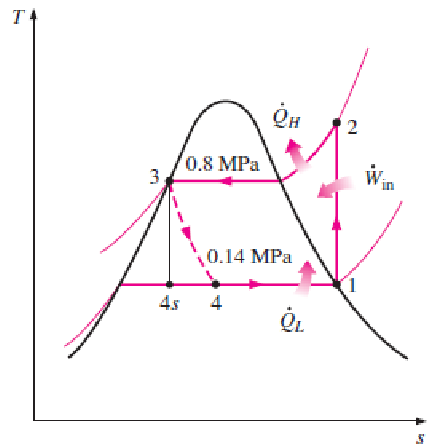
Example 11

A refrigerator uses refrigerant-134a as working fluid and operates on an ideal vapor-compression refrigeration cycle between 0.14 and 0.8 MPa. If the mass flow rate of the refrigerant is 0.05 kg/s, determine (*a*) rate of heat removal from the refrigerated space and the power input to the compressor, (*b*) rate of heat rejection to the environment, and (*c*) COP of the refrigerator.



This is an ideal vapor-compression refrigeration cycle, and thus

- compressor is isentropic and the refrigerant leaves the condenser as a saturated liquid
- enters the compressor as saturated vapor

From the refrigerant-134a tables, enthalpies are determined as follows:

$$P_1 = 0.14\text{MPa} \Rightarrow h_1 = h_{g@0.14\text{MPa}} = 239.16\text{kJ}/\text{kg}$$
$$s_1 = s_{g@0.14\text{MPa}} = 0.94456\text{kJ}/\text{kgK}$$

$$P_2 = 0.8\text{MPa} \Rightarrow s_2 = s_1 = 0.94456\text{kJ}/\text{kgK}$$
$$h_2 = 275.39\text{kJ}/\text{kg}$$

$$P_3 = 0.8\text{ MPa} \Rightarrow h_3 = h_{f@0.8\text{MPa}} = 95.47\text{ kJ/kg}$$

$$h_4 \approx h_3(\text{throttling valve}) \Rightarrow h_4 = 95.47\text{ kJ}/\text{kg}$$

a) Rate of heat removal from refrigerated space and the power input to compressor;

$$\dot{Q}_L = \dot{m}\left(h_1 - h_4\right) = 0.05\left[\left(239.16 - 95.47\right) kJ/kg\right] = 7.18\ kW$$

$$\dot{W}_{in} = \dot{m}\left(h_2 - h_1\right) = 0.05\left[\left(275.39 - 239.16\right) kJ/kg\right] = 1.81\ kW$$

b) Rate of heat rejection from the refrigerant to the environment

$$\dot{Q}_H = \dot{m}\left(h_2 - h_3\right) = 0.05\ kg/s 2 3 1275.39\ \ 95.47 2\ kJ/kg = 9.0\ kW$$

It could also be determined from,

$$\dot{Q}_H = \dot{Q}_L + \dot{W}_{in} = 7.18 + 1.81 = 8.99\ kW$$

c) Coefficient of performance of the refrigerator is,

$$COP_R = \frac{\dot{Q}_L}{\dot{W}_{in}} = \frac{7.18\ kW}{1.81\ kW} = 3.97$$

d) It would be interesting to see what happens if the throttling valve were replaced by an isentropic turbine.

$$\text{At } P_{4s} = 0.14\ MPa$$
$$s_{4s} = s_3 = 0.35404\ kJ/kg \cdot K$$

$$s = s_f + x s_{fg}$$
$$0.35404 = 0.11087 + x(0.83368)$$
$$x = 0.2917$$

$$h = h_f + x h_{fg}$$
$$= 27.08 + 0.2917(212.08)$$
$$\Rightarrow h_{4s} = 88.94\ kJ/kg$$

$$W_{turbine} = \dot{m}\left(h_3 - h_{4s}\right) = 0.05\left(95.47 - 88.94\right) = 0.33 kW$$

Turbine would produce 0.33 kW of power.

It would increase the rate of heat removal from the refrigerated space from 7.18 to 7.51 kW.

$$\dot{Q}_L = \dot{m}\left(h_1 - h_{4s}\right) = \left(0.05\ \text{kg/s}\right)\left[\left(239.16 - 88.94\right)\ \text{kJ/kg}\right] = 7.51\text{kW}$$

$$\dot{W}_{in} = 1.81 - 0.3265 = 1.48\text{kW}$$

$$COP_R = \frac{\dot{Q}_L}{\dot{W}_{in}} = \frac{7.51\ \text{kW}}{1.48\ \text{kW}} = 5.07$$

As a result, the COP of the refrigerator would increase from 3.97 to 5.07, an increase of 28 percent.