11-26 A vapor-compression refrigeration cycle with refrigerant-134a as the working fluid is considered. The rate of cooling, the power input, and the COP are to be determined. Also, the same parameters are to be determined if the cycle operated on the ideal vapor-compression refrigeration cycle between the same pressure limits.

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

Analysis (a) From the refrigerant-134a tables (Tables A-11 through A-13)

$$T_{\text{sat@200 kPa}} = -10.1°\text{C}$$

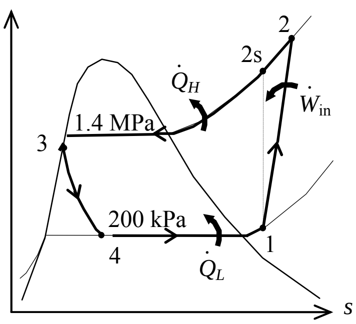
$$\left.\begin{array}{l} P_1 = 200 \text{ kPa} \\ T_1 = -10.1 + 10.1 = 0°\text{C} \end{array}\right\} \begin{array}{l} h_1 = 253.05 \text{ kJ/kg} \\ s_1 = 0.9698 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 1400 \text{ kPa} \\ s_1 = s_1 \end{array}\right\} h_{2s} = 295.90 \text{ kJ/kg}$$

$$T_{\text{sat@1400 kPa}} = 52.4°\text{C}$$

$$\left.\begin{array}{l} P_3 = 1400 \text{ kPa} \\ T_3 = 52.4 - 4.4 = 48°\text{C} \end{array}\right\} h_3 \cong h_{f@48°\text{C}} = 120.39 \text{ kJ/kg}$$

$$h_4 = h_3 = 120.39 \text{ kJ/kg}$$



$$\eta_C = \frac{h_{2s} - h_1}{h_2 - h_1}$$

$$0.88 = \frac{295.90 - 253.05}{h_2 - 253.05} \longrightarrow h_2 = 301.74 \text{ kJ/kg}$$

$$\dot{Q}_L = \dot{m}(h_1 - h_4) = (0.025 \text{ kg/s})(253.05 - 120.39) = \mathbf{3.317 \text{ kW}}$$

$$\dot{Q}_H = \dot{m}(h_2 - h_3) = (0.025 \text{ kg/s})(301.74 - 120.39) = \mathbf{4.534 \text{ kW}}$$

$$\dot{W}_{\text{in}} = \dot{m}(h_2 - h_1) = (0.025 \text{ kg/s})(301.74 - 253.05) = \mathbf{1.217 \text{ kW}}$$

$$\text{COP} = \frac{\dot{Q}_L}{\dot{W}_{\text{in}}} = \frac{3.317 \text{ kW}}{1.217 \text{ kW}} = \mathbf{2.725}$$

(b) Ideal vapor-compression refrigeration cycle solution

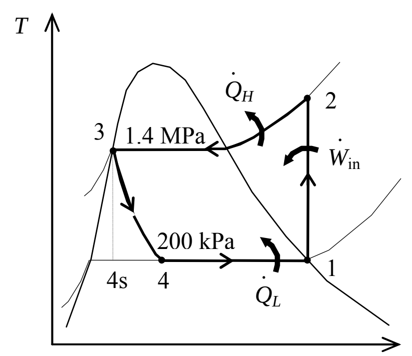
From the refrigerant-134a tables (Tables A-11 through A-13)

$$\left.\begin{array}{l} P_1 = 200 \text{ kPa} \\ x_1 = 1 \end{array}\right\} \begin{array}{l} h_1 = 244.46 \text{ kJ/kg} \\ s_1 = 0.9377 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 1400 \text{ kPa} \\ s_1 = s_1 \end{array}\right\} h_2 = 285.08 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_3 = 1400 \text{ kPa} \\ x_3 = 0 \end{array}\right\} h_3 = 127.22 \text{ kJ/kg}$$

$$h_4 = h_3 = 127.22 \text{ kJ/kg}$$



$$\dot{Q}_L = \dot{m}(h_1 - h_4) = (0.025 \text{ kg/s})(244.46 - 127.22) = \mathbf{3.931 \text{kW}}$$

$$\dot{Q}_H = \dot{m}(h_2 - h_3) = (0.025 \text{ kg/s})(285.08 - 127.22) = \mathbf{3.947 \text{ kW}}$$

$$\dot{W}_{\text{in}} = \dot{m}(h_2 - h_1) = (0.025 \text{ kg/s})(285.08 - 244.46) = \mathbf{1.016 \text{ kW}}$$

$$\text{COP} = \frac{\dot{Q}_L}{\dot{W}_{\text{in}}} = \frac{3.931 \text{ kW}}{1.016 \text{ kW}} = \mathbf{2.886}$$

Discussion The cooling load increases by 18.5% while the COP increases by 5.9% when the cycle operates on the ideal vapor-compression cycle.

11-35 An ideal vapor-compression refrigeration cycle is used to keep a space at a low temperature. The cooling load, the COP, the exergy destruction in each component, the total 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.

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

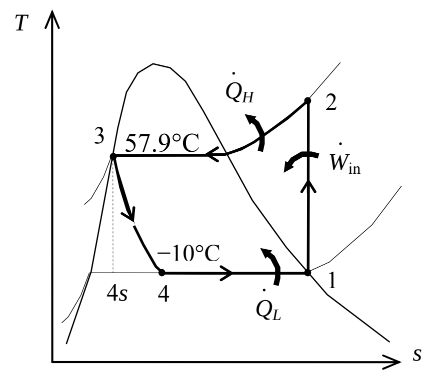
$$\left.\begin{array}{l} T_1 = -10°\text{C} \\ x_1 = 1 \end{array}\right\} \begin{array}{l} h_1 = 244.51 \text{ kJ/kg} \\ s_1 = 0.9377 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = P_{\text{sat@57.9°C}} = 1600 \text{ kPa} \\ s_2 = s_1 \end{array}\right\} h_2 = 287.85 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_3 = 1600 \text{ kPa} \\ x_3 = 0 \end{array}\right\} \begin{array}{l} h_3 = 135.93 \text{ kJ/kg} \\ s_3 = 0.4791 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$h_4 = h_3 = 135.93 \text{ kJ/kg}$$

$$\left.\begin{array}{l} T_4 = -10°\text{C} \\ h_4 = 135.93 \text{ kJ/kg} \end{array}\right\} s_4 = 0.5251 \text{ kJ/kg}\cdot\text{K}$$



The energy interactions in the components and the COP are

$$q_L = h_1 - h_4 = 244.51 - 135.93 = \mathbf{108.6 \text{ kJ/kg}}$$

$$q_H = h_2 - h_3 = 287.85 - 135.93 = 151.9 \text{ kJ/kg}$$

$$w_{\text{in}} = h_2 - h_1 = 287.85 - 244.51 = 43.33 \text{ kJ/kg}$$

$$\text{COP} = \frac{q_L}{w_{\text{in}}} = \frac{108.6 \text{ kJ/kg}}{43.33 \text{ kJ/kg}} = \mathbf{2.506}$$

(b) The exergy destruction in each component of the cycle is determined as follows

Compressor:

$$s_{\text{gen},1-2} = s_2 - s_1 = 0$$

$$Ex_{\text{dest,1-2}} = T_0 s_{\text{gen,1-2}} = \mathbf{0}$$

Condenser:

$$s_{\text{gen},2-3} = s_3 - s_2 + \frac{q_H}{T_H} = (0.4791 - 0.9377) \text{ kJ/kg}\cdot\text{K} + \frac{151.9 \text{ kJ/kg}}{298 \text{ K}} = 0.05124 \text{ kJ/kg}\cdot\text{K}$$

$$Ex_{\text{dest,2-3}} = T_0 s_{\text{gen,2-3}} = (298 \text{ K})(0.05124 \text{ kJ/kg}\cdot\text{K}) = \mathbf{15.27 \text{ kJ/kg}}$$

Expansion valve:

$$s_{\text{gen},3-4} = s_4 - s_3 = 0.5251 - 0.4791 = 0.04595 \text{ kJ/kg}\cdot\text{K}$$

$$Ex_{\text{dest,3-4}} = T_0 s_{\text{gen,3-4}} = (298 \text{ K})(0.04595 \text{ kJ/kg}\cdot\text{K}) = \mathbf{13.69 \text{ kJ/kg}}$$

Evaporator:

$$s_{\text{gen},4-1} = s_1 - s_4 - \frac{q_L}{T_L} = (0.9377 - 0.5251) \text{ kJ/kg}\cdot\text{K} - \frac{108.6 \text{ kJ/kg}}{278 \text{ K}} = 0.02201 \text{ kJ/kg}\cdot\text{K}$$

$$Ex_{\text{dest,4-1}} = T_0 s_{\text{gen,4-1}} = (298 \text{ K})(0.02201 \text{ kJ/kg}\cdot\text{K}) = \mathbf{6.56 \text{ kJ/kg}}$$

The total exergy destruction can be determined by adding exergy destructions in each component:

$$\begin{aligned} \dot{E}x_{\text{dest,total}} &= \dot{E}x_{\text{dest,1-2}} + \dot{E}x_{\text{dest,2-3}} + \dot{E}x_{\text{dest,3-4}} + \dot{E}x_{\text{dest,4-1}} \\ &= 0 + 15.27 + 13.69 + 6.56 = \mathbf{35.52 \text{ kJ/kg}} \end{aligned}$$

(c) The exergy of the heat transferred from the low-temperature medium is

$$Ex_{q_L} = -q_L\left(1-\frac{T_0}{T_L}\right) = -(108.6\text{ kJ/kg})\left(1-\frac{298}{278}\right) = 7.812\text{ kJ/kg}$$

The second-law efficiency of the cycle is

$$\eta_{\text{II}} = \frac{Ex_{q_L}}{w_{\text{in}}} = \frac{7.812}{43.33} = 0.1803 = \mathbf{18.0\%}$$

The total exergy destruction in the cycle can also be determined from

$$Ex_{\text{dest,total}} = w_{\text{in}} - Ex_{q_L} = 43.33 - 7.812 = 35.52\text{ kJ/kg}$$

The result is identical as expected.

The second-law efficiency of the compressor is determined from

$$\eta_{\text{II,Comp}} = \frac{\dot{X}_{\text{recovered}}}{\dot{X}_{\text{expended}}} = \frac{\dot{W}_{\text{rev}}}{\dot{W}_{\text{act, in}}} = \frac{\dot{m}[h_2 - h_1 - T_0(s_2 - s_1)]}{\dot{m}(h_2 - h_1)}$$

since the compression through the compressor is isentropic ($s_2 = s_1$), the second-law efficiency is

$$\eta_{\text{II,Comp}} = 1 = \mathbf{100\%}$$

The second-law efficiency of the evaporator is determined from

$$\eta_{\text{II, Evap}} = \frac{\dot{X}_{\text{recovered}}}{\dot{X}_{\text{expended}}} = \frac{\dot{Q}_L(T_0 - T_L)/T_L}{\dot{m}[h_4 - h_1 - T_0(s_4 - s_1)]} = 1 - \frac{\dot{X}_{\text{dest,4-1}}}{\dot{X}_4 - \dot{X}_1}$$

where

$$\begin{aligned} x_4 - x_1 &= h_4 - h_1 - T_0(s_4 - s_1) \\ &= (135.93 - 244.51)\text{ kJ/kg} - (298\text{ K})(0.5251 - 0.9377)\text{ kJ/kg}\cdot\text{K} \\ &= 14.37\text{ kJ/kg} \end{aligned}$$

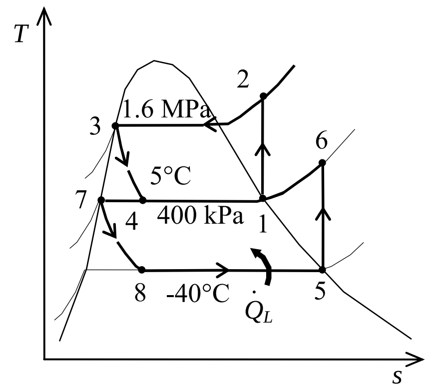
Substituting,

$$\eta_{\text{II, Evap}} = 1 - \frac{x_{\text{dest,4-1}}}{x_4 - x_1} = 1 - \frac{6.56\text{ kJ/kg}}{14.37\text{ kJ/kg}} = 0.544 = \mathbf{54.4\%}$$

11-64 A two-stage cascade refrigeration system is considered. Each stage operates on the ideal vapor-compression cycle with upper cycle using water and lower cycle using refrigerant-134a as the working fluids. The mass flow rate of R-134a and water in their respective cycles and the overall COP of this system are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible. **3** The heat exchanger is adiabatic.

Analysis From the water and refrigerant tables (Tables A-4, A-5, A-6, A-11, A-12, and A-13),



$$\left.\begin{array}{l} T_1 = 5°\text{C} \\ \text{sat. vapor} \end{array}\right\} \begin{array}{l} h_1 = h_{g\ @\ 5°\text{C}} = 2510.1\ \text{kJ/kg} \\ s_1 = s_{g\ @\ 5°\text{C}} = 9.0249\ \text{kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 1.6\ \text{MPa} \\ s_2 = s_1 \end{array}\right\} h_2 = 5083.4\ \text{kJ/kg}$$

$$\left.\begin{array}{l} P_3 = 1.6\ \text{MPa} \\ \text{sat. liquid} \end{array}\right\} h_3 = h_{f\ @\ 1.6\ \text{MPa}} = 858.44\ \text{kJ/kg}$$

$$h_4 \cong h_3 = 858.44\ \text{kJ/kg} \quad \text{(throttling)}$$

$$\left.\begin{array}{l} T_5 = -40°\text{C} \\ \text{sat. vapor} \end{array}\right\} \begin{array}{l} h_5 = h_{g\ @\ -40°\text{C}} = 225.86\ \text{kJ/kg} \\ s_5 = s_{g\ @\ -40°\text{C}} = 0.96866\ \text{kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_6 = 400\ \text{kPa} \\ s_6 = s_5 \end{array}\right\} h_6 = 267.59\ \text{kJ/kg}$$

$$\left.\begin{array}{l} P_7 = 400\ \text{kPa} \\ \text{sat. liquid} \end{array}\right\} h_7 = h_{f\ @\ 400\ \text{kPa}} = 63.94\ \text{kJ/kg}$$

$$h_8 \cong h_7 = 63.94\ \text{kJ/kg} \quad \text{(throttling)}$$

The mass flow rate of R-134a is determined from

$$\dot{Q}_L = \dot{m}_R(h_5 - h_8) \longrightarrow \dot{m}_R = \frac{\dot{Q}_L}{h_5 - h_8} = \frac{20\ \text{kJ/s}}{(225.86 - 63.94)\ \text{kJ/kg}} = \mathbf{0.1235\ kg/s}$$

An energy balance on the heat exchanger gives the mass flow rate of water

$$\dot{m}_R(h_6 - h_7) = \dot{m}_w(h_1 - h_4)$$

$$\longrightarrow \dot{m}_w = \dot{m}_R \frac{h_6 - h_7}{h_1 - h_4} = (0.1235\ \text{kg/s})\frac{267.59 - 63.94}{2510.1 - 858.44} = \mathbf{0.01523\ kg/s}$$

The total power input to the compressors is

$$\begin{aligned} \dot{W}_{\text{in}} &= \dot{m}_R(h_6 - h_5) + \dot{m}_w(h_2 - h_1) \\ &= (0.1235\ \text{kg/s})(267.59 - 225.86)\ \text{kJ/kg} + (0.01523\ \text{kg/s})(5083.4 - 2510.1)\ \text{kJ/kg} \\ &= 44.35\ \text{kJ/s} \end{aligned}$$

The COP of this refrigeration system is determined from its definition,

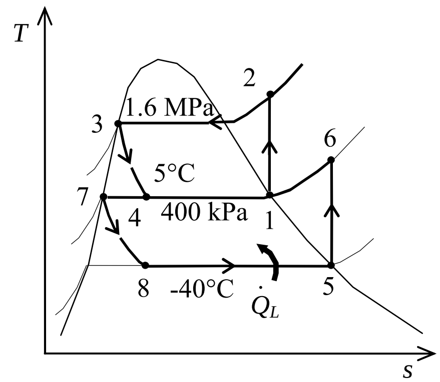
$$\text{COP}_\text{R} = \frac{\dot{Q}_L}{\dot{W}_{\text{in}}} = \frac{20\ \text{kJ/s}}{44.35\ \text{kJ/s}} = \mathbf{0.451}$$

11-65 A two-stage vapor-compression refrigeration system with refrigerant-134a as the working fluid is considered. The process with the greatest exergy destruction is to be determined.

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

Analysis From Prob. 11-55 and the water and refrigerant tables (Tables A-4, A-5, A-6, A-11, A-12, and A-13),

$$
\begin{aligned}
s_1 &= s_2 = 9.0249 \text{ kJ/kg}\cdot\text{K} \\
s_3 &= 2.3435 \text{ kJ/kg}\cdot\text{K} \\
s_4 &= 3.0869 \text{ kJ/kg}\cdot\text{K} \\
s_5 &= s_6 = 0.96866 \text{ kJ/kg}\cdot\text{K} \\
s_7 &= 0.24757 \text{ kJ/kg}\cdot\text{K} \\
s_8 &= 0.27423 \text{ kJ/kg}\cdot\text{K} \\
\dot{m}_R &= 0.1235 \text{ kg/s} \\
\dot{m}_w &= 0.01523 \text{ kg/s} \\
q_L &= h_5 - h_8 = 161.92 \text{ kJ/kg} \\
q_H &= h_2 - h_3 = 4225.0 \text{ kJ/kg} \\
T_L &= -30°\text{C} = 243 \text{ K} \\
T_H &= 30°\text{C} = 303 \text{ K} \\
T_0 &= 30°\text{C} = 303 \text{ K}
\end{aligned}
$$



The exergy destruction during a process of a stream from an inlet state to exit state is given by

$$x_{\text{dest}} = T_0 s_{\text{gen}} = T_0 \left(s_e - s_i - \frac{q_{\text{in}}}{T_{\text{source}}} + \frac{q_{\text{out}}}{T_{\text{sink}}} \right)$$

Application of this equation for each process of the cycle gives

$$
\begin{aligned}
\dot{X}_{\text{destroyed},23} &= \dot{m}_w T_0 \left(s_3 - s_2 + \frac{q_H}{T_H} \right) \\
&= (0.01523)(303\text{ K}) \left(2.3435 - 9.0249 + \frac{4225.0}{303} \right) = 33.52 \text{ kJ/s} \\
\dot{X}_{\text{destroyed},34} &= \dot{m}_\text{w} T_0 (s_4 - s_3) = (0.01523)(303)(3.0869 - 2.3435) = 3.43 \text{ kJ/s} \\
\dot{X}_{\text{destroyed},78} &= \dot{m}_\text{R} T_0 (s_8 - s_7) = (0.1235)(303)(0.27423 - 0.24757) = 0.996 \text{ kJ/s} \\
\dot{X}_{\text{destroyed},85} &= \dot{m}_\text{R} T_0 \left(s_5 - s_8 - \frac{q_L}{T_L} \right) \\
&= (0.1235)(303) \left(0.96866 - 0.27423 - \frac{161.92}{243} \right) = 1.05 \text{ kJ/s}
\end{aligned}
$$

$$
\begin{aligned}
\dot{X}_{\text{destroyed, heat exch}} &= T_0 \left[\dot{m}_\text{w} (s_1 - s_4) + \dot{m}_\text{R} (s_7 - s_6) \right] \\
&= (303)\left[(0.01523)(9.0249 - 3.0869) + (0.1235)(0.24757 - 0.96866) \right] = 0.417 \text{ kJ/s}
\end{aligned}
$$

For isentropic processes, the exergy destruction is zero:

$$\dot{X}_{\text{destroyed},12} = 0$$

$$\dot{X}_{\text{destroyed},56} = 0$$

Note that heat is absorbed from a reservoir at -30°C (243 K) and rejected to a reservoir at 30°C (303 K), which is also taken as the dead state temperature. Alternatively, one may use the standard 25°C (298 K) as the dead state temperature, and perform the calculations accordingly. The greatest exergy destruction occurs in the condenser.

11-116 An air conditioner operates on the vapor-compression refrigeration cycle. The rate of cooling provided to the space, the COP, the isentropic efficiency and the exergetic efficiency of the compressor, the exergy destruction in each component of the cycle, the total exergy destruction, the minimum power input, and the second-law efficiency of the cycle 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)

$$T_{\text{sat@180 kPa}} = -12.7°\text{C}$$

$$\left.\begin{array}{l} P_1 = 180\text{ kPa} \\ T_1 = -12.7 + 2.7 = 10°\text{C} \end{array}\right\} \begin{array}{l} h_1 = 245.14\text{ kJ/kg} \\ s_1 = 0.9483\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 1200\text{ kPa} \\ s_1 = s_1 \end{array}\right\} h_{2s} = 285.32\text{ kJ/kg}$$

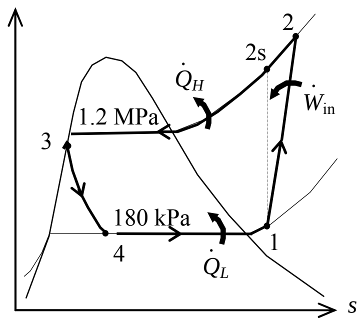
$$\left.\begin{array}{l} P_2 = 1200\text{ kPa} \\ T_2 = 60°\text{C} \end{array}\right\} \begin{array}{l} h_2 = 289.64\text{ kJ/kg} \\ s_2 = 0.9614\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$T_{\text{sat@1200 kPa}} = 46.3°\text{C}$$

$$\left.\begin{array}{l} P_3 = 1200\text{ kPa} \\ T_3 = 46.3 - 6.3 = 40°\text{C} \end{array}\right\} \begin{array}{l} h_3 \cong h_{f@40°\text{C}} = 108.26\text{ kJ/kg} \\ s_3 \cong s_{f@40°\text{C}} = 0.3948\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$h_4 = h_3 = 108.26\text{ kJ/kg}$$

$$\left.\begin{array}{l} P_4 = 180\text{ kPa} \\ h_4 = 108.26\text{ kJ/kg} \end{array}\right\} s_4 = 0.4228\text{ kJ/kg}\cdot\text{K}$$



The cooling load and the COP are

$$\dot{Q}_L = \dot{m}(h_1 - h_4) = (0.06\text{ kg/s})(245.14 - 108.26)\text{kJ/kg} = 8.213\text{ kW}$$
$$= (8.213\text{ kW})\left(\frac{3412\text{ Btu/h}}{1\text{ kW}}\right) = \mathbf{28{,}020\ Btu/h}$$

$$\dot{Q}_H = \dot{m}(h_2 - h_3) = (0.06\text{ kg/s})(289.64 - 108.26)\text{kJ/kg} = 10.88\text{ kW}$$
$$\dot{W}_{\text{in}} = \dot{m}(h_2 - h_1) = (0.06\text{ kg/s})(289.64 - 245.14)\text{kJ/kg} = 2.670\text{ kW}$$

$$\text{COP} = \frac{\dot{Q}_L}{\dot{W}_{\text{in}}} = \frac{8.213\text{ kW}}{2.670\text{ kW}} = \mathbf{3.076}$$

(b) The isentropic efficiency of the compressor is

$$\eta_C = \frac{h_{2s} - h_1}{h_2 - h_1} = \frac{285.32 - 245.14}{289.64 - 245.14} = 0.9029 = \mathbf{90.3\%}$$

The reversible power and the exergy efficiency for the compressor are

$$\dot{W}_{rev} = \dot{m}\left[(h_2 - h_1) - T_0(s_2 - s_1)\right]$$
$$= (0.06\text{ kg/s})\left[(289.64 - 245.14)\text{kJ/kg} - (310\text{ K})(0.9614 - 0.9483)\text{kJ/kg}\cdot\text{K}\right]$$
$$= 2.428\text{ kW}$$

$$\eta_{ex,C} = \frac{\dot{W}_{\text{rev}}}{\dot{W}_{\text{in}}} = \frac{2.428\text{ kW}}{2.670\text{ kW}} = 0.9091 = \mathbf{90.9\%}$$

(c) The exergy destruction in each component of the cycle is determined as follows

Compressor:

$$\dot{S}_{\text{gen},1-2} = \dot{m}(s_2 - s_1) = (0.06\text{ kg/s})(0.9614 - 0.9483)\text{ kJ/kg}\cdot\text{K} = 0.0007827\text{ kW/K}$$

$$\dot{E}x_{\text{dest,1-2}} = T_0\dot{S}_{\text{gen,1-2}} = (310\text{ K})(0.0007827\text{ kW/K}) = \mathbf{0.2426\ kW}$$

Condenser:

$$\dot{S}_{\text{gen},2-3} = \dot{m}(s_3 - s_2) + \frac{\dot{Q}_H}{T_H} = (0.06 \text{ kg/s})(0.3948 - 0.9614) \text{ kJ/kg}\cdot\text{K} + \frac{10.88 \text{ kW}}{310 \text{ K}} = 0.001114 \text{ kW/K}$$

$$\dot{E}x_{\text{dest,2-3}} = T_0 \dot{S}_{\text{gen,2-3}} = (310 \text{ K})(0.001114 \text{ kJ/kg}\cdot\text{K}) = \mathbf{0.3452 \text{ kW}}$$

Expansion valve:

$$\dot{S}_{\text{gen},3-4} = \dot{m}(s_4 - s_3) = (0.06 \text{ kg/s})(0.4228 - 00.3948) \text{ kJ/kg}\cdot\text{K} = 0.001678 \text{ kW/K}$$

$$\dot{E}x_{\text{dest,3-4}} = T_0 \dot{S}_{\text{gen,3-4}} = (310 \text{ K})(0.001678 \text{ kJ/kg}\cdot\text{K}) = \mathbf{0.5203 \text{ kJ/kg}}$$

Evaporator:

$$\dot{S}_{\text{gen},4-1} = \dot{m}(s_1 - s_4) - \frac{\dot{Q}_L}{T_L} = (0.06 \text{ kg/s})(0.9483 - 0.4228) \text{ kJ/kg}\cdot\text{K} - \frac{8.213 \text{ kW}}{294 \text{ K}} = 0.003597 \text{ kW/K}$$

$$\dot{E}x_{\text{dest,4-1}} = T_0 \dot{S}_{\text{gen,4-1}} = (310 \text{ K})(0.003597 \text{ kJ/kg}\cdot\text{K}) = \mathbf{1.115 \text{ kW}}$$

The total exergy destruction can be determined by adding exergy destructions in each component:

$$\begin{aligned}
\dot{E}x_{\text{dest,total}} &= \dot{E}x_{\text{dest,1-2}} + \dot{E}x_{\text{dest,2-3}} + \dot{E}x_{\text{dest,3-4}} + \dot{E}x_{\text{dest,4-1}} \\
&= 0.2426 + 0.3452 + 0.5203 + 1.115 \\
&= \mathbf{2.223 \text{ kW}}
\end{aligned}$$

(d) The exergy of the heat transferred from the low-temperature medium is

$$\dot{E}x_{\dot{Q}_L} = -\dot{Q}_L\left(1 - \frac{T_0}{T_L}\right) = -(8.213 \text{ kW})\left(1 - \frac{310}{294}\right) = 0.4470 \text{ kW}$$

This is the minimum power input to the cycle:

$$\dot{W}_{\text{in,min}} = \dot{E}x_{\dot{Q}_L} = \mathbf{0.4470 \text{ kW}}$$

The second-law efficiency of the cycle is

$$\eta_{\text{II}} = \frac{\dot{W}_{\text{in,min}}}{\dot{W}_{\text{in}}} = \frac{0.4470}{2.670} = 0.1674 = \mathbf{16.7\%}$$

The total exergy destruction in the cycle can also be determined from

$$\dot{E}x_{\text{dest,total}} = \dot{W}_{\text{in}} - Ex_{\dot{Q}_L} = 2.670 - 0.4470 = 2.223 \text{ kW}$$

The result is the same as expected.