2$]

h2s – h1 = -2057.5 Btu/lbm

Wis = m*(h2s – h1)

Using a mass flow rate of 1 lbm/min:

Wis = (1 lbm/min)*(-2057.5 Btu/lbm)

Wis = -2057.5 Btu/min

Converting this to horsepower:

Wis = -2057.5 Btu/min * (1 hp / 42.41 Btu/min)

Wis = -48.5 hp

Wact = Wis/n

Wact = -48.5 hp / 0.75

Wact = -64.7 hp

Problem 9

Answer 1 of 2:

<u>No, heat must be input</u>

Mass Balance:

m1 = m2 + m3

Also, it is known that:

m2 = (10/11)*m1

m3 = (1/11)*m1

Energy balance:

Q = change in enthalpy of the system

Q = m2*h2 + m3*h3 – m1*h1

Q = m1*[(10/11)*h2 + (1/11)*h3 – h1)

Consulting the thermodynamic property tables the enthalpy values may be obtained:

h1 = 1167.2 Btu/lb

h2 = 1263.6 Btu/lb

h3 = 180.15 Btu/lb

Q = m1*(-2.095)

Regardless of what the mass flow rate is through the control volume, heat must be input!
Thus your friend's claims are invalid, and you really should consider not investing any money.

Answer 2 of 2:
-2.095
Mass Balance:
m1 = m2 + m3
Also, it is known that:
m2 = (10/11)*m1
m3 = (1/11)*m1
Energy balance:
Q = change in enthalpy of the system
Q = m2*h2 + m3*h3 – m1*h1
Q = m1*[(10/11)*h2 + (1/11)*h3 – h1)
Consulting the thermodynamic property tables the enthalpy values may be obtained:
h1 = 1167.2 Btu/lb
h2 = 1263.6 Btu/lb
h3 = 180.15 Btu/lb
Q = m1*(-2.095)

Q/m1 = -2.095