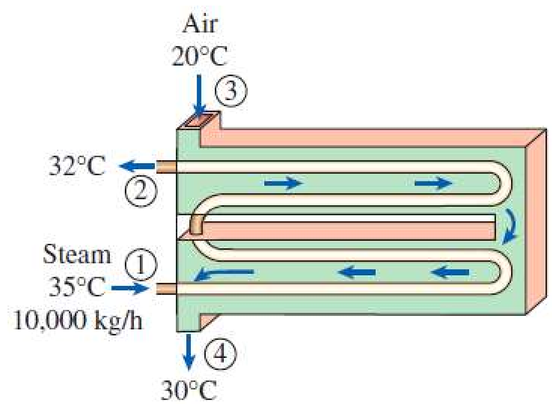
Given: $kJ := 1000J$

Air in a large building is kept warm by heating it with steam in a heat exchanger. Saturated water vapor enters the unit at 35°C at a rate of 10,000 kg/hr and leaves as saturated liquid at 32°C. Air at 1 atm enters the unit at 20°C and leaves at 30°C at about the same pressure.

$$T_1 := 35\,°C \quad T_2 := 32\,°C \quad m'_s := 10000\,\frac{kg}{hr}$$

$$T_3 := 20\,°C \quad T_4 := 30\,°C \quad P_{air} := 1atm$$



Required:

Determine the rate of entropy generated during this process.

Solution:

Starting with an entropy balance for a steady flow device shows

$$\frac{d}{dt}S_{sys} = \Sigma S'_{in} - \Sigma S'_{out} + S'_{gen}$$

$$0 = \Sigma S'_{in} - \Sigma S'_{out} + S'_{gen}$$

$$S'_{gen} = \Sigma S'_{out} - \Sigma S'_{in} = m'_s \cdot s_2 + m'_{air} \cdot s_4 - m'_s \cdot s_1 - m'_{air} \cdot s_3 = m'_s \cdot (s_2 - s_1) + m'_{air} \cdot (s_4 - s_3)$$

If the air is assumed to behave as an ideal gas with a constant specific heat, the rate of entropy generation becomes

$$S'_{gen} = m'_s \cdot (s_2 - s_1) + m'_{air} \cdot \left(c_{pavg} \cdot \ln\left(\frac{T_4}{T_3}\right) + R \cdot \ln\left(\frac{P_4}{P_3}\right)\right)$$

Knowing the pressure of the air remains constant throughout the process, the rate of entropy generation becomes

$$S'_{gen} = m'_s \cdot (s_2 - s_1) + m'_{air} \cdot \left(c_{pavg} \cdot \ln\left(\frac{T_4}{T_3}\right) + R \cdot \ln\left(\frac{P_{air}}{P_{air}}\right)\right) = m'_s \cdot (s_2 - s_1) + m'_{air} \cdot c_{pavg} \cdot \ln\left(\frac{T_4}{T_3}\right)$$

Going to Table A-4 @ $T_1 = 35 \cdot °C$ & $x_1 = 1$ shows

$$s_1 := 8.3517\,\frac{kJ}{kg \cdot K} \qquad h_1 := 2564.6\,\frac{kJ}{kg}$$

Going to Table A-4 @ $T_2 = 32 \cdot °C$ & $x_2 = 0$ shows that interpolation is needed.

$$T_a := 30\,°C \qquad T_b := 35\,°C$$

$$s_a := 0.4368\,\frac{kJ}{kg \cdot K} \qquad s_b := 0.5051\,\frac{kJ}{kg \cdot K} \qquad h_a := 125.74\,\frac{kJ}{kg} \qquad h_b := 146.64\,\frac{kJ}{kg}$$

$$s_2 := \frac{T_2 - T_a}{T_b - T_a} \cdot (s_b - s_a) + s_a = 0.464 \cdot \frac{kJ}{kg \cdot K} \qquad h_2 := \frac{T_2 - T_a}{T_b - T_a} \cdot (h_b - h_a) + h_a = 134.1 \cdot \frac{kJ}{kg}$$

Solution (contd.):

The mass flow rate of the air may be found by performing an energy balance on the system. This is shown below for a steady flow device with negligible changes in KE and PE.

$$\frac{d}{dt}E_{sys} = \Sigma E'_{in} - \Sigma E'_{out}$$

$$0 = m'_{s,in} \cdot h_1 + m'_{air,in} \cdot h_3 - m'_{s,out} \cdot h_2 - m'_{air,out} \cdot h_4$$

Realizing the steam and air mass streams remain constant, the energy balance becomes

$$0 = m'_s \cdot (h_1 - h_2) + m'_{air} \cdot (h_3 - h_4)$$

Solving for the mass flow rate of the air shows

$$m'_{air} = \frac{m'_s \cdot (h_2 - h_1)}{h_3 - h_4}$$

Assuming air has a constant specific heat over the range of the process, the mass flow rate of air becomes

$$m'_{air} = \frac{m'_s \cdot (h_2 - h_1)}{c_{p,avg} \cdot (T_3 - T_4)}$$

Going to Table A-2(a) @ air shows

$$c_{p,avg} := 1.005 \frac{kJ}{kg \cdot K}$$

The mass flow rate of air may then be found by

$$m'_{air} := \frac{m'_s \cdot (h_2 - h_1)}{c_{p,avg} \cdot (T_3 - T_4)} = 671.78 \frac{kg}{s}$$

The rate of entropy generation is then found to be

$$\boxed{S'_{gen} := m'_s \cdot (s_2 - s_1) + m'_{air} \cdot c_{p,avg} \cdot \ln\left(\frac{T_4}{T_3}\right) = 0.7364 \cdot \frac{kW}{K}}$$