Thermodynamics: Homework A – Set 1 -Answers
Jennifer West (2004)

Problem 1
Answer 1 of 2:
Aswers 1 through 4 are all suitable assumptions for this problem. The control volume is assumed to operate at steady state conditions and is described as an adiabatic desuperheater, thus Q = 0. Additionally, between the inlet and exit points the change in potential and kinetic energies may be assumed to be negligible.

Steady state implies that there is no net change in processing conditions (e.g. flow rates) with respect to time. Adiabatic processes do not transfer thermal energy to or from a system and its surroundings. Potential and Kinetic energies are functions of height and velocity, respectively, and are generally measured from inlet point to exit point in control volume systems.

Answer 2 of 2:
There are two unknowns in this problem: the amount of liquid water that is entering the system and the amount of water vapor that is leaving the system. Note that what goes in must either come out or be used up in some way. There are two equations that can be generated for the problem: the energy balance equation and the mass balance equation. Other necessary information, such as specific enthalpy values of the streams, can be obtained from the tables.
An energy balance yields:
$dE_{cv}/dt = Q_{cv} – W_{cv} + \sum m_i*(h_i + ½ V_i^2 – g*z_i) - \sum m_e*(h_e + ½ V_e^2 – g*z_e)$
Ther term on the left becomes zero, as at steady-state there is no change in Energy. Also, neglect changes in PE and KE. The system is adiabatic so Q = 0 and no shaft is present so W = 0 also.
$0 = \sum m_i*(h_i) - \sum m_e*(h_e)$
$0 = m_1*h_1 + m_2*h_2 – m_3*h_3$ (1)
Note: Because of conservation of mass principle for a steady state system, which states that the amount of mass does not change in the system with respect to time, we can also use the relationship:
$m_1 + m_2 = m_3$ (2)
Thus combining (1) and (2):
$0 = m_1*h_1 + m_2*h_2 – (m_1 + m_2)*h_3$
Simplify to get:
$m_2(h_3 – h_2) = m_1*(h_1 – h_3)$
$m_2 = m_1*(h_1 – h_3) / (h_3 – h_2)$
Using the given pressures, temperature, and saturation conditions, and using a mass flow rate for the superheated vapor of 0.25 kg/s, the specific enthalpies may be found from the thermodynamic property tables:
$h_1 = h_1|_{320\ C,\ 3\ MPa,\ superheated} = 3043.4$ kJ/kg

Source URL: http://thermodynamics.eng.usf.edu/indexA.html
Saylor URL: http://www.saylor.org/courses/ME103/#4.3.6

$h_2 = h_2|_{40\ C,\ 5\ MPa,\ superheated} = 171.97$ kJ/kg
$h_3 = h_3|_{3\ MPa,\ saturated\ steam} = 2804.2$ kJ/kg
Substitution into the formulas yields:
m_2 = (0.25 kg/s)*(3043.4 kJ/kg – 2804.2 kJ/kg) / (2804.2 kJ/kg – 171.97 kJ/kg)
m_2 = 0.0227 kg/s

Problem 2
Answer 1 of 3:
In this steady state process, changes in KE and PE are negligible. Additionally, the compressor is describes as adiabatic, thus Q = 0. <u>So answers 1, 3, and 4 are all correct choices.</u>
You should be familiiar with the following concepts in order to answer this question.
Steady state implies that conditions in the process do not vary with respect to time.
Adiabatic process have Q = 0.
Isothermal Processes have contant temperature.
Additionally, kinetic and potential energy changes are usually neglected in compressors.

Answer 2 of 3:
<u>1045.12 Btu/lbm</u>
Since there are two known properties for the initial state, it is completely specified and all other properties may be detrmined. Thus you may use the information obtained from the thermodynamic property tables along with the quality equation to find the enthalpy.
At P = 10 psia, using the English system thermodynamic property tables for saturated steam:
h_f (enthalpy of saturated liquid) = 161.23 Btu/lbm
h_{fg} (enthalpy of saturated vapor - enthalpy of saturated liquid) = 982.1 Btu/lbm
$h_i = h_f + x * h_{fg}$
Assuming a quality of x = 0.90:
h_i = (161.23 Btu/lbm) + (0.9)*(982.1 Btu/lbm)
h_i = 1045.12 Btu/lbm

Answer 3 of 3:
<u>129, 018 hp</u>
Horsepower is a unit of measure for work. Thus, use mass and energy balance equations to solve for work. In the energy balance equation, make sure to cross out all terms equal to zero (or whose change is equal to zero). Also make sure to note the steady state relationship for the mass balance for this problem.
Using the hi found in the previous question of 1045.12 Btu/lbm and a mass flow rate of 500 lbm/s:
From the thermodynamic property tables, at P = 100 psia and T = 400 °F,
he = 1227.5 Btu/lbm
Also, mi = me = M = 500 lbm/s from the mass balance considerations.
Assume that KE and PE are negligible and that the process is steady-state.
First write the general energy balance equation.

dEcv/dt = Qcv – Wcv + mi*(hi + ½*Vi2 + g*zi) – me*(he + ½*Ve2 + g*ze)
Applying the assumptions stated earlier:
0 = – Wcv + mi*(hi) – me*(he)
Using the fact that mi = me = M:
Wcv = M(hi – he)
Wcv = (500 lbm/s)*(1045.12 Btu/lbm – 1227.5 Btu/lbm)
Wcv = - 91190 Btu/s
The negative simply indicates that work must be input.
A simple conversion changes Btu/s to hp.
1 hp = 0.7068 Btu/s
So the hp required for the process is:
-129, 018 hp

Problem 3
Answer 1 of 3:
A. Water enters as a saturated liquid and using this property along with the temperature listing of 180 °F, the specific enthalpy is: 147.99 Btu/lbm

Answer 2 of 3:

Note that the energy given up by the water is transferred to the air, in an equal amount, resulting in an increase in the temeprature of the air. Use the tables to determine the enthalpy changes in the water stream. Then you may use the heat capacity of air to calculate the change in enthalpy for the air. Remember that energy is neither creaed nor destroyed, it merely changes form.
Note that Q for the system is 0. Also, The total change in energy = 0. Thus:
$E_{in} = E_{out}$
$M_W*h_{Win} + M_A*h_{Ain} = M_W*h_{Wout} + M_A*h_{Aout}$
$M_W*(h_{Win} – h_{Wout}) = M_A*(h_{Aout} – h_{Ain})$
Note that the change in enthalpy can be accurately estimated by Cp(T1 – T2)
Also note that at the given temperatures, water exists as a compressed liquid.
A compressed liquid may be approximated as saturated liquid.
Finally, note that the change in degrees F is equal to the change in degrees R.
Cp for air at temperatures 40-100 F is given as 0.240 Btu/(lbm*R)
hf for water at 180 °F is 147.99 Btu/lbm.
hf for water at 160 °F is 127.96 Btu/lbm.
Using a mass flow rate for water of 40 lbm/min:
$M_W*(h_{Win} – h_{Wout}) = M_A*Cp(T2 – T1)$
(40 lbm/min)*(147.99 Btu/lbm – 127.96 Btu/lbm) = M_A*(0.240 Btu/(lbm*R))*(100 °F – 60 °F)
M_A = 83.46 lbm/min

Answer 3 of 3:
801.2 Btu/min
Choose a new control volume within the boundaries of the system so that it contains only the water. Note that heat is lost by this control volume. Also note that the lost heat is transferred to the air.
Note that the total change in energy is still = 0.
Therefore:
$E_{in} = E_{out}$
$M_W*h_{Win} = M_W*h_{Wout} + Q$
$M_W*(h_{Win} – h_{Wout}) = Q$
Again, using a mass flow rate for water of 40 lbm/min and using the previously found values for h_{Win} and h_{Wout}:
Q = (40 lbm/min)*(147.99 Btu/lbm – 127.96 Btu/lbm)
Q = 801.2 Btu/min

Problem 4
Answer 1 of 3
D. 1514.9 Btu/lbm
Note that the steam enters as superheated steam; thus you must use the superheated steam tables with the given temperature and pressure to find the requested answer.
Using the superheated steam tables:
Find the listing for the pressure of 700 psia.
Look for the row heaed by a temperature of 1000 °F.
Read off the value for specific enthalpy, h.
h = 1514.9 Btu/lbm

Answer 2 of 3:
38.6 hp
After listing all known properties for each state, write out the energy balance for the system, crossing out all unnecessary terms. Note: should you use u or h?
Note that the change in total energy is zero.
Also, KE = PE = W = 0
Therefore:
$M*(h_{out} – h_{in}) = -W$
From the superheated steam tables:
h_{out} = 1416.6 Btu/lbm
h_{in} = 1514.9 Btu/lbm
Using a mass flow rate of 1000 lbm/h:
W = - (1000 lbm/h)*(1416.6 Btu/lbm – 1514.9 Btu/lbm)
W = 98300 Btu/h = 38.6 hp

Answer 3 of 3:
The volumetric flow rate may be found using the specific volumes given in the property tables along with the given mass flow rate.

From the tables:
v_{in} = 1.816 ft^3/lbm
v_{out} = 1.204 ft^3/lbm
The volumetric flow rate can be found using:
V = v*M
Using a flow rate of 1000 lbm/hr
$V_{in} = v_{in}$*M
V_{in} = (1.816 ft^3/lbm)*(1000 lbm/h)
V_{in} = 1816 ft^3/h
$V_{out} = v_{out}$*M
V_{out} = (1.204 ft^3/lbm)*(1000 lbm/h)
V_{out} = 1204 ft^3/h
Since you want the velocities at the inlet and outlet to be the same:
V_{in}/A_{in} = velocity = V_{out}/A_{out}
Since you want the ratio of A_{out} to A_{in}:
$A_{out}/A_{in} = V_{out}/V_{in}$
A_{out}/A_{in} = 0.663
The physical significance of this is that the area of the outlet needs to be 0.663 times smaller than the inlet in order for the velocities to be the same.

Problem 5
Answer 1 of 3:
3091.75 kJ/kg
List what is known about the state and then use the known information to determine how to look up the needed information. After choosing the appropriate thermodynamic property table, simply find the listing for the enthalpy in the row with the correct heading...unless there is no row with that temperature heading. Then interpolation must be used.
Going to the tables to find the h values:
Note: h_{in} requires interpolation!

$$\frac{360\ °C - 350\ °C}{360\ °C - 320\ °C} = \frac{3117.2\ kJ/kg\ -\ h_{in}\ kJ/kg}{3117.2\ kJ/kg - 3015.4\ kJ.kg}$$

h_{in} = 3091.75 kJ/kg

Answer 2 of 3:
108 kW
Note that the total change in energy for the system is zero.
$E_{in} = E_{out}$
$M*h_{in} = M*h_{out} + W$
$M*(h_{in} - h_{out}) = W$
Going to the tables to find the h values:
h_{in} requires Interpolation!!
$\underline{360\ °C - 350\ °C} = \underline{3117.2\ kJ/kg\ -\ h_{in}\ kJ/kg}$

360 °C – 320 °C   3117.2 kJ/kg – 3015.4 kJ.kg
h_{in} = 3091.75 kJ/kg
$h_{out} = h_f + x*h_{fg}$
h_{out} = (251.40 kJ/kg) + 0.95*(2358.3 kJ/kg)
h_{out} = 2491.785 kJ/kg
Using a flow rate of 0.25 kg/s for the steam:
W = (0.25 kg/s)*(3091.75 kJ/kg – 2491.75 kJ/kg)
W = 150 kJ/s = 150 kW
NOTE: This is the total work
Work to generator = 150 kW – 42 kW
Work to generator = 108 kW

Answer 3 of 3:
<u>42.623 kJ/s</u>
After listing the properties and conditions for each state, perform mass and energy balances to solve for the required variable. Note that Nitrogen, like air, is able to have its change in specific enthalpy accurately approximated by Cp*(T2-T1).
$M*(h_{out} – h_{in}) = Q – W$
$Q = M*(h_{out} – h_{in}) + W$
Q = M*Cp*(T2-T1) + W
From the tables, Cp = 1.039 kJ/(kg*K)
Using a mass flow rate for Nitrogen of 0.04 kg/s:
Q = (0.04 kg/s)*(1.039 kJ/(kg*K))*(35 °C – 20 °C) + 42 kJ/s
Q = 42.623 kJ/s

Problem 6
Answer 1 of 2:
<u>B.</u> 589 F
Begin with listing known properties and conditions for each state. Note that throttling across a valve implies that h1 = h2 across the valve. You need only consult the thermodynamic property tables and you can easily finish this problem.
Across a throttling valve, h1 = h2. You can find h1 using the information given for point 1. The h at that point is also the h for point 2. Now you know the pressure for point 2 and the specific enthalpy. By using interpolation, you can find the temperature at point 2, which is the temperature of the inlet for the turbine.
h1 = h2 = 1322.1 Btu/lbm

$$\frac{T\ °C – 500\ °C}{600\ °C – 500\ °C} = \frac{1322.1\ Btu/lbm – 1277.1\ Btu/lbm}{1327.8\ Btu/lbm – 1277.1\ Btu/lbm}$$

T = 589 F

Answer 2 of 2:
320 Btu/lbm
Note that the mass flow rate is constant throughout.
After simplification, the balance equation can be written as:

W = M*(hin – hout)
W/M = hin – hout
hin = 1322.1 Btu/lbm (from previous section of problem)
hout = hf + x*hfg
Using a quality of 90%:
hout = 69.74 Btu/lbm + (0.90)*(1036 Btu/lbm)
hout = 1002.1 Btu/lbm
W/M = 1322.1 Btu/lbm – 1002.1 Btu/lbm
W/M = 320 Btu/lbm

Problem 7
Answer 1 of 2:
E. None of these
After determining which table is appropriate, find which heading to look under. Note: compressed liquid properties may be approximated as saturated liquid properties.
The enthalpy of stream two is for a compressed liquid, but can be approximated using the value for the saturated liquid. Thus:
$h2 = h_f|_{4\ bar}$ = 62 kJ/kg

Answer 2 of 2:
There are two unknowns and two equations (the mass and the energy balances).
M1 = M2 + M3
Thus:
M3 = M2 – M1
0 = M1*h1 – M2*h2 – M3*h3
M1*h1 – M2*h2 – (M1 – M2)*h3
Rearranging, you get:
M2 = M1*[(h1 – h3)/(h2 – h3)]
The compressed liquid properties may be approximated as saturated vapor properties at the respective temperatures or pressures.
$h1 = h_f|_{36\ C}$ = 100.25 kJ/kg
$h2 = h_f|_{4\ bar}$ = 62 kJ/kg
$h3 = h_g|_{4bar}$ = 252.32 kJ/kg
Using a mass flow rate for stream one of 482 kg/h:
M2 = (482 kg/h)*[(100.25 kJ/kg – 252.32 kJ/kg) / (62 kJ/kg – 252.32 kJ/kg)]
M2 = 385.1 kg/h