

**5–85** A well-insulated shell-and-tube heat exchanger is used to heat water ( $c_p = 4.18 \text{ kJ/kg}\cdot^\circ\text{C}$ ) in the tubes from  $20$  to  $70^\circ\text{C}$  at a rate of  $4.5 \text{ kg/s}$ . Heat is supplied by hot oil ( $c_p = 2.30 \text{ kJ/kg}\cdot^\circ\text{C}$ ) that enters the shell side at  $170^\circ\text{C}$  at a rate of  $10 \text{ kg/s}$ . Determine the rate of heat transfer in the heat exchanger and the exit temperature of oil.

**5-85** Water is heated by hot oil in a heat exchanger. The rate of heat transfer in the heat exchanger and the outlet temperature of oil are to be determined.

**Assumptions** 1 Steady operating conditions exist. 2 The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. 3 Changes in the kinetic and potential energies of fluid streams are negligible. 4 Fluid properties are constant.

**Properties** The specific heats of water and oil are given to be  $4.18$  and  $2.3 \text{ kJ/kg}\cdot^\circ\text{C}$ , respectively.

**Analysis** We take the cold water tubes as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\text{Rate of net energy transfer by heat, work, and mass}} = \underbrace{\Delta \dot{E}_{system}}_{\text{Rate of change in internal, kinetic, potential, etc. energies}} \stackrel{\nearrow 0 \text{ (steady)}}{=} 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{Q}_{in} + \dot{m}h_1 = \dot{m}h_2 \quad (\text{since } \Delta ke \cong \Delta pe \cong 0)$$

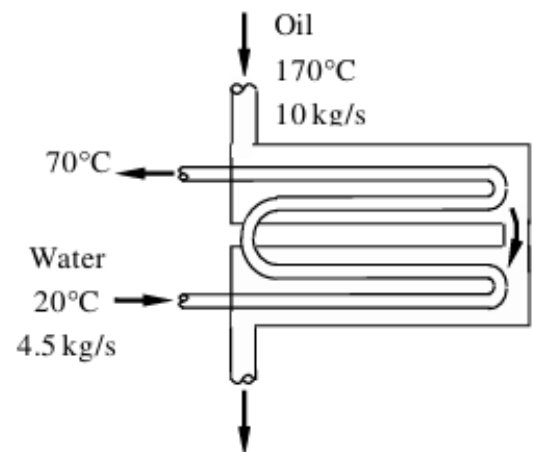
$$\dot{Q}_{in} = \dot{m}c_p(T_2 - T_1)$$

Then the rate of heat transfer to the cold water in this heat exchanger becomes

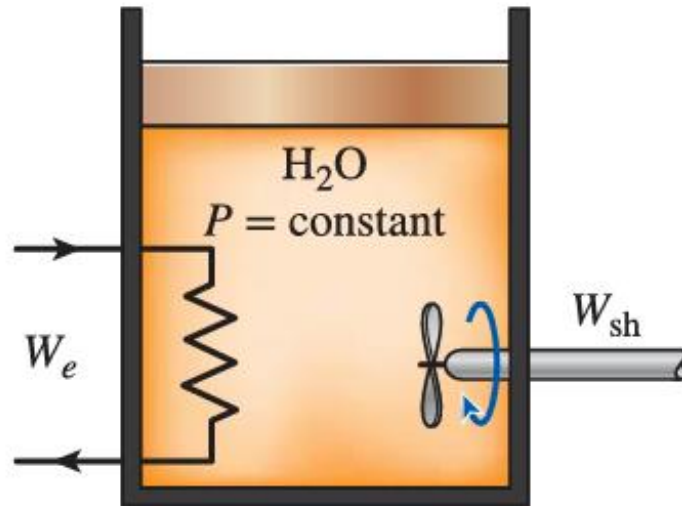
$$\dot{Q} = [\dot{m}c_p(T_{out} - T_{in})]_{\text{water}} = (4.5 \text{ kg/s})(4.18 \text{ kJ/kg}\cdot^\circ\text{C})(70^\circ\text{C} - 20^\circ\text{C}) = \mathbf{940.5 \text{ kW}}$$

Noting that heat gain by the water is equal to the heat loss by the oil, the outlet temperature of oil is determined from

$$\dot{Q} = [\dot{m}c_p(T_{in} - T_{out})]_{\text{oil}} \longrightarrow T_{out} = T_{in} - \frac{\dot{Q}}{\dot{m}c_p} = 170^\circ\text{C} - \frac{940.5 \text{ kW}}{(10 \text{ kg/s})(2.3 \text{ kJ/kg}\cdot^\circ\text{C})} = \mathbf{129.1^\circ\text{C}}$$



**4–38** An insulated piston–cylinder device contains 5 L of saturated liquid water at a constant pressure of 175 kPa. Water is stirred by a paddle wheel while a current of 8 A flows for 45 min through a resistor placed in the water. If one-half of



**FIGURE P4–38**

**4-38** A cylinder is initially filled with saturated liquid water at a specified pressure. The water is heated electrically as it is stirred by a paddle-wheel at constant pressure. The voltage of the current source is to be determined, and the process is to be shown on a  $P$ - $\nu$  diagram.

**Assumptions** **1** The cylinder is stationary and thus the kinetic and potential energy changes are zero. **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** 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

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

$$W_{e,in} + W_{pw,in} - W_{b,out} = \Delta U \quad (\text{since } Q = KE = PE = 0)$$

$$W_{e,in} + W_{pw,in} = m(h_2 - h_1)$$

$$(VI\Delta t) + W_{pw,in} = m(h_2 - h_1)$$

since  $\Delta U + W_b = \Delta H$  during a constant pressure quasi-equilibrium process. The properties of water are (Tables A-4 through A-6)

$$\left. \begin{array}{l} P_1 = 175 \text{ kPa} \\ \text{sat. liquid} \end{array} \right\} \begin{array}{l} h_1 = h_{f@175 \text{ kPa}} = 487.01 \text{ kJ/kg} \\ \nu_1 = \nu_{f@175 \text{ kPa}} = 0.001057 \text{ m}^3/\text{kg} \end{array}$$

$$\left. \begin{array}{l} P_2 = 175 \text{ kPa} \\ x_2 = 0.5 \end{array} \right\} h_2 = h_f + x_2 h_{fg} = 487.01 + (0.5 \times 2213.1) = 1593.6 \text{ kJ/kg}$$

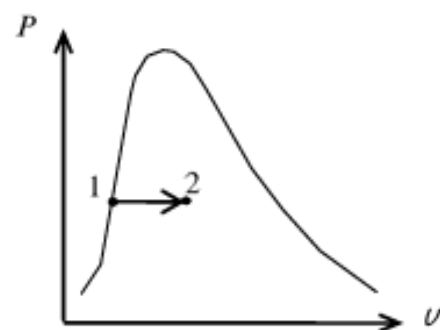
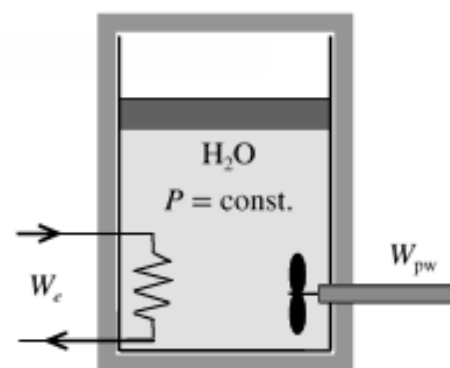
$$m = \frac{\nu_1}{\nu_1} = \frac{0.005 \text{ m}^3}{0.001057 \text{ m}^3/\text{kg}} = 4.731 \text{ kg}$$

Substituting,

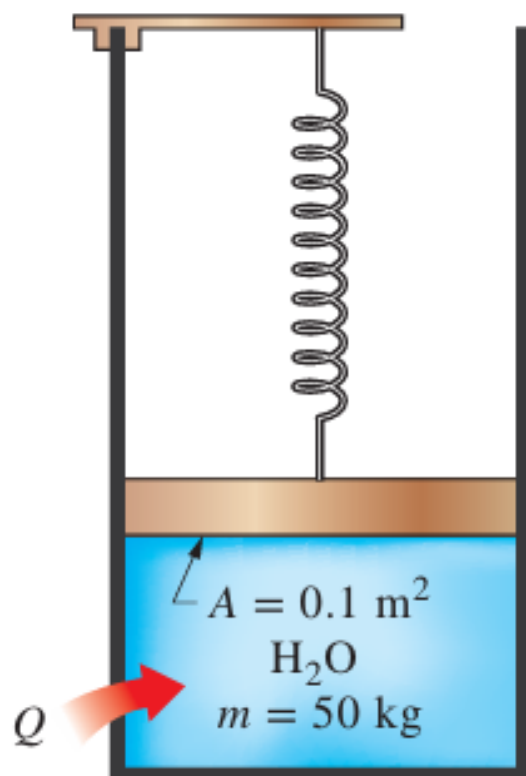
$$VI\Delta t + (400 \text{ kJ}) = (4.731 \text{ kg})(1593.6 - 487.01) \text{ kJ/kg}$$

$$VI\Delta t = 4835 \text{ kJ}$$

$$V = \frac{4835 \text{ kJ}}{(8 \text{ A})(45 \times 60 \text{ s})} \left( \frac{1000 \text{ VA}}{1 \text{ kJ/s}} \right) = \mathbf{223.9 \text{ V}}$$



**4–24** A piston–cylinder device contains 50 kg of water at 250 kPa and 25°C. The cross-sectional area of the piston is 0.1 m<sup>2</sup>. Heat is now transferred to the water, causing part of it to evaporate and expand. When the volume reaches 0.2 m<sup>3</sup>, the piston reaches a linear spring whose spring constant is 100 kN/m. More heat is transferred to the water until the piston rises 20 cm more. Determine (a) the final pressure and temperature and (b) the work done during this process. Also, show the process on a  $P$ - $V$  diagram. *Answers: (a) 450 kPa, 147.9°C, (b) 44.5 kJ*



**4-24** Water in a cylinder equipped with a spring is heated and evaporated. The vapor expands until it compresses the spring 20 cm. The final pressure and temperature, and the boundary work done are to be determined, and the process is to be shown on a  $P$ - $v$  diagram.

**Assumptions** The process is quasi-equilibrium.

**Analysis** (a) The final pressure is determined from

$$P_3 = P_2 + \frac{F_s}{A} = P_2 + \frac{kx}{A} = (250 \text{ kPa}) + \frac{(100 \text{ kN/m})(0.2 \text{ m})}{0.1 \text{ m}^2} \left( \frac{1 \text{ kPa}}{1 \text{ kN/m}^2} \right) = \mathbf{450 \text{ kPa}}$$

The specific and total volumes at the three states are

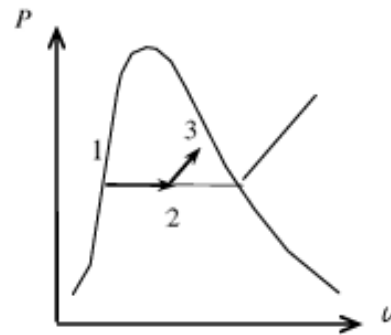
$$\left. \begin{array}{l} T_1 = 25^\circ\text{C} \\ P_1 = 250 \text{ kPa} \end{array} \right\} v_1 \cong v_{f@25^\circ\text{C}} = 0.001003 \text{ m}^3/\text{kg}$$

$$V_1 = m v_1 = (50 \text{ kg})(0.001003 \text{ m}^3/\text{kg}) = 0.05 \text{ m}^3$$

$$V_2 = 0.2 \text{ m}^3$$

$$V_3 = V_2 + x_{23} A_p = (0.2 \text{ m}^3) + (0.2 \text{ m})(0.1 \text{ m}^2) = 0.22 \text{ m}^3$$

$$v_3 = \frac{V_3}{m} = \frac{0.22 \text{ m}^3}{50 \text{ kg}} = 0.0044 \text{ m}^3/\text{kg}$$



At 450 kPa,  $v_f = 0.001088 \text{ m}^3/\text{kg}$  and  $v_g = 0.41392 \text{ m}^3/\text{kg}$ . Noting that  $v_f < v_3 < v_g$ , the final state is a saturated mixture and thus the final temperature is

$$T_3 = T_{\text{sat}@450 \text{ kPa}} = \mathbf{147.9^\circ\text{C}}$$

(b) The pressure remains constant during process 1-2 and changes linearly (a straight line) during process 2-3. Then the boundary work during this process is simply the total area under the process curve,

$$\begin{aligned} W_{b,\text{out}} &= \text{Area} = P_1(V_2 - V_1) + \frac{P_2 + P_3}{2}(V_3 - V_2) \\ &= \left( (250 \text{ kPa})(0.2 - 0.05) \text{ m}^3 + \frac{(250 + 450) \text{ kPa}}{2}(0.22 - 0.2) \text{ m}^3 \right) \left( \frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3} \right) \\ &= \mathbf{44.5 \text{ kJ}} \end{aligned}$$

**Discussion** The positive sign indicates that work is done by the system (work output).



