

**5-40 CD EES** A cylinder equipped with an external spring is initially filled with steam at a specified state. Heat is transferred to the steam, and both the temperature and pressure rise. The final temperature, the boundary work done by the steam, and the amount of heat transfer are to be determined, and the process is to be shown on a  $P$ - $v$  diagram.

**Assumptions** **1** The cylinder is stationary and thus the kinetic and potential energy changes are zero. **2** The thermal energy stored in the cylinder itself is negligible. **3** The compression or expansion process is quasi-equilibrium. **4** The spring is a linear spring.

**Analysis** We take the contents of the cylinder as the system. This is a closed system since no mass enters or leaves. Noting that the spring is not part of the system (it is external), the energy balance for this stationary closed system can be expressed as

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

$$Q_{\text{in}} - W_{b,\text{out}} = \Delta U = m(u_2 - u_1) \quad (\text{since KE} = \text{PE} = 0)$$

$$Q_{\text{in}} = m(u_2 - u_1) + W_{b,\text{out}}$$

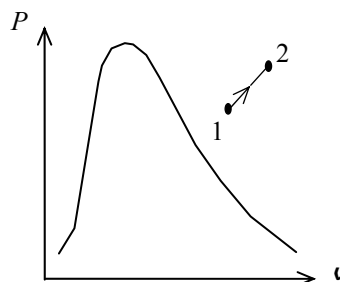
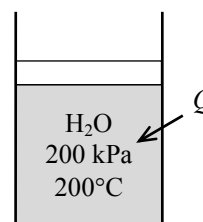
The properties of steam are (Tables A-4 through A-6)

$$\left. \begin{array}{l} P_1 = 200 \text{ kPa} \\ T_1 = 200^\circ\text{C} \end{array} \right\} \begin{array}{l} v_1 = 1.08049 \text{ m}^3/\text{kg} \\ u_1 = 2654.6 \text{ kJ/kg} \end{array}$$

$$m = \frac{V_1}{v_1} = \frac{0.5 \text{ m}^3}{1.08049 \text{ m}^3/\text{kg}} = 0.4628 \text{ kg}$$

$$v_2 = \frac{V_2}{m} = \frac{0.6 \text{ m}^3}{0.4628 \text{ kg}} = 1.2966 \text{ m}^3/\text{kg}$$

$$\left. \begin{array}{l} P_2 = 500 \text{ kPa} \\ v_2 = 1.2966 \text{ m}^3/\text{kg} \end{array} \right\} \begin{array}{l} T_2 = \mathbf{1132^\circ\text{C}} \\ u_2 = 4325.2 \text{ kJ/kg} \end{array}$$



(b) The pressure of the gas changes linearly with volume, and thus the process curve on a  $P$ - $V$  diagram will be a straight line. The boundary work during this process is simply the area under the process curve, which is a trapezoidal. Thus,

$$W_b = \text{Area} = \frac{P_1 + P_2}{2} (v_2 - v_1) = \frac{(200 + 500) \text{ kPa}}{2} (0.6 - 0.5) \text{ m}^3 \left( \frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3} \right) = \mathbf{35 \text{ kJ}}$$

(c) From the energy balance we have

$$Q_{\text{in}} = (0.4628 \text{ kg})(4325.2 - 2654.6) \text{ kJ/kg} + 35 \text{ kJ} = \mathbf{808 \text{ kJ}}$$