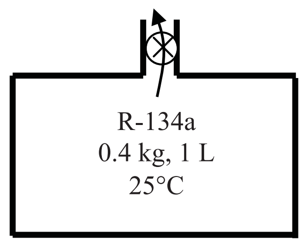
6-167 A tank initially contains saturated mixture of R-134a. A valve is opened and R-134a vapor only is allowed to escape slowly such that temperature remains constant. The heat transfer necessary with the surroundings to maintain the temperature and pressure of the R-134a constant is to be determined.

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 exit remains constant. **2** Kinetic and potential energies are negligible. **3** There are no work interactions involved.

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:

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



Energy balance:

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

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

Combining the two balances:

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

The specific volume at the initial state is

$$v_1 = \frac{V}{m_1} = \frac{0.001\ \text{m}^3}{0.4\ \text{kg}} = 0.0025\ \text{m}^3/\text{kg}$$

The initial state properties of R-134a in the tank are

$$\left.\begin{array}{l} T_1 = 26°\text{C} \\ v_1 = 0.0025\ \text{m}^3/\text{kg} \end{array}\right\} \begin{array}{l} x_1 = \dfrac{v_1 - v_f}{v_{fg}} = \dfrac{0.0025 - 0.0008313}{0.029976 - 0.0008313} = 0.05726 \\ u_1 = u_f + x_1 u_{fg} = 87.26 + (0.05726)(156.87) = 96.24\ \text{kJ/kg} \end{array} \quad \text{(Table A-11)}$$

The enthalpy of saturated vapor refrigerant leaving the bottle is

$$h_e = h_{g\,@\,26°\text{C}} = 264.68\ \text{kJ/kg}$$

The specific volume at the final state is

$$v_2 = \frac{V}{m_2} = \frac{0.001\ \text{m}^3}{0.1\ \text{kg}} = 0.01\ \text{m}^3/\text{kg}$$

The internal energy at the final state is

$$\left.\begin{array}{l} T_2 = 26°\text{C} \\ v_2 = 0.01\ \text{m}^3/\text{kg} \end{array}\right\} \begin{array}{l} x_2 = \dfrac{v_2 - v_f}{v_{fg}} = \dfrac{0.01 - 0.0008313}{0.029976 - 0.0008313} = 0.3146 \\ u_2 = u_f + x_1 u_{fg} = 87.26 + (0.3146)(156.87) = 136.61\ \text{kJ/kg} \end{array} \quad \text{(Table A-11)}$$

Substituting into the energy balance equation,

$$\begin{aligned} Q_{\text{in}} &= m_2 u_2 - m_1 u_1 + (m_1 - m_2) h_e \\ &= (0.1\ \text{kg})(136.61\ \text{kJ/kg}) - (0.4\ \text{kg})(96.24\ \text{kJ/kg}) + (0.4 - 0.1\ \text{kg})(264.68\ \text{kJ/kg}) \\ &= \mathbf{54.6\ kJ} \end{aligned}$$