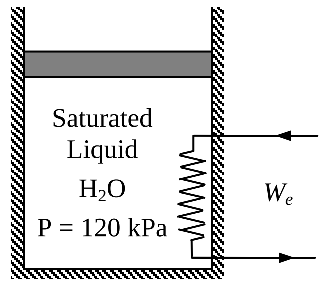
8-36 An insulated cylinder is initially filled with saturated liquid water at a specified pressure. The water is heated electrically at constant pressure. The minimum work by which this process can be accomplished and the exergy destroyed are to be determined.

Assumptions **1** The kinetic and potential energy changes are negligible. **2** The cylinder is well-insulated and thus heat transfer is negligible. **3** The thermal energy stored in the cylinder itself is negligible. **4** The compression or expansion process is quasi-equilibrium.

Analysis (a) From the steam tables (Tables A-4 through A-6),



$$\left.\begin{array}{l} P_1 = 120 \text{ kPa} \\ \text{sat. liquid} \end{array}\right\} \begin{array}{l} u_1 = u_{f\,@120\text{ kPa}} = 439.27 \text{ kJ/kg} \\ \boldsymbol{v}_1 = \boldsymbol{v}_{f\,@120\text{ kPa}} = 0.001047 \text{ m}^3\text{/kg} \\ h_1 = h_{f\,@120\text{ kPa}} = 439.36 \text{ kJ/kg} \\ s_1 = s_{f\,@120\text{ kPa}} = 1.3609 \text{ kJ/kg}\cdot\text{K} \end{array}$$

The mass of the steam is

$$m = \frac{\boldsymbol{V}}{\boldsymbol{v}_1} = \frac{0.008 \text{ m}^3}{0.001047 \text{ m}^3/\text{kg}} = 7.639 \text{ kg}$$

We take the contents of the cylinder as the system. This is a closed system since no mass enters or leaves. The energy balance for this stationary closed system can be expressed as

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

$$W_{\text{e,in}} - W_{\text{b,out}} = \Delta U$$

$$W_{\text{e,in}} = m(h_2 - h_1)$$

since $\Delta U + W_b = \Delta H$ during a constant pressure quasi-equilibrium process. Solving for h_2,

$$h_2 = h_1 + \frac{W_{e,in}}{m} = 439.36 + \frac{1400 \text{ kJ}}{7.639 \text{ kg}} = 622.63 \text{ kJ/kg}$$

Thus,

$$\left.\begin{array}{l} P_2 = 120 \text{ kPa} \\ h_2 = 622.63 \text{ kJ/kg} \end{array}\right\} \begin{array}{l} x_2 = \dfrac{h_2 - h_f}{h_{fg}} = \dfrac{622.63 - 439.36}{2243.7} = 0.08168 \\ s_2 = s_f + x_2 s_{fg} = 1.3609 + 0.08168 \times 5.93687 = 1.8459 \text{ kJ/kg}\cdot\text{K} \\ u_2 = u_f + x_2 u_{fg} = 439.24 + 0.08168 \times 2072.4 = 608.52 \text{ kJ/kg} \\ \boldsymbol{v}_2 = \boldsymbol{v}_f + x_2 \boldsymbol{v}_{fg} = 0.001047 + 0.08168 \times (1.4285 - 0.001047) = 0.1176 \text{ m}^3\text{/kg} \end{array}$$

The reversible work input, which represents the minimum work input $W_{\text{rev,in}}$ in this case can be determined from the exergy balance by setting the exergy destruction equal to zero,

$$\underbrace{X_{\text{in}} - X_{\text{out}}}_{\substack{\text{Net exergy transfer} \\ \text{by heat, work, and mass}}} - \underbrace{X_{\text{destroyed}}^{\nearrow 0 \text{ (reversible)}}}_{\substack{\text{Exergy} \\ \text{destruction}}} = \underbrace{\Delta X_{\text{system}}}_{\substack{\text{Change} \\ \text{in exergy}}} \rightarrow W_{\text{rev,in}} = X_2 - X_1$$

Substituting the closed system exergy relation, the reversible work input during this process is determined to be

$$\begin{aligned} W_{\text{rev,in}} &= -m\left[(u_1 - u_2) - T_0(s_1 - s_2) + P_0(\boldsymbol{v}_1 - \boldsymbol{v}_2)\right] \\ &= -(7.639 \text{ kg})\{(439.27 - 608.52) \text{ kJ/kg} - (298 \text{ K})(1.3609 - 1.8459) \text{ kJ/kg}\cdot\text{K} \\ &\quad + (100 \text{ kPa})(0.001047 - 0.1176)\text{m}^3/\text{kg}[1 \text{ kJ}/1 \text{ kPa}\cdot\text{m}^3]\} \\ &= \mathbf{278 \text{ kJ}} \end{aligned}$$

(b) The exergy destruction (or irreversibility) associated with this process can be determined from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$ where the entropy generation is determined from an entropy balance on the cylinder, which is an insulated closed system,

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

$$S_{\text{gen}} = \Delta S_{\text{system}} = m(s_2 - s_1)$$

Substituting,

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} = mT_0(s_2 - s_1) = (298 \text{ K})(7.639 \text{ kg})(1.8459 - 1.3609)\text{kJ/kg}\cdot\text{K} = \mathbf{1104 \text{ kJ}}$$