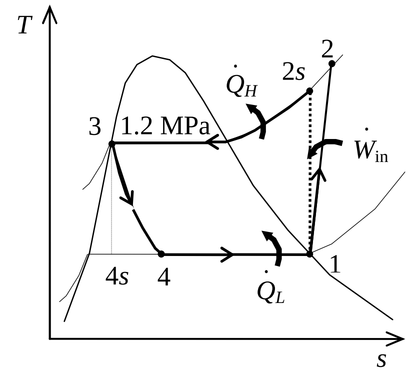
11-34 A vapor-compression refrigeration cycle is used to keep a space at a low temperature. The mass flow rate of R-134a, the COP, The exergy destruction in each component and the exergy efficiency of the compressor, the second-law efficiency, and the exergy destruction are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible.



Analysis (a) The properties of R-134a are (Tables A-11 through A-13)

$$\left.\begin{array}{l} P_2 = 1.2\text{ MPa} \\ T_2 = 50°\text{C} \end{array}\right\} \begin{array}{l} h_2 = 278.27\text{ kJ/kg} \\ s_2 = 0.9267\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_3 = 1.2\text{ MPa} \\ x_3 = 0 \end{array}\right\} \begin{array}{l} h_3 = 117.77\text{ kJ/kg} \\ s_3 = 0.4244\text{ kJ/kg}\cdot\text{K} \end{array}$$

The rate of heat transferred to the water is the energy change of the water from inlet to exit

$$\dot{Q}_H = \dot{m}_w c_p (T_{w,2} - T_{w,1}) = (0.15\text{ kg/s})(4.18\text{ kJ/kg}\cdot°\text{C})(28-20)°\text{C} = 5.016\text{ kW}$$

The energy decrease of the refrigerant is equal to the energy increase of the water in the condenser. That is,

$$\dot{Q}_H = \dot{m}_R (h_2 - h_3) \longrightarrow \dot{m}_R = \frac{\dot{Q}_H}{h_2 - h_3} = \frac{5.016\text{ kW}}{(278.27-117.77)\text{ kJ/kg}} = 0.03125\text{ kg/s}$$

The refrigeration load is

$$\dot{Q}_L = \dot{Q}_H - \dot{W}_{in} = 5.016 - 2.2 = 2.816\text{ kW} = (2.816\text{ kW})\left(\frac{3412\text{ Btu/h}}{1\text{ kW}}\right) = \mathbf{9610\text{ Btu/h}}$$

The COP of the refrigerator is determined from its definition,

$$\text{COP} = \frac{\dot{Q}_L}{\dot{W}_{in}} = \frac{2.816\text{ kW}}{2.2\text{ kW}} = \mathbf{1.28}$$

(*b*) The COP of a reversible refrigerator operating between the same temperature limits is

$$\text{COP}_{\text{Carnot}} = \frac{T_L}{T_H - T_L} = \frac{-12+273}{(20+273)-(-12+273)} = 8.156$$

The minimum power input to the compressor for the same refrigeration load would be

$$\dot{W}_{in,min} = \frac{\dot{Q}_L}{\text{COP}_{\text{Carnot}}} = \frac{2.816\text{ kW}}{8.156} = 0.3453\text{ kW}$$

The second-law efficiency of the cycle is

$$\eta_{II} = \frac{\dot{W}_{in,min}}{\dot{W}_{in}} = \frac{0.3453}{2.2} = 0.1569 = \mathbf{15.7\%}$$

The total exergy destruction in the cycle is the difference between the actual and the minimum power inputs:

$$\dot{E}x_{\text{dest,total}} = \dot{W}_{in} - \dot{W}_{in,min} = 2.2 - 0.3453 = \mathbf{1.85\text{ kW}}$$

(*c*) The entropy generation in the condenser is

$$\dot{S}_{\text{gen,cond}} = \dot{m}_w c_p \ln\left(\frac{T_{w,2}}{T_{w,1}}\right) + \dot{m}_R (s_3 - s_2)$$

$$= (0.15\text{ kg/s})(4.18\text{ kJ/kg}\cdot°\text{C})\ln\left(\frac{28+273}{20+273}\right) + (0.03125\text{ kg/s})(0.4004 - 0.9267)\text{ kJ/kg}\cdot\text{K})$$

$$= 0.001191\text{ kW/K}$$

The exergy destruction in the condenser is

$$\dot{E}x_{\text{dest,cond}} = T_0 \dot{S}_{\text{gen,cond}} = (293\text{ K})(0.001191\text{ kW/K}) = \mathbf{0.349\text{ kW}}$$