The homework is due Monday, November 14, 2016. Each problem is worth the points indicated. Copying of the solution from another is not acceptable.

(1). Multiple choice (20 points)

1a). Which statement is invalid regarding the entropy generation ($S_{gen}$)?
A). Entropy generation is always a positive quantity or zero.
B). The value of entropy generation depends on the process.
C). The value of entropy generation is zero during an internal reversible process.
D). Entropy generation is a property of a system.
E). None of the above

1b). The entropy of an isolated system increases during a process.
A). sometimes
B). always
C). never
D). may decrease
E). None of the above

1c). Which statement is invalid regarding the Clausius Inequality?
A). For any thermodynamic cycle (reversible or irreversible), $\int_{T_1}^{T_2} \frac{dQ}{T}$ is always less than or equal to zero.
B). The equality in the Clausius inequality holds for totally or just internally reversible cycles.
C). The Clausius Inequality Statement only reflects the first law of thermodynamics.
D). The Clausius Inequality Statement reflects the second law of thermodynamics.
E). None of the above

1d). Which statement is invalid regarding the entropy?
A). Entropy is a property. Like all other properties, it has a fixed value at a fixed state.
B). The entropy change of a system between two specified states is the same whether the process is reversible or irreversible.
C). On a T-S diagram, the area under the process curve represents the heat transfer for an internally reversible process.
D). Entropy is a path function; and the entropy change is dependent on the path of a process.
E). None of the above
1e). If an adiabatic compressor undergoes an internally reversible process, we can conclude
A). It obviously is not an isentropic process.
B). Entropy generation ($S_{gen}$) is greater than zero.
C). **Entropy generation** ($S_{gen}$) is zero
D). Heat may transfer from the compressor to the surrounding.
E). The change in the entropy between the initial and the final state may not be zero.

1f). Which statement is invalid?
A). **Entropy is a conserved property, and there exist a conservation of entropy principle.**
B). Processes can occur in a *certain* direction only, not in *any* direction. A process must proceed
   in the direction that complies with the increase of entropy principle.
C). Entropy generation ($S_{gen}$) is a measure of the magnitudes of the irreversibilities during a
   process.
D). Entropy may be transferred by heat transfer and mass transfer.
E). None of the above

1g). Which statement is invalid?
A). The $T$-$s$ diagram serves as a valuable tool for visualizing the second law aspects of processes
   and cycles. An isentropic process appears as a vertical line segment on a $T$-$s$ diagram.
B). The $h$-$s$ diagram is useful analysis of adiabatic steady-flow devices, such as turbines,
   compressors and nozzles. The horizontal distance $\Delta s$ is a measure of irreversibilities
   associated with the process.
C). The $h$-$s$ diagram is useful analysis of adiabatic steady-flow devices. The vertical distance $\Delta h$
   (between the inlet and the exit states) on an $h$-$s$ diagram is a measure of work.
D). From the microscopic viewpoint, entropy is a measure of molecular disorder or molecular
   randomness.
E). **According to the third law of thermodynamics, a pure crystalline substance at absolute zero temperature is in perfect order. But its entropy never is zero.**
2. An insulated rigid tank contains 10 kg water. Initially it is a saturated liquid-vapor mixture of water with a quality of 0.25 at pressure of 150 kPa. An electric heater inside is turned on and kept on until all the liquid vaporized. Determine the entropy change of the water during this process (10 points).

Solution

From the steam tables (Tables A-4 through A-6)

\[
P_1 = 100 \text{kPa} \quad v_1 = v_f + x_1 v_{fg} = 0.001 + (0.25)(1.694 - 0.001) = 0.4243 \text{m}^3/\text{kg}
\]

\[
x_1 = 0.25 \quad s_1 = s_f + x_1 s_{fg} = 1.3026 + (0.25)(6.0568) = 2.8168 \text{kJ/kg} \cdot \text{K}
\]

\[
v_2 = v_1
\]

\[
sat.vapor \quad s_2 = 6.8649 \text{kJ/kg} \cdot \text{K}
\]

Then the entropy change of the steam becomes

\[
\Delta S = m(s_2 - s_1) = (10 \text{kg})(6.8649 - 2.8168) \text{kJ/kg} \cdot \text{K} = 40.53 \text{kJ/K}
\]
3. A reversible heat pump delivers heat at a rate of 300 kJ/s to warm a house maintained at 24 °C. The exterior air, which is at 7 °C, serves as the cool reservoir (9 points).

(a) Draw a carton to illustrate the heat pump device

(b) Calculate the rate of entropy change of the hot and cool reservoirs, respectively, as well as the entire heat pump system

(c) Justify if this heat pump satisfies the increase of entropy principle

Solution

Since the heat pump is completely reversible, the combination of the coefficient of performance expression, first Law, and thermodynamic temperature scale gives

\[
\text{COP}_{HP,\text{rev}} = \frac{1}{1 - \frac{T_L}{T_H}} = \frac{1}{1 - \frac{(280 \text{ K})/(297 \text{ K})}{1}} = 17.47
\]

The power required to drive this heat pump, according to the coefficient of performance, is then

\[
\dot{W}_{\text{net, in}} = \frac{\dot{Q}_H}{\text{COP}_{HP,\text{rev}}} = \frac{300 \text{ kW}}{17.47} = 17.17 \text{ kW}
\]

According to the first law, the rate at which heat is removed from the low-temperature energy reservoir is

\[
\dot{Q}_L = \dot{Q}_H - \dot{W}_{\text{net, in}} = 300 \text{ kW} - 17.17 \text{ kW} = 282.8 \text{ kW}
\]

The rate at which the entropy of the high temperature reservoir changes, according to the definition of the entropy, is

\[
\Delta S_H = \frac{\dot{Q}_H}{T_H} = \frac{300 \text{ kW}}{297 \text{ K}} = 1.01 \text{ kW/K}
\]

and that of the low-temperature reservoir is

\[
\Delta S_L = \frac{\dot{Q}_L}{T_L} = \frac{-17.17 \text{ kW}}{280 \text{ K}} = -1.01 \text{ kW/K}
\]

The net rate of entropy change of everything in this system is

\[
\Delta S_{\text{total}} = \Delta S_H + \Delta S_L = 1.01 - 1.01 = 0 \text{ kW/K}
\]

as it must be since the heat pump is completely reversible.
4. A rubber bag initially contains 2 kg of water at 160 °C and 10 bar. It undergoes an isothermal internally reversible expansion process during which 3000 kJ is received by heat transfer (24 points).
(a) Determine the final pressure, in kPa
(b) Calculate the work done during the process, in kJ
(c) Draw a T-s diagram, and locate the initial and final states in the T-s diagram, label the temperatures and entropy at the initial and final states.

Solution
(a). for an isothermal internally reversible processes:

\[ Q = \int_1^2 TdS = m \int_1^2 Tds = mT(s_2 - s_1) \]

At T_1=160 °C and P_1=1000 kPa. It is compressed liquid, \( s_1 = s_{fg;T_1} = 1.9426 \text{ kJ/kg·K} \) and \( u_1 = 674.79 \text{ kJ/kg} \) (Table A-4).

\[ s_2 = s_1 + \frac{Q}{mT} = 1.9426 + \frac{2700}{2 \times (160 + 273)} = 5.0605 \text{ kJ/kg·K} \]

At T_2=160 °C, \( s_f < s_2 < s_g \), hence it is a mixture, \( P_2 = 618.23 \text{ kPa} \) (Table A-4).

\[ x = \frac{s_2 - s_f}{s_{fg}} = \frac{5.0605 - 1.9426}{4.8066} = 0.652 \]

\[ u_2 = u_f + x_2u_{fg} = 674.79 + 0.652 \times 1893 = 1909.14 \]

(b) from the first law:

\[ Q - W = \Delta U = m(u_2 - u_1) \]

\[ W = Q - m(u_2 - u_1) = 3000 - 2(1909.14 - 674.79) = 530.1 \text{ kJ} \]

(c) see the curve
5. An insulated piston-cylinder system is initially filled with 0.07164 m³ of steam at 300 kPa and 200 °C. The steam is now compressed in an internal reversible manner until the pressure reaches 4.5 MPa.

(a) Determine the specific entropy at the initial state (8 points)
(b) Calculate the total work input during this process, in kJ (10 points).

Solution
(a) This is an internal reversible adiabatic (i.e., isentropic) process, and thus \( s_2 = s_1 \). It is an isentropic process.
The kinetic and potential energy changes are negligible. 2 The cylinder is well-insulated and thus heat transfer is negligible. 3 The thermal energy stored in the cylinder itself is negligible. 4 The process is stated to be reversible.

Analysis This is a reversible adiabatic (i.e., isentropic) process, and thus \( s_2 = s_1 \). From the steam tables (Tables A-4 through A-6),

\[
\begin{align*}
P_1 &= 300 \text{kPa} \quad \Rightarrow v_1 = 0.71643 \text{m}^3/\text{kg} \\
T_1 &= 200 \degree \text{C} \quad \Rightarrow u_1 = 2651.0 \text{kJ/kg} \\
v_1 &= \frac{0.07164 \text{m}^3}{0.71643 \text{m}^3/\text{kg}} = 0.1 \text{kg}
\end{align*}
\]

Also,

\[
\frac{m}{v_1} = \frac{0.07164 \text{m}^3}{0.71643 \text{m}^3/\text{kg}} = 0.1 \text{kg}
\]

(b) We take the contents of the cylinder as the system. This is a closed system since no mass enters or leaves. The energy balance for this adiabatic closed system can be expressed as

\[
W_{b, \text{in}} = \Delta U = m(u_2 - u_1)
\]

Substituting, the work input during this adiabatic process is determined to be

\[
W_{b, \text{in}} = m(u_2 - u_1) = (0.1 \text{kg})(3276.4 - 2651.0) \text{kJ/kg} = 62.54 \text{kJ}
\]
6. Steam is expanded in an adiabatic turbine with a single inlet and a single outlet in an internally reversible manner. At the inlet, the steam is at 2 MPa and 360 °C. The steam pressure at the outlet is 100 kPa.

(a) Find the specific entropy and quality of water at exit? (6 points)
(b) Calculate the work per unit mass produced by the turbine (8 points).
(c) Draw a $T$-$s$ diagram, schematically locate the initial and final state in the $T$-$s$ diagram and schematically show the process (5 points).

**Solution**

(a) The inlet state properties are

\[
\begin{align*}
P_1 &= 2 \text{ MPa} \quad h_1 = 3159.9 \text{ kJ/kg} \\
T_1 &= 360^\circ \text{C} \quad s_1 = 6.9938 \text{ kJ/kg} \cdot \text{K} \\
\end{align*}
\]

For this isentropic process, the final state properties are (Table A-5)

\[
\begin{align*}
P_2 &= 100 \text{ kPa} \\
s_2 &= s_1 = 6.9938 \text{ kJ/kg} \cdot \text{K} \\
\end{align*}
\]

\[
\begin{align*}
x_2 &= \frac{s_2 - s_f}{s_{fg}} = \frac{6.9938 - 1.3028}{6.0562} = 0.9397 \\
h_2 &= h_f + x_2 h_{fg} = 417.51 + (0.9397)(2257.5) = 2538.9 \text{ kJ/kg} \\
\end{align*}
\]

(b) This is a steady-flow process. There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the turbine as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

\[
\dot{Q}_{\text{in}} + \dot{W}_{\text{in}} + \sum_{\text{in}} \dot{m} \left( h + \frac{V^2}{2} + gz \right) = \dot{Q}_{\text{out}} + \dot{W}_{\text{out}} + \sum_{\text{out}} \dot{m} \left( h + \frac{V^2}{2} + gz \right)
\]

\[
\dot{m}h_1 = \dot{m}h_2 + \dot{W}_{\text{out}}
\]

\[
\dot{W}_{\text{out}} = \dot{m}(h_1 - h_2)
\]

Substituting,

\[
w_{\text{out}} = h_1 - h_2 = (3159.9 - 2538.9) \text{ kJ/kg} = 621.0 \text{ kJ/kg}
\]

(c) See the $T$-$s$ diagram