8-111 Two rigid tanks that contain water at different states are connected by a valve. The valve is opened and steam flows from tank A to tank B until the pressure in tank A drops to a specified value. Tank B loses heat to the surroundings. The final temperature in each tank and the work potential wasted during this process are to be determined.

Assumptions **1** Tank A is insulated and thus heat transfer is negligible. **2** The water that remains in tank A undergoes a reversible adiabatic process. **3** The thermal energy stored in the tanks themselves is negligible. **4** The system is stationary and thus kinetic and potential energy changes are negligible. **5** There are no work interactions.

Analysis (a) The steam in tank A undergoes a reversible, adiabatic process, and thus $s_2 = s_1$. From the steam tables (Tables A-4 through A-6),

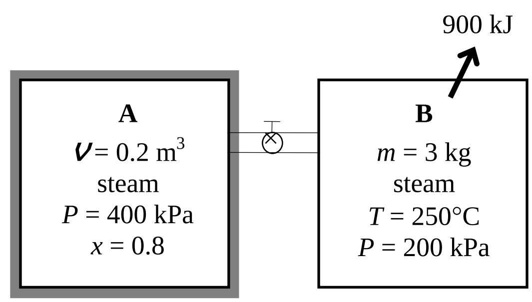
Tank A:

$$\left.\begin{array}{l} P_1 = 400 \text{ kPa} \\ x_1 = 0.8 \end{array}\right\} \begin{array}{l} \boldsymbol{v}_{1,A} = \boldsymbol{v}_f + x_1 \boldsymbol{v}_{fg} = 0.001084 + (0.8)(0.46242 - 0.001084) = 0.37015 \text{ m}^3\text{/kg} \\ u_{1,A} = u_f + x_1 u_{fg} = 604.22 + (0.8)(1948.9) = 2163.3 \text{ kJ/kg} \\ s_{1,A} = s_f + x_1 s_{fg} = 1.7765 + (0.8)(5.1191) = 5.8717 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 300 \text{ kPa} \\ s_2 = s_1 \\ (\text{sat. mixture}) \end{array}\right\} \begin{array}{l} T_{2,A} = T_{sat@300kPa} = \mathbf{133.52^\circ C} \\ x_{2,A} = \dfrac{s_{2,A} - s_f}{s_{fg}} = \dfrac{5.8717 - 1.6717}{5.3200} = 0.7895 \\ \boldsymbol{v}_{2,A} = \boldsymbol{v}_f + x_{2,A} \boldsymbol{v}_{fg} = 0.001073 + (0.7895)(0.60582 - 0.001073) = 0.47850 \text{ m}^3\text{/kg} \\ u_{2,A} = u_f + x_{2,A} u_{fg} = 561.11 + (0.7895)(1982.1 \text{ kJ/kg}) = 2125.9 \text{ kJ/kg} \end{array}$$

Tank B:

$$\left.\begin{array}{l} P_1 = 200 \text{ kPa} \\ T_1 = 250^\circ\text{C} \end{array}\right\} \begin{array}{l} \boldsymbol{v}_{1,B} = 1.1989 \text{ m}^3\text{/kg} \\ u_{1,B} = 2731.4 \text{ kJ/kg} \\ s_{1,B} = 7.7100 \text{ kJ/kg}\cdot\text{K} \end{array}$$



The initial and the final masses in tank A are

$$m_{1,A} = \frac{\boldsymbol{V}_A}{\boldsymbol{v}_{1,A}} = \frac{0.2 \text{ m}^3}{0.37015 \text{ m}^3\text{/kg}} = 0.5403 \text{ kg}$$

and

$$m_{2,A} = \frac{\boldsymbol{V}_A}{\boldsymbol{v}_{2,A}} = \frac{0.2\text{m}^3}{0.479\text{m}^3\text{/kg}} = 0.4180 \text{ kg}$$

Thus, 0.540 - 0.418 = 0.122 kg of mass flows into tank B. Then,

$$m_{2,B} = m_{1,B} - 0.122 = 3 + 0.122 = 3.122 \text{ kg}$$

The final specific volume of steam in tank B is determined from

$$v_{2,B} = \frac{\boldsymbol{V}_B}{m_{2,B}} = \frac{(m_1 v_1)_B}{m_{2,B}} = \frac{(3 \text{ kg})(1.1989 \text{ m}^3\text{/kg})}{3.122 \text{ m}^3} = 1.152 \text{ m}^3\text{/kg}$$

We take the entire contents of both tanks as the system, which is a closed system. The energy balance for this stationary closed system can be expressed as

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

$$-Q_{\text{out}} = \Delta U = (\Delta U)_A + (\Delta U)_B \quad (\text{since } W = \text{KE} = \text{PE} = 0)$$

$$-Q_{\text{out}} = (m_2 u_2 - m_1 u_1)_A + (m_2 u_2 - m_1 u_1)_B$$

Substituting,

$$-900 = \{(0.418)(2125.9) - (0.5403)(2163.3)\} + \{(3.122)u_{2,B} - (3)(2731.4)\}$$

$$u_{2,B} = 2425.9 \text{ kJ/kg}$$

Thus,

$$\left.\begin{aligned} v_{2,B} &= 1.152 \text{ m}^3/\text{kg} \\ u_{2,B} &= 2425.9 \text{ kJ/kg} \end{aligned}\right\} \begin{aligned} T_{2,B} &= \mathbf{110.1°C} \\ s_{2,B} &= 6.9772 \text{ kJ/kg}\cdot\text{K} \end{aligned}$$

(*b*) The total entropy generation during this process is determined by applying the entropy balance on an *extended system* that includes both tanks and their immediate surroundings so that the boundary temperature of the extended system is the temperature of the surroundings at all times. It gives

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

$$-\frac{Q_{\text{out}}}{T_{\text{b,surr}}} + S_{\text{gen}} = \Delta S_{\text{A}} + \Delta S_{\text{B}}$$

Rearranging and substituting, the total entropy generated during this process is determined to be

$$\begin{aligned} S_{\text{gen}} &= \Delta S_A + \Delta S_B + \frac{Q_{\text{out}}}{T_{\text{b,surr}}} = (m_2 s_2 - m_1 s_1)_A + (m_2 s_2 - m_1 s_1)_B + \frac{Q_{\text{out}}}{T_{\text{b,surr}}} \\ &= \{(0.418)(5.8717) - (0.5403)(5.8717)\} + \{(3.122)(6.9772) - (3)(7.7100)\} + \frac{900 \text{ kJ}}{273 \text{ K}} \\ &= 1.234 \text{ kJ/K} \end{aligned}$$

The work potential wasted is equivalent to the exergy destroyed during a process, which can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$,

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} = (273 \text{ K})(1.234 \text{ kJ/K}) = \mathbf{337\ kJ}$$