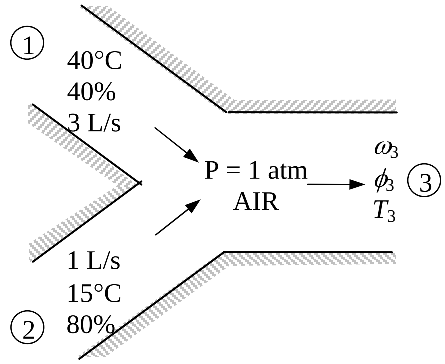
14-111 Two airstreams are mixed steadily. The rate of exergy destruction is to be determined.

Assumptions **1** Steady operating conditions exist **2** Dry air and water vapor are ideal gases. **3** The kinetic and potential energy changes are negligible. **4** The mixing section is adiabatic.

Properties Properties of each inlet stream are determined from the psychrometric chart (Fig. A-31 or from EES) to be

$$h_1 = 88.5 \text{ kJ/kg dry air}$$
$$\omega_1 = 0.0187 \text{ kg H}_2\text{O/kg dry air}$$
$$v_1 = 0.914 \text{ m}^3\text{/kg dry air}$$



and

$$h_2 = 36.7 \text{ kJ/kg dry air}$$
$$\omega_2 = 0.0085 \text{ kg H}_2\text{O/kg dry air}$$
$$v_2 = 0.828 \text{ m}^3\text{/kg dry air}$$

The entropies of water vapor in the air streams are

$$s_{g1} = s_{g\,@\,40°\text{C}} = 8.2556 \text{ kJ/kg} \cdot \text{K}$$
$$s_{g2} = s_{g\,@\,15°\text{C}} = 8.7803 \text{ kJ/kg} \cdot \text{K}$$

Analysis The mass flow rate of dry air in each stream is

$$\dot{m}_{a1} = \frac{\dot{V}_1}{v_1} = \frac{0.003 \text{ m}^3 \text{ / s}}{0.914 \text{ m}^3 \text{ / kg dry air}} = 0.003282 \text{ kg/s}$$
$$\dot{m}_{a2} = \frac{\dot{V}_2}{v_2} = \frac{0.001 \text{ m}^3 \text{ / s}}{0.828 \text{ m}^3 \text{ / kg dry air}} = 0.001208 \text{ kg/s}$$

From the conservation of mass,

$$\dot{m}_{a3} = \dot{m}_{a1} + \dot{m}_{a2} = (0.003282 + 0.001208) \text{ kg/s} = 0.00449 \text{ kg/s}$$

The specific humidity and the enthalpy of the mixture can be determined from Eqs. 14-24, which are obtained by combining the conservation of mass and energy equations for the adiabatic mixing of two streams:

$$\frac{\dot{m}_{a1}}{\dot{m}_{a2}} = \frac{\omega_2 - \omega_3}{\omega_3 - \omega_1} = \frac{h_2 - h_3}{h_3 - h_1}$$
$$\frac{0.003282}{0.001208} = \frac{0.0085 - \omega_3}{\omega_3 - 0.0187} = \frac{36.7 - h_3}{h_3 - 88.5}$$

which yields

$$\omega_3 = 0.0160 \text{ kg H}_2\text{O/kg dry air}$$
$$h_3 = 74.6 \text{ kJ/kg dry air}$$

These two properties fix the state of the mixture. Other properties of the mixture are determined from the psychrometric chart:

$$T_3 = 33.4°\text{C}$$
$$\phi_3 = 0.493$$

The entropy of water vapor in the mixture is

$$s_{g3} = s_{g\,@\,33.4°\text{C}} = 8.3833 \text{ kJ/kg} \cdot \text{K}$$

An entropy balance on the mixing chamber for the water gives

$$\Delta\dot{S}_w = \dot{m}_{a3}\omega_3 s_3 - \dot{m}_{a1}\omega_1 s_1 - \dot{m}_{a2}\omega_2 s_2$$
$$= 0.00449\times 0.0160\times 8.3833 - 0.003282\times 0.0187\times 8.2556 - 0.001208\times 0.0085\times 8.7803$$
$$= 5.426\times 10^{-6}\ \text{kW/K}$$

The partial pressures of water vapor and dry air for all three air streams are

$$P_{v1} = \phi_1 P_{g1} = \phi_1 P_{\text{sat @ 40°C}} = (0.40)(7.3851\ \text{kPa}) = 2.954\ \text{kPa}$$
$$P_{a1} = P_1 - P_{v1} = 101.325 - 2.954 = 98.37\ \text{kPa}$$
$$P_{v2} = \phi_2 P_{g2} = \phi_2 P_{\text{sat @ 15°C}} = (0.80)(1.7057\ \text{kPa}) = 1.365\ \text{kPa}$$
$$P_{a2} = P_2 - P_{v2} = 101.325 - 1.365 = 99.96\ \text{kPa}$$
$$P_{v3} = \phi_3 P_{g3} = \phi_3 P_{\text{sat @ 33.4°C}} = (0.493)(5.150\ \text{kPa}) = 2.539\ \text{kPa}$$
$$P_{a3} = P_3 - P_{v3} = 101.325 - 2.539 = 98.79\ \text{kPa}$$

An entropy balance on the mixing chamber for the dry air gives

$$\Delta\dot{S}_a = \dot{m}_{a1}(s_3 - s_1) + \dot{m}_{a2}(s_3 - s_2)$$
$$= \dot{m}_{a1}\left(c_p \ln\frac{T_3}{T_1} - R\ln\frac{P_{a3}}{P_{a1}}\right) + \dot{m}_{a2}\left(c_p \ln\frac{T_3}{T_2} - R\ln\frac{P_{a3}}{P_{a2}}\right)$$
$$= 0.003282\left[(1.005)\ln\frac{306.4}{313} - (0.287)\ln\frac{98.79}{98.37}\right] + 0.001208\left[(1.005)\ln\frac{306.4}{288} - (0.287)\ln\frac{98.79}{99.96}\right]$$
$$= (0.003282)(-0.02264) + (0.001208)(0.06562)$$
$$= 4.964\times 10^{-6}\ \text{kW/K}$$

The rate of entropy generation is

$$\dot{S}_{\text{gen}} = \Delta\dot{S}_a + \Delta\dot{S}_w = 4.964\times 10^{-6} + 5.426\times 10^{-6} = 10.39\times 10^{-6}\ \text{kW/K}$$

Finally, the rate of exergy destruction is

$$\dot{X}_{\text{dest}} = T_0\dot{S}_{\text{gen}} = (298\ \text{K})(10.39\times 10^{-6}\ \text{kW/K}) = \mathbf{0.0031\ kW}$$