

Charging and Discharging Processes

5-121 A large reservoir supplies steam to a balloon whose initial state is specified. The final temperature in the balloon and the boundary work are to be determined.

Analysis Noting that the volume changes linearly with the pressure, the final volume and the initial mass are determined from

$$\left. \begin{array}{l} P_1 = 100 \text{ kPa} \\ T_1 = 150^\circ\text{C} \end{array} \right\} \nu_1 = 1.9367 \text{ m}^3/\text{kg} \quad (\text{Table A-6})$$

$$\nu_2 = \frac{P_2}{P_1} \nu_1 = \frac{150 \text{ kPa}}{100 \text{ kPa}} (50 \text{ m}^3) = 75 \text{ m}^3$$

$$m_1 = \frac{\nu_1}{\nu_1} = \frac{50 \text{ m}^3}{1.9367 \text{ m}^3/\text{kg}} = 25.82 \text{ kg}$$

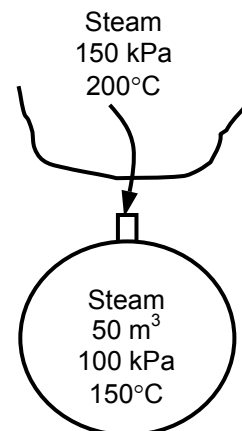
The final temperature may be determined if we first calculate specific volume at the final state

$$\nu_2 = \frac{V_2}{m_2} = \frac{V_2}{2m_1} = \frac{75 \text{ m}^3}{2 \times (25.82 \text{ kg})} = 1.4525 \text{ m}^3/\text{kg}$$

$$\left. \begin{array}{l} P_2 = 150 \text{ kPa} \\ \nu_2 = 1.4525 \text{ m}^3/\text{kg} \end{array} \right\} T_2 = \mathbf{202.5^\circ\text{C}} \quad (\text{Table A-6})$$

Noting again that the volume changes linearly with the pressure, the boundary work can be determined from

$$W_b = \frac{P_1 + P_2}{2} (\nu_2 - \nu_1) = \frac{(100 + 150) \text{ kPa}}{2} (75 - 50) \text{ m}^3 = \mathbf{3125 \text{ kJ}}$$



5-122 Steam in a supply line is allowed to enter an initially evacuated tank. The temperature of the steam in the supply line and the flow work are to be determined.

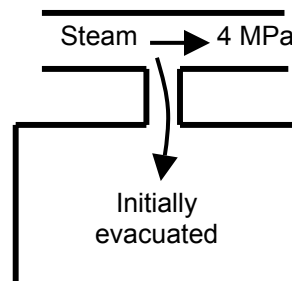
Analysis Flow work of the steam in the supply line is converted to sensible internal energy in the tank. That is,

$$h_{\text{line}} = u_{\text{tank}}$$

$$\text{where } \left. \begin{array}{l} P_{\text{tank}} = 4 \text{ MPa} \\ T_{\text{tank}} = 550^\circ\text{C} \end{array} \right\} u_{\text{tank}} = 3189.5 \text{ kJ/kg} \quad (\text{Table A-6})$$

Now, the properties of steam in the line can be calculated

$$\left. \begin{array}{l} P_{\text{line}} = 4 \text{ MPa} \\ h_{\text{line}} = 3189.5 \text{ kJ/kg} \end{array} \right\} \begin{array}{l} T_{\text{line}} = \mathbf{389.5^\circ\text{C}} \\ u_{\text{line}} = 2901.5 \text{ kJ/kg} \end{array} \quad (\text{Table A-6})$$



The flow work per unit mass is the difference between enthalpy and internal energy of the steam in the line

$$w_{\text{flow}} = h_{\text{line}} - u_{\text{line}} = 3189.5 - 2901.5 = \mathbf{288 \text{ kJ/kg}}$$

5-123 A vertical piston-cylinder device contains air at a specified state. Air is allowed to escape from the cylinder by a valve connected to the cylinder. The final temperature and the boundary work are to be determined.

Properties The gas constant of air is $R = 0.287 \text{ kJ/kg}\cdot\text{K}$ (Table A-1).

Analysis The initial and final masses in the cylinder are

$$m_1 = \frac{P\mathcal{V}_1}{RT_1} = \frac{(600 \text{ kPa})(0.25 \text{ m}^3)}{(0.287 \text{ kJ/kg}\cdot\text{K})(300 + 273 \text{ K})} = 0.9121 \text{ m}^3$$

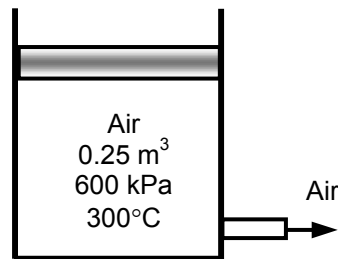
$$m_2 = 0.25m_1 = 0.25(0.9121 \text{ kg}) = 0.2280 \text{ kg}$$

Then the final temperature becomes

$$T_2 = \frac{P\mathcal{V}_2}{m_2R} = \frac{(600 \text{ kPa})(0.05 \text{ m}^3)}{(0.2280 \text{ kg})(0.287 \text{ kJ/kg}\cdot\text{K})} = \mathbf{458.4 \text{ K}}$$

Noting that pressure remains constant during the process, the boundary work is determined from

$$W_b = P(\mathcal{V}_1 - \mathcal{V}_2) = (600 \text{ kPa})(0.25 - 0.05) \text{ m}^3 = \mathbf{120 \text{ kJ}}$$



5-124 Helium flows from a supply line to an initially evacuated tank. The flow work of the helium in the supply line and the final temperature of the helium in the tank are to be determined.

Properties The properties of helium are $R = 2.0769 \text{ kJ/kg}\cdot\text{K}$, $c_p = 5.1926 \text{ kJ/kg}\cdot\text{K}$, $c_v = 3.1156 \text{ kJ/kg}\cdot\text{K}$ (Table A-2a).

Analysis The flow work is determined from its definition but we first determine the specific volume

$$\nu = \frac{RT_{\text{line}}}{P} = \frac{(2.0769 \text{ kJ/kg}\cdot\text{K})(120 + 273 \text{ K})}{(200 \text{ kPa})} = 4.0811 \text{ m}^3/\text{kg}$$

$$w_{\text{flow}} = P\nu = (200 \text{ kPa})(4.0811 \text{ m}^3/\text{kg}) = \mathbf{816.2 \text{ kJ/kg}}$$

Noting that the flow work in the supply line is converted to sensible internal energy in the tank, the final helium temperature in the tank is determined as follows

$$u_{\text{tank}} = h_{\text{line}}$$

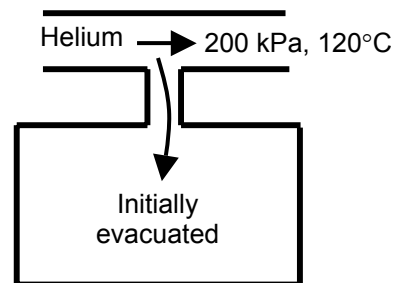
$$h_{\text{line}} = c_p T_{\text{line}} = (5.1926 \text{ kJ/kg}\cdot\text{K})(120 + 273 \text{ K}) = 2040.7 \text{ kJ/kg}$$

$$u_{\text{-tank}} = c_v T_{\text{tank}} \longrightarrow 2040.7 \text{ kJ/kg} = (3.1156 \text{ kJ/kg}\cdot\text{K})T_{\text{tank}} \longrightarrow T_{\text{tank}} = \mathbf{655.0 \text{ K}}$$

Alternative Solution: Noting the definition of specific heat ratio, the final temperature in the tank can also be determined from

$$T_{\text{tank}} = kT_{\text{line}} = 1.667(120 + 273 \text{ K}) = \mathbf{655.1 \text{ K}}$$

which is practically the same result.



5-125 An evacuated bottle is surrounded by atmospheric air. A valve is opened, and air is allowed to fill the bottle. The amount of heat transfer through the wall of the bottle when thermal and mechanical equilibrium is established is 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 Air is an ideal gas with variable specific heats. 3 Kinetic and potential energies are negligible. 4 There are no work interactions involved. 5 The direction of heat transfer is to the air in the bottle (will be verified).

Properties The gas constant of air is $0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K}$ (Table A-1).

Analysis We take the bottle 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

$$\text{Mass balance: } m_{\text{in}} - m_{\text{out}} = \Delta m_{\text{system}} \rightarrow m_i = m_2 \quad (\text{since } m_{\text{out}} = m_{\text{initial}} = 0)$$

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

$$Q_{\text{in}} + m_i h_i = m_2 u_2 \quad (\text{since } W \cong E_{\text{out}} = E_{\text{initial}} = ke \cong pe \cong 0)$$

Combining the two balances:

$$Q_{\text{in}} = m_2 (u_2 - h_i)$$

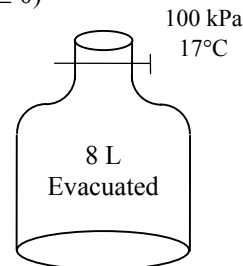
where

$$m_2 = \frac{P_2 V}{RT_2} = \frac{(100 \text{ kPa})(0.008 \text{ m}^3)}{(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(290 \text{ K})} = 0.0096 \text{ kg}$$

$$T_i = T_2 = 290 \text{ K} \xrightarrow{\text{Table A-17}} \begin{aligned} h_i &= 290.16 \text{ kJ/kg} \\ u_2 &= 206.91 \text{ kJ/kg} \end{aligned}$$

$$\text{Substituting, } Q_{\text{in}} = (0.0096 \text{ kg})(206.91 - 290.16) \text{ kJ/kg} = -0.8 \text{ kJ} \rightarrow Q_{\text{out}} = \mathbf{0.8 \text{ kJ}}$$

Discussion The negative sign for heat transfer indicates that the assumed direction is wrong. Therefore, we reverse the direction.



5-126 An insulated rigid tank is evacuated. A valve is opened, and air is allowed to fill the tank until mechanical equilibrium is established. The final temperature in the tank is 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 Air is an ideal gas with constant specific heats. 3 Kinetic and potential energies are negligible. 4 There are no work interactions involved. 5 The device is adiabatic and thus heat transfer is negligible.

Properties The specific heat ratio for air at room temperature is $k = 1.4$ (Table A-2).

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

$$\text{Mass balance: } m_{\text{in}} - m_{\text{out}} = \Delta m_{\text{system}} \rightarrow m_i = m_2 \quad (\text{since } m_{\text{out}} = m_{\text{initial}} = 0)$$

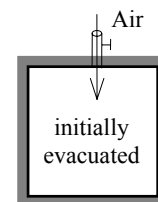
$$\text{Energy balance: } \underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$m_i h_i = m_2 u_2 \quad (\text{since } Q \cong W \cong E_{\text{out}} = E_{\text{initial}} = ke \cong pe \cong 0)$$

Combining the two balances:

$$u_2 = h_i \rightarrow c_v T_2 = c_p T_i \rightarrow T_2 = (c_p / c_v) T_i = k T_i$$

$$\text{Substituting, } T_2 = 1.4 \times 290 \text{ K} = 406 \text{ K} = \mathbf{133^\circ \text{C}}$$



5-127 A rigid tank initially contains air at atmospheric conditions. The tank is connected to a supply line, and air is allowed to enter the tank until mechanical equilibrium is established. The mass of air that entered and the amount of heat transfer 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** Air is an ideal gas with variable specific heats. **3** Kinetic and potential energies are negligible. **4** There are no work interactions involved. **5** The direction of heat transfer is to the tank (will be verified).

Properties The gas constant of air is $0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}$ (Table A-1). The properties of air are (Table A-17)

$$\begin{aligned} T_i &= 295 \text{ K} \longrightarrow h_i = 295.17 \text{ kJ/kg} \\ T_1 &= 295 \text{ K} \longrightarrow u_1 = 210.49 \text{ kJ/kg} \\ T_2 &= 350 \text{ K} \longrightarrow u_2 = 250.02 \text{ kJ/kg} \end{aligned}$$

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

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

The initial and the final masses in the tank are

$$\begin{aligned} m_1 &= \frac{P_1 V}{RT_1} = \frac{(100 \text{ kPa})(2 \text{ m}^3)}{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(295 \text{ K})} = 2.362 \text{ kg} \\ m_2 &= \frac{P_2 V}{RT_2} = \frac{(600 \text{ kPa})(2 \text{ m}^3)}{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(350 \text{ K})} = 11.946 \text{ kg} \end{aligned}$$

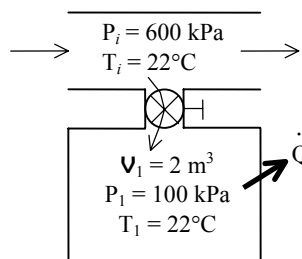
Then from the mass balance,

$$m_i = m_2 - m_1 = 11.946 - 2.362 = \mathbf{9.584 \text{ kg}}$$

(b) The heat transfer during this process is determined from

$$\begin{aligned} Q_{\text{in}} &= -m_i h_i + m_2 u_2 - m_1 u_1 \\ &= -(9.584 \text{ kg})(295.17 \text{ kJ/kg}) + (11.946 \text{ kg})(250.02 \text{ kJ/kg}) - (2.362 \text{ kg})(210.49 \text{ kJ/kg}) \\ &= -339 \text{ kJ} \rightarrow Q_{\text{out}} = \mathbf{339 \text{ kJ}} \end{aligned}$$

Discussion The negative sign for heat transfer indicates that the assumed direction is wrong. Therefore, we reversed the direction.



5-128 A rigid tank initially contains saturated R-134a liquid-vapor mixture. The tank is connected to a supply line, and R-134a is allowed to enter the tank. The final temperature in the tank, the mass of R-134a that entered, and the heat transfer 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)

$$\left. \begin{array}{l} T_1 = 8^\circ\text{C} \\ x_1 = 0.7 \end{array} \right\} \begin{array}{l} \nu_1 = \nu_f + x_1 \nu_{fg} = 0.0007887 + 0.7 \times (0.052762 - 0.0007887) = 0.03717 \text{ m}^3/\text{kg} \\ u_1 = u_f + x_1 u_{fg} = 62.39 + 0.7 \times 172.19 = 182.92 \text{ kJ/kg} \end{array}$$

$$\left. \begin{array}{l} P_2 = 800 \text{ kPa} \\ \text{sat. vapor} \end{array} \right\} \begin{array}{l} \nu_2 = \nu_{g@800 \text{ kPa}} = 0.02562 \text{ m}^3/\text{kg} \\ u_2 = u_{g@800 \text{ kPa}} = 246.79 \text{ kJ/kg} \end{array}$$

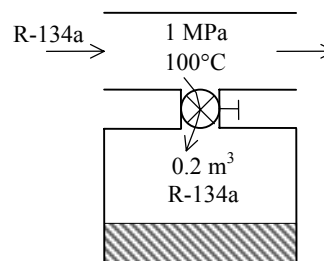
$$\left. \begin{array}{l} P_i = 1.0 \text{ MPa} \\ T_i = 100^\circ\text{C} \end{array} \right\} h_i = 335.06 \text{ kJ/kg}$$

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

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

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



(a) The tank contains saturated vapor at the final state at 800 kPa, and thus the final temperature is the saturation temperature at this pressure,

$$T_2 = T_{\text{sat @ 800 kPa}} = \mathbf{31.31^\circ\text{C}}$$

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

$$m_1 = \frac{\nu}{\nu_1} = \frac{0.2 \text{ m}^3}{0.03717 \text{ m}^3/\text{kg}} = 5.38 \text{ kg}$$

$$m_2 = \frac{\nu}{\nu_2} = \frac{0.2 \text{ m}^3}{0.02562 \text{ m}^3/\text{kg}} = 7.81 \text{ kg}$$

Then from the mass balance

$$m_i = m_2 - m_1 = 7.81 - 5.38 = \mathbf{2.43 \text{ kg}}$$

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

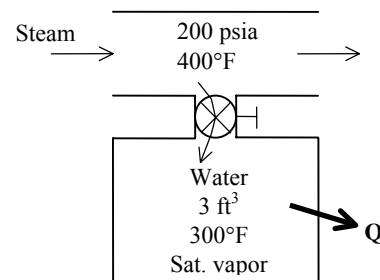
$$\begin{aligned} Q_{\text{in}} &= -m_i h_i + m_2 u_2 - m_1 u_1 \\ &= -(2.43 \text{ kg})(335.06 \text{ kJ/kg}) + (7.81 \text{ kg})(246.79 \text{ kJ/kg}) - (5.38 \text{ kg})(182.92 \text{ kJ/kg}) \\ &= \mathbf{130 \text{ kJ}} \end{aligned}$$

5-129E A rigid tank initially contains saturated water vapor. The tank is connected to a supply line, and water vapor is allowed to enter the tank until one-half of the tank is filled with liquid water. The final pressure in the tank, the mass of steam that entered, and the heat transfer 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 water are (Tables A-4E through A-6E)

$$\begin{aligned} T_1 = 300^\circ\text{F} \quad & \left\{ \begin{array}{l} \nu_1 = \nu_{g@300^\circ\text{F}} = 6.4663 \text{ ft}^3/\text{lbm} \\ \text{sat. vapor} \quad u_1 = u_{g@300^\circ\text{F}} = 1099.8 \text{ Btu/lbm} \end{array} \right. \\ T_2 = 300^\circ\text{F} \quad & \left\{ \begin{array}{l} \nu_f = 0.01745, \quad \nu_g = 6.4663 \text{ ft}^3/\text{lbm} \\ \text{sat. mixture} \quad u_f = 269.51, \quad u_g = 1099.8 \text{ Btu/lbm} \end{array} \right. \\ P_i = 200 \text{ psia} \quad & \left\{ \begin{array}{l} h_i = 1210.9 \text{ Btu/lbm} \\ T_i = 400^\circ\text{F} \end{array} \right. \end{aligned}$$



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

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

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

(a) The tank contains saturated mixture at the final state at 250°F, and thus the exit pressure is the saturation pressure at this temperature,

$$P_2 = P_{\text{sat}@ 300^\circ\text{F}} = \mathbf{67.03 \text{ psia}}$$

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

$$\begin{aligned} m_1 &= \frac{\nu}{\nu_1} = \frac{3 \text{ ft}^3}{6.4663 \text{ ft}^3/\text{lbm}} = 0.464 \text{ lbm} \\ m_2 &= m_f + m_g = \frac{\nu_f}{\nu_f} + \frac{\nu_g}{\nu_g} = \frac{1.5 \text{ ft}^3}{0.01745 \text{ ft}^3/\text{lbm}} + \frac{1.5 \text{ ft}^3}{6.4663 \text{ ft}^3/\text{lbm}} = 85.97 + 0.232 = 86.20 \text{ lbm} \end{aligned}$$

Then from the mass balance

$$m_i = m_2 - m_1 = 86.20 - 0.464 = \mathbf{85.74 \text{ lbm}}$$

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

$$\begin{aligned} Q_{\text{in}} &= -m_i h_i + m_2 u_2 - m_1 u_1 \\ &= -(85.74 \text{ lbm})(1210.9 \text{ Btu/lbm}) + 23,425 \text{ Btu} - (0.464 \text{ lbm})(1099.8 \text{ Btu/lbm}) \\ &= -80,900 \text{ Btu} \rightarrow Q_{\text{out}} = \mathbf{80,900 \text{ Btu}} \end{aligned}$$

since $U_2 = m_2 u_2 = m_f u_f + m_g u_g = 85.97 \times 269.51 + 0.232 \times 1099.8 = 23,425 \text{ Btu}$

Discussion A negative result for heat transfer indicates that the assumed direction is wrong, and should be reversed.

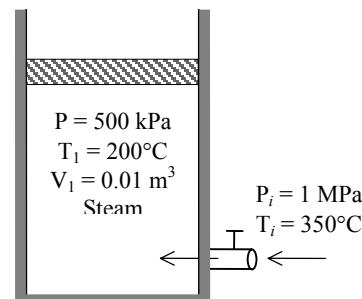
5-130 A cylinder initially contains superheated steam. The cylinder is connected to a supply line, and is superheated steam is allowed to enter the cylinder until the volume doubles at constant pressure. The final temperature in the cylinder and the mass of the steam that entered are to be determined.

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. **3** There are no work interactions involved other than boundary work. **4** The device is insulated and thus heat transfer is negligible.

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

$$\left. \begin{array}{l} P_1 = 500 \text{ kPa} \\ T_1 = 200^\circ\text{C} \end{array} \right\} \begin{array}{l} v_1 = 0.42503 \text{ m}^3/\text{kg} \\ u_1 = 2643.3 \text{ kJ/kg} \end{array}$$

$$\left. \begin{array}{l} P_i = 1 \text{ MPa} \\ T_i = 350^\circ\text{C} \end{array} \right\} h_i = 3158.2 \text{ kJ/kg}$$



Analysis (a) We take the cylinder 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:
$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\text{Net energy transfer by heat, work, and mass}} = \underbrace{\Delta E_{\text{system}}}_{\text{Change in internal, kinetic, potential, etc. energies}}$$

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

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

The boundary work done during this process is

$$W_{b,\text{out}} = \int_1^2 P dV = P(v_2 - v_1) = (500 \text{ kPa})(0.02 - 0.01) \text{ m}^3 \left(\frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3} \right) = 5 \text{ kJ}$$

The initial and the final masses in the cylinder are

$$m_1 = \frac{V_1}{v_1} = \frac{0.01 \text{ m}^3}{0.42503 \text{ m}^3/\text{kg}} = 0.0235 \text{ kg}$$

$$m_2 = \frac{V_2}{v_2} = \frac{0.02 \text{ m}^3}{v_2}$$

Substituting, $0 = 5 - \left(\frac{0.02}{v_2} - 0.0235 \right) (3158.2) + \frac{0.02}{v_2} u_2 - (0.0235)(2643.3)$

Then by trial and error (or using EES program), $T_2 = 261.7^\circ\text{C}$ and $v_2 = 0.4858 \text{ m}^3/\text{kg}$

(b) The final mass in the cylinder is

$$m_2 = \frac{V_2}{v_2} = \frac{0.02 \text{ m}^3}{0.4858 \text{ m}^3/\text{kg}} = 0.0412 \text{ kg}$$

Then, $m_i = m_2 - m_1 = 0.0412 - 0.0235 = \mathbf{0.0176 \text{ kg}}$

5-131 A 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 final temperature in the cylinder and the mass of the steam that entered are to be determined.

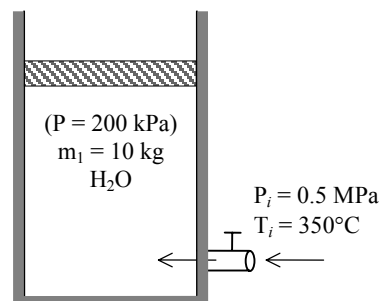
Assumptions **1** This is an unsteady process since the conditions within the device are changing during the process, but it can be analyzed as a uniform-flow process since the state of fluid at the inlet remains constant. **2** The expansion process is quasi-equilibrium. **3** Kinetic and potential energies are negligible. **3** There are no work interactions involved other than boundary work. **4** The device is insulated and thus heat transfer is negligible.

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

$$\left. \begin{array}{l} P_1 = 200 \text{ kPa} \\ x_1 = 0.6 \end{array} \right\} h_1 = h_f + x_1 h_{fg} = 504.71 + 0.6 \times 2201.6 = 1825.6 \text{ kJ/kg}$$

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

$$\left. \begin{array}{l} P_i = 0.5 \text{ MPa} \\ T_i = 350^\circ\text{C} \end{array} \right\} h_i = 3168.1 \text{ kJ/kg}$$



Analysis (a) The cylinder contains saturated vapor at the final state at a pressure of 200 kPa, thus the final temperature in the cylinder must be

$$T_2 = T_{\text{sat}@200 \text{ kPa}} = \mathbf{120.2^\circ\text{C}}$$

(b) We take the cylinder 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:
$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

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

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

or,
$$0 = -(m_2 - m_1)h_i + m_2 h_2 - m_1 h_1$$

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

$$m_2 = \frac{h_i - h_1}{h_i - h_2} m_1 = \frac{(3168.1 - 1825.6) \text{ kJ/kg}}{(3168.1 - 2706.3) \text{ kJ/kg}} (10 \text{ kg}) = 29.07 \text{ kg}$$

Thus,

$$m_i = m_2 - m_1 = 29.07 - 10 = \mathbf{19.07 \text{ kg}}$$

5-132 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 and the heat transfer are to be determined.

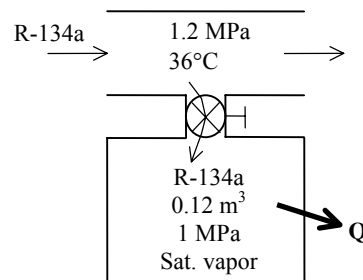
Assumptions 1 This is an unsteady process since the conditions within the device are changing during the process, but it can be analyzed as a uniform-flow process since the state of fluid at the inlet remains constant. **2** Kinetic and potential energies are negligible. **3** There are no work interactions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

$$\left. \begin{array}{l} P_1 = 1 \text{ MPa} \\ \text{sat. vapor} \end{array} \right\} \begin{array}{l} \nu_1 = \nu_{g@1 \text{ MPa}} = 0.02031 \text{ m}^3/\text{kg} \\ u_1 = u_{g@1 \text{ MPa}} = 250.68 \text{ kJ/kg} \end{array}$$

$$\left. \begin{array}{l} P_2 = 1.2 \text{ MPa} \\ \text{sat. liquid} \end{array} \right\} \begin{array}{l} \nu_2 = \nu_{f@1.2 \text{ MPa}} = 0.0008934 \text{ m}^3/\text{kg} \\ u_2 = u_{f@1.2 \text{ MPa}} = 116.70 \text{ kJ/kg} \end{array}$$

$$\left. \begin{array}{l} P_i = 1.2 \text{ MPa} \\ T_i = 36^\circ\text{C} \end{array} \right\} h_i = h_{f@36^\circ\text{C}} = 102.30 \text{ kJ/kg}$$



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

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

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

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

$$m_1 = \frac{\nu_1}{\nu_1} = \frac{0.12 \text{ m}^3}{0.02031 \text{ m}^3/\text{kg}} = 5.91 \text{ kg}$$

$$m_2 = \frac{\nu_2}{\nu_2} = \frac{0.12 \text{ m}^3}{0.0008934 \text{ m}^3/\text{kg}} = 134.31 \text{ kg}$$

Then from the mass balance

$$m_i = m_2 - m_1 = 134.31 - 5.91 = \mathbf{128.4 \text{ kg}}$$

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

$$\begin{aligned} Q_{\text{in}} &= -m_i h_i + m_2 u_2 - m_1 u_1 \\ &= -(128.4 \text{ kg})(102.30 \text{ kJ/kg}) + (134.31 \text{ kg})(116.70 \text{ kJ/kg}) - (5.91 \text{ kg})(250.68 \text{ kJ/kg}) \\ &= \mathbf{1057 \text{ kJ}} \end{aligned}$$

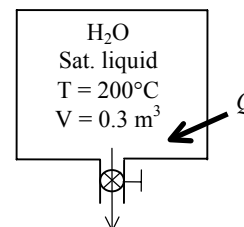
5-133 A rigid tank initially contains saturated liquid water. A valve at the bottom of the tank is opened, and half of the mass in liquid form is withdrawn from the tank. The temperature in the tank is maintained constant. The amount of heat transfer is to be determined.

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)

$$\left. \begin{array}{l} T_1 = 200^\circ\text{C} \\ \text{sat. liquid} \end{array} \right\} \begin{array}{l} v_1 = v_{f@200^\circ\text{C}} = 0.001157 \text{ m}^3/\text{kg} \\ u_1 = u_{f@200^\circ\text{C}} = 850.46 \text{ kJ/kg} \end{array}$$

$$\left. \begin{array}{l} T_e = 200^\circ\text{C} \\ \text{sat. liquid} \end{array} \right\} h_e = h_{f@200^\circ\text{C}} = 852.26 \text{ kJ/kg}$$



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

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

The initial and the final masses in the tank are

$$m_1 = \frac{v_1}{v_f} = \frac{0.3 \text{ m}^3}{0.001157 \text{ m}^3/\text{kg}} = 259.4 \text{ kg}$$

$$m_2 = \frac{1}{2} m_1 = \frac{1}{2} (259.4 \text{ kg}) = 129.7 \text{ kg}$$

Then from the mass balance,

$$m_e = m_1 - m_2 = 259.4 - 129.7 = 129.7 \text{ kg}$$

Now we determine the final internal energy,

$$v_2 = \frac{v}{m_2} = \frac{0.3 \text{ m}^3}{129.7 \text{ kg}} = 0.002313 \text{ m}^3/\text{kg}$$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.002313 - 0.001157}{0.12721 - 0.001157} = 0.009171$$

$$\left. \begin{array}{l} T_2 = 200^\circ\text{C} \\ x_2 = 0.009171 \end{array} \right\} u_2 = u_f + x_2 u_{fg} = 850.46 + (0.009171)(1743.7) = 866.46 \text{ kJ/kg}$$

Then the heat transfer during this process is determined from the energy balance by substitution to be

$$\begin{aligned} Q &= (129.7 \text{ kg})(852.26 \text{ kJ/kg}) + (129.7 \text{ kg})(866.46 \text{ kJ/kg}) - (259.4 \text{ kg})(850.46 \text{ kJ/kg}) \\ &= \mathbf{2308 \text{ kJ}} \end{aligned}$$

5-134 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 amount of heat transfer is 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).

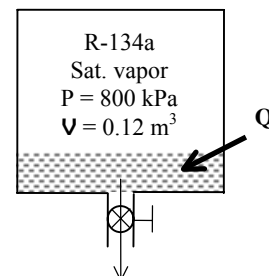
Properties The properties of R-134a are (Tables A-11 through A-13)

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

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

$$\left. \begin{array}{l} P_2 = 800 \text{ kPa} \\ \text{sat. vapor} \end{array} \right\} \begin{array}{l} \nu_2 = \nu_{g@800 \text{ kPa}} = 0.025621 \text{ m}^3/\text{kg} \\ u_2 = u_{g@800 \text{ kPa}} = 246.79 \text{ kJ/kg} \end{array}$$

$$\left. \begin{array}{l} P_e = 800 \text{ kPa} \\ \text{sat. liquid} \end{array} \right\} h_e = h_{f@800 \text{ kPa}} = 95.47 \text{ kJ/kg}$$



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

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

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

$$m_1 = m_f + m_g = \frac{\nu_f}{\nu_f} + \frac{\nu_g}{\nu_g} = \frac{0.12 \times 0.25 \text{ m}^3}{0.0008458 \text{ m}^3/\text{kg}} + \frac{0.12 \times 0.75 \text{ m}^3}{0.025621 \text{ m}^3/\text{kg}} = 35.47 + 3.513 = 38.98 \text{ kg}$$

$$U_1 = m_1 u_1 = m_f u_f + m_g u_g = (35.47)(94.79) + (3.513)(246.79) = 4229.2 \text{ kJ}$$

$$m_2 = \frac{\nu}{\nu_2} = \frac{0.12 \text{ m}^3}{0.025621 \text{ m}^3/\text{kg}} = 4.684 \text{ kg}$$

Then from the mass and energy balances,

$$m_e = m_1 - m_2 = 38.98 - 4.684 = 34.30 \text{ kg}$$

$$Q_{\text{in}} = (34.30 \text{ kg})(95.47 \text{ kJ/kg}) + (4.684 \text{ kg})(246.79 \text{ kJ/kg}) - 4229 \text{ kJ} = \mathbf{201.2 \text{ kJ}}$$

5-135E A rigid tank initially contains saturated liquid-vapor mixture of R-134a. A valve at the top of the tank is opened, and vapor is allowed to escape at constant pressure until all the liquid in the tank disappears. The amount of heat transfer is 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.

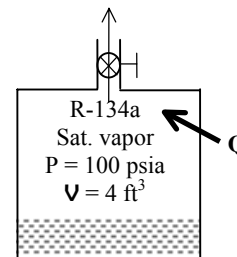
Properties The properties of R-134a are (Tables A-11E through A-13E)

$$P_1 = 100 \text{ psia} \rightarrow \nu_f = 0.01332 \text{ ft}^3/\text{lbm}, \nu_g = 0.4776 \text{ ft}^3/\text{lbm}$$

$$u_f = 37.623 \text{ Btu/lbm}, u_g = 104.99 \text{ Btu/lbm}$$

$$\left. \begin{array}{l} P_2 = 100 \text{ psia} \\ \text{sat. vapor} \end{array} \right\} \begin{array}{l} \nu_2 = \nu_g @ 100 \text{ psia} = 0.4776 \text{ ft}^3/\text{lbm} \\ u_2 = u_g @ 100 \text{ psia} = 104.99 \text{ Btu/lbm} \end{array}$$

$$\left. \begin{array}{l} P_e = 100 \text{ psia} \\ \text{sat. vapor} \end{array} \right\} h_e = h_g @ 100 \text{ psia} = 113.83 \text{ Btu/lbm}$$



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

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

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

$$m_1 = m_f + m_g = \frac{\nu_f}{\nu_f} + \frac{\nu_g}{\nu_g} = \frac{4 \times 0.2 \text{ ft}^3}{0.01332 \text{ ft}^3/\text{lbm}} + \frac{4 \times 0.8 \text{ ft}^3}{0.4776 \text{ ft}^3/\text{lbm}} = 60.04 + 6.70 = 66.74 \text{ lbm}$$

$$U_1 = m_1 u_1 = m_f u_f + m_g u_g = (60.04)(37.623) + (6.70)(104.99) = 2962 \text{ Btu}$$

$$m_2 = \frac{\nu}{\nu_2} = \frac{4 \text{ ft}^3}{0.4776 \text{ ft}^3/\text{lbm}} = 8.375 \text{ lbm}$$

Then from the mass and energy balances,

$$m_e = m_1 - m_2 = 66.74 - 8.375 = 58.37 \text{ lbm}$$

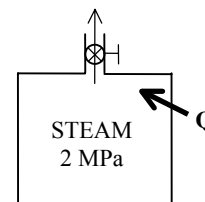
$$\begin{aligned} Q_{\text{in}} &= m_e h_e + m_2 u_2 - m_1 u_1 \\ &= (58.37 \text{ lbm})(113.83 \text{ Btu/lbm}) + (8.375 \text{ lbm})(104.99 \text{ Btu/lbm}) - 2962 \text{ Btu} \\ &= \mathbf{4561 \text{ Btu}} \end{aligned}$$

5-136 A rigid tank initially contains superheated steam. A valve at the top of the tank is opened, and vapor is allowed to escape at constant pressure until the temperature rises to 500°C. The amount of heat transfer is 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 steam leaving the tank. **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)

$$\begin{aligned} P_1 = 2 \text{ MPa} \quad \left\{ \begin{array}{l} \nu_1 = 0.12551 \text{ m}^3/\text{kg} \\ T_1 = 300^\circ\text{C} \end{array} \right. \quad \left\{ \begin{array}{l} u_1 = 2773.2 \text{ kJ/kg}, \quad h_1 = 3024.2 \text{ kJ/kg} \\ P_2 = 2 \text{ MPa} \end{array} \right. \quad \left\{ \begin{array}{l} \nu_2 = 0.17568 \text{ m}^3/\text{kg} \\ T_2 = 500^\circ\text{C} \end{array} \right. \quad \left\{ \begin{array}{l} u_2 = 3116.9 \text{ kJ/kg}, \quad h_2 = 3468.3 \text{ kJ/kg} \end{array} \right. \end{aligned}$$



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

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

The state and thus the enthalpy of the steam leaving the tank is changing during this process. But for simplicity, we assume constant properties for the exiting steam at the average values. Thus,

$$h_e \cong \frac{h_1 + h_2}{2} = \frac{3024.2 + 3468.3 \text{ kJ/kg}}{2} = 3246.2 \text{ kJ/kg}$$

The initial and the final masses in the tank are

$$\begin{aligned} m_1 &= \frac{\nu_1}{\nu_1} = \frac{0.2 \text{ m}^3}{0.12551 \text{ m}^3/\text{kg}} = 1.594 \text{ kg} \\ m_2 &= \frac{\nu_2}{\nu_2} = \frac{0.2 \text{ m}^3}{0.17568 \text{ m}^3/\text{kg}} = 1.138 \text{ kg} \end{aligned}$$

Then from the mass and energy balance relations,

$$m_e = m_1 - m_2 = 1.594 - 1.138 = 0.456 \text{ kg}$$

$$\begin{aligned} Q_{\text{in}} &= m_e h_e + m_2 u_2 - m_1 u_1 \\ &= (0.456 \text{ kg})(3246.2 \text{ kJ/kg}) + (1.138 \text{ kg})(3116.9 \text{ kJ/kg}) - (1.594 \text{ kg})(2773.2 \text{ kJ/kg}) \\ &= \mathbf{606.8 \text{ kJ}} \end{aligned}$$

5-137 A pressure cooker is initially half-filled with liquid water. If the pressure cooker is not to run out of liquid water for 1 h, the highest rate of heat transfer allowed is 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.

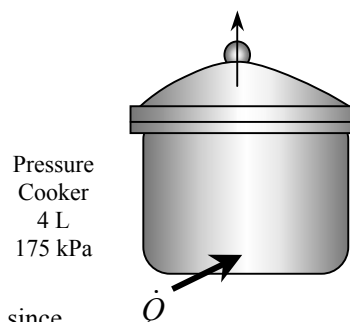
Properties The properties of water are (Tables A-4 through A-6)

$$P_1 = 175 \text{ kPa} \rightarrow \nu_f = 0.001057 \text{ m}^3/\text{kg}, \nu_g = 1.0037 \text{ m}^3/\text{kg}$$

$$u_f = 486.82 \text{ kJ/kg}, u_g = 2524.5 \text{ kJ/kg}$$

$$P_2 = 175 \text{ kPa} \left\{ \begin{array}{l} \nu_2 = \nu_{g@175 \text{ kPa}} = 1.0036 \text{ m}^3/\text{kg} \\ \text{sat. vapor} \end{array} \right. \left\{ \begin{array}{l} u_2 = u_{g@175 \text{ kPa}} = 2524.5 \text{ kJ/kg} \end{array} \right.$$

$$P_e = 175 \text{ kPa} \left\{ \begin{array}{l} h_e = h_{g@175 \text{ kPa}} = 2700.2 \text{ kJ/kg} \\ \text{sat. vapor} \end{array} \right.$$



Analysis We take the cooker 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

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

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

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

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

$$m_1 = m_f + m_g = \frac{\nu_f}{\nu_f} + \frac{\nu_g}{\nu_g} = \frac{0.002 \text{ m}^3}{0.001057 \text{ m}^3/\text{kg}} + \frac{0.002 \text{ m}^3}{1.0036 \text{ m}^3/\text{kg}} = 1.893 + 0.002 = 1.895 \text{ kg}$$

$$U_1 = m_1 u_1 = m_f u_f + m_g u_g = (1.893)(486.82) + (0.002)(2524.5) = 926.6 \text{ kJ}$$

$$m_2 = \frac{\nu}{\nu_2} = \frac{0.004 \text{ m}^3}{1.0037 \text{ m}^3/\text{kg}} = 0.004 \text{ kg}$$

Then from the mass and energy balances,

$$m_e = m_1 - m_2 = 1.895 - 0.004 = 1.891 \text{ kg}$$

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

$$= (1.891 \text{ kg})(2700.2 \text{ kJ/kg}) + (0.004 \text{ kg})(2524.5 \text{ kJ/kg}) - 926.6 \text{ kJ} = 4188 \text{ kJ}$$

Thus,

$$\dot{Q} = \frac{Q}{\Delta t} = \frac{4188 \text{ kJ}}{3600 \text{ s}} = \mathbf{1.163 \text{ kW}}$$

5-138 An insulated rigid tank initially contains helium gas at high pressure. A valve is opened, and half of the mass of helium is allowed to escape. The final temperature and pressure in the tank 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. **4** The tank is insulated and thus heat transfer is negligible. **5** Helium is an ideal gas with constant specific heats.

Properties The specific heat ratio of helium is $k = 1.667$ (Table A-2).

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

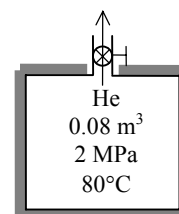
Mass balance: $m_{\text{in}} - m_{\text{out}} = \Delta m_{\text{system}} \rightarrow m_e = m_1 - m_2$

$$m_2 = \frac{1}{2} m_1 \quad (\text{given}) \quad \longrightarrow \quad m_e = m_2 = \frac{1}{2} m_1$$

Energy balance:

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

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



Note that the state and thus the enthalpy of helium leaving the tank is changing during this process. But for simplicity, we assume constant properties for the exiting steam at the average values.

Combining the mass and energy balances: $0 = \frac{1}{2} m_1 h_e + \frac{1}{2} m_1 u_2 - m_1 u_1$

Dividing by $m_1/2$ $0 = h_e + u_2 - 2u_1$ or $0 = c_p \frac{T_1 + T_2}{2} + c_v T_2 - 2c_v T_1$

Dividing by c_v : $0 = k(T_1 + T_2) + 2T_2 - 4T_1$ since $k = c_p / c_v$

Solving for T_2 : $T_2 = \frac{(4-k)}{(2+k)} T_1 = \frac{(4-1.667)}{(2+1.667)} (353 \text{ K}) = \mathbf{225 \text{ K}}$

The final pressure in the tank is

$$\frac{P_1 V}{P_2 V} = \frac{m_1 R T_1}{m_2 R T_2} \longrightarrow P_2 = \frac{m_2 T_2}{m_1 T_1} P_1 = \frac{1}{2} \frac{225}{353} (2000 \text{ kPa}) = \mathbf{637 \text{ kPa}}$$

5-139E 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 transferred is 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.

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)

$$\begin{aligned} T_i &= 580 \text{ R} & \longrightarrow & h_i = 138.66 \text{ Btu/lbm} \\ T_1 &= 580 \text{ R} & \longrightarrow & u_1 = 98.90 \text{ Btu/lbm} \\ T_2 &= 580 \text{ R} & \longrightarrow & u_2 = 98.90 \text{ Btu/lbm} \end{aligned}$$

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

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

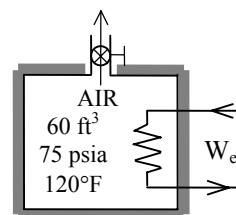
The initial and the final masses of air in the tank are

$$\begin{aligned} m_1 &= \frac{P_1 \mathcal{V}}{RT_1} = \frac{(75 \text{ psia})(60 \text{ ft}^3)}{(0.3704 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R})(580 \text{ R})} = 20.95 \text{ lbm} \\ m_2 &= \frac{P_2 \mathcal{V}}{RT_2} = \frac{(30 \text{ psia})(60 \text{ ft}^3)}{(0.3704 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R})(580 \text{ R})} = 8.38 \text{ lbm} \end{aligned}$$

Then from the mass and energy balances,

$$m_e = m_1 - m_2 = 20.95 - 8.38 = 12.57 \text{ lbm}$$

$$\begin{aligned} W_{e,\text{in}} &= m_e h_e + m_2 u_2 - m_1 u_1 \\ &= (12.57 \text{ lbm})(138.66 \text{ Btu/lbm}) + (8.38 \text{ lbm})(98.90 \text{ Btu/lbm}) - (20.95 \text{ lbm})(98.90 \text{ Btu/lbm}) \\ &= \mathbf{500 \text{ Btu}} \end{aligned}$$



5-140 A vertical cylinder initially contains air at room temperature. Now a valve is opened, and air is allowed to escape at constant pressure and temperature until the volume of the cylinder goes down by half. The amount air that left the cylinder and the amount of heat transfer 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** There are no work interactions. **4** Air is an ideal gas with constant specific heats. **5** The direction of heat transfer is to the cylinder (will be verified).

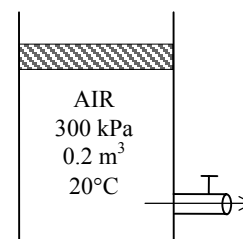
Properties The gas constant of air is $R = 0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K}$ (Table A-1).

Analysis (a) We take the cylinder 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:
$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

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



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

$$m_1 = \frac{P_1 V_1}{RT_1} = \frac{(300 \text{ kPa})(0.2 \text{ m}^3)}{(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(293 \text{ K})} = 0.714 \text{ kg}$$

$$m_2 = \frac{P_2 V_2}{RT_2} = \frac{(300 \text{ kPa})(0.1 \text{ m}^3)}{(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(293 \text{ K})} = 0.357 \text{ kg} = \frac{1}{2} m_1$$

Then from the mass balance,

$$m_e = m_1 - m_2 = 0.714 - 0.357 = \mathbf{0.357 \text{ kg}}$$

(b) This is a constant pressure process, and thus the W_b and the ΔU terms can be combined into ΔH to yield

$$Q = m_e h_e + m_2 h_2 - m_1 h_1$$

Noting that the temperature of the air remains constant during this process, we have $h_i = h_1 = h_2 = h$.

Also, $m_e = m_2 = \frac{1}{2} m_1$. Thus,

$$Q = \left(\frac{1}{2} m_1 + \frac{1}{2} m_1 - m_1 \right) h = \mathbf{0}$$

5-141 A balloon is initially filled with helium gas at atmospheric conditions. The tank is connected to a supply line, and helium is allowed to enter the balloon until the pressure rises from 100 to 150 kPa. The final temperature in the balloon is 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** Helium is an ideal gas with constant specific heats. **3** The expansion process is quasi-equilibrium. **4** Kinetic and potential energies are negligible. **5** There are no work interactions involved other than boundary work. **6** Heat transfer is negligible.

Properties The gas constant of helium is $R = 2.0769 \text{ kJ/kg} \cdot \text{K}$ (Table A-1). The specific heats of helium are $c_p = 5.1926$ and $c_v = 3.1156 \text{ kJ/kg} \cdot \text{K}$ (Table A-2a).

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

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

$$m_1 = \frac{P_1 \mathcal{V}_1}{RT_1} = \frac{(100 \text{ kPa})(65 \text{ m}^3)}{(2.0769 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(295 \text{ K})} = 10.61 \text{ kg}$$

$$\frac{P_1}{P_2} = \frac{\mathcal{V}_1}{\mathcal{V}_2} \rightarrow \mathcal{V}_2 = \frac{P_2}{P_1} \mathcal{V}_1 = \frac{150 \text{ kPa}}{100 \text{ kPa}} (65 \text{ m}^3) = 97.5 \text{ m}^3$$

$$m_2 = \frac{P_2 \mathcal{V}_2}{RT_2} = \frac{(150 \text{ kPa})(97.5 \text{ m}^3)}{(2.0769 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(T_2 \text{ K})} = \frac{7041.74}{T_2} \text{ kg}$$

Then from the mass balance,

$$m_i = m_2 - m_1 = \frac{7041.74}{T_2} - 10.61 \text{ kg}$$

Noting that P varies linearly with \mathcal{V} , the boundary work done during this process is

$$W_b = \frac{P_1 + P_2}{2} (\mathcal{V}_2 - \mathcal{V}_1) = \frac{(100 + 150) \text{ kPa}}{2} (97.5 - 65) \text{ m}^3 = 4062.5 \text{ kJ}$$

Using specific heats, the energy balance relation reduces to

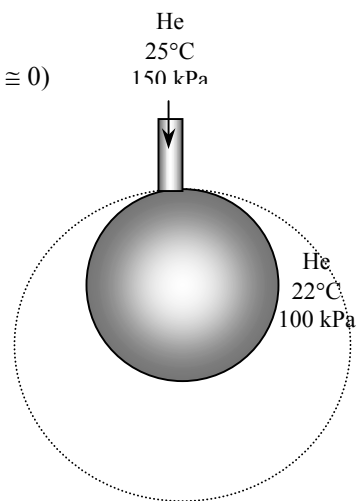
$$W_{b,\text{out}} = m_i c_p T_i - m_2 c_v T_2 + m_1 c_v T_1$$

Substituting,

$$4062.5 = \left(\frac{7041.74}{T_2} - 10.61 \right) (5.1926)(298) - \frac{7041.74}{T_2} (3.1156)T_2 + (10.61)(3.1156)(295)$$

It yields

$$T_2 = \mathbf{333.6 \text{ K}}$$



5-142 An insulated piston-cylinder device with a linear spring is applying force to the piston. A valve at the bottom of the cylinder is opened, and refrigerant is allowed to escape. The amount of refrigerant that escapes and the final temperature of the refrigerant 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 assuming that the state of fluid leaving the device remains constant. **2** Kinetic and potential energies are negligible.

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

$$\left. \begin{array}{l} P_1 = 1.2 \text{ MPa} \\ T_1 = 120^\circ\text{C} \end{array} \right\} \begin{array}{l} \nu_1 = 0.02423 \text{ m}^3/\text{kg} \\ u_1 = 325.03 \text{ kJ/kg} \\ h_1 = 354.11 \text{ kJ/kg} \end{array}$$

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

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

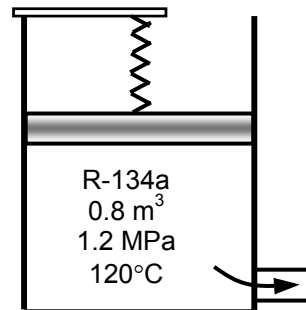
$$W_{b,\text{in}} - m_e h_e = m_2 u_2 - m_1 u_1 \quad (\text{since } Q \cong ke \cong pe \cong 0)$$

The initial mass and the relations for the final and exiting masses are

$$m_1 = \frac{\nu_1}{\nu_1} = \frac{0.8 \text{ m}^3}{0.02423 \text{ m}^3/\text{kg}} = 33.02 \text{ kg}$$

$$m_2 = \frac{\nu_2}{\nu_2} = \frac{0.5 \text{ m}^3}{\nu_2}$$

$$m_e = m_1 - m_2 = 33.02 - \frac{0.5 \text{ m}^3}{\nu_2}$$



Noting that the spring is linear, the boundary work can be determined from

$$W_{b,\text{in}} = \frac{P_1 + P_2}{2} (\nu_1 - \nu_2) = \frac{(1200 + 600) \text{ kPa}}{2} (0.8 - 0.5) \text{ m}^3 = 270 \text{ kJ}$$

Substituting the energy balance,

$$270 - \left(33.02 - \frac{0.5 \text{ m}^3}{\nu_2} \right) h_e = \left(\frac{0.5 \text{ m}^3}{\nu_2} \right) u_2 - (33.02 \text{ kg})(325.03 \text{ kJ/kg}) \quad (\text{Eq. 1})$$

where the enthalpy of exiting fluid is assumed to be the average of initial and final enthalpies of the refrigerant in the cylinder. That is,

$$h_e = \frac{h_1 + h_2}{2} = \frac{(354.11 \text{ kJ/kg}) + h_2}{2}$$

Final state properties of the refrigerant (h_2 , u_2 , and ν_2) are all functions of final pressure (known) and temperature (unknown). The solution may be obtained by a trial-error approach by trying different final state temperatures until Eq. (1) is satisfied. Or solving the above equations simultaneously using an equation solver with built-in thermodynamic functions such as EES, we obtain

$$T_2 = \mathbf{96.8^\circ\text{C}}, \quad m_e = \mathbf{22.47 \text{ kg}}, \quad h_2 = 336.20 \text{ kJ/kg},$$

$$u_2 = 307.77 \text{ kJ/kg}, \quad \nu_2 = 0.04739 \text{ m}^3/\text{kg}, \quad m_2 = 10.55 \text{ kg}$$

5-143 Steam flowing in a supply line is allowed to enter into an insulated tank until a specified state is achieved in the tank. The mass of the steam that has entered and the pressure of the steam in the supply line 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 entering the tank remains constant. **2** Kinetic and potential energies are negligible.

Properties The initial and final properties of steam in the tank are (Tables A-5 and A-6)

$$\left. \begin{array}{l} P_1 = 1 \text{ MPa} \\ x_1 = 1 \text{ (sat. vap.)} \end{array} \right\} \begin{array}{l} v_1 = 0.19436 \text{ m}^3/\text{kg} \\ u_1 = 2582.8 \text{ kJ/kg} \end{array}$$

$$\left. \begin{array}{l} P_2 = 2 \text{ MPa} \\ T_2 = 300^\circ\text{C} \end{array} \right\} \begin{array}{l} v_2 = 0.12551 \text{ m}^3/\text{kg} \\ u_2 = 2773.2 \text{ kJ/kg} \end{array}$$

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

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

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

The initial and final masses and the mass that has entered are

$$m_1 = \frac{v}{v_1} = \frac{2 \text{ m}^3}{0.19436 \text{ m}^3/\text{kg}} = 10.29 \text{ kg}$$

$$m_2 = \frac{v}{v_2} = \frac{2 \text{ m}^3}{0.12551 \text{ m}^3/\text{kg}} = 15.94 \text{ kg}$$

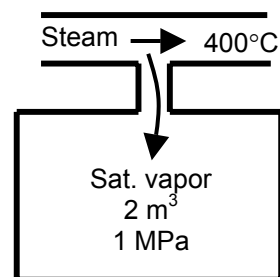
$$m_i = m_2 - m_1 = 15.94 - 10.29 = \mathbf{5.645 \text{ kg}}$$

Substituting,

$$(5.645 \text{ kg})h_i = (15.94 \text{ kg})(2773.2 \text{ kJ/kg}) - (10.29 \text{ kg})(2582.8 \text{ kJ/kg}) \longrightarrow h_i = 3120.3 \text{ kJ/kg}$$

The pressure in the supply line is

$$\left. \begin{array}{l} h_i = 3120.3 \text{ kJ/kg} \\ T_i = 400^\circ\text{C} \end{array} \right\} P_i = \mathbf{8931 \text{ kPa}} \quad (\text{determined from EES})$$



5-144 Steam at a specified state is allowed to enter a piston-cylinder device in which steam undergoes a constant pressure expansion process. The amount of mass that enters and the amount of heat transfer 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 entering the device remains constant. **2** Kinetic and potential energies are negligible.

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

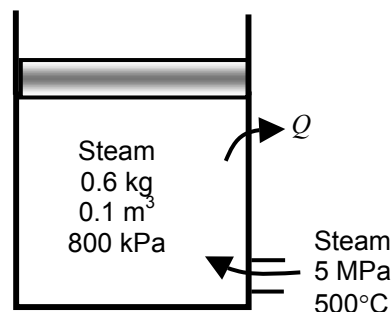
$$\nu_1 = \frac{\nu_1}{m_1} = \frac{0.1 \text{ m}^3}{0.6 \text{ kg}} = 0.16667 \text{ m}^3/\text{kg}$$

$$P_2 = P_1$$

$$\left. \begin{array}{l} P_1 = 800 \text{ kPa} \\ \nu_1 = 0.16667 \text{ m}^3/\text{kg} \end{array} \right\} u_1 = 2004.4 \text{ kJ/kg}$$

$$\left. \begin{array}{l} P_2 = 800 \text{ kPa} \\ T_2 = 250^\circ\text{C} \end{array} \right\} \begin{array}{l} \nu_2 = 0.29321 \text{ m}^3/\text{kg} \\ u_2 = 2715.9 \text{ kJ/kg} \end{array}$$

$$\left. \begin{array}{l} P_i = 5 \text{ MPa} \\ T_i = 500^\circ\text{C} \end{array} \right\} h_i = 3434.7 \text{ kJ/kg}$$



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

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

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

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

Noting that the pressure remains constant, the boundary work is determined from

$$W_{\text{b,out}} = P(\nu_2 - \nu_1) = (800 \text{ kPa})(2 \times 0.1 - 0.1) \text{ m}^3 = 80 \text{ kJ}$$

The final mass and the mass that has entered are

$$m_2 = \frac{\nu_2}{\nu_2} = \frac{0.2 \text{ m}^3}{0.29321 \text{ m}^3/\text{kg}} = 0.682 \text{ kg}$$

$$m_i = m_2 - m_1 = 0.682 - 0.6 = \mathbf{0.082 \text{ kg}}$$

(b) Finally, substituting into energy balance equation

$$Q_{\text{in}} - 80 \text{ kJ} + (0.082 \text{ kg})(3434.7 \text{ kJ/kg}) = (0.682 \text{ kg})(2715.9 \text{ kJ/kg}) - (0.6 \text{ kg})(2004.4 \text{ kJ/kg})$$

$$Q_{\text{in}} = \mathbf{447.9 \text{ kJ}}$$