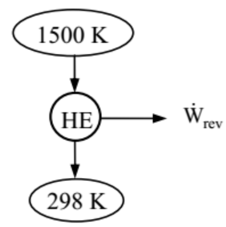
Homework-9 Solutions

Q 8-19

Analysis The exergy of the supplied heat, in the rate form, is the amount of power that would be produced by a reversible heat engine,



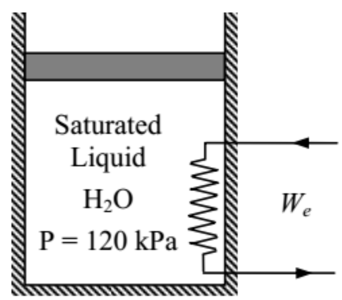
$$\eta_{th,max} = \eta_{th,rev} = 1 - \frac{T_0}{T_H} = 1 - \frac{298\text{ K}}{1500\text{ K}} = 0.8013$$

$$\begin{aligned}\text{Exergy} = \dot{W}_{max,out} = \dot{W}_{rev,out} &= \eta_{th,rev}\dot{Q}_{in} \\ &= (0.8013)(150{,}000/3600\text{ kJ/s}) \\ &= \mathbf{33.4\ kW}\end{aligned}$$

Q 8-36

Assumptions **1** The kinetic and potential energy changes are negligible. **2** The cylinder is well-insulated and thus heat transfer is negligible. **3** The thermal energy stored in the cylinder itself is negligible. **4** The compression or expansion process is quasi-equilibrium.

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



$$\left.\begin{array}{l} P_1 = 120\text{ kPa} \\ \text{sat. liquid}\end{array}\right\} \begin{array}{l} u_1 = u_{f\,@120\text{ kPa}} = 439.27\text{ kJ/kg} \\ v_1 = v_{f\,@120\text{ kPa}} = 0.001047\text{ m}^3\text{/kg} \\ h_1 = h_{f\,@120\text{ kPa}} = 439.36\text{ kJ/kg} \\ s_1 = s_{f\,@120\text{ kPa}} = 1.3609\text{ kJ/kg}\cdot\text{K}\end{array}$$

The mass of the steam is

$$m = \frac{V}{v_1} = \frac{0.008\text{ m}^3}{0.001047\text{ m}^3\text{/kg}} = 7.639\text{ kg}$$

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

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

$$W_{\text{e,in}} - W_{\text{b,out}} = \Delta U$$

$$W_{\text{e,in}} = m(h_2 - h_1)$$

since $\Delta U + W_b = \Delta H$ during a constant pressure quasi-equilibrium process. Solving for h_2,

$$h_2 = h_1 + \frac{W_{e,in}}{m} = 439.36 + \frac{1400\text{ kJ}}{7.639\text{ kg}} = 622.63\text{ kJ/kg}$$

Thus,

$$\left.\begin{array}{l} P_2 = 120\text{ kPa} \\ h_2 = 622.63\text{ kJ/kg} \end{array}\right\} \begin{array}{l} x_2 = \dfrac{h_2 - h_f}{h_{fg}} = \dfrac{622.63 - 439.36}{2243.7} = 0.08168 \\ s_2 = s_f + x_2 s_{fg} = 1.3609 + 0.08168 \times 5.93687 = 1.8459\text{ kJ/kg}\cdot\text{K} \\ u_2 = u_f + x_2 u_{fg} = 439.24 + 0.08168 \times 2072.4 = 608.52\text{ kJ/kg} \\ \boldsymbol{v}_2 = \boldsymbol{v}_f + x_2 \boldsymbol{v}_{fg} = 0.001047 + 0.08168 \times (1.4285 - 0.001047) = 0.1176\text{ m}^3\text{/kg} \end{array}$$

The reversible work input, which represents the minimum work input $W_{\text{rev,in}}$ in this case can be determined from the exergy balance by setting the exergy destruction equal to zero,

$$\underbrace{X_{\text{in}} - X_{\text{out}}}_{\substack{\text{Net exergy transfer}\\ \text{by heat, work, and mass}}} \underbrace{- X_{\text{destroyed}}^{\nearrow 0\text{ (reversible)}}}_{\substack{\text{Exergy}\\ \text{destruction}}} = \underbrace{\Delta X_{\text{system}}}_{\substack{\text{Change}\\ \text{in exergy}}} \rightarrow W_{\text{rev,in}} = X_2 - X_1$$

Substituting the closed system exergy relation, the reversible work input during this process is determined to be

$$\begin{aligned} W_{\text{rev,in}} &= -m\left[(u_1 - u_2) - T_0(s_1 - s_2) + P_0(\boldsymbol{v}_1 - \boldsymbol{v}_2)\right] \\ &= -(7.639\text{ kg})\{(439.27 - 608.52)\text{ kJ/kg} - (298\text{ K})(1.3609 - 1.8459)\text{ kJ/kg}\cdot\text{K} \\ &\quad + (100\text{ kPa})(0.001047 - 0.1176)\text{m}^3/\text{kg}[1\text{ kJ/1 kPa}\cdot\text{m}^3]\} \\ &= \mathbf{278\text{ kJ}} \end{aligned}$$

(b) The exergy destruction (or irreversibility) associated with this process can be determined from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$ where the entropy generation is determined from an entropy balance on the cylinder, which is an insulated closed system,

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

$$S_{\text{gen}} = \Delta S_{\text{system}} = m(s_2 - s_1)$$

Substituting,

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} = mT_0(s_2 - s_1) = (298\text{ K})(7.639\text{ kg})(1.8459 - 1.3609)\text{kJ/kg}\cdot\text{K} = \mathbf{1104\text{ kJ}}$$

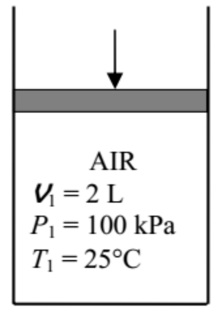
Q 8-40

Assumptions **1** Air is an ideal gas with constant specific heats. **2** The kinetic and potential energies are negligible.

Properties The gas constant of air is $R = 0.287$ kPa.m^3/kg.K (Table A-1). The specific heats of air at the average temperature of (298+423)/2=360 K are $c_p = 1.009$ kJ/kg·K and $c_v = 0.722$ kJ/kg·K (Table A-2).

Analysis (a) We realize that $X_1 = \Phi_1 = \mathbf{0}$ since air initially is at the dead state. The mass of air is

$$m = \frac{P_1 V_1}{RT_1} = \frac{(100\text{ kPa})(0.002\text{ m}^3)}{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(298\text{ K})} = 0.00234\text{ kg}$$



Also,

$$\frac{P_2 V_2}{T_2} = \frac{P_1 V_1}{T_1} \longrightarrow V_2 = \frac{P_1 T_2}{P_2 T_1} V_1 = \frac{(100\text{ kPa})(423\text{ K})}{(600\text{ kPa})(298\text{ K})}(2\text{ L}) = 0.473\text{ L}$$

and

$$\begin{aligned} s_2 - s_0 &= c_{p,\text{avg}} \ln\frac{T_2}{T_0} - R\ln\frac{P_2}{P_0} \\ &= (1.009\text{ kJ/kg}\cdot\text{K})\ln\frac{423\text{ K}}{298\text{ K}} - (0.287\text{ kJ/kg}\cdot\text{K})\ln\frac{600\text{ kPa}}{100\text{ kPa}} \\ &= -0.1608\text{ kJ/kg}\cdot\text{K} \end{aligned}$$

Thus, the exergy of air at the final state is

$$\begin{aligned} X_2 = \Phi_2 &= m\left[c_{v,\text{avg}}(T_2 - T_0) - T_0(s_2 - s_0)\right] + P_0(V_2 - V_0) \\ &= (0.00234\text{ kg})\left[(0.722\text{ kJ/kg}\cdot\text{K})(423-298)\text{K} - (298\text{ K})(-0.1608\text{ kJ/kg}\cdot\text{K})\right] \\ &\quad + (100\text{ kPa})(0.000473 - 0.002)\text{m}^3[\text{kJ/m}^3\cdot\text{kPa}] \\ &= \mathbf{0.171\text{ kJ}} \end{aligned}$$

(*b*) The minimum work input is the reversible work input, which can be determined from the exergy balance by setting the exergy destruction equal to zero,

$$\underbrace{X_\text{in} - X_\text{out}}_{\substack{\text{Net exergy transfer}\\ \text{by heat, work, and mass}}} \underbrace{- X_\text{destroyed}^{\nearrow 0\text{ (reversible)}}}_{\substack{\text{Exergy}\\ \text{destruction}}} = \underbrace{\Delta X_\text{system}}_{\substack{\text{Change}\\ \text{in exergy}}}$$

$$\begin{aligned} W_\text{rev,in} &= X_2 - X_1 \\ &= 0.171 - 0 = \mathbf{0.171 kJ} \end{aligned}$$

(c) The second-law efficiency of this process is

$$\eta_\text{II} = \frac{W_\text{rev,in}}{W_\text{u,in}} = \frac{0.171\text{ kJ}}{1.2\text{ kJ}} = \mathbf{14.3\%}$$

Q 8-45

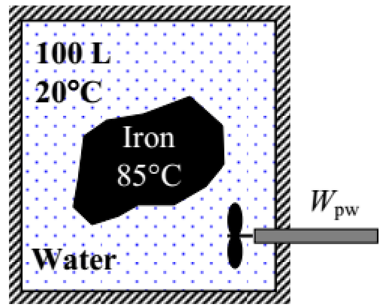
Assumptions: **1** Both the water and the iron block are incompressible substances with constant specific heats at room temperature. **2** The system is stationary and thus the kinetic and potential energies are negligible. **3** The tank is well insulated and thus there is no heat transfer. ***Properties:*** The density and specific heat of water at 25°C are ρ = 997 kg/m3 and c_p= 4.18 kJ/kg.°F. The specific heat of iron at room temperature (the only value available in the tables) is *cp*= 0.45 kJ/kg.°C (Table A-3).

Analysis We take the entire contents of the tank, water + iron block, as the system, which is a closed system. The energy balance for this system can be expressed as

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

$$W_{\text{pw,in}} = \Delta U = \Delta U_{\text{iron}} + \Delta U_{\text{water}}$$

$$W_{\text{pw,in}} = [mc(T_2 - T_1)]_{\text{iron}} + [mc(T_2 - T_1)]_{\text{water}}$$



where

$$m_{\text{water}} = \rho \boldsymbol{V} = (997\ \text{kg/m}^3)(0.1\ \text{m}^3) = 99.7\ \text{kg}$$

$$W_{\text{pw}} = \dot{W}_{\text{pw,in}} \Delta t = (0.2\ \text{kJ/s})(20 \times 60\ \text{s}) = 240\ \text{kJ}$$

Substituting,

$$240\ \text{kJ} = m_{\text{iron}}(0.45\ \text{kJ/kg}\cdot°\text{C})(24-85)°\text{C} + (99.7\ \text{kg})(4.18\ \text{kJ/kg}\cdot°\text{C})(24-20)°\text{C}$$

$$m_{\text{iron}} = \mathbf{52.0\ kg}$$

(*b*) The exergy destruction (or irreversibility) can be determined from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$ where the entropy generation is determined from an entropy balance on the system, which is an insulated closed system,

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

$$S_{\text{gen}} = \Delta S_{\text{system}} = \Delta S_{\text{iron}} + \Delta S_{\text{water}}$$

where

$$\Delta S_{\text{iron}} = mc_{\text{avg}} \ln\left(\frac{T_2}{T_1}\right) = (52.0\ \text{kg})(0.45\ \text{kJ/kg}\cdot\text{K}) \ln\left(\frac{297\ \text{K}}{358\ \text{K}}\right) = -4.371\ \text{kJ/K}$$

$$\Delta S_{\text{water}} = mc_{\text{avg}} \ln\left(\frac{T_2}{T_1}\right) = (99.7\ \text{kg})(4.18\ \text{kJ/kg}\cdot\text{K}) \ln\left(\frac{297\ \text{K}}{293\ \text{K}}\right) = 5.651\ \text{kJ/K}$$

Substituting,

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} = (293\ \text{K})(-4.371 + 5.651)\ \text{kJ/K} = \mathbf{375.0\ kJ}$$

Q 8-61

Solution:

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Potential energy change is negligible. **3** The temperature of the surroundings is given to be 25°C. ***Properties*** From the steam tables (Tables A-4 through A-6)

$$\left.\begin{array}{l} P_1 = 6\text{ MPa} \\ T_1 = 600°\text{C} \end{array}\right\} \begin{array}{l} h_1 = 3658.8\text{ kJ/kg} \\ s_1 = 7.1693\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 50\text{ kPa} \\ T_2 = 100°\text{C} \end{array}\right\} \begin{array}{l} h_2 = 2682.4\text{ kJ/kg} \\ s_2 = 7.6953\text{ kJ/kg}\cdot\text{K} \end{array}$$

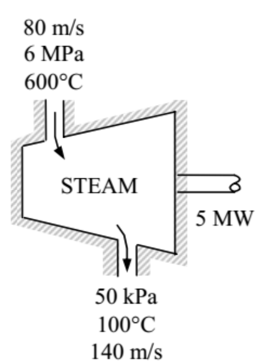
Analysis (*b*) There is only one inlet and one exit, and thus $\dot m_1 = \dot m_2 = \dot m$. We take the turbine as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

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

$$\dot E_{\text{in}} = \dot E_{\text{out}}$$

$$\dot m(h_1 + V_1^2/2) = \dot W_{\text{out}} + \dot m(h_2 + V_2^2/2)$$

$$\dot W_{\text{out}} = \dot m\left[h_1 - h_2 + \frac{V_1^2 - V_2^2}{2}\right]$$



Substituting,

$$5000\text{ kJ/s} = \dot m\left(3658.8 - 2682.4 + \frac{(80\text{ m/s})^2 - (140\text{ m/s})^2}{2}\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right)\right)$$

$$\dot m = 5.156\ \text{ kg/s}$$

The reversible (or maximum) power output is determined from the rate form of the exergy balance applied on the turbine and setting the exergy destruction term equal to zero,

$$\underbrace{\dot X_{\text{in}} - \dot X_{\text{out}}}_{\substack{\text{Rate of net exergy transfer}\\ \text{by heat, work, and mass}}} - \underbrace{\dot X_{\text{destroyed}}^{\nearrow 0\text{ (reversible)}}}_{\substack{\text{Rate of exergy}\\ \text{destruction}}} = \underbrace{\Delta \dot X_{\text{system}}^{\nearrow 0\text{ (steady)}}}_{\substack{\text{Rate of change}\\ \text{of exergy}}} = 0$$

$$\dot X_{\text{in}} = \dot X_{\text{out}}$$

$$\dot m\psi_1 = \dot W_{\text{rev,out}} + \dot m\psi_2$$

$$\dot W_{\text{rev,out}} = \dot m(\psi_1 - \psi_2) = \dot m[(h_1 - h_2) - T_0(s_1 - s_2) - \Delta\text{ke} - \Delta\text{pe}^{\nearrow 0}]$$

Substituting,

$$\begin{aligned}\dot W_{\text{rev,out}} &= \dot W_{\text{out}} - \dot m T_0(s_1 - s_2) \\ &= 5000\text{ kW} - (5.156\text{ kg/s})(298\text{ K})(7.1693 - 7.6953)\text{ kJ/kg}\cdot\text{K} = \mathbf{5808\ \ kW}\end{aligned}$$

(*b*) The second-law efficiency of a turbine is the ratio of the actual work output to the reversible work,

$$\eta_{\text{II}} = \frac{\dot W_{\text{out}}}{\dot W_{\text{rev,out}}} = \frac{5\text{ MW}}{5.808\text{ MW}} = \mathbf{86.1\%}$$

Discussion Note that 13.9% percent of the work potential of the steam is wasted as it flows through the turbine during this process.

Q 8-86

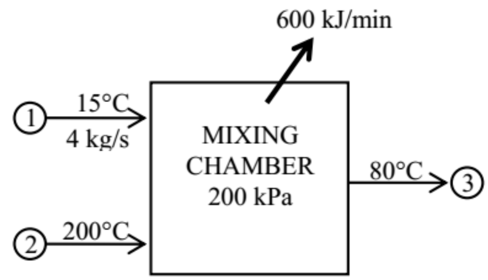
Assumptions **1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** There are no work interactions.

Properties Noting that $T < T_{\text{sat @ 200 kPa}} = 120.23°\text{C}$, the cold water and the exit mixture streams exist as a compressed liquid, which can be approximated as a saturated liquid at the given temperature. From Tables A-4 through A-6,

$$\left.\begin{array}{l} P_1 = 200\text{ kPa} \\ T_1 = 15°\text{C} \end{array}\right\} \begin{array}{l} h_1 \cong h_{f@15°\text{C}} = 62.98\text{ kJ/kg} \\ s_1 \cong s_{f@15°\text{C}} = 0.22447\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 200\text{ kPa} \\ T_2 = 200°\text{C} \end{array}\right\} \begin{array}{l} h_2 = 2870.4\text{ kJ/kg} \\ s_2 = 7.5081\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_3 = 200\text{ kPa} \\ T_3 = 80°\text{C} \end{array}\right\} \begin{array}{l} h_3 \cong h_{f@80°\text{C}} = 335.02\text{ kJ/kg} \\ s_3 \cong s_{f@80°\text{C}} = 1.0756\text{ kJ/kg}\cdot\text{K} \end{array}$$



Analysis (a) We take the mixing chamber 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

Mass balance: $\dot{m}_{\text{in}} - \dot{m}_{\text{out}} = \Delta\dot{m}_{\text{system}}^{\nearrow 0\text{ (steady)}} = 0 \longrightarrow \dot{m}_1 + \dot{m}_2 = \dot{m}_3$

Energy balance:

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

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

$$\dot{m}h_1 + \dot{m}_2 h_2 = \dot{Q}_{\text{out}} + \dot{m}_3 h_3$$

Combining the two relations gives $\dot{Q}_{\text{out}} = \dot{m}_1 h_1 + \dot{m}_2 h_2 - (\dot{m}_1 + \dot{m}_2)h_3 = \dot{m}_1(h_1 - h_3) + \dot{m}_2(h_2 - h_3)$

Solving for $\dot{m}_2$ and substituting, the mass flow rate of the superheated steam is determined to be

$$\dot{m}_2 = \frac{\dot{Q}_{\text{out}} - \dot{m}_1(h_1 - h_3)}{h_2 - h_3} = \frac{(600/60\text{ kJ/s}) - (4\text{ kg/s})(62.98 - 335.02)\text{kJ/kg}}{(2870.4 - 335.02)\text{kJ/kg}} = \mathbf{0.429\ kg/s}$$

Also, $\dot{m}_3 = \dot{m}_1 + \dot{m}_2 = 4 + 0.429 = 4.429\text{ kg/s}$

(*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 an *extended system* that includes the mixing chamber and its immediate surroundings. It gives

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

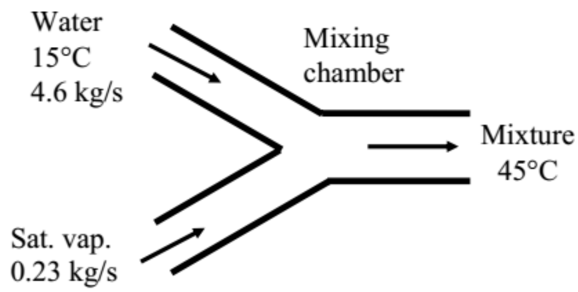
$$\dot{m}_1 s_1 + \dot{m}_2 s_2 - \dot{m}_3 s_3 - \frac{\dot{Q}_{\text{out}}}{T_{\text{b,surr}}} + \dot{S}_{\text{gen}} = 0 \rightarrow \dot{S}_{\text{gen}} = \dot{m}_3 s_3 - \dot{m}_1 s_1 - \dot{m}_2 s_2 + \frac{\dot{Q}_{\text{out}}}{T_0}$$

Substituting, the exergy destruction is determined to be

$$\begin{aligned} \dot{X}_{\text{destroyed}} &= T_0 \dot{S}_{\text{gen}} = T_0\left(\dot{m}_3 s_3 - \dot{m}_2 s_2 - \dot{m}_1 s_1 + \frac{\dot{Q}_{out}}{T_{b,surr}}\right) \\ &= (298\text{ K})(4.429 \times 1.0756 - 0.429 \times 7.5081 - 4 \times 0.22447 + 10/298)\text{kW/K} \\ &= \mathbf{202\ kW} \end{aligned}$$

Q 8-92

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



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

$$\left.\begin{array}{l} T_1 = 15°\text{C} \\ x_1 = 0 \end{array}\right\} \begin{array}{l} h_1 = h_0 = 62.98 \text{ kJ/kg} \\ s_1 = s_0 = 0.22447 \text{ kJ/kg.K} \end{array}$$

$$\left.\begin{array}{l} T_3 = 45°\text{C} \\ x_1 = 0 \end{array}\right\} \begin{array}{l} h_3 = 188.44 \text{ kJ/kg} \\ s_3 = 0.63862 \text{ kJ/kg.K} \end{array}$$

An energy balance on the chamber gives

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

The remaining properties of the saturated steam are

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

(*b*) The specific exergy of each stream is

$$\psi_1 = 0$$

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

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

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

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

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

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