7-184 The validity of the Clausius inequality is to be demonstrated using a reversible and an irreversible heat engine operating between the same temperature limits.

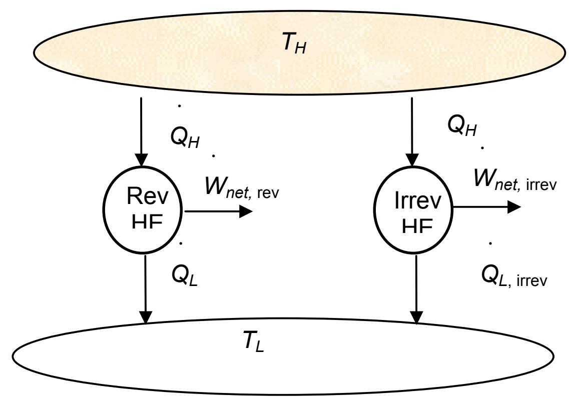
Analysis Consider two heat engines, one reversible and one irreversible, both operating between a high-temperature reservoir at T_H and a low-temperature reservoir at T_L. Both heat engines receive the same amount of heat, Q_H. The reversible heat engine rejects heat in the amount of Q_L, and the irreversible one in the amount of $Q_{L,\text{ irrev}} = Q_L + Q_{\text{diff}}$, where Q_{diff} is a positive quantity since the irreversible heat engine produces less work. Noting that Q_H and Q_L are transferred at constant temperatures of T_H and T_L, respectively, the cyclic integral of $\delta Q/T$ for the reversible and irreversible heat engine cycles become

$$\oint\left(\frac{\delta Q}{T}\right)_{\text{rev}} = \int\frac{\delta Q_H}{T_H} - \int\frac{\delta Q_L}{T_L} = \frac{1}{T_H}\int\delta Q_H - \frac{1}{T_L}\int\delta Q_L = \frac{Q_H}{T_H} - \frac{Q_L}{T_L} = 0$$

since $(Q_H/T_H) = (Q_L/T_L)$ for reversible cycles. Also,

$$\oint\left(\frac{\delta Q}{T}\right)_{\text{irrev}} = \frac{Q_H}{T_H} - \frac{Q_{L,\text{irrev}}}{T_L} = \frac{Q_H}{T_H} - \frac{Q_L}{T_L} - \frac{Q_{\text{diff}}}{T_L} = -\frac{Q_{\text{diff}}}{T_L} < 0$$

since Q_{diff} is a positive quantity. Thus, $\oint\left(\frac{\delta Q}{T}\right) \le 0$.

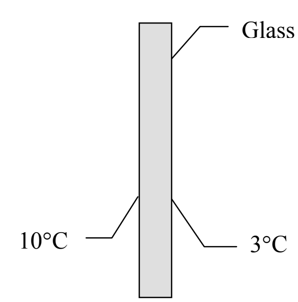


7-185 The inner and outer surfaces of a window glass are maintained at specified temperatures. The amount of heat transfer through the glass and the amount of entropy generation within the glass in 5 h are to be determined

Assumptions **1** Steady operating conditions exist since the surface temperatures of the glass remain constant at the specified values. **2** Thermal properties of the glass are constant.

Analysis The amount of heat transfer over a period of 5 h is

$$Q = \dot{Q}_{\text{cond}}\Delta t = (3.2\text{ kJ/s})(5\times 3600\text{ s}) = \mathbf{57{,}600\ \ kJ}$$



We take the glass to be the system, which is a closed system. Under steady conditions, the rate form of the entropy balance for the glass simplifies to

$$\underbrace{\dot{S}_{\text{in}} - \dot{S}_{\text{out}}}_{\substack{\text{Rate of net entropy transfer}\\\text{by heat and mass}}} + \underbrace{\dot{S}_{\text{gen}}}_{\substack{\text{Rate of entropy}\\\text{generation}}} = \underbrace{\Delta\dot{S}_{\text{system}}^{\nearrow 0}}_{\substack{\text{Rate of change}\\\text{of entropy}}} = 0$$

$$\frac{\dot{Q}_{\text{in}}}{T_{\text{b,in}}} - \frac{\dot{Q}_{\text{out}}}{T_{\text{b,out}}} + \dot{S}_{\text{gen,glass}} = 0$$

$$\frac{3200\text{ W}}{283\text{ K}} - \frac{3200\text{ W}}{276\text{ K}} + \dot{S}_{\text{gen,wall}} = 0 \quad\rightarrow\quad \dot{S}_{\text{gen,glass}} = \mathbf{0.287\ W/K}$$

7-186 Two rigid tanks that contain water at different states are connected by a valve. The valve is opened and steam flows from tank A to tank B until the pressure in tank A drops to a specified value. Tank B loses heat to the surroundings. The final temperature in each tank and the entropy generated during this process are to be determined.

Assumptions **1** Tank A is insulated, and thus heat transfer is negligible. **2** The water that remains in tank A undergoes a reversible adiabatic process. **3** The thermal energy stored in the tanks themselves is negligible. **4** The system is stationary and thus kinetic and potential energy changes are negligible. **5** There are no work interactions.

Analysis (*a*) The steam in tank A undergoes a reversible, adiabatic process, and thus $s_2 = s_1$. From the steam tables (Tables A-4 through A-6),

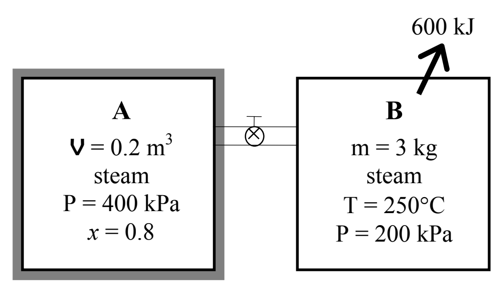
Tank A :

$$\left.\begin{array}{l} P_1 = 400 \text{ kPa} \\ x_1 = 0.8 \end{array}\right\} \begin{array}{l} \boldsymbol{v}_{1,A} = \boldsymbol{v}_f + x_1 \boldsymbol{v}_{fg} = 0.001084 + (0.8)(0.46242 - 0.001084) = 0.37015 \text{ m}^3/\text{kg} \\ u_{1,A} = u_f + x_1 u_{fg} = 604.22 + (0.8)(1948.9) = 2163.3 \text{ kJ/kg} \\ s_{1,A} = s_f + x_1 s_{fg} = 1.7765 + (0.8)(5.1191) = 5.8717 \text{ kJ/kg} \cdot \text{K} \end{array}$$

$$\left.\begin{array}{l} P_1 = 300 \text{ kPa} \\ s_2 = s_1 \\ (\text{sat. mixture}) \end{array}\right\} \begin{array}{l} T_{2,A} = T_{\text{sat@300 kPa}} = \mathbf{133.52^\circ C} \\ x_{2,A} = \dfrac{s_{2,A} - s_f}{s_{fg}} = \dfrac{5.8717 - 1.6717}{5.3200} = 0.7895 \\ \boldsymbol{v}_{2,A} = \boldsymbol{v}_f + x_{2,A} \boldsymbol{v}_{fg} = 0.001073 + (0.7895)(0.60582 - 0.001073) = 0.47850 \text{ m}^3/\text{kg} \\ u_{2,A} = u_f + x_{2,A} u_{fg} = 561.11 + (0.7895)(1982.1 \text{ kJ/kg}) = 2125.9 \text{ kJ/kg} \end{array}$$

Tank B :

$$\left.\begin{array}{l} P_1 = 200 \text{ kPa} \\ T_1 = 250^\circ\text{C} \end{array}\right\} \begin{array}{l} \boldsymbol{v}_{1,B} = 1.1989 \text{ m}^3/\text{kg} \\ u_{1,B} = 2731.4 \text{ kJ/kg} \\ s_{1,B} = 7.7100 \text{ kJ/kg} \cdot \text{K} \end{array}$$



The initial and the final masses in tank A are

$$m_{1,A} = \frac{\boldsymbol{V}_A}{\boldsymbol{v}_{1,A}} = \frac{0.2 \text{ m}^3}{0.37015 \text{ m}^3/\text{kg}} = 0.5403 \text{ kg}$$

and

$$m_{2,A} = \frac{\boldsymbol{V}_A}{\boldsymbol{v}_{2,A}} = \frac{0.2 \text{ m}^3}{0.47850 \text{ m}^3/\text{kg}} = 0.4180 \text{ kg}$$

Thus, 0.5403 - 0.4180 = 0.1223 kg of mass flows into tank B. Then,

$$m_{2,B} = m_{1,B} + 0.1223 = 3 + 0.1223 = 3.1223 \text{ kg}$$

The final specific volume of steam in tank B is determined from

$$\boldsymbol{v}_{2,B} = \frac{\boldsymbol{V}_B}{m_{2,B}} = \frac{(m_1 \boldsymbol{v}_1)_B}{m_{2,B}} = \frac{(3 \text{ kg})(1.1989 \text{ m}^3/\text{kg})}{3.1223 \text{ kg}} = 1.1519 \text{ m}^3/\text{kg}$$

We take the entire contents of both tanks as the system, which is a closed system. The energy balance for this stationary closed system can be expressed as

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$-Q_{\text{out}} = \Delta U = (\Delta U)_A + (\Delta U)_B \quad (\text{since } W = \text{KE} = \text{PE} = 0)$$

$$-Q_{\text{out}} = (m_2 u_2 - m_1 u_1)_A + (m_2 u_2 - m_1 u_1)_B$$

Substituting,

$$-600 = \{(0.418)(2125.9)-(0.5403)(2163.3)\} + \{(3.1223)u_{2,B} - (3)(2731.4)\}$$
$$u_{2,B} = 2522.0 \text{ kJ/kg}$$

Thus,

$$\left.\begin{array}{l} v_{2,B} = 1.1519 \text{ m}^3\text{/kg} \\ u_{2,B} = 2522.0 \text{ kJ/kg} \end{array}\right\} \begin{array}{l} T_{2,B} = \mathbf{113.2°C} \\ s_{2,B} = 7.2274 \text{ kJ/kg}\cdot\text{K} \end{array}$$

(*b*) The total entropy generation during this process is determined by applying the entropy balance on an *extended system* that includes both tanks and their immediate surroundings so that the boundary temperature of the extended system is the temperature of the surroundings at all times. It gives

$$\underbrace{S_{\text{in}} - S_{\text{out}}}_{\substack{\text{Net entropy transfer} \\ \text{by heat and mass}}} + \underbrace{S_{\text{gen}}}_{\substack{\text{Entropy} \\ \text{generation}}} = \underbrace{\Delta S_{\text{system}}}_{\substack{\text{Change} \\ \text{in entropy}}}$$

$$-\frac{Q_{\text{out}}}{T_{\text{b,surr}}} + S_{\text{gen}} = \Delta S_{\text{A}} + \Delta S_{\text{B}}$$

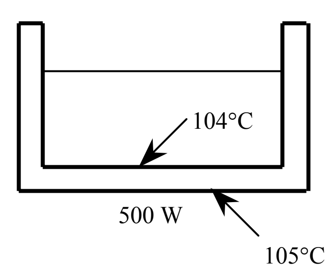
Rearranging and substituting, the total entropy generated during this process is determined to be

$$\begin{aligned} S_{\text{gen}} &= \Delta S_A + \Delta S_B + \frac{Q_{\text{out}}}{T_{\text{b,surr}}} = (m_2 s_2 - m_1 s_1)_A + (m_2 s_2 - m_1 s_1)_B + \frac{Q_{\text{out}}}{T_{\text{b,surr}}} \\ &= \{(0.418)(5.8717)-(0.5403)(5.8717)\} + \{(3.1223)(7.2274)-(3)(7.7100)\} + \frac{600 \text{ kJ}}{273 \text{ K}} \\ &= \mathbf{0.916 \text{ kJ/K}} \end{aligned}$$

7-187 Heat is transferred steadily to boiling water in a pan through its bottom. The rate of entropy generation within the bottom plate is to be determined.

Assumptions Steady operating conditions exist since the surface temperatures of the pan remain constant at the specified values.

Analysis We take the bottom of the pan to be the system, which is a closed system. Under steady conditions, the rate form of the entropy balance for this system can be expressed as



$$\underbrace{\dot{S}_{\text{in}} - \dot{S}_{\text{out}}}_{\substack{\text{Rate of net entropy transfer} \\ \text{by heat and mass}}} + \underbrace{\dot{S}_{\text{gen}}}_{\substack{\text{Rate of entropy} \\ \text{generation}}} = \underbrace{\Delta \dot{S}_{\text{system}}^{\nearrow 0}}_{\substack{\text{Rate of change} \\ \text{of entropy}}} = 0$$

$$\frac{\dot{Q}_{\text{in}}}{T_{\text{b,in}}} - \frac{\dot{Q}_{\text{out}}}{T_{\text{b,out}}} + \dot{S}_{\text{gen,system}} = 0$$

$$\frac{500 \text{ W}}{378 \text{ K}} - \frac{500 \text{ W}}{377 \text{ K}} + \dot{S}_{\text{gen,system}} = 0 \quad \rightarrow \quad \dot{S}_{\text{gen,system}} = \mathbf{0.00351 \text{ W/K}}$$

Discussion Note that there is a small temperature drop across the bottom of the pan, and thus a small amount of entropy generation.

7-188 An electric resistance heater is immersed in water. The time it will take for the electric heater to raise the water temperature to a specified temperature and the entropy generated during this process are to be determined.

Assumptions **1** Water is an incompressible substance with constant specific heats. **2** The energy stored in the container itself and the heater is negligible. **3** Heat loss from the container is negligible.

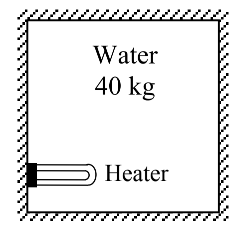
Properties The specific heat of water at room temperature is $c = 4.18$ kJ/kg·°C (Table A-3).

Analysis Taking the water in the container as the system, which is a closed system, the energy balance can be expressed as

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$W_{\text{e,in}} = (\Delta U)_{\text{water}}$$

$$\dot{W}_{\text{e,in}} \Delta t = mc(T_2 - T_1)_{\text{water}}$$



Substituting,

$$(1200 \text{ J/s})\Delta t = (40 \text{ kg})(4180 \text{ J/kg·°C})(50 - 20)\text{°C}$$

Solving for Δt gives

$$\Delta t = \mathbf{4180 \text{ s} = 69.7 \text{ min} = 1.16 \text{ h}}$$

Again we take the water in the tank to be the system. Noting that no heat or mass crosses the boundaries of this system and the energy and entropy contents of the heater are negligible, the entropy balance for it can be expressed as

$$\underbrace{S_{\text{in}} - S_{\text{out}}}_{\substack{\text{Net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{S_{\text{gen}}}_{\substack{\text{Entropy}\\ \text{generation}}} = \underbrace{\Delta S_{\text{system}}}_{\substack{\text{Change}\\ \text{in entropy}}}$$

$$0 + S_{\text{gen}} = \Delta S_{\text{water}}$$

Therefore, the entropy generated during this process is

$$S_{\text{gen}} = \Delta S_{\text{water}} = mc \ln \frac{T_2}{T_1} = (40 \text{ kg})(4.18 \text{ kJ/kg}\cdot\text{K}) \ln \frac{323 \text{ K}}{293 \text{ K}} = \mathbf{16.3 \text{ kJ/K}}$$

7-189 A hot water pipe at a specified temperature is losing heat to the surrounding air at a specified rate. The rate of entropy generation in the surrounding air due to this heat transfer are to be determined.

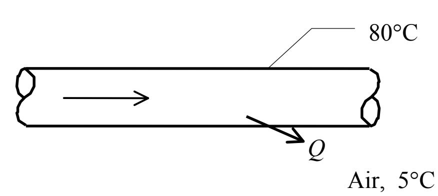
Assumptions Steady operating conditions exist.

Analysis We take the air in the vicinity of the pipe (excluding the pipe) as our system, which is a closed system.. The system extends from the outer surface of the pipe to a distance at which the temperature drops to the surroundings temperature. In steady operation, the rate form of the entropy balance for this system can be expressed as

$$\underbrace{\dot{S}_{\text{in}} - \dot{S}_{\text{out}}}_{\substack{\text{Rate of net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{\dot{S}_{\text{gen}}}_{\substack{\text{Rate of entropy}\\ \text{generation}}} = \underbrace{\Delta \dot{S}_{\text{system}}^{\nearrow 0}}_{\substack{\text{Rate of change}\\ \text{of entropy}}} = 0$$

$$\frac{\dot{Q}_{\text{in}}}{T_{\text{b,in}}} - \frac{\dot{Q}_{\text{out}}}{T_{\text{b,out}}} + \dot{S}_{\text{gen,system}} = 0$$

$$\frac{2200 \text{ W}}{353 \text{ K}} - \frac{2200 \text{ W}}{278 \text{ K}} + \dot{S}_{\text{gen,system}} = 0 \quad \rightarrow \quad \dot{S}_{\text{gen,system}} = \mathbf{1.68 \text{ W/K}}$$



7-190 The feedwater of a steam power plant is preheated using steam extracted from the turbine. The ratio of the mass flow rates of the extracted steam to the feedwater and entropy generation per unit mass of feedwater are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** Heat loss from the device to the surroundings is negligible.

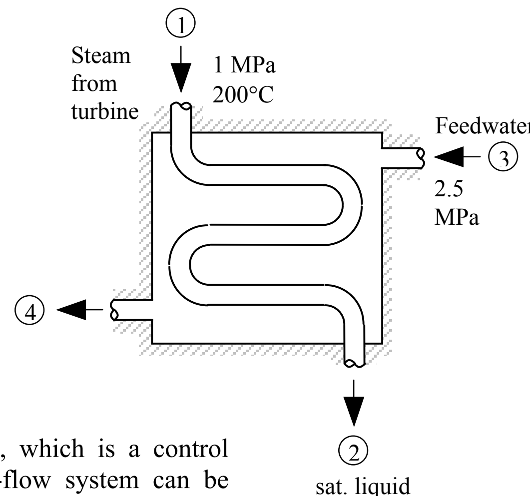
Properties The properties of steam and feedwater are (Tables A-4 through A-6)

$$\left.\begin{array}{l} P_1 = 1 \text{ MPa} \\ T_1 = 200°\text{C} \end{array}\right\} \begin{array}{l} h_1 = 2828.3 \text{ kJ/kg} \\ s_1 = 6.6956 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 1 \text{ MPa} \\ \text{sat. liquid} \end{array}\right\} \begin{array}{l} h_2 = h_{f@1\text{ MPa}} = 762.51 \text{ kJ/kg} \\ s_2 = s_{f@1\text{ MPa}} = 2.1381 \text{ kJ/kg}\cdot\text{K} \\ T_2 = 179.88°\text{C} \end{array}$$

$$\left.\begin{array}{l} P_3 = 2.5 \text{ MPa} \\ T_3 = 50°\text{C} \end{array}\right\} \begin{array}{l} h_3 \cong h_{f@50^\circ\text{C}} = 209.34 \text{ kJ/kg} \\ s_3 \cong s_{f@50^\circ\text{C}} = 0.7038 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_4 = 2.5 \text{ MPa} \\ T_4 = T_2 - 10^\circ\text{C} \cong 170^\circ\text{C} \end{array}\right\} \begin{array}{l} h_4 \cong h_{f@170^\circ\text{C}} = 719.08 \text{ kJ/kg} \\ s_4 \cong s_{f@170^\circ\text{C}} = 2.0417 \text{ kJ/kg}\cdot\text{K} \end{array}$$



Analysis (*a*) We take the heat exchanger as the system, which is a control volume. The mass and energy balances for this steady-flow system can be expressed in the rate form as follows:

Mass balance (for each fluid stream):

$$\dot{m}_{\text{in}} - \dot{m}_{\text{out}} = \Delta\dot{m}_{\text{system}}^{\nearrow 0 \text{ (steady)}} = 0 \rightarrow \dot{m}_{\text{in}} = \dot{m}_{\text{out}} \rightarrow \dot{m}_1 = \dot{m}_2 = \dot{m}_s \quad \text{and} \quad \dot{m}_3 = \dot{m}_4 = \dot{m}_{fw}$$

Energy balance (for the heat exchanger):

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta\dot{E}_{\text{system}}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} = 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}_1 h_1 + \dot{m}_3 h_3 = \dot{m}_2 h_2 + \dot{m}_4 h_4 \quad (\text{since } \dot{Q} = \dot{W} = \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

Combining the two, $\dot{m}_s(h_2 - h_1) = \dot{m}_{fw}(h_3 - h_4)$

Dividing by $\dot{m}_{fw}$ and substituting, $\dfrac{\dot{m}_s}{\dot{m}_{fw}} = \dfrac{h_4 - h_3}{h_1 - h_2} = \dfrac{(719.08 - 209.34) \text{ kJ/kg}}{(2828.3 - 762.51) \text{ kJ/kg}} = \mathbf{0.247}$

(*b*) The total entropy change (or entropy generation) during this process per unit mass of feedwater can be determined from an entropy balance expressed in the rate form as

$$\underbrace{\dot{S}_{\text{in}} - \dot{S}_{\text{out}}}_{\substack{\text{Rate of net entropy transfer} \\ \text{by heat and mass}}} + \underbrace{\dot{S}_{\text{gen}}}_{\substack{\text{Rate of entropy} \\ \text{generation}}} = \underbrace{\Delta\dot{S}_{\text{system}}^{\nearrow 0}}_{\substack{\text{Rate of change} \\ \text{of entropy}}} = 0$$

$$\dot{m}_1 s_1 - \dot{m}_2 s_2 + \dot{m}_3 s_3 - \dot{m}_4 s_4 + \dot{S}_{\text{gen}} = 0$$

$$\dot{m}_s(s_1 - s_2) + \dot{m}_{fw}(s_3 - s_4) + \dot{S}_{\text{gen}} = 0$$

$$\frac{\dot{S}_{\text{gen}}}{\dot{m}_{fw}} = \frac{\dot{m}_s}{\dot{m}_{fw}}(s_2 - s_1) + (s_4 - s_3) = (0.247)(2.1381 - 6.6956) + (2.0417 - 0.7038)$$

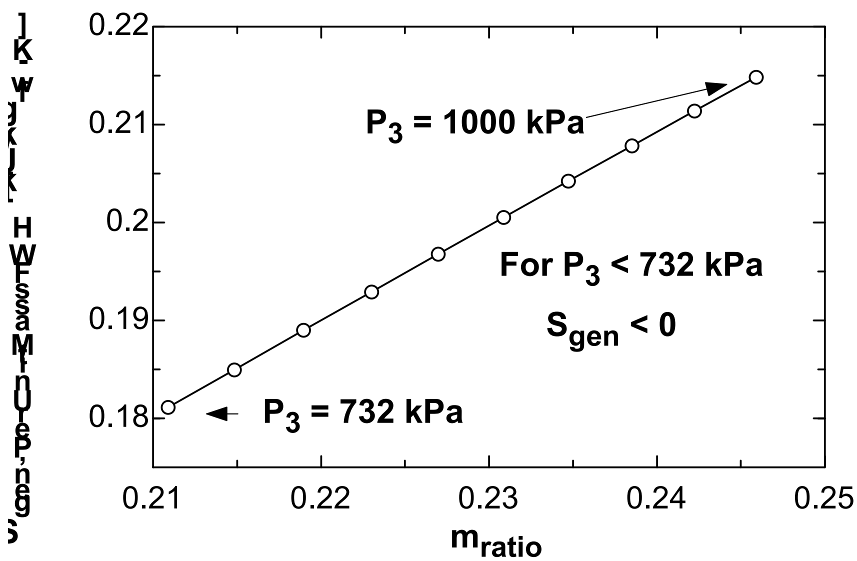
$$= \mathbf{0.213 \text{ kJ/K}} \text{ per kg of feedwater}$$

7-191 EES Problem 7-190 is reconsidered. The effect of the state of the steam at the inlet to the feedwater heater is to be investigated. The entropy of the extraction steam is assumed to be constant at the value for 1 MPa, 200°C, and the extraction steam pressure is to be varied from 1 MPa to 100 kPa. Both the ratio of the mass flow rates of the extracted steam and the feedwater heater and the total entropy change for this process per unit mass of the feedwater are to be plotted as functions of the extraction pressure.

Analysis The problem is solved using EES, and the results are tabulated and plotted below.

```
"Knowns:"
WorkFluid$ = 'Steam_iapws'
"P[3] = 1000 [kPa]"  "place {} around P[3] and T[3] eqations to solve the table"
T[3] = 200 [C]
P[4] = P[3]
x[4]=0
T[4]=temperature(WorkFluid$,P=P[4],x=x[4])
P[1] = 2500 [kPa]
T[1] = 50 [C]
P[2] = 2500  [kPa]
T[2] = T[4] - 10"[C]"

"Since we don't know the mass flow rates and we want to determine the ratio of mass flow rate of
the extracted steam and the feedwater, we can assume the mass flow rate of the feedwater is 1
kg/s without loss of generality.  We write the conservation of energy."
"Conservation of mass for the steam extracted from the turbine: "
m_dot_steam[3]= m_dot_steam[4]

"Conservation of mass for the condensate flowing through the feedwater heater:"
m_dot_fw[1] = 1
m_dot_fw[2]= m_dot_fw[1]

"Conservation of Energy - SSSF energy balance for the feedwater heater -- neglecting the
change in potential energy, no  heat transfer, no work:"
h[3]=enthalpy(WorkFluid$,P=P[3],T=T[3])
"To solve the table, place {} around s[3] and remove them from the 2nd and 3rd equations"
s[3]=entropy(WorkFluid$,P=P[3],T=T[3])
{s[3] =6.693 [kJ/kg-K]  "This s[3] is  for the initial T[3], P[3]"
T[3]=temperature(WorkFluid$,P=P[3],s=s[3])  "Use this equation for T[3] only when s[3] is given."}
h[4]=enthalpy(WorkFluid$,P=P[4],x=x[4])
s[4]=entropy(WorkFluid$,P=P[4],x=x[4])
h[1]=enthalpy(WorkFluid$,P=P[1],T=T[1])
s[1]=entropy(WorkFluid$,P=P[1],T=T[1])
h[2]=enthalpy(WorkFluid$,P=P[2],T=T[2])
s[2]=entropy(WorkFluid$,P=P[2],T=T[2])

"For the feedwater heater:"
E_dot_in = E_dot_out
E_dot_in = m_dot_steam[3]*h[3] +m_dot_fw[1]*h[1]
E_dot_out= m_dot_steam[4]*h[4] + m_dot_fw[2]*h[2]
m_ratio = m_dot_steam[3]/ m_dot_fw[1]

"Second Law analysis:"
S_dot_in - S_dot_out + S_dot_gen = DELTAS_dot_sys
DELTAS_dot_sys = 0 "[KW/K]" "steady-flow result"
S_dot_in = m_dot_steam[3]*s[3] +m_dot_fw[1]*s[1]
S_dot_out= m_dot_steam[4]*s[4] + m_dot_fw[2]*s[2]
S_gen_PerUnitMassFWH = S_dot_gen/m_dot_fw[1]"[kJ/kg_fw-K]"
```

m_{ratio}	$S_{gen,PerUnitMass}$ [kJ/kg-K]	P_3 [kPa]
0.2109	0.1811	732
0.2148	0.185	760
0.219	0.189	790
0.223	0.1929	820
0.227	0.1968	850
0.2309	0.2005	880
0.2347	0.2042	910
0.2385	0.2078	940
0.2422	0.2114	970
0.2459	0.2149	1000



7-192E A rigid tank initially contains saturated R-134a vapor. The tank is connected to a supply line, and is charged until the tank contains saturated liquid at a specified pressure. The mass of R-134a that entered the tank, the heat transfer with the surroundings at 110°F, and the entropy generated during this process are to be determined.

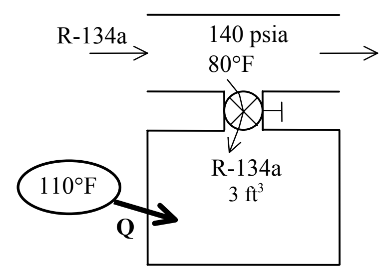
Assumptions **1** This is an unsteady process since the conditions within the device are changing during the process, but it can be analyzed as a uniform-flow process since the state of fluid at the inlet remains constant. **2** Kinetic and potential energies are negligible. **3** There are no work interactions involved. **4** The direction of heat transfer is to the tank (will be verified).

Properties The properties of R-134a are (Tables A-11 through A-13)

$$\left.\begin{array}{l} P_1 = 100 \text{ psia} \\ \text{sat. vapor} \end{array}\right\} \begin{array}{l} \boldsymbol{v}_1 = \boldsymbol{v}_{g@100 \text{ psia}} = 0.47760 \text{ ft}^3/\text{lbm} \\ u_1 = u_{g@100 \text{ psia}} = 104.99 \text{ Btu/lbm} \\ s_1 = s_{g@100 \text{ psia}} = 0.2198 \text{ Btu/lbm}\cdot\text{R} \end{array}$$

$$\left.\begin{array}{l} P_2 = 120 \text{ psia} \\ \text{sat. liquid} \end{array}\right\} \begin{array}{l} \boldsymbol{v}_2 = \boldsymbol{v}_{f@120 \text{ psia}} = 0.01360 \text{ ft}^3/\text{lbm} \\ u_2 = u_{f@120 \text{ psia}} = 41.49 \text{ Btu/lbm} \\ s_2 = s_{f@120 \text{ psia}} = 0.08589 \text{ Btu/lbm}\cdot\text{R} \end{array}$$

$$\left.\begin{array}{l} P_i = 140 \text{ psia} \\ T_i = 80°\text{F} \end{array}\right\} \begin{array}{l} h_i \cong h_{f@80°\text{F}} = 38.17 \text{ Btu/lbm} \\ s_i \cong s_{f@80°\text{F}} = 0.07934 \text{ Btu/lbm}\cdot\text{R} \end{array}$$



Analysis (*a*) We take the tank as the system, which is a control volume since mass crosses the boundary. Noting that the energies of flowing and nonflowing fluids are represented by enthalpy h and internal energy u, respectively, the mass and energy balances for this uniform-flow system can be expressed as

Mass balance: $m_{\text{in}} - m_{\text{out}} = \Delta m_{\text{system}} \rightarrow m_i = m_2 - m_1$

Energy balance:
$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$Q_{\text{in}} + m_i h_i = m_2 u_2 - m_1 u_1 \quad (\text{since } W \cong \text{ke} \cong \text{pe} \cong 0)$$

The initial and the final masses in the tank are

$$m_1 = \frac{\boldsymbol{V}}{\boldsymbol{v}_1} = \frac{3 \text{ ft}^3}{0.4776 \text{ ft}^3/\text{lbm}} = 6.28 \text{ lbm} \qquad m_2 = \frac{\boldsymbol{V}}{\boldsymbol{v}_2} = \frac{3 \text{ ft}^3}{0.01360 \text{ ft}^3/\text{lbm}} = 220.55 \text{ lbm}$$

Then from the mass balance,

$$m_i = m_2 - m_1 = 220.55 - 6.28 = \mathbf{214.3\ lbm}$$

(*b*) The heat transfer during this process is determined from the energy balance to be

$$Q_{\text{in}} = -m_i h_i + m_2 u_2 - m_1 u_1$$
$$= -(214.3 \text{ lbm})(38.17 \text{ Btu/lbm}) + (220.55 \text{ lbm})(41.49 \text{ Btu/lbm}) - (6.28 \text{ lbm})(104.99 \text{ Btu/lbm}) = \mathbf{312\ Btu}$$

(*c*) The entropy generated during this process is determined by applying the entropy balance on an *extended system* that includes the tank and its immediate surroundings so that the boundary temperature of the extended system is the temperature of the surroundings at all times. The entropy balance for it can be expressed as

$$\underbrace{S_{\text{in}} - S_{\text{out}}}_{\substack{\text{Net entropy transfer} \\ \text{by heat and mass}}} + \underbrace{S_{\text{gen}}}_{\substack{\text{Entropy} \\ \text{generation}}} = \underbrace{\Delta S_{\text{system}}}_{\substack{\text{Change} \\ \text{in entropy}}} \longrightarrow \frac{Q_{\text{in}}}{T_{\text{b,in}}} + m_i s_i + S_{\text{gen}} = \Delta S_{\text{tank}} = m_2 s_2 - m_1 s_1$$

Therefore, the total entropy generated during this process is

$$S_{\text{gen}} = -m_i s_i + (m_2 s_2 - m_1 s_1) - \frac{Q_{\text{in}}}{T_{\text{b,in}}}$$
$$= -(214.3)(0.07934) + (220.55)(0.08589) - (6.28)(0.2198) - \frac{312 \text{ Btu}}{570 \text{ R}} = \mathbf{0.0169\ Btu/R}$$

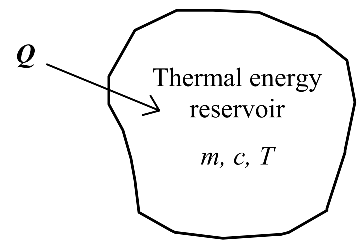
7-193 It is to be shown that for thermal energy reservoirs, the entropy change relation $\Delta S = mc\ln(T_2/T_1)$ reduces to $\Delta S = Q/T$ as $T_2 \rightarrow T_1$.

Analysis Consider a thermal energy reservoir of mass m, specific heat c, and initial temperature T_1. Now heat, in the amount of Q, is transferred to this reservoir. The first law and the entropy change relations for this reservoir can be written as

$$Q = mc(T_2 - T_1) \longrightarrow mc = \frac{Q}{T_2 - T_1}$$

and

$$\Delta S = mc\ln\frac{T_2}{T_1} = Q\frac{\ln(T_2/T_1)}{T_2 - T_1}$$



Taking the limit as $T_2 \rightarrow T_1$ by applying the L'Hospital's rule,

$$\Delta S = Q\frac{1/T_1}{1} = \frac{Q}{T_1}$$

which is the desired result.

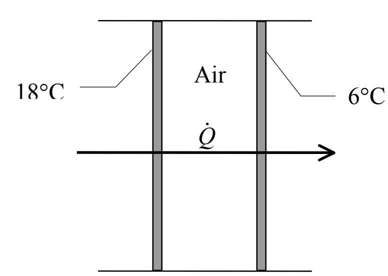
7-194 The inner and outer glasses of a double pane window are at specified temperatures. The rates of entropy transfer through both sides of the window and the rate of entropy generation within the window are to be determined.

Assumptions Steady operating conditions exist since the surface temperatures of the glass remain constant at the specified values.

Analysis The entropy flows associated with heat transfer through the left and right glasses are

$$\dot{S}_{\text{left}} = \frac{\dot{Q}_{\text{left}}}{T_{\text{left}}} = \frac{110\text{ W}}{291\text{ K}} = \mathbf{0.378\ \ W/K}$$

$$\dot{S}_{\text{right}} = \frac{\dot{Q}_{\text{right}}}{T_{\text{right}}} = \frac{110\text{ W}}{279\text{ K}} = \mathbf{0.394\ \ W/K}$$



We take the double pane window as the system, which is a closed system. In steady operation, the rate form of the entropy balance for this system can be expressed as

$$\underbrace{\dot{S}_{\text{in}} - \dot{S}_{\text{out}}}_{\substack{\text{Rate of net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{\dot{S}_{\text{gen}}}_{\substack{\text{Rate of entropy}\\ \text{generation}}} = \underbrace{\Delta\dot{S}_{\text{system}}^{\nearrow 0}}_{\substack{\text{Rate of change}\\ \text{of entropy}}} = 0$$

$$\frac{\dot{Q}_{\text{in}}}{T_{\text{b,in}}} - \frac{\dot{Q}_{\text{out}}}{T_{\text{b,out}}} + \dot{S}_{\text{gen,system}} = 0$$

$$\frac{110\text{ W}}{291\text{ K}} - \frac{110\text{ W}}{279\text{ K}} + \dot{S}_{\text{gen,system}} = 0 \quad \rightarrow \quad \dot{S}_{\text{gen,system}} = \mathbf{0.016\ \ W/K}$$

7-195 A well-insulated room is heated by a steam radiator, and the warm air is distributed by a fan. The average temperature in the room after 30 min, the entropy changes of steam and air, and the entropy generated during this process are to be determined.

Assumptions **1** Air is an ideal gas with constant specific heats at room temperature. **2** The kinetic and potential energy changes are negligible. **3** The air pressure in the room remains constant and thus the air expands as it is heated, and some warm air escapes.

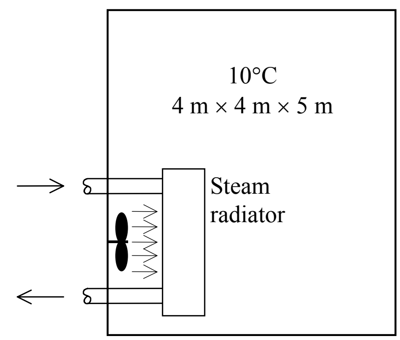
Properties The gas constant of air is $R = 0.287$ kPa.m^3/kg.K (Table A-1). Also, $c_p = 1.005$ kJ/kg.K for air at room temperature (Table A-2).

Analysis We first take the radiator as the system. This is a closed system since no mass enters or leaves. The energy balance for this closed system can be expressed as

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$-Q_{\text{out}} = \Delta U = m(u_2 - u_1) \quad (\text{since } W = \text{KE} = \text{PE} = 0)$$

$$Q_{\text{out}} = m(u_1 - u_2)$$



Using data from the steam tables (Tables A-4 through A-6), some properties are determined to be

$$\left.\begin{array}{l} P_1 = 200 \text{ kPa} \\ T_1 = 200°\text{C} \end{array}\right\} \begin{array}{l} \boldsymbol{v}_1 = 1.0805 \text{ m}^3/\text{kg} \\ u_1 = 2654.6 \text{ kJ/kg} \\ s_1 = 7.5081 \text{ kJ/kg.K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 100 \text{ kPa} \\ (\boldsymbol{v}_2 = \boldsymbol{v}_1) \end{array}\right\} \begin{array}{ll} \boldsymbol{v}_f = 0.001043, & \boldsymbol{v}_g = 1.6941 \text{ m}^3/\text{kg} \\ u_f = 417.40, & u_{fg} = 2088.2 \text{ kJ/kg} \\ s_f = 1.3028, & s_{fg} = 6.0562 \text{ kJ/kg.K} \end{array}$$

$$x_2 = \frac{\boldsymbol{v}_2 - \boldsymbol{v}_f}{\boldsymbol{v}_{fg}} = \frac{1.0805 - 0.001043}{1.6941 - 0.001043} = 0.6376$$

$$u_2 = u_f + x_2 u_{fg} = 417.40 + 0.6376 \times 2088.2 = 1748.7 \text{ kJ/kg}$$

$$s_2 = s_f + x_2 s_{fg} = 1.3028 + 0.6376 \times 6.0562 = 5.1642 \text{ kJ/kg.K}$$

$$m = \frac{\boldsymbol{V}_1}{\boldsymbol{v}_1} = \frac{0.015 \text{ m}^3}{1.0805 \text{ m}^3/\text{kg}} = 0.01388 \text{ kg}$$

Substituting,

$$Q_{\text{out}} = (0.01388 \text{ kg})(\ 2654.6 - 1748.7)\text{kJ/kg} = 12.6 \text{ kJ}$$

The volume and the mass of the air in the room are $V = 4\times4\times5 = 80$ m³ and

$$m_{\text{air}} = \frac{P_1 \boldsymbol{V}_1}{RT_1} = \frac{(100 \text{ kPa})(80 \text{ m}^3)}{(0.2870 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(283 \text{ K})} = 98.5 \text{ kg}$$

The amount of fan work done in 30 min is

$$W_{\text{fan,in}} = \dot{W}_{\text{fan,in}} \Delta t = (0.120 \text{ kJ/s})(30 \times 60 \text{ s}) = 216 \text{kJ}$$

We now take the air in the room as the system. The energy balance for this closed system is expressed as

$$E_{\text{in}} - E_{\text{out}} = \Delta E_{\text{system}}$$

$$Q_{\text{in}} + W_{\text{fan,in}} - W_{\text{b,out}} = \Delta U$$

$$Q_{\text{in}} + W_{\text{fan,in}} = \Delta H \cong mc_p(T_2 - T_1)$$

since the boundary work and ΔU combine into ΔH for a constant pressure expansion or compression process.

Substituting, $(12.6 \text{ kJ}) + (216 \text{ kJ}) = (98.5 \text{ kg})(1.005 \text{ kJ/kg°C})(T_2 - 10)°\text{C}$

which yields $T_2 = \mathbf{12.3°C}$

Therefore, the air temperature in the room rises from 10°C to 12.3°C in 30 min.

(*b*) The entropy change of the steam is

$$\Delta S_{\text{steam}} = m(s_2 - s_1) = (0.01388 \text{ kg})(5.1642 - 7.5081)\text{kJ/kg}\cdot\text{K} = \mathbf{-0.0325 \text{ kJ/K}}$$

(*c*) Noting that air expands at constant pressure, the entropy change of the air in the room is

$$\Delta S_{\text{air}} = mc_p \ln\frac{T_2}{T_1} - mR\ln\frac{P_2}{P_1}^{\nearrow 0} = (98.5 \text{ kg})(1.005 \text{ kJ/kg}\cdot\text{K})\ln\frac{285.3 \text{ K}}{283 \text{ K}} = \mathbf{0.8013 \text{ kJ/K}}$$

(*d*) We take the air in the room (including the steam radiator) as our system, which is a closed system. Noting that no heat or mass crosses the boundaries of this system, the entropy balance for it can be expressed as

$$\underbrace{S_{\text{in}} - S_{\text{out}}}_{\substack{\text{Net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{S_{\text{gen}}}_{\substack{\text{Entropy}\\ \text{generation}}} = \underbrace{\Delta S_{\text{system}}}_{\substack{\text{Change}\\ \text{in entropy}}}$$

$$0 + S_{\text{gen}} = \Delta S_{\text{steam}} + \Delta S_{\text{air}}$$

Substituting, the entropy generated during this process is determined to be

$$S_{\text{gen}} = \Delta S_{\text{steam}} + \Delta S_{\text{air}} = -0.0325 + 0.8013 = \mathbf{0.7688 \text{ kJ/K}}$$

7-196 The heating of a passive solar house at night is to be assisted by solar heated water. The length of time that the electric heating system would run that night and the amount of entropy generated that night are to be determined.

Assumptions **1** Water is an incompressible substance with constant specific heats. **2** The energy stored in the glass containers themselves is negligible relative to the energy stored in water. **3** The house is maintained at 22°C at all times.

Properties The density and specific heat of water at room temperature are ρ = 1 kg/L and c = 4.18 kJ/kg·°C (Table A-3).

Analysis The total mass of water is

$$m_w = \rho V = (1 \text{ kg/L})(50 \times 20 \text{ L}) = 1000 \text{ kg}$$

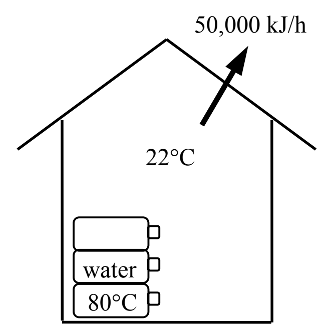
Taking the contents of the house, including the water as our system, the energy balance relation can be written as

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$W_{\text{e,in}} - Q_{\text{out}} = \Delta U = (\Delta U)_{\text{water}} + (\Delta U)_{\text{air}}$$

$$= (\Delta U)_{\text{water}}$$

$$= mc(T_2 - T_1)_{\text{water}}$$



or,

$$\dot{W}_{\text{e,in}} \Delta t - Q_{\text{out}} = [mc(T_2 - T_1)]_{\text{water}}$$

Substituting,

$$(15 \text{ kJ/s})\Delta t \text{ - } (50{,}000 \text{ kJ/h})(10 \text{ h}) = (1000 \text{ kg})(4.18 \text{ kJ/kg·°C})(22 \text{ - } 80)\text{°C}$$

It gives

$$\Delta t = 17{,}170 \text{ s} = \mathbf{4.77 \text{ h}}$$

We take the house as the system, which is a closed system. The entropy generated during this process is determined by applying the entropy balance on an *extended system* that includes the house and its immediate surroundings so that the boundary temperature of the extended system is the temperature of the surroundings at all times. The entropy balance for the extended system can be expressed as

$$\underbrace{S_{\text{in}} - S_{\text{out}}}_{\substack{\text{Net entropy transfer} \\ \text{by heat and mass}}} + \underbrace{S_{\text{gen}}}_{\substack{\text{Entropy} \\ \text{generation}}} = \underbrace{\Delta S_{\text{system}}}_{\substack{\text{Change} \\ \text{in entropy}}}$$

$$-\frac{Q_{\text{out}}}{T_{\text{b,out}}} + S_{\text{gen}} = \Delta S_{\text{water}} + \Delta S_{\text{air}}^{\nearrow 0} = \Delta S_{\text{water}}$$

since the state of air in the house remains unchanged. Then the entropy generated during the 10-h period that night is

$$S_{\text{gen}} = \Delta S_{\text{water}} + \frac{Q_{\text{out}}}{T_{\text{b,out}}} = \left(mc \ln \frac{T_2}{T_1}\right)_{\text{water}} + \frac{Q_{\text{out}}}{T_{\text{surr}}}$$

$$= (1000 \text{ kg})(4.18 \text{ kJ/kg} \cdot \text{K})\ln \frac{295 \text{ K}}{353 \text{ K}} + \frac{500{,}000 \text{ kJ}}{276 \text{ K}}$$

$$= -750 + 1811 = \mathbf{1061 \ kJ/K}$$

7-197E A steel container that is filled with hot water is allowed to cool to the ambient temperature. The total entropy generated during this process is to be determined.

Assumptions **1** Both the water and the steel tank are incompressible substances with constant specific heats at room temperature. **2** The system is stationary and thus the kinetic and potential energy changes are zero. **3** Specific heat of iron can be used for steel. **4** There are no work interactions involved.

Properties The specific heats of water and the iron at room temperature are $c_{p,\,\text{water}}$ = 1.00 Btu/lbm.°F and $C_{p,\,\text{iron}}$ = 0.107 Btu/lbm.°C. The density of water at room temperature is 62.1 lbm/ft³ (Table A-3E).

Analysis The mass of the water is

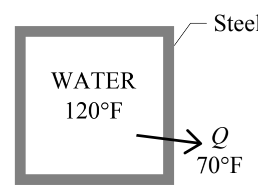
$$m_{\text{water}} = \rho V = (62.1\ \text{lbm/ft}^3)(15\ \text{ft}^3) = 931.5\ \text{lbm}$$

We take the steel container and the water in it as the system, which is a closed system. The energy balance on the system can be expressed as

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$-Q_{\text{out}} = \Delta U = \Delta U_{\text{container}} + \Delta U_{\text{water}}$$

$$= [mc(T_2 - T_1)]_{\text{container}} + [mc(T_2 - T_1)]_{\text{water}}$$



Substituting, the heat loss to the surrounding air is determined to be

$$Q_{\text{out}} = [mc(T_1 - T_2)]_{\text{container}} + [mc(T_1 - T_2)]_{\text{water}}$$

$$= (75\ \text{lbm})(0.107\ \text{Btu/lbm}\cdot{}^\circ\text{F})(120 - 70)^\circ\text{F} + (931.5\ \text{lbm})(1.00\ \text{Btu/lbm}\cdot{}^\circ\text{F})(120 - 70)^\circ\text{F}$$

$$= 46{,}976\ \text{Btu}$$

We again take the container and the water In it as the system. The entropy generated during this process is determined by applying the entropy balance on an *extended system* that includes the container and its immediate surroundings so that the boundary temperature of the extended system is the temperature of the surrounding air at all times. The entropy balance for the extended system can be expressed as

$$\underbrace{S_{\text{in}} - S_{\text{out}}}_{\substack{\text{Net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{S_{\text{gen}}}_{\substack{\text{Entropy}\\ \text{generation}}} = \underbrace{\Delta S_{\text{system}}}_{\substack{\text{Change}\\ \text{in entropy}}}$$

$$-\frac{Q_{\text{out}}}{T_{\text{b,out}}} + S_{\text{gen}} = \Delta S_{\text{container}} + \Delta S_{\text{water}}$$

where

$$\Delta S_{\text{container}} = mc_{\text{avg}} \ln\frac{T_2}{T_1} = (75\ \text{lbm})(0.107\ \text{Btu/lbm}\cdot\text{R})\ln\frac{530\ \text{R}}{580\ \text{R}} = -0.72\ \text{Btu/R}$$

$$\Delta S_{\text{water}} = mc_{\text{avg}} \ln\frac{T_2}{T_1} = (931.5\ \text{lbm})(1.00\ \text{Btu/lbm}\cdot\text{R})\ln\frac{530\ \text{R}}{580\ \text{R}} = -83.98\ \text{Btu/R}$$

Therefore, the total entropy generated during this process is

$$S_{\text{gen}} = \Delta S_{\text{container}} + \Delta S_{\text{water}} + \frac{Q_{\text{out}}}{T_{\text{b,out}}} = -0.72 - 83.98 + \frac{46{,}976\ \text{Btu}}{70 + 460\ \text{R}} = \mathbf{3.93\ \ Btu/R}$$