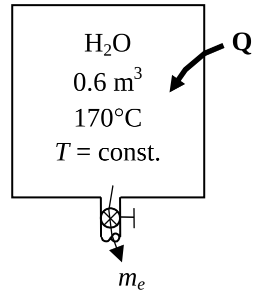
8-80 A rigid tank initially contains saturated liquid water. A valve at the bottom of the tank is opened, and half of mass in liquid form is withdrawn from the tank. The temperature in the tank is maintained constant. The amount of heat transfer, the reversible work, and the exergy destruction during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



$$\left.\begin{array}{l} T_1 = 170°\text{C} \\ \text{sat. liquid} \end{array}\right\} \begin{array}{l} \boldsymbol{v}_1 = \boldsymbol{v}_{f@170^\circ\text{C}} = 0.001114 \text{ m}^3/\text{kg} \\ u_1 = u_{f@170^\circ\text{C}} = 718.20 \text{ kJ/kg} \\ s_1 = s_{f@170^\circ\text{C}} = 2.0417 \text{ kJ/kg}\cdot\text{K} \end{array}$$

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

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:

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

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

$$m_1 = \frac{\boldsymbol{V}}{\boldsymbol{v}_1} = \frac{0.6 \text{ m}^3}{0.001114 \text{ m}^3/\text{kg}} = 538.47 \text{ kg}$$

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

Now we determine the final internal energy and entropy,

$$\boldsymbol{v}_2 = \frac{\boldsymbol{V}}{m_2} = \frac{0.6 \text{ m}^3}{269.24 \text{ kg}} = 0.002229 \text{ m}^3/\text{kg}$$

$$x_2 = \frac{\boldsymbol{v}_2 - \boldsymbol{v}_f}{\boldsymbol{v}_{fg}} = \frac{0.002229 - 0.001114}{0.24260 - 0.001114} = 0.004614$$

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

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

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

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

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

Substituting, the exergy destruction is determined to be

$$\begin{aligned} X_{\text{destroyed}} &= T_0 S_{\text{gen}} = T_0 \left[m_2 s_2 - m_1 s_1 + m_e s_e - \frac{Q_{\text{in}}}{T_{\text{source}}} \right] \\ &= (298\text{ K})[269.24 \times 2.0630 - 538.47 \times 2.0417 + 269.24 \times 2.0417 - (2545\text{ kJ})/(523\text{ K})] \\ &= \mathbf{141.2\ kJ} \end{aligned}$$

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

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