11-12E A refrigerator operating on the ideal vapor-compression refrigeration cycle with refrigerant-134a as the working fluid is considered. The increase in the COP if the throttling process were replaced by an isentropic expansion is to be determined.

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

Analysis In an ideal vapor-compression refrigeration cycle, the compression process is isentropic, the refrigerant enters the compressor as a saturated vapor at the evaporator pressure, and leaves the condenser as saturated liquid at the condenser pressure. From the refrigerant tables (Tables A-11E, A-12E, and A-13E),

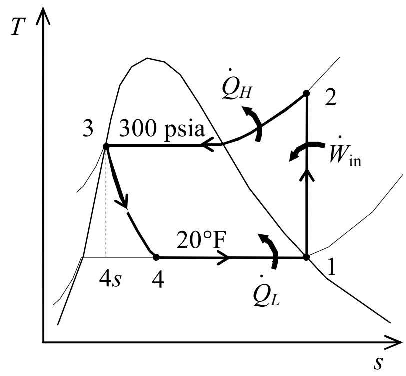
$$\left.\begin{array}{l} T_1 = 20°\text{F} \\ \text{sat. vapor} \end{array}\right\} \begin{array}{l} h_1 = h_{g\,@\,20°\text{F}} = 105.98 \text{ Btu/lbm} \\ s_1 = s_{g\,@\,20°\text{F}} = 0.22341 \text{ Btu/lbm}\cdot\text{R} \end{array}$$

$$\left.\begin{array}{l} P_2 = 300 \text{ psia} \\ s_2 = s_1 \end{array}\right\} h_2 = 125.68 \text{ Btu/lbm}$$

$$\left.\begin{array}{l} P_3 = 300 \text{ psia} \\ \text{sat. liquid} \end{array}\right\} \begin{array}{l} h_3 = h_{f\,@\,300\text{ psia}} = 66.339 \text{ Btu/lbm} \\ s_3 = s_{f\,@\,300\text{ psia}} = 0.12715 \text{ Btu/lbm}\cdot\text{R} \end{array}$$

$$h_4 \cong h_3 = 66.339 \text{ Btu/lbm} \quad \text{(throttling)}$$

$$\left.\begin{array}{l} T_4 = 20°\text{F} \\ s_4 = s_3 \end{array}\right\} \begin{array}{l} h_{4s} = 59.80 \text{ Btu/lbm} \\ x_{4s} = 0.4723 \end{array} \quad \text{(isentropic expansion)}$$



The COP of the refrigerator for the throttling case is

$$\text{COP}_\text{R} = \frac{q_L}{w_\text{in}} = \frac{h_1\text{-}h_4}{h_2\text{-}h_1} = \frac{105.98-66.339}{125.68-105.98} = \mathbf{2.012}$$

The COP of the refrigerator for the isentropic expansion case is

$$\text{COP}_\text{R} = \frac{q_L}{w_\text{in}} = \frac{h_1\text{-}h_{4s}}{h_2\text{-}h_1} = \frac{105.98-59.80}{125.68-105.98} = \mathbf{2.344}$$

The increase in the COP by isentropic expansion is **16.5%**.

11-17 A refrigerator with refrigerant-134a as the working fluid is considered. The rate of heat removal from the refrigerated space, the power input to the compressor, the isentropic efficiency of the compressor, and the COP of the refrigerator are to be determined.

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

Analysis (*a*) From the refrigerant tables (Tables A-12 and A-13),

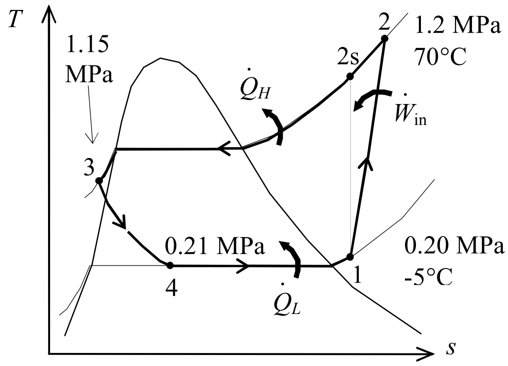
$$\left.\begin{array}{l} P_1 = 0.20 \text{ MPa} \\ T_1 = -5°\text{C} \end{array}\right\} \begin{array}{l} h_1 = 248.80 \text{ kJ/kg} \\ s_1 = 0.95407 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 1.2 \text{ MPa} \\ T_2 = 70°\text{C} \end{array}\right\} h_2 = 300.61 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_{2s} = 1.2 \text{ MPa} \\ s_{2s} = s_1 \end{array}\right\} h_{2s} = 287.21 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_3 = 1.15 \text{ MPa} \\ T_3 = 44°\text{C} \end{array}\right\} h_3 = h_{f\,@\,44°\text{C}} = 114.28 \text{ kJ/kg}$$

$$h_4 \cong h_3 = 114.28 \text{ kJ/kg (throttling)}$$



Then the rate of heat removal from the refrigerated space and the power input to the compressor are determined from

$$\dot{Q}_L = \dot{m}(h_1 - h_4) = (0.07 \text{ kg/s})(248.80 - 114.28) \text{ kJ/kg} = \mathbf{9.42 \text{ kW}}$$

and

$$\dot{W}_{\text{in}} = \dot{m}(h_2 - h_1) = (0.07 \text{ kg/s})(300.61 - 248.80) \text{ kJ/kg} = \mathbf{3.63 \text{ kW}}$$

(*b*) The isentropic efficiency of the compressor is determined from

$$\eta_C = \frac{h_{2s} - h_1}{h_2 - h_1} = \frac{287.21 - 248.80}{300.61 - 248.80} = 0.741 = \mathbf{74.1\%}$$

(*c*) The COP of the refrigerator is determined from its definition,

$$\text{COP}_\text{R} = \frac{\dot{Q}_L}{\dot{W}_{\text{in}}} = \frac{9.42 \text{ kW}}{3.63 \text{ kW}} = \mathbf{2.60}$$

11-21 A refrigerator with refrigerant-134a as the working fluid is considered. The power input to the compressor, the rate of heat removal from the refrigerated space, and the pressure drop and the rate of heat gain in the line between the evaporator and the compressor are to be determined.

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

Analysis (*a*) From the refrigerant tables (Tables A-12 and A-13),

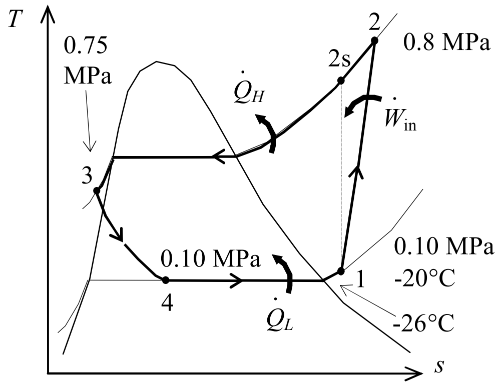
$$\left.\begin{array}{l} P_1 = 100 \text{ kPa} \\ T_1 = -20°\text{C} \end{array}\right\} \begin{array}{l} h_1 = 239.50 \text{ kJ/kg} \\ s_1 = 0.97207 \text{ kJ/kg}\cdot\text{K} \\ v_1 = 0.19841 \text{ m}^3\text{/kg} \end{array}$$

$$\left.\begin{array}{l} P_2 = 0.8 \text{ MPa} \\ s_{2s} = s_1 \end{array}\right\} h_{2s} = 284.07 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_3 = 0.75 \text{ MPa} \\ T_3 = 26°\text{C} \end{array}\right\} h_3 \cong h_{f\,@\,26\,°\text{C}} = 87.83 \text{ kJ/kg}$$

$$h_4 \cong h_3 = 87.83 \text{ kJ/kg (throttling)}$$

$$\left.\begin{array}{l} T_5 = -26°\text{C} \\ \text{sat. vapor} \end{array}\right\} \begin{array}{l} P_5 = 0.10173 \text{ MPa} \\ h_5 = 234.68 \text{ kJ/kg} \end{array}$$



Then the mass flow rate of the refrigerant and the power input becomes

$$\dot{m} = \frac{\dot{V}_1}{v_1} = \frac{0.5/60 \text{ m}^3\text{/s}}{0.19841 \text{ m}^3\text{/kg}} = 0.0420 \text{ kg/s}$$

$$\dot{W}_{\text{in}} = \dot{m}(h_{2s} - h_1)/\eta_C = (0.0420 \text{ kg/s})[(284.07 - 239.50) \text{ kJ/kg}]/(0.78) = \mathbf{2.40 \text{ kW}}$$

(*b*) The rate of heat removal from the refrigerated space is

$$\dot{Q}_L = \dot{m}(h_5 - h_4) = (0.0420 \text{ kg/s})(234.68 - 87.83) \text{ kJ/kg} = \mathbf{6.17 \text{ kW}}$$

(*c*) The pressure drop and the heat gain in the line between the evaporator and the compressor are

$$\Delta P = P_5 - P_1 = 101.73 - 100 = \mathbf{1.73}$$

and

$$\dot{Q}_{\text{gain}} = \dot{m}(h_1 - h_5) = (0.0420 \text{ kg/s})(239.50 - 234.68) \text{ kJ/kg} = \mathbf{0.203 \text{ kW}}$$