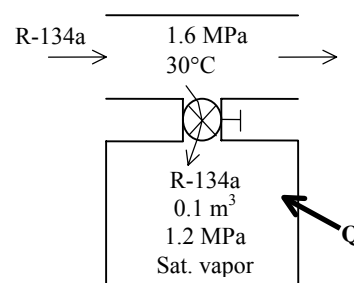


8-79 A rigid tank initially contains saturated R-134a vapor. The tank is connected to a supply line, and R-134a is allowed to enter the tank. The mass of the R-134a that entered the tank and the exergy destroyed during this process are to be determined.

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 refrigerant are (Tables A-11 through A-13)

$$\begin{aligned}
 P_1 = 1.2 \text{ MPa} \quad \left\{ \begin{array}{l} \nu_1 = \nu_g @ 1.2 \text{ MPa} = 0.01672 \text{ m}^3/\text{kg} \\ u_1 = u_g @ 1.2 \text{ MPa} = 253.81 \text{ kJ/kg} \\ s_1 = s_g @ 1.2 \text{ MPa} = 0.91303 \text{ kJ/kg} \cdot \text{K} \end{array} \right. \\
 T_2 = 1.4 \text{ MPa} \quad \left\{ \begin{array}{l} \nu_2 = \nu_f @ 1.4 \text{ MPa} = 0.0009166 \text{ m}^3/\text{kg} \\ u_2 = u_f @ 1.4 \text{ MPa} = 125.94 \text{ kJ/kg} \\ s_2 = s_f @ 1.4 \text{ MPa} = 0.45315 \text{ kJ/kg} \cdot \text{K} \end{array} \right. \\
 P_i = 1.6 \text{ MPa} \quad \left\{ \begin{array}{l} h_i = 93.56 \text{ kJ/kg} \\ T_i = 30^\circ\text{C} \quad s_i = 0.34554 \text{ kJ/kg} \cdot \text{K} \end{array} \right.
 \end{aligned}$$



Analysis We take the tank as the system, which is a control volume. Noting that the microscopic 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: $\underbrace{E_{\text{in}} - E_{\text{out}}}_{\text{Net energy transfer by heat, work, and mass}} = \underbrace{\Delta E_{\text{system}}}_{\text{Change in internal, kinetic, potential, etc. energies}}$

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

(a) The initial and the final masses in the tank are

$$m_1 = \frac{V_1}{\nu_1} = \frac{0.1 \text{ m}^3}{0.01672 \text{ m}^3/\text{kg}} = 5.983 \text{ kg} \quad m_2 = \frac{V_2}{\nu_2} = \frac{0.1 \text{ m}^3}{0.0009166 \text{ m}^3/\text{kg}} = 109.10 \text{ kg}$$

Then from the mass balance

$$m_i = m_2 - m_1 = 109.10 - 5.983 = \mathbf{103.11 \text{ kg}}$$

The heat transfer during this process is determined from the energy balance to be

$$\begin{aligned}
 Q_{\text{in}} &= -m_i h_i + m_2 u_2 - m_1 u_1 \\
 &= -(103.11 \text{ kg})(93.56 \text{ kJ/kg}) + (109.10)(125.94 \text{ kJ/kg}) - (5.983 \text{ kg})(253.81 \text{ kJ/kg}) = 2573 \text{ kJ}
 \end{aligned}$$

(b) The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$. The entropy generation S_{gen} in this case is determined from an 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 surroundings temperature T_{surr} at all times. It gives

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

$$S_{\text{gen}} = m_2 s_2 - m_1 s_1 - m_i s_i - \frac{Q_{\text{in}}}{T_0}$$

Substituting, the exergy destruction is determined to be

$$\begin{aligned}
 X_{\text{destroyed}} &= T_0 S_{\text{gen}} = T_0 \left[m_2 s_2 - m_1 s_1 - m_i s_i - \frac{Q_{\text{in}}}{T_0} \right] \\
 &= (318 \text{ K}) [109.10 \times 0.45315 - 5.983 \times 0.91303 - 103.11 \times 0.34554 - (2573 \text{ kJ})/(318 \text{ K})] \\
 &= \mathbf{80.3 \text{ kJ}}
 \end{aligned}$$

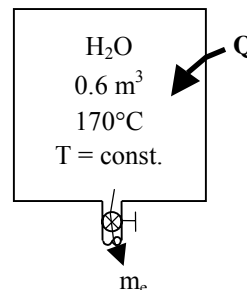
8-80 A rigid tank initially contains saturated liquid water. A valve at the bottom of the tank is opened, and half of mass in liquid form is withdrawn from the tank. The temperature in the tank is maintained constant. The amount of heat transfer, the reversible work, and the exergy destruction during 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 leaving the device 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 water are (Tables A-4 through A-6)

$$T_1 = 170^\circ\text{C} \left\{ \begin{array}{l} \nu_1 = \nu_{f@170^\circ\text{C}} = 0.001114 \text{ m}^3/\text{kg} \\ u_1 = u_{f@170^\circ\text{C}} = 718.20 \text{ kJ/kg} \\ s_1 = s_{f@170^\circ\text{C}} = 2.0417 \text{ kJ/kg} \cdot \text{K} \end{array} \right.$$

$$T_e = 170^\circ\text{C} \left\{ \begin{array}{l} h_e = h_{f@170^\circ\text{C}} = 719.08 \text{ kJ/kg} \\ s_e = s_{f@170^\circ\text{C}} = 2.0417 \text{ kJ/kg} \cdot \text{K} \end{array} \right.$$



Analysis We take the tank as the system, which is a control volume since mass crosses the boundary. Noting that the microscopic 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: $m_{\text{in}} - m_{\text{out}} = \Delta m_{\text{system}} \rightarrow m_e = m_1 - m_2$

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

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

The initial and the final masses in the tank are

$$m_1 = \frac{\nu}{\nu_1} = \frac{0.6 \text{ m}^3}{0.001114 \text{ m}^3/\text{kg}} = 538.47 \text{ kg}$$

$$m_2 = \frac{1}{2} m_1 = \frac{1}{2} (538.47 \text{ kg}) = 269.24 \text{ kg} = m_e$$

Now we determine the final internal energy and entropy,

$$\nu_2 = \frac{\nu}{m_2} = \frac{0.6 \text{ m}^3}{269.24 \text{ kg}} = 0.002229 \text{ m}^3/\text{kg}$$

$$x_2 = \frac{\nu_2 - \nu_f}{\nu_{fg}} = \frac{0.002229 - 0.001114}{0.24260 - 0.001114} = 0.004614$$

$$\left. \begin{array}{l} T_2 = 170^\circ\text{C} \\ x_2 = 0.004614 \end{array} \right\} \begin{array}{l} u_2 = u_f + x_2 u_{fg} = 718.20 + (0.004614)(1857.5) = 726.77 \text{ kJ/kg} \\ s_2 = s_f + x_2 s_{fg} = 2.0417 + (0.004614)(4.6233) = 2.0630 \text{ kJ/kg} \cdot \text{K} \end{array}$$

The heat transfer during this process is determined by substituting these values into the energy balance equation,

$$\begin{aligned} Q_{\text{in}} &= m_e h_e + m_2 u_2 - m_1 u_1 \\ &= (269.24 \text{ kg})(719.08 \text{ kJ/kg}) + (269.24 \text{ kg})(726.77 \text{ kJ/kg}) - (538.47 \text{ kg})(718.20 \text{ kJ/kg}) \\ &= \mathbf{2545 \text{ kJ}} \end{aligned}$$

(b) The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$. The entropy generation S_{gen} in this case is determined from an entropy balance on an *extended system* that includes the tank and the region between the tank and the source so that the boundary temperature of the extended system at the location of heat transfer is the source temperature T_{source} at all times. It gives

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

$$\frac{Q_{\text{in}}}{T_{\text{b,in}}} - m_e s_e + S_{\text{gen}} = \Delta S_{\text{tank}} = (m_2 s_2 - m_1 s_1)_{\text{tank}}$$

$$S_{\text{gen}} = m_2 s_2 - m_1 s_1 + m_e s_e - \frac{Q_{\text{in}}}{T_{\text{source}}}$$

Substituting, the exergy destruction is determined to be

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} = T_0 \left[m_2 s_2 - m_1 s_1 + m_e s_e - \frac{Q_{\text{in}}}{T_{\text{source}}} \right]$$

$$= (298 \text{ K}) [269.24 \times 2.0630 - 538.47 \times 2.0417 + 269.24 \times 2.0417 - (2545 \text{ kJ}) / (523 \text{ K})]$$

$$= \mathbf{141.2 \text{ kJ}}$$

For processes that involve no actual work, the reversible work output and exergy destruction are identical. Therefore,

$$X_{\text{destroyed}} = W_{\text{rev,out}} - W_{\text{act,out}} \rightarrow W_{\text{rev,out}} = X_{\text{destroyed}} = \mathbf{141.2 \text{ kJ}}$$

8-81E An insulated rigid tank equipped with an electric heater initially contains pressurized air. A valve is opened, and air is allowed to escape at constant temperature until the pressure inside drops to 30 psia. The amount of electrical work done and the exergy destroyed 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 exit temperature (and enthalpy) of air remains constant. **2** Kinetic and potential energies are negligible. **3** The tank is insulated and thus heat transfer is negligible. **4** Air is an ideal gas with variable specific heats. **5** The environment temperature is given to be 70°F.

Properties The gas constant of air is $R = 0.3704 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R}$ (Table A-1E). The properties of air are (Table A-17E)

$$T_e = 600 \text{ R} \longrightarrow h_e = 143.47 \text{ Btu/lbm},$$

$$T_1 = 600 \text{ R} \longrightarrow u_1 = 102.34 \text{ Btu/lbm}$$

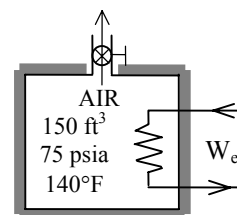
$$T_2 = 600 \text{ R} \longrightarrow u_2 = 102.34 \text{ Btu/lbm}$$

Analysis We take the tank as the system, which is a control volume. Noting that the microscopic 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: $m_{\text{in}} - m_{\text{out}} = \Delta m_{\text{system}} \rightarrow m_e = m_1 - m_2$

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

$$W_{e,\text{in}} - m_e h_e = m_2 u_2 - m_1 u_1 \quad (\text{since } Q \cong \text{ke} \cong \text{pe} \cong 0)$$



The initial and the final masses of air in the tank are

$$m_1 = \frac{P_1 V}{RT_1} = \frac{(75 \text{ psia})(150 \text{ ft}^3)}{(0.3704 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R})(600 \text{ R})} = 50.62 \text{ lbm}$$

$$m_2 = \frac{P_2 V}{RT_2} = \frac{(30 \text{ psia})(150 \text{ ft}^3)}{(0.3704 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R})(600 \text{ R})} = 20.25 \text{ lbm}$$

Then from the mass and energy balances,

$$m_e = m_1 - m_2 = 50.62 - 20.25 = 30.37 \text{ lbm}$$

$$\begin{aligned} W_{e,\text{in}} &= m_e h_e + m_2 u_2 - m_1 u_1 \\ &= (30.37 \text{ lbm})(143.47 \text{ Btu/lbm}) + (20.25 \text{ lbm})(102.34 \text{ Btu/lbm}) - (50.62 \text{ lbm})(102.34 \text{ Btu/lbm}) \\ &= \mathbf{1249 \text{ Btu}} \end{aligned}$$

(b) The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$ where the entropy generation S_{gen} is determined from an entropy balance on the insulated tank. It gives

$$\underbrace{S_{\text{in}} - S_{\text{out}}}_{\substack{\text{Net entropy transfer} \\ \text{by heat and mass}}} + \underbrace{S_{\text{gen}}}_{\substack{\text{Entropy} \\ \text{generation}}} = \underbrace{\Delta S_{\text{system}}}_{\substack{\text{Change} \\ \text{in entropy}}} \longrightarrow -m_e s_e + S_{\text{gen}} = \Delta S_{\text{tank}} = (m_2 s_2 - m_1 s_1)_{\text{tank}}$$

$$S_{\text{gen}} = m_2 s_2 - m_1 s_1 + m_e s_e = m_2 s_2 - m_1 s_1 + (m_1 - m_2) s_e = m_2 (s_2 - s_e) - m_1 (s_1 - s_e)$$

Assuming a constant average pressure of $(75 + 30) / 2 = 52.5 \text{ psia}$ for the exit stream, the entropy changes are determined to be

$$s_2 - s_e = c_p \ln \frac{T_2}{T_e} - R \ln \frac{P_2}{P_e} = -(0.06855 \text{ Btu/lbm} \cdot \text{R}) \ln \frac{30 \text{ psia}}{52.5 \text{ psia}} = 0.03836 \text{ Btu/lbm} \cdot \text{R}$$

$$s_1 - s_e = c_p \ln \frac{T_1}{T_e} - R \ln \frac{P_1}{P_e} = -(0.06855 \text{ Btu/lbm} \cdot \text{R}) \ln \frac{75 \text{ psia}}{52.5 \text{ psia}} = -0.02445 \text{ Btu/lbm} \cdot \text{R}$$

Substituting, the exergy destruction is determined to be

$$\begin{aligned} X_{\text{destroyed}} &= T_0 S_{\text{gen}} = T_0 [m_2 (s_2 - s_e) - m_1 (s_1 - s_e)] \\ &= (530 \text{ R}) [(20.25 \text{ lbm})(0.03836 \text{ Btu/lbm} \cdot \text{R}) - (50.62 \text{ lbm})(-0.02445 \text{ Btu/lbm} \cdot \text{R})] = \mathbf{1068 \text{ Btu}} \end{aligned}$$

8-82 A rigid tank initially contains saturated liquid-vapor mixture of refrigerant-134a. A valve at the bottom of the tank is opened, and liquid is withdrawn from the tank at constant pressure until no liquid remains inside. The final mass in the tank and the reversible work associated with this process are to be determined.

Assumptions **1** This is an unsteady process since the conditions within the device are changing during the process. It can be analyzed as a uniform-flow process since the state of fluid leaving the device 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)

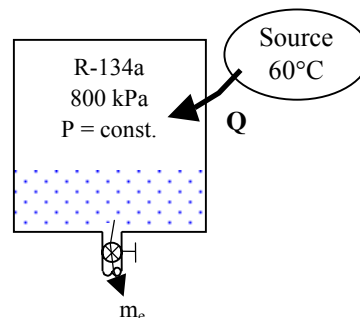
$$P_1 = 800 \text{ kPa} \rightarrow \nu_f = 0.0008458 \text{ m}^3/\text{kg}, \nu_g = 0.025621 \text{ m}^3/\text{kg}$$

$$u_f = 94.79 \text{ kJ/kg}, u_g = 246.79 \text{ kJ/kg}$$

$$s_f = 0.35404 \text{ kJ/kg}\cdot\text{K}, s_g = 0.91835 \text{ kJ/kg}\cdot\text{K}$$

$$P_2 = 800 \text{ kPa} \left\{ \begin{array}{l} \nu_2 = \nu_g @ 800 \text{ kPa} = 0.02562 \text{ m}^3/\text{kg} \\ u_2 = u_g @ 800 \text{ kPa} = 246.79 \text{ kJ/kg} \\ s_2 = s_g @ 800 \text{ kPa} = 0.91835 \text{ kJ/kg}\cdot\text{K} \end{array} \right.$$

$$P_e = 800 \text{ kPa} \left\{ \begin{array}{l} h_e = h_f @ 800 \text{ kPa} = 95.47 \text{ kJ/kg} \\ s_e = s_f @ 800 \text{ kPa} = 0.35404 \text{ kJ/kg}\cdot\text{K} \end{array} \right.$$



Analysis (b) We take the tank as the system, which is a control volume. Noting that the microscopic 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

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

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

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

The initial mass, initial internal energy, and final mass in the tank are

$$m_1 = m_f + m_g = \frac{\nu_f}{\nu_f} + \frac{\nu_g}{\nu_g} = \frac{0.1 \times 0.3 \text{ m}^3}{0.0008458 \text{ m}^3/\text{kg}} + \frac{0.1 \times 0.7 \text{ m}^3}{0.025621 \text{ m}^3/\text{kg}} = 35.470 + 2.732 = 38.202 \text{ kg}$$

$$U_1 = m_1 u_1 = m_f u_f + m_g u_g = 35.470 \times 94.79 + 2.732 \times 246.79 = 4036.4 \text{ kJ}$$

$$S_1 = m_1 s_1 = m_f s_f + m_g s_g = 35.470 \times 0.35404 + 2.732 \times 0.91835 = 15.067 \text{ kJ/K}$$

$$m_2 = \frac{\nu}{\nu_2} = \frac{0.1 \text{ m}^3}{0.02562 \text{ m}^3/\text{kg}} = 3.903 \text{ kg}$$

Then from the mass and energy balances,

$$m_e = m_1 - m_2 = 38.202 - 3.903 = 34.299 \text{ kg}$$

$$Q_{\text{in}} = (34.299 \text{ kg})(95.47 \text{ kJ/kg}) + (3.903 \text{ kg})(246.79 \text{ kJ/kg}) - 4036.4 \text{ kJ} = 201.2 \text{ kJ}$$

(b) This process involves no actual work, thus the reversible work and exergy generation are identical since $X_{\text{destroyed}} = W_{\text{rev,out}} - W_{\text{act,out}} \rightarrow W_{\text{rev,out}} = X_{\text{destroyed}}$.

The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$. The entropy generation S_{gen} in this case is determined from an entropy balance on an *extended system* that includes the tank and the region between the tank and the heat source so that the boundary temperature of the extended system at the location of heat transfer is the source temperature T_{source} at all times. It gives

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

$$\frac{Q_{\text{in}}}{T_{\text{b,in}}} - m_e s_e + S_{\text{gen}} = \Delta S_{\text{tank}} = (m_2 s_2 - m_1 s_1)_{\text{tank}}$$

$$S_{\text{gen}} = m_2 s_2 - m_1 s_1 + m_e s_e - \frac{Q_{\text{in}}}{T_{\text{source}}}$$

Substituting,

$$\begin{aligned} W_{\text{rev,out}} = X_{\text{destroyed}} &= T_0 S_{\text{gen}} = T_0 \left[m_2 s_2 - m_1 s_1 + m_e s_e - \frac{Q_{\text{in}}}{T_{\text{source}}} \right] \\ &= (298 \text{ K}) [3.903 \times 0.91835 - 15.067 + 34.299 \times 0.35404 - 201.2 / 333] \\ &= \mathbf{16.87 \text{ kJ}} \end{aligned}$$

That is, 16.87 kJ of work could have been produced during this process.

8-83 A cylinder initially contains helium gas at a specified pressure and temperature. A valve is opened, and helium is allowed to escape until its volume decreases by half. The work potential of the helium at the initial state and the exergy destroyed during the 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 by using constant average properties for the helium leaving the tank. **2** Kinetic and potential energies are negligible. **3** There are no work interactions involved other than boundary work. **4** The tank is insulated and thus heat transfer is negligible. **5** Helium is an ideal gas with constant specific heats.

Properties The gas constant of helium is $R = 2.0769 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K} = 2.0769 \text{ kJ/kg} \cdot \text{K}$. The specific heats of helium are $c_p = 5.1926 \text{ kJ/kg} \cdot \text{K}$ and $c_v = 3.1156 \text{ kJ/kg} \cdot \text{K}$ (Table A-2).

Analysis (a) From the ideal gas relation, the initial and the final masses in the cylinder are determined to be

$$m_1 = \frac{P_1 V}{RT_1} = \frac{(300 \text{ kPa})(0.1 \text{ m}^3)}{(2.0769 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(293 \text{ K})} = 0.0493 \text{ kg}$$

$$m_e = m_2 = m_1 / 2 = 0.0493 / 2 = 0.0247 \text{ kg}$$

The work potential of helium at the initial state is simply the initial exergy of helium, and is determined from the closed-system exergy relation,

$$\Phi_1 = m_1 \phi = m_1 [(u_1 - u_0) - T_0 (s_1 - s_0) + P_0 (v_1 - v_0)]$$

where

$$v_1 = \frac{RT_1}{P_1} = \frac{(2.0769 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(293 \text{ K})}{300 \text{ kPa}} = 2.0284 \text{ m}^3/\text{kg}$$

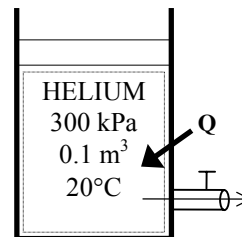
$$v_0 = \frac{RT_0}{P_0} = \frac{(2.0769 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(293 \text{ K})}{95 \text{ kPa}} = 6.405 \text{ m}^3/\text{kg}$$

and

$$\begin{aligned} s_1 - s_0 &= c_p \ln \frac{T_1}{T_0} - R \ln \frac{P_1}{P_0} \\ &= (5.1926 \text{ kJ/kg} \cdot \text{K}) \ln \frac{293 \text{ K}}{293 \text{ K}} - (2.0769 \text{ kJ/kg} \cdot \text{K}) \ln \frac{300 \text{ kPa}}{100 \text{ kPa}} \\ &= -2.28 \text{ kJ/kg} \cdot \text{K} \end{aligned}$$

Thus,

$$\begin{aligned} \Phi_1 &= (0.0493 \text{ kg}) \{ (3.1156 \text{ kJ/kg} \cdot \text{K})(20 - 20)^\circ\text{C} - (293 \text{ K})(-2.28 \text{ kJ/kg} \cdot \text{K}) \\ &\quad + (95 \text{ kPa})(2.0284 - 6.405) \text{ m}^3/\text{kg} [\text{kJ/kPa} \cdot \text{m}^3] \} \\ &= \mathbf{12.44 \text{ kJ}} \end{aligned}$$



(b) We take the cylinder as the system, which is a control volume. Noting that the microscopic 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

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

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

$$Q_{\text{in}} - m_e h_e + W_{\text{b,in}} = m_2 u_2 - m_1 u_1$$

Combining the two relations gives

$$\begin{aligned}
Q_{\text{in}} &= (m_1 - m_2)h_e + m_2u_2 - m_1u_1 - W_{\text{b,in}} \\
&= (m_1 - m_2)h_e + m_2h_2 - m_1h_1 \\
&= (m_1 - m_2 + m_2 - m_1)h_1 \\
&= 0
\end{aligned}$$

since the boundary work and ΔU combine into ΔH for constant pressure expansion and compression processes.

The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$ where the entropy generation S_{gen} can be determined from an entropy balance on the cylinder. Noting that the pressure and temperature of helium in the cylinder are maintained constant during this process and heat transfer is zero, it gives

$$\begin{aligned}
\underbrace{S_{\text{in}} - S_{\text{out}}}_{\text{Net entropy transfer by heat and mass}} + \underbrace{S_{\text{gen}}}_{\text{Entropy generation}} &= \underbrace{\Delta S_{\text{system}}}_{\text{Change in entropy}} \\
-m_e s_e + S_{\text{gen}} &= \Delta S_{\text{cylinder}} = (m_2 s_2 - m_1 s_1)_{\text{cylinder}} \\
S_{\text{gen}} &= m_2 s_2 - m_1 s_1 + m_e s_e \\
&= m_2 s_2 - m_1 s_1 + (m_1 - m_2) s_e \\
&= (m_2 - m_1 + m_1 - m_2) s_1 \\
&= 0
\end{aligned}$$

since the initial, final, and the exit states are identical and thus $s_e = s_2 = s_1$. Therefore, this discharge process is reversible, and

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} = \mathbf{0}$$

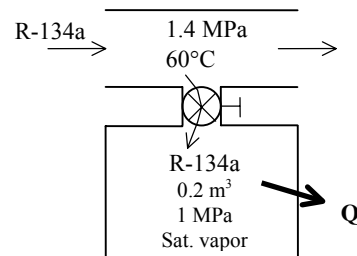
8-84 A rigid tank initially contains saturated R-134a vapor at a specified pressure. The tank is connected to a supply line, and R-134a is allowed to enter the tank. The amount of heat transfer with the surroundings and the exergy destruction are to be determined.

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 from the tank (will be verified).

Properties The properties of refrigerant are (Tables A-11 through A-13)

$$\left. \begin{array}{l} P_1 = 1 \text{ MPa} \\ \text{sat. vapor} \end{array} \right\} \begin{array}{l} u_1 = u_g @ 1 \text{ MPa} = 250.68 \text{ kJ/kg} \\ s_1 = s_g @ 1 \text{ MPa} = 0.91558 \text{ kJ/kg} \cdot \text{K} \\ v_1 = v_g @ 1 \text{ MPa} = 0.020313 \text{ m}^3 / \text{kg} \end{array}$$

$$\left. \begin{array}{l} P_i = 1.4 \text{ MPa} \\ T_i = 60^\circ\text{C} \end{array} \right\} \begin{array}{l} h_i = 285.47 \text{ kJ/kg} \\ s_i = 0.93889 \text{ kJ/kg} \cdot \text{K} \end{array}$$



Analysis (a) We take the tank as the system, which is a control volume since mass crosses the boundary. Noting that the microscopic 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: $\underbrace{E_{\text{in}} - E_{\text{out}}}_{\text{Net energy transfer by heat, work, and mass}} = \underbrace{\Delta E_{\text{system}}}_{\text{Change in internal, kinetic, potential, etc. energies}}$

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

The initial and the final masses in the tank are

$$m_1 = \frac{V}{v_1} = \frac{0.2 \text{ m}^3}{0.020313 \text{ m}^3 / \text{kg}} = 9.846 \text{ kg}$$

$$m_2 = m_f + m_g = \frac{V_f}{v_f} + \frac{V_g}{v_g} = \frac{0.1 \text{ m}^3}{0.0008934 \text{ m}^3 / \text{kg}} + \frac{0.1 \text{ m}^3}{0.016715 \text{ m}^3 / \text{kg}} = 111.93 + 5.983 = 117.91 \text{ kg}$$

$$U_2 = m_2 u_2 = m_f u_f + m_g u_g = 111.93 \times 116.70 + 5.983 \times 253.81 = 14,581 \text{ kJ}$$

$$S_2 = m_2 s_2 = m_f s_f + m_g s_g = 111.93 \times 0.42441 + 5.983 \times 0.91303 = 52.967 \text{ kJ/K}$$

Then from the mass and energy balances,

$$m_i = m_2 - m_1 = 117.91 - 9.846 = 108.06 \text{ kg}$$

The heat transfer during this process is determined from the energy balance to be

$$Q_{\text{out}} = m_i h_i - m_2 u_2 + m_1 u_1 = 108.06 \times 285.47 - 14,581 + 9.846 \times 250.68 = \mathbf{18,737 \text{ kJ}}$$

(b) The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$. The entropy generation S_{gen} in this case is determined from an entropy balance on an *extended system* that includes the cylinder and its immediate surroundings so that the boundary temperature of the extended system is the surroundings temperature T_{surr} at all times. It gives

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

$$S_{\text{gen}} = m_2 s_2 - m_1 s_1 - m_i s_i + \frac{Q_{\text{out}}}{T_0}$$

Substituting, the exergy destruction is determined to be

$$\begin{aligned} X_{\text{destroyed}} &= T_0 S_{\text{gen}} = T_0 \left[m_2 s_2 - m_1 s_1 - m_i s_i + \frac{Q_{\text{out}}}{T_0} \right] \\ &= (298 \text{ K}) [52.967 - 9.846 \times 0.91558 - 108.06 \times 0.93889 + 18,737 / 298] = \mathbf{1599 \text{ kJ}} \end{aligned}$$

8-85 An insulated cylinder initially contains saturated liquid-vapor mixture of water. The cylinder is connected to a supply line, and the steam is allowed to enter the cylinder until all the liquid is vaporized. The amount of steam that entered the cylinder and the exergy destroyed 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** The expansion process is quasi-equilibrium. **3** Kinetic and potential energies are negligible. **4** The device is insulated and thus heat transfer is negligible.

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

$$\left. \begin{array}{l} P_1 = 200 \text{ kPa} \\ x_1 = 9/15 = 0.6 \end{array} \right\} \begin{array}{l} h_1 = h_f + x_1 h_{fg} = 504.71 + 0.6 \times 2201.6 = 1825.6 \text{ kJ/kg} \\ s_1 = s_f + x_1 s_{fg} = 1.5302 + 0.6 \times 5.5968 = 4.8883 \text{ kJ/kg} \cdot \text{K} \end{array}$$

$$\left. \begin{array}{l} P_2 = 200 \text{ kPa} \\ \text{sat. vapor} \end{array} \right\} \begin{array}{l} h_2 = h_{g@200 \text{ kPa}} = 2706.3 \text{ kJ/kg} \\ s_2 = s_{g@200 \text{ kPa}} = 7.1270 \text{ kJ/kg} \cdot \text{K} \end{array}$$

$$\left. \begin{array}{l} P_i = 1 \text{ MPa} \\ T_i = 400^\circ\text{C} \end{array} \right\} \begin{array}{l} h_i = 3264.5 \text{ kJ/kg} \\ s_i = 7.4670 \text{ kJ/kg} \cdot \text{K} \end{array}$$

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

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

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

$$m_i h_i = W_{\text{b,out}} + m_2 u_2 - m_1 u_1 \quad (\text{since } Q \cong \text{ke} \cong \text{pe} \cong 0)$$

$$\text{Combining the two relations gives} \quad 0 = W_{\text{b,out}} - (m_2 - m_1) h_i + m_2 u_2 - m_1 u_1$$

$$\text{or,} \quad 0 = -(m_2 - m_1) h_i + m_2 h_2 - m_1 h_1$$

since the boundary work and ΔU combine into ΔH for constant pressure expansion and compression processes. Solving for m_2 and substituting,

$$m_2 = \frac{h_i - h_1}{h_i - h_2} m_1 = \frac{(3264.5 - 1825.6) \text{ kJ/kg}}{(3264.5 - 2706.3) \text{ kJ/kg}} (15 \text{ kg}) = 38.66 \text{ kg}$$

Thus,

$$m_i = m_2 - m_1 = 38.66 - 15 = \mathbf{23.66 \text{ kg}}$$

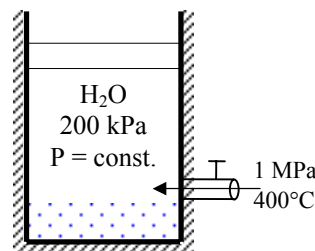
(b) The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$ where the entropy generation S_{gen} is determined from an entropy balance on the insulated cylinder,

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

$$m_i s_i + S_{\text{gen}} = \Delta S_{\text{system}} = m_2 s_2 - m_1 s_1 \rightarrow S_{\text{gen}} = m_2 s_2 - m_1 s_1 - m_i s_i$$

Substituting, the exergy destruction is determined to be

$$\begin{aligned} X_{\text{destroyed}} &= T_0 S_{\text{gen}} = T_0 [m_2 s_2 - m_1 s_1 - m_i s_i] \\ &= (298 \text{ K})(38.66 \times 7.1270 - 15 \times 4.8883 - 23.66 \times 7.4670) = \mathbf{7610 \text{ kJ}} \end{aligned}$$



8-86 Each member of a family of four take a shower every day. The amount of exergy destroyed by this family per year is to be determined.

Assumptions **1** Steady operating conditions exist. **2** The kinetic and potential energies are negligible. **3** Heat losses from the pipes, mixing section are negligible and thus $\dot{Q} \cong 0$. **4** Showers operate at maximum flow conditions during the entire shower. **5** Each member of the household takes a shower every day. **6** Water is an incompressible substance with constant properties at room temperature. **7** The efficiency of the electric water heater is 100%.

Properties The density and specific heat of water are at room temperature are $\rho = 1 \text{ kg/L} = 1000 \text{ kg/m}^3$ and $c = 4.18 \text{ kJ/kg}\cdot^\circ\text{C}$ (Table A-3).

Analysis The mass flow rate of water at the shower head is

$$\dot{m} = \rho \dot{V} = (1 \text{ kg/L})(10 \text{ L/min}) = 10 \text{ kg/min}$$

The mass balance for the mixing chamber can be expressed in the rate form as

$$\dot{m}_{\text{in}} - \dot{m}_{\text{out}} = \Delta \dot{m}_{\text{system}}^{\text{no (steady)}} = 0 \rightarrow \dot{m}_{\text{in}} = \dot{m}_{\text{out}} \rightarrow \dot{m}_1 + \dot{m}_2 = \dot{m}_3$$

where the subscript 1 denotes the cold water stream, 2 the hot water stream, and 3 the mixture.

The rate of entropy generation during this process can be determined by applying the rate form of the entropy balance on a system that includes the electric water heater and the mixing chamber (the T-elbow). Noting that there is no entropy transfer associated with work transfer (electricity) and there is no heat transfer, the entropy balance for this steady-flow system can be expressed as

$$\underbrace{\dot{S}_{\text{in}} - \dot{S}_{\text{out}}}_{\text{Rate of net entropy transfer by heat and mass}} + \underbrace{\dot{S}_{\text{gen}}}_{\text{Rate of entropy generation}} = \underbrace{\Delta \dot{S}_{\text{system}}^{\text{no (steady)}}}_{\text{Rate of change of entropy}}$$

$$\dot{m}_1 s_1 + \dot{m}_2 s_2 - \dot{m}_3 s_3 + \dot{S}_{\text{gen}} = 0 \quad (\text{since } \dot{Q} = 0 \text{ and work is entropy free})$$

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

Noting from mass balance that $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$ and $s_2 = s_1$ since hot water enters the system at the same temperature as the cold water, the rate of entropy generation is determined to be

$$\dot{S}_{\text{gen}} = \dot{m}_3 s_3 - (\dot{m}_1 + \dot{m}_2) s_1 = \dot{m}_3 (s_3 - s_1) = \dot{m}_3 c_p \ln \frac{T_3}{T_1}$$

$$= (10 \text{ kg/min})(4.18 \text{ kJ/kg}\cdot\text{K}) \ln \frac{42 + 273}{15 + 273} = 3.746 \text{ kJ/min}\cdot\text{K}$$

Noting that 4 people take a 6-min shower every day, the amount of entropy generated per year is

$$S_{\text{gen}} = (\dot{S}_{\text{gen}}) \Delta t (\text{No. of people}) (\text{No. of days})$$

$$= (3.746 \text{ kJ/min}\cdot\text{K})(6 \text{ min/person}\cdot\text{day})(4 \text{ persons})(365 \text{ days/year})$$

$$= 32,815 \text{ kJ/K (per year)}$$

The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$,

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} = (298 \text{ K})(32,815 \text{ kJ/K}) = \mathbf{9,779,000 \text{ kJ}}$$

Discussion The value above represents the exergy destroyed within the water heater and the T-elbow in the absence of any heat losses. It does not include the exergy destroyed as the shower water at 42°C is discarded or cooled to the outdoor temperature. Also, an entropy balance on the mixing chamber alone (hot water entering at 55°C instead of 15°C) will exclude the exergy destroyed within the water heater.

8-87 Air is compressed in a steady-flow device isentropically. The work done, the exit exergy of compressed air, and the exergy of compressed air after it is cooled to ambient temperature are to be determined.

Assumptions **1** Air is an ideal gas with constant specific heats at room temperature. **2** The process is given to be reversible and adiabatic, and thus isentropic. Therefore, isentropic relations of ideal gases apply. **3** The environment temperature and pressure are given to be 300 K and 100 kPa. **4** The kinetic and potential energies are negligible.

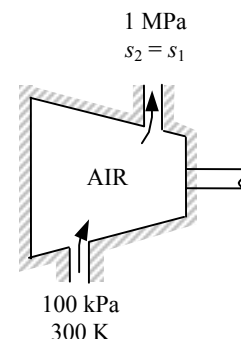
Properties The gas constant of air is $R = 0.287 \text{ kJ/kg}\cdot\text{K}$ (Table A-1). The constant pressure specific heat and specific heat ratio of air at room temperature are $c_p = 1.005 \text{ kJ/kg}\cdot\text{K}$ and $k = 1.4$ (Table A-2).

Analysis (a) From the constant specific heats ideal gas isentropic relations,

$$T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{(k-1)/k} = (300 \text{ K}) \left(\frac{1000 \text{ kPa}}{100 \text{ kPa}} \right)^{0.4/1.4} = 579.2 \text{ K}$$

For a steady-flow isentropic compression process, the work input is determined from

$$\begin{aligned} w_{\text{comp, in}} &= \frac{kRT_1}{k-1} \left\{ \left(P_2/P_1 \right)^{(k-1)/k} - 1 \right\} \\ &= \frac{(1.4)(0.287 \text{ kJ/kg}\cdot\text{K})(300 \text{ K})}{1.4-1} \left\{ (1000/100)^{0.4/1.4} - 1 \right\} \\ &= \mathbf{280.5 \text{ kJ/kg}} \end{aligned}$$



(b) The exergy of air at the compressor exit is simply the flow exergy at the exit state,

$$\begin{aligned} \psi_2 &= h_2 - h_0 - T_0(s_2 - s_0) + \frac{V_2^2}{2} + gz_2 \quad (\text{since the process } 0-2 \text{ is isentropic}) \\ &= c_p(T_2 - T_0) \\ &= (1.005 \text{ kJ/kg}\cdot\text{K})(579.2 - 300) \text{ K} = \mathbf{280.6 \text{ kJ/kg}} \end{aligned}$$

which is the same as the compressor work input. This is not surprising since the compression process is reversible.

(c) The exergy of compressed air at 1 MPa after it is cooled to 300 K is again the flow exergy at that state,

$$\begin{aligned} \psi_3 &= h_3 - h_0 - T_0(s_3 - s_0) + \frac{V_3^2}{2} + gz_3 \\ &= c_p(T_3 - T_0) - T_0(s_3 - s_0) \quad (\text{since } T_3 = T_0 = 300 \text{ K}) \\ &= -T_0(s_3 - s_0) \end{aligned}$$

where

$$s_3 - s_0 = c_p \ln \frac{T_3}{T_0} - R \ln \frac{P_3}{P_0} = -R \ln \frac{P_3}{P_0} = -(0.287 \text{ kJ/kg}\cdot\text{K}) \ln \frac{1000 \text{ kPa}}{100 \text{ kPa}} = -0.661 \text{ kJ/kg}\cdot\text{K}$$

Substituting,

$$\psi_3 = -(300 \text{ K})(-0.661 \text{ kJ/kg}\cdot\text{K}) = \mathbf{198 \text{ kJ/kg}}$$

Note that the exergy of compressed air decreases from 280.6 to 198 as it is cooled to ambient temperature.

8-88 Cold water is heated by hot water in a heat exchanger. The rate of heat transfer and the rate of exergy destruction within the heat exchanger are to be determined.

Assumptions 1 Steady operating conditions exist. 2 The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. 3 Changes in the kinetic and potential energies of fluid streams are negligible. 4 Fluid properties are constant. 5 The temperature of the environment is 25°C.

Properties The specific heats of cold and hot water are given to be 4.18 and 4.19 kJ/kg·°C, respectively.

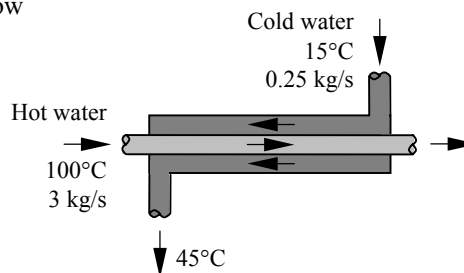
Analysis We take the cold water tubes as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as

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

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

$$\dot{Q}_{\text{in}} + \dot{m}h_1 = \dot{m}h_2 \quad (\text{since } \Delta \text{ke} \cong \Delta \text{pe} \cong 0)$$

$$\dot{Q}_{\text{in}} = \dot{m}c_p(T_2 - T_1)$$



Then the rate of heat transfer to the cold water in this heat exchanger becomes

$$\dot{Q}_{\text{in}} = [\dot{m}c_p(T_{\text{out}} - T_{\text{in}})]_{\text{cold water}} = (0.25 \text{ kg/s})(4.18 \text{ kJ/kg} \cdot ^\circ\text{C})(45^\circ\text{C} - 15^\circ\text{C}) = \mathbf{31.35 \text{ kW}}$$

Noting that heat gain by the cold water is equal to the heat loss by the hot water, the outlet temperature of the hot water is determined to be

$$\dot{Q} = [\dot{m}c_p(T_{\text{in}} - T_{\text{out}})]_{\text{hot water}} \longrightarrow T_{\text{out}} = T_{\text{in}} - \frac{\dot{Q}}{\dot{m}c_p}$$

$$= 100^\circ\text{C} - \frac{31.35 \text{ kW}}{(3 \text{ kg/s})(4.19 \text{ kJ/kg} \cdot ^\circ\text{C})} = \mathbf{97.5^\circ\text{C}}$$

(b) The rate of entropy generation within the heat exchanger is determined by applying the rate form of the entropy balance on the entire heat exchanger:

$$\underbrace{\dot{S}_{\text{in}} - \dot{S}_{\text{out}}}_{\text{Rate of net entropy transfer by heat and mass}} + \underbrace{\dot{S}_{\text{gen}}}_{\text{Rate of entropy generation}} = \underbrace{\Delta \dot{S}_{\text{system}}}_{\text{Rate of change of entropy}} \overset{\approx 0 \text{ (steady)}}{=} 0$$

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

$$\dot{m}_{\text{cold}} s_1 + \dot{m}_{\text{hot}} s_3 - \dot{m}_{\text{cold}} s_2 - \dot{m}_{\text{hot}} s_4 + \dot{S}_{\text{gen}} = 0$$

$$\dot{S}_{\text{gen}} = \dot{m}_{\text{cold}}(s_2 - s_1) + \dot{m}_{\text{hot}}(s_4 - s_3)$$

Noting that both fluid streams are liquids (incompressible substances), the rate of entropy generation is determined to be

$$\dot{S}_{\text{gen}} = \dot{m}_{\text{cold}} c_p \ln \frac{T_2}{T_1} + \dot{m}_{\text{hot}} c_p \ln \frac{T_4}{T_3}$$

$$= (0.25 \text{ kg/s})(4.18 \text{ kJ/kg} \cdot \text{K}) \ln \frac{45 + 273}{15 + 273} + (3 \text{ kg/s})(4.19 \text{ kJ/kg} \cdot \text{K}) \ln \frac{97.5 + 273}{100 + 273} = \mathbf{0.0190 \text{ kW/K}}$$

The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$,

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} = (298 \text{ K})(0.019 \text{ kW/K}) = \mathbf{5.66 \text{ kW}}$$

8-89 Air is preheated by hot exhaust gases in a cross-flow heat exchanger. The rate of heat transfer and the rate of exergy destruction in the heat exchanger are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** Fluid properties are constant.

Properties The specific heats of air and combustion gases are given to be 1.005 and 1.10 kJ/kg.°C, respectively. The gas constant of air is $R = 0.287$ kJ/kg.K (Table A-1).

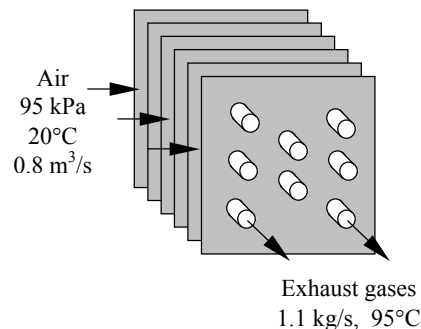
Analysis We take the exhaust pipes as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as

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

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

$$\dot{m}h_1 = \dot{Q}_{\text{out}} + \dot{m}h_2 \quad (\text{since } \Delta \text{ke} \cong \Delta \text{pe} \cong 0)$$

$$\dot{Q}_{\text{out}} = \dot{m}C_p(T_1 - T_2)$$



Then the rate of heat transfer from the exhaust gases becomes

$$\dot{Q} = [\dot{m}c_p(T_{\text{in}} - T_{\text{out}})]_{\text{gas.}} = (1.1 \text{ kg/s})(1.1 \text{ kJ/kg.°C})(180^\circ\text{C} - 95^\circ\text{C}) = \mathbf{102.85 \text{ kW}}$$

The mass flow rate of air is

$$\dot{m} = \frac{P\dot{V}}{RT} = \frac{(95 \text{ kPa})(0.8 \text{ m}^3/\text{s})}{(0.287 \text{ kPa.m}^3/\text{kg.K}) \times 293 \text{ K}} = 0.904 \text{ kg/s}$$

Noting that heat loss by exhaust gases is equal to the heat gain by the air, the air exit temperature becomes

$$\dot{Q} = [\dot{m}C_p(T_{\text{out}} - T_{\text{in}})]_{\text{air}} \rightarrow T_{\text{out}} = T_{\text{in}} + \frac{\dot{Q}}{\dot{m}c_p} = 20^\circ\text{C} + \frac{102.85 \text{ kW}}{(0.904 \text{ kg/s})(1.005 \text{ kJ/kg.°C})} = 133.2^\circ\text{C}$$

The rate of entropy generation within the heat exchanger is determined by applying the rate form of the entropy balance on the entire heat exchanger:

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

$$\dot{m}_1s_1 + \dot{m}_3s_3 - \dot{m}_2s_2 - \dot{m}_4s_4 + \dot{S}_{\text{gen}} = 0 \quad (\text{since } \dot{Q} = 0)$$

$$\dot{m}_{\text{exhaust}}s_1 + \dot{m}_{\text{air}}s_3 - \dot{m}_{\text{exhaust}}s_2 - \dot{m}_{\text{air}}s_4 + \dot{S}_{\text{gen}} = 0$$

$$\dot{S}_{\text{gen}} = \dot{m}_{\text{exhaust}}(s_2 - s_1) + \dot{m}_{\text{air}}(s_4 - s_3)$$

Noting that both fluid streams are liquids (incompressible substances), the rate of entropy generation is

$$\dot{S}_{\text{gen}} = \dot{m}_{\text{exhaust}}c_p \ln \frac{T_2}{T_1} + \dot{m}_{\text{air}}c_p \ln \frac{T_4}{T_3}$$

$$= (1.1 \text{ kg/s})(1.1 \text{ kJ/kg.K}) \ln \frac{95 + 273}{180 + 273} + (0.904 \text{ kg/s})(1.005 \text{ kJ/kg.K}) \ln \frac{133.2 + 273}{20 + 273} = 0.0453 \text{ kW/K}$$

The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $\dot{X}_{\text{destroyed}} = T_0 \dot{S}_{\text{gen}}$,

$$\dot{X}_{\text{destroyed}} = T_0 \dot{S}_{\text{gen}} = (293 \text{ K})(0.0453 \text{ kW/K}) = \mathbf{13.3 \text{ kW}}$$

8-90 Water is heated by hot oil in a heat exchanger. The outlet temperature of the oil and the rate of exergy destruction within the heat exchanger are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** Fluid properties are constant.

Properties The specific heats of water and oil are given to be 4.18 and 2.3 kJ/kg·°C, respectively.

Analysis We take the cold water tubes as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\text{Rate of net energy transfer by heat, work, and mass}} = \underbrace{\Delta \dot{E}_{\text{system}}}_{\text{Rate of change in internal, kinetic, potential, etc. energies}} \overset{\text{no (steady)}}{=} 0$$

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

$$\dot{Q}_{\text{in}} + \dot{m}h_1 = \dot{m}h_2 \quad (\text{since } \Delta ke \cong \Delta pe \cong 0)$$

$$\dot{Q}_{\text{in}} = \dot{m}c_p(T_2 - T_1)$$

Then the rate of heat transfer to the cold water in this heat exchanger becomes

$$\dot{Q} = [\dot{m}c_p(T_{\text{out}} - T_{\text{in}})]_{\text{water}} = (4.5 \text{ kg/s})(4.18 \text{ kJ/kg} \cdot ^\circ\text{C})(70^\circ\text{C} - 20^\circ\text{C}) = 940.5 \text{ kW}$$

Noting that heat gain by the water is equal to the heat loss by the oil, the outlet temperature of the hot water is determined from

$$\dot{Q} = [\dot{m}c_p(T_{\text{in}} - T_{\text{out}})]_{\text{oil}} \rightarrow T_{\text{out}} = T_{\text{in}} - \frac{\dot{Q}}{\dot{m}c_p} = 170^\circ\text{C} - \frac{940.5 \text{ kW}}{(10 \text{ kg/s})(2.3 \text{ kJ/kg} \cdot ^\circ\text{C})} = 129.1^\circ\text{C}$$

(b) The rate of entropy generation within the heat exchanger is determined by applying the rate form of the entropy balance on the entire heat exchanger:

$$\underbrace{\dot{S}_{\text{in}} - \dot{S}_{\text{out}}}_{\text{Rate of net entropy transfer by heat and mass}} + \underbrace{\dot{S}_{\text{gen}}}_{\text{Rate of entropy generation}} = \underbrace{\Delta \dot{S}_{\text{system}}}_{\text{Rate of change of entropy}} \overset{\text{no (steady)}}{=} 0$$

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

$$\dot{m}_{\text{water}} s_1 + \dot{m}_{\text{oil}} s_3 - \dot{m}_{\text{water}} s_2 - \dot{m}_{\text{oil}} s_4 + \dot{S}_{\text{gen}} = 0$$

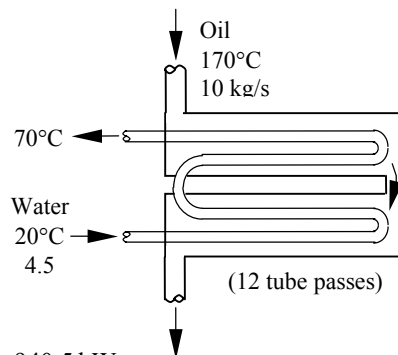
$$\dot{S}_{\text{gen}} = \dot{m}_{\text{water}}(s_2 - s_1) + \dot{m}_{\text{oil}}(s_4 - s_3)$$

Noting that both fluid streams are liquids (incompressible substances), the rate of entropy generation is determined to be

$$\begin{aligned} \dot{S}_{\text{gen}} &= \dot{m}_{\text{water}} c_p \ln \frac{T_2}{T_1} + \dot{m}_{\text{oil}} c_p \ln \frac{T_4}{T_3} \\ &= (4.5 \text{ kg/s})(4.18 \text{ kJ/kg} \cdot \text{K}) \ln \frac{70 + 273}{20 + 273} + (10 \text{ kg/s})(2.3 \text{ kJ/kg} \cdot \text{K}) \ln \frac{129.1 + 273}{170 + 273} = 0.736 \text{ kW/K} \end{aligned}$$

The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $\dot{X}_{\text{destroyed}} = T_0 \dot{S}_{\text{gen}}$,

$$\dot{X}_{\text{destroyed}} = T_0 \dot{S}_{\text{gen}} = (298 \text{ K})(0.736 \text{ kW/K}) = 219 \text{ kW}$$



8-91E Steam is condensed by cooling water in a condenser. The rate of heat transfer and the rate of exergy destruction within the heat exchanger are to be determined.

Assumptions 1 Steady operating conditions exist. 2 The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. 3 Changes in the kinetic and potential energies of fluid streams are negligible. 4 Fluid properties are constant. 5 The temperature of the environment is 77°F.

Properties The specific heat of water is 1.0 Btu/lbm·°F (Table A-3E). The enthalpy and entropy of vaporization of water at 120°F are 1025.2 Btu/lbm and $s_{fg} = 1.7686$ Btu/lbm·R (Table A-4E).

Analysis We take the tube-side of the heat exchanger where cold water is flowing as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\text{Rate of net energy transfer by heat, work, and mass}} = \underbrace{\Delta \dot{E}_{system}}_{\text{Rate of change in internal, kinetic, potential, etc. energies}} \overset{\text{no (steady)}}{=} 0$$

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

$$\dot{Q}_{in} + \dot{m}h_1 = \dot{m}h_2 \quad (\text{since } \Delta ke \cong \Delta pe \cong 0)$$

$$\dot{Q}_{in} = \dot{m}c_p(T_2 - T_1)$$

Then the rate of heat transfer to the cold water in this heat exchanger becomes

$$\begin{aligned} \dot{Q} &= [\dot{m}c_p(T_{out} - T_{in})]_{\text{water}} \\ &= (115.3 \text{ lbm/s})(1.0 \text{ Btu/lbm} \cdot \text{°F})(73\text{°F} - 60\text{°F}) = \mathbf{1499 \text{ Btu/s}} \end{aligned}$$

Noting that heat gain by the water is equal to the heat loss by the condensing steam, the rate of condensation of the steam in the heat exchanger is determined from

$$\dot{Q} = (\dot{m}h_{fg})_{\text{steam}} \longrightarrow \dot{m}_{\text{steam}} = \frac{\dot{Q}}{h_{fg}} = \frac{1499 \text{ Btu/s}}{1025.2 \text{ Btu/lbm}} = 1.462 \text{ lbm/s}$$

(b) The rate of entropy generation within the heat exchanger is determined by applying the rate form of the entropy balance on the entire heat exchanger:

$$\underbrace{\dot{S}_{in} - \dot{S}_{out}}_{\text{Rate of net entropy transfer by heat and mass}} + \underbrace{\dot{S}_{gen}}_{\text{Rate of entropy generation}} = \underbrace{\Delta \dot{S}_{system}}_{\text{Rate of change of entropy}} \overset{\text{no (steady)}}{=} 0$$

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

$$\dot{m}_{\text{water}} s_1 + \dot{m}_{\text{steam}} s_3 - \dot{m}_{\text{water}} s_2 - \dot{m}_{\text{steam}} s_4 + \dot{S}_{gen} = 0$$

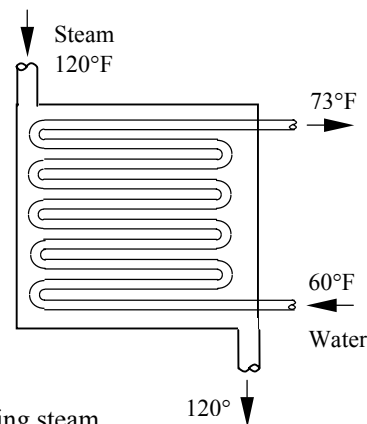
$$\dot{S}_{gen} = \dot{m}_{\text{water}}(s_2 - s_1) + \dot{m}_{\text{steam}}(s_4 - s_3)$$

Noting that water is an incompressible substance and steam changes from saturated vapor to saturated liquid, the rate of entropy generation is determined to be

$$\begin{aligned} \dot{S}_{gen} &= \dot{m}_{\text{water}} c_p \ln \frac{T_2}{T_1} + \dot{m}_{\text{steam}}(s_f - s_g) = \dot{m}_{\text{water}} c_p \ln \frac{T_2}{T_1} - \dot{m}_{\text{steam}} s_{fg} \\ &= (115.3 \text{ lbm/s})(1.0 \text{ Btu/lbm} \cdot \text{R}) \ln \frac{73 + 460}{60 + 460} - (1.462 \text{ lbm/s})(1.7686 \text{ Btu/lbm} \cdot \text{R}) = 0.2613 \text{ Btu/s} \cdot \text{R} \end{aligned}$$

The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $\dot{X}_{\text{destroyed}} = T_0 \dot{S}_{gen}$,

$$\dot{X}_{\text{destroyed}} = T_0 \dot{S}_{gen} = (537 \text{ R})(0.2613 \text{ Btu/s} \cdot \text{R}) = \mathbf{140.3 \text{ Btu/s}}$$



8-92 Steam expands in a turbine, which is not insulated. The reversible power, the exergy destroyed, the second-law efficiency, and the possible increase in the turbine power if the turbine is well insulated are to be determined.

Assumptions 1 Steady operating conditions exist. 2 Potential energy change is negligible.

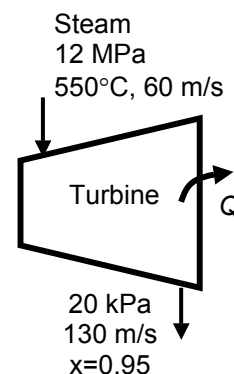
Analysis (a) The properties of the steam at the inlet and exit of the turbine are (Tables A-4 through A-6)

$$\begin{aligned} P_1 = 12 \text{ MPa} \quad \left. \begin{aligned} h_1 &= 3481.7 \text{ kJ/kg} \\ T_1 &= 550^\circ\text{C} \end{aligned} \right\} s_1 = 6.6554 \text{ kJ/kg}\cdot\text{K} \\ P_2 = 20 \text{ kPa} \quad \left. \begin{aligned} h_2 &= 2491.1 \text{ kJ/kg} \\ x_2 &= 0.95 \end{aligned} \right\} s_2 = 7.5535 \text{ kJ/kg}\cdot\text{K} \end{aligned}$$

The enthalpy at the dead state is

$$\begin{aligned} T_0 = 25^\circ\text{C} \\ x = 0 \end{aligned} \left. \right\} h_0 = 104.83 \text{ kJ/kg}$$

The mass flow rate of steam may be determined from an energy balance on the turbine



$$\begin{aligned} \dot{m} \left(h_1 + \frac{V_1^2}{2} \right) &= \dot{m} \left(h_2 + \frac{V_2^2}{2} \right) + \dot{Q}_{\text{out}} + \dot{W}_a \\ \dot{m} \left[3481.7 \text{ kJ/kg} + \frac{(60 \text{ m/s})^2}{2} \left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2} \right) \right] &= \dot{m} \left[2491.1 \text{ kJ/kg} + \frac{(130 \text{ m/s})^2}{2} \left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2} \right) \right] \\ + 150 \text{ kW} + 2500 \text{ kW} &\longrightarrow \dot{m} = 2.693 \text{ kg/s} \end{aligned}$$

The reversible power may be determined from

$$\begin{aligned} \dot{W}_{\text{rev}} &= \dot{m} \left[h_1 - h_2 - T_0 (s_1 - s_2) + \frac{V_1^2 - V_2^2}{2} \right] \\ &= (2.693) \left[(3481.7 - 2491.1) - (298)(6.6554 - 7.5535) + \frac{(60 \text{ m/s})^2 - (130 \text{ m/s})^2}{2} \left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2} \right) \right] \\ &= \mathbf{3371 \text{ kW}} \end{aligned}$$

(b) The exergy destroyed in the turbine is

$$\dot{X}_{\text{dest}} = \dot{W}_{\text{rev}} - \dot{W}_a = 3371 - 2500 = \mathbf{871 \text{ kW}}$$

(c) The second-law efficiency is

$$\eta_{II} = \frac{\dot{W}_a}{\dot{W}_{\text{rev}}} = \frac{2500 \text{ kW}}{3371 \text{ kW}} = \mathbf{0.742}$$

(d) The energy of the steam at the turbine inlet in the given dead state is

$$\dot{Q} = \dot{m}(h_1 - h_0) = (2.693 \text{ kg/s})(3481.7 - 104.83) \text{ kJ/kg} = 9095 \text{ kW}$$

The fraction of energy at the turbine inlet that is converted to power is

$$f = \frac{\dot{W}_a}{\dot{Q}} = \frac{2500 \text{ kW}}{9095 \text{ kW}} = 0.2749$$

Assuming that the same fraction of heat loss from the turbine could have been converted to work, the possible increase in the power if the turbine is to be well-insulated becomes

$$\dot{W}_{\text{increase}} = f\dot{Q}_{\text{out}} = (0.2749)(150 \text{ kW}) = \mathbf{41.2 \text{ kW}}$$

8-93 Air is compressed in a compressor that is intentionally cooled. The actual and reversible power inputs, the second law efficiency, and the mass flow rate of cooling water are to be determined.

Assumptions 1 Steady operating conditions exist. 2 Potential energy change is negligible. 3 Air is an ideal gas with constant specific heats.

Properties The gas constant of air is $R = 0.287 \text{ kJ/kg}\cdot\text{K}$ and the specific heat of air at room is $c_p = 1.005 \text{ kJ/kg}\cdot\text{K}$. the specific heat of water at room temperature is $c_w = 4.18 \text{ kJ/kg}\cdot\text{K}$ (Tables A-2, A-3).

Analysis (a) The mass flow rate of air is

$$\dot{m} = \rho \dot{V}_1 = \frac{P_1}{RT_1} \dot{V}_1 = \frac{(100 \text{ kPa})}{(0.287 \text{ kJ/kg}\cdot\text{K})(20 + 273 \text{ K})} (4.5 \text{ m}^3/\text{s}) = 5.351 \text{ kg/s}$$

The power input for a reversible-isothermal process is given by

$$\dot{W}_{\text{rev}} = \dot{m} R T_1 \ln \frac{P_2}{P_1} = (5.351 \text{ kg/s})(0.287 \text{ kJ/kg}\cdot\text{K})(20 + 273 \text{ K}) \ln \left(\frac{900 \text{ kPa}}{100 \text{ kPa}} \right) = \mathbf{988.8 \text{ kW}}$$

Given the isothermal efficiency, the actual power may be determined from

$$\dot{W}_{\text{actual}} = \frac{\dot{W}_{\text{rev}}}{\eta_T} = \frac{988.8 \text{ kW}}{0.70} = \mathbf{1413 \text{ kW}}$$

(b) The given isothermal efficiency is actually the second-law efficiency of the compressor

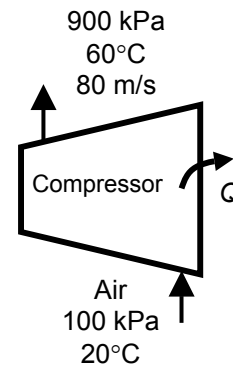
$$\eta_{\text{II}} = \eta_T = \mathbf{0.70}$$

(c) An energy balance on the compressor gives

$$\begin{aligned} \dot{Q}_{\text{out}} &= \dot{m} \left[C_p (T_1 - T_2) + \frac{V_1^2 - V_2^2}{2} \right] + \dot{W}_{\text{actual, in}} \\ &= (5.351 \text{ kg/s}) \left[(1.005 \text{ kJ/kg}\cdot^\circ\text{C})(20 - 60)^\circ\text{C} + \frac{0 - (80 \text{ m/s})^2}{2} \left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2} \right) \right] + 1413 \text{ kW} \\ &= \mathbf{1181 \text{ kW}} \end{aligned}$$

The mass flow rate of the cooling water is

$$\dot{m}_w = \frac{\dot{Q}_{\text{out}}}{c_w \Delta T} = \frac{1181 \text{ kW}}{(4.18 \text{ kJ/kg}\cdot^\circ\text{C})(10^\circ\text{C})} = \mathbf{28.25 \text{ kg/s}}$$

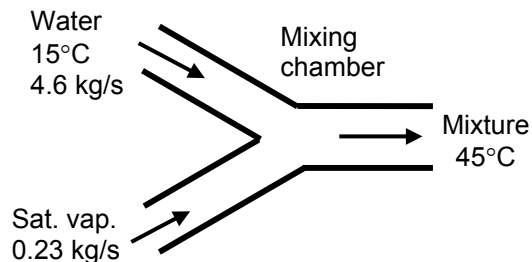


8-94 Water is heated in a chamber by mixing it with saturated steam. The temperature of the steam entering the chamber, the exergy destruction, and the second-law efficiency are to be determined.

Assumptions 1 Steady operating conditions exist. 2 Kinetic and potential energy changes are negligible. 3 Heat loss from the chamber is negligible.

Analysis (a) The properties of water are (Tables A-4 through A-6)

$$\begin{aligned} T_1 = 15^\circ\text{C} \quad \left\{ \begin{array}{l} h_1 = h_0 = 62.98 \text{ kJ/kg} \\ s_1 = s_0 = 0.22447 \text{ kJ/kg}\cdot\text{K} \end{array} \right. \\ x_1 = 0 \\ T_3 = 45^\circ\text{C} \quad \left\{ \begin{array}{l} h_3 = 188.44 \text{ kJ/kg} \\ s_3 = 0.63862 \text{ kJ/kg}\cdot\text{K} \end{array} \right. \\ x_1 = 0 \end{aligned}$$



An energy balance on the chamber gives

$$\begin{aligned} \dot{m}_1 h_1 + \dot{m}_2 h_2 &= \dot{m}_3 h_3 = (\dot{m}_1 + \dot{m}_2) h_3 \\ (4.6 \text{ kg/s})(62.98 \text{ kJ/kg}) + (0.23 \text{ kg/s}) h_2 &= (4.6 + 0.23 \text{ kg/s})(188.44 \text{ kJ/kg}) \\ h_2 &= 2697.5 \text{ kJ/kg} \end{aligned}$$

The remaining properties of the saturated steam are

$$\begin{aligned} h_2 = 2697.5 \text{ kJ/kg} \quad \left\{ \begin{array}{l} T_2 = \mathbf{114.3^\circ\text{C}} \\ s_2 = 7.1907 \text{ kJ/kg}\cdot\text{K} \end{array} \right. \\ x_2 = 1 \end{aligned}$$

(b) The specific exergy of each stream is

$$\psi_1 = 0$$

$$\psi_2 = h_2 - h_0 - T_0(s_2 - s_0) = (2697.5 - 62.98) \text{ kJ/kg} - (15 + 273 \text{ K})(7.1907 - 0.22447) \text{ kJ/kg}\cdot\text{K} = 628.28 \text{ kJ/kg}$$

$$\psi_3 = h_3 - h_0 - T_0(s_3 - s_0) = (188.44 - 62.98) \text{ kJ/kg} - (15 + 273 \text{ K})(0.63862 - 0.22447) \text{ kJ/kg}\cdot\text{K} = 6.18 \text{ kJ/kg}$$

The exergy destruction is determined from an exergy balance on the chamber to be

$$\begin{aligned} \dot{X}_{\text{dest}} &= \dot{m}_1 \psi_1 + \dot{m}_2 \psi_2 - (\dot{m}_1 + \dot{m}_2) \psi_3 \\ &= 0 + (0.23 \text{ kg/s})(628.28 \text{ kJ/kg}) - (4.6 + 0.23 \text{ kg/s})(6.18 \text{ kJ/kg}) \\ &= \mathbf{114.7 \text{ kW}} \end{aligned}$$

(c) The second-law efficiency for this mixing process may be determined from

$$\eta_{\text{II}} = \frac{(\dot{m}_1 + \dot{m}_2) \psi_3}{\dot{m}_1 \psi_1 + \dot{m}_2 \psi_2} = \frac{(4.6 + 0.23 \text{ kg/s})(6.18 \text{ kJ/kg})}{0 + (0.23 \text{ kg/s})(628.28 \text{ kJ/kg})} = \mathbf{0.207}$$