

**14-78** Air is first heated and then humidified by wet steam. The temperature and relative humidity of air at the exit of heating section, the rate of heat transfer, and the rate at which water is added to the air are to be determined.

**Assumptions** 1 This is a steady-flow process and thus the mass flow rate of dry air remains constant during the entire process ( $\dot{m}_{a1} = \dot{m}_{a2} = \dot{m}_a$ ). 2 Dry air and water vapor are ideal gases. 3 The kinetic and potential energy changes are negligible.

**Properties** The inlet and the exit states of the air are completely specified, and the total pressure is 1 atm. The properties of the air at various states are determined from the psychrometric chart (Figure A-31) to be

$$h_1 = 23.5 \text{ kJ/kg dry air}$$

$$\omega_1 = 0.0053 \text{ kg H}_2\text{O/kg dry air} (= \omega_2)$$

$$\nu_1 = 0.809 \text{ m}^3/\text{kg dry air}$$

$$h_3 = 42.3 \text{ kJ/kg dry air}$$

$$\omega_3 = 0.0087 \text{ kg H}_2\text{O/kg dry air}$$

**Analysis** (a) The amount of moisture in the air remains constant it flows through the heating section ( $\omega_1 = \omega_2$ ), but increases in the humidifying section ( $\omega_3 > \omega_2$ ). The mass flow rate of dry air is

$$\dot{m}_a = \frac{\dot{V}_1}{\nu_1} = \frac{35 \text{ m}^3/\text{min}}{0.809 \text{ m}^3/\text{kg}} = 43.3 \text{ kg/min}$$

Noting that  $Q = W = 0$ , the energy balance on the humidifying section can be expressed as

$$\begin{aligned} \dot{E}_{\text{in}} - \dot{E}_{\text{out}} &= \Delta \dot{E}_{\text{system}} \stackrel{\text{no (steady)}}{=} 0 \\ \dot{E}_{\text{in}} &= \dot{E}_{\text{out}} \\ \sum \dot{m}_i h_i &= \sum \dot{m}_e h_e \quad \longrightarrow \quad \dot{m}_w h_w + \dot{m}_a h_2 = \dot{m}_a h_3 \\ &(\omega_3 - \omega_2) h_w + h_2 = h_3 \end{aligned}$$

Solving for  $h_2$ ,

$$h_2 = h_3 - (\omega_3 - \omega_2) h_{g @ 100^\circ\text{C}} = 42.3 - (0.0087 - 0.0053)(2675.6) = 33.2 \text{ kJ/kg dry air}$$

Thus at the exit of the heating section we have  $\omega_2 = 0.0053 \text{ kg H}_2\text{O dry air}$  and  $h_2 = 33.2 \text{ kJ/kg dry air}$ , which completely fixes the state. Then from the psychrometric chart we read

$$T_2 = 19.5^\circ\text{C}$$

$$\phi_2 = 37.8\%$$

(b) The rate of heat transfer to the air in the heating section is

$$\dot{Q}_{\text{in}} = \dot{m}_a (h_2 - h_1) = (43.3 \text{ kg/min})(33.2 - 23.5) \text{ kJ/kg} = \mathbf{420 \text{ kJ/min}}$$

(c) The amount of water added to the air in the humidifying section is determined from the conservation of mass equation of water in the humidifying section,

$$\dot{m}_w = \dot{m}_a (\omega_3 - \omega_2) = (43.3 \text{ kg/min})(0.0087 - 0.0053) = \mathbf{0.15 \text{ kg/min}}$$

