8-84 An insulated 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 amount of steam that entered the cylinder and the exergy destroyed are to be determined.

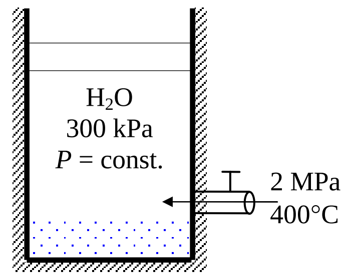
Assumptions **1** This is an unsteady process since the conditions within the device are changing during the process, but it can be analyzed as a uniform-flow process since the state of fluid at the inlet remains constant. **2** The expansion process is quasi-equilibrium. **3** Kinetic and potential energies are negligible. **4** The device is insulated and thus heat transfer is negligible.

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

$$\left.\begin{array}{l} P_1 = 300\text{ kPa} \\ x_1 = 13/15 = 0.8667 \end{array}\right\} \begin{array}{l} h_1 = h_f + x_1 h_{fg} = 561.43 + 0.8667 \times 2163.5 = 2436.5\text{ kJ/kg} \\ s_1 = s_f + x_1 s_{fg} = 1.6716 + 0.8667 \times 5.3200 = 6.2824\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 300\text{ kPa} \\ \text{sat.vapor} \end{array}\right\} \begin{array}{l} h_2 = h_{g\,@\,300\text{ kPa}} = 2724.9\text{ kJ/kg} \\ s_2 = s_{g\,@\,300\text{ kPa}} = 6.9917\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_i = 2\text{ MPa} \\ T_i = 400°\text{C} \end{array}\right\} \begin{array}{l} h_i = 3248.4\text{ kJ/kg} \\ s_i = 7.1292\text{ kJ/kg}\cdot\text{K} \end{array}$$



Analysis (*a*) We take the cylinder as the system, which is a control volume. 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 unsteady-flow system can be expressed as

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

Energy balance:

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

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

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,

$$m_2 = \frac{h_i - h_1}{h_i - h_2} m_1 = \frac{(3248.4 - 2436.5)\text{kJ/kg}}{(3248.4 - 2724.9)\text{kJ/kg}}(15\text{ kg}) = 23.27\text{ kg}$$

Thus, $m_i = m_2 - m_1 = 23.27 - 15 = \mathbf{8.27\ kg}$

(*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 the insulated cylinder,

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

$$m_i s_i + S_{\text{gen}} = \Delta S_{\text{system}} = m_2 s_2 - m_1 s_1$$

$$S_{\text{gen}} = m_2 s_2 - m_1 s_1 - m_i s_i$$

Substituting, the exergy destruction is determined to be

$$\begin{aligned} X_{\text{destroyed}} &= T_0 S_{\text{gen}} = T_0 [m_2 s_2 - m_1 s_1 - m_i s_i] \\ &= (298\text{ K})(23.27 \times 6.9917 - 15 \times 6.2824 - 8.27 \times 7.1292) \\ &= \mathbf{2832\ kJ} \end{aligned}$$