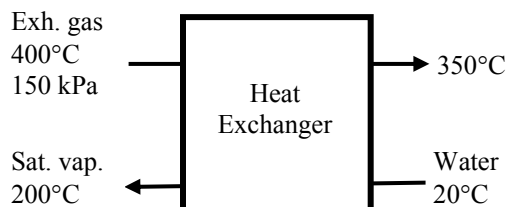**8-101** Hot exhaust gases leaving an internal combustion engine is to be used to obtain saturated steam in an adiabatic heat exchanger. The rate at which the steam is obtained, the rate of exergy destruction, and the second-law efficiency are to be determined.

*Assumptions* **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible. **3** Air properties are used for exhaust gases. **4** Pressure drops in the heat exchanger are negligible.

*Properties* The gas constant of air is $R = 0.287$ kJkg.K. The specific heat of air at the average temperature of exhaust gases (650 K) is $c_p = 1.063$ kJ/kg.K (Table A-2).

*Analysis* (*a*) We denote the inlet and exit states of exhaust gases by (1) and (2) and that of the water by (3) and (4). The properties of water are (Table A-4)

$$T_3 = 20°C \left.\right] h_3 = 83.91 \text{ kJ/kg}$$
$$x_3 = 0 \quad \left.\right\} s_3 = 0.29649 \text{ kJ/kg.K}$$

$$T_4 = 200°C \left.\right] h_4 = 2792.0 \text{ kJ/kg}$$
$$x_4 = 1 \quad \left.\right\} s_4 = 6.4302 \text{ kJ/kg.K}$$

Exh. gas 400°C 150 kPa → Heat Exchanger → 350°C

Sat. vap. 200°C ← Heat Exchanger ← Water 20°C

An energy balance on the heat exchanger gives

$$\dot{m}_a h_1 + \dot{m}_w h_3 = \dot{m}_a h_2 + \dot{m}_w h_4$$
$$\dot{m}_a c_p (T_1 - T_2) = \dot{m}_w (h_4 - h_3)$$
$$(0.8 \text{ kg/s})(1.063 \text{ kJ/kg°C})(400 - 350)°C = \dot{m}_w (2792.0 - 83.91) \text{kJ/kg}$$
$$\dot{m}_w = \textbf{0.01570 kg/s}$$

(*b*) The specific exergy changes of each stream as it flows in the heat exchanger is

$$\Delta s_a = c_p \ln \frac{T_2}{T_1} = (0.8 \text{ kg/s})(1.063 \text{ kJ/kg.K}) \ln \frac{(350 + 273) \text{ K}}{(400 + 273) \text{ K}} = -0.08206 \text{ kJ/kg.K}$$

$$\Delta \psi_a = c_p (T_2 - T_1) - T_0 \Delta s_a$$
$$= (1.063 \text{ kJ/kg.°C})(350 - 400)°C - (20 + 273 \text{ K})(-0.08206 \text{ kJ/kg.K})$$
$$= -29.106 \text{ kJ/kg}$$

$$\Delta \psi_w = h_4 - h_3 - T_0(s_4 - s_3)$$
$$= (2792.0 - 83.91) \text{kJ/kg} - (20 + 273 \text{ K})(6.4302 - 0.29649) \text{kJ/kg.K}$$
$$= 910.913 \text{ kJ/kg}$$

The exergy destruction is determined from an exergy balance on the heat exchanger to be

$$-\dot{X}_{\text{dest}} = \dot{m}_a \Delta \psi_a + \dot{m}_w \Delta \psi_w = (0.8 \text{ kg/s})(-29.106 \text{ kJ/kg}) + (0.01570 \text{ kg/s})(910.913) \text{ kJ/kg} = -8.98 \text{ kW}$$

or

$$\dot{X}_{\text{dest}} = \textbf{8.98 kW}$$

(*c*) The second-law efficiency for a heat exchanger may be defined as the exergy increase of the cold fluid divided by the exergy decrease of the hot fluid. That is,

$$\eta_{\text{II}} = \frac{\dot{m}_w \Delta \psi_w}{-\dot{m}_a \Delta \psi_a} = \frac{(0.01570 \text{ kg/s})(910.913 \text{ kJ/kg})}{-(0.8 \text{ kg/s})(-29.106 \text{ kJ/kg})} = \textbf{0.614}$$