ciency and the exergy destruction for the cycle. The specific heat of bananas above freezing is 3.35 kJ/kg·°C. *Answers:* (*a*) 61,100 kJ/h, 1.97, (*b*) 0.463 kW, (*c*) 5.4 percent, 8.14 kW.

11–29 A vapor-compression refrigeration system absorbs heat from a space at 0°C at a rate of 24,000 Btu/h and rejects heat to water in the condenser. The water experiences a temperature rise of 12°C in the condenser. The COP of the system is estimated to be 2.05. Determine (*a*) the power input to the system, in kW, (*b*) the mass flow rate of water through the condenser, and (*c*) the second-law efficiency and the exergy destruction for the refrigerator. Take T_0 = 20°C and $c_{p,\text{water}}$ = 4.18 kJ/kg·°C.

11–30 A refrigerator operating on the vapor-compression refrigeration cycle using refrigerant-134a as the refrigerant is considered. The temperature of the cooled space and the ambient air are at −13°C and 27°C, respectively. R-134a enters the compressor at 140 kPa as a saturated vapor and leaves at 1 MPa and 70°C. The refrigerant leaves the condenser as a saturated liquid. The rate of cooling provided by the system is 13 kW. Determine (*a*) the mass flow rate of R-134a and the COP, (*b*) the exergy destruction in each component of the cycle and the exergy efficiency of the compressor, and (*c*) the second-law efficiency of the cycle and the total exergy destruction in the cycle.

11–31 A room is kept at −12°C by a vapor-compression refrigeration cycle with R-134a as the refrigerant. Heat is rejected to cooling water that enters the condenser at 20°C at a rate of 0.15 kg/s and leaves at 28°C. The refrigerant enters the condenser at 1.2 MPa and 50°C and leave as a saturated liquid. If the compressor consumes 2.2 kW of power, determine (*a*) the refrigeration load, in Btu/h and the COP, (*b*) the second-law efficiency of the refrigerator and the total exergy destruction in the cycle, and (*c*) the exergy destruction in the condenser. Take T_0 = 20°C and $c_{p,\text{water}}$ = 4.18 kJ/kg·°C. *Answers:* (*a*) 9610 Btu/h, 1.28, (*b*) 15.7 percent, 4.72 kW, (*c*) 0.349 kW

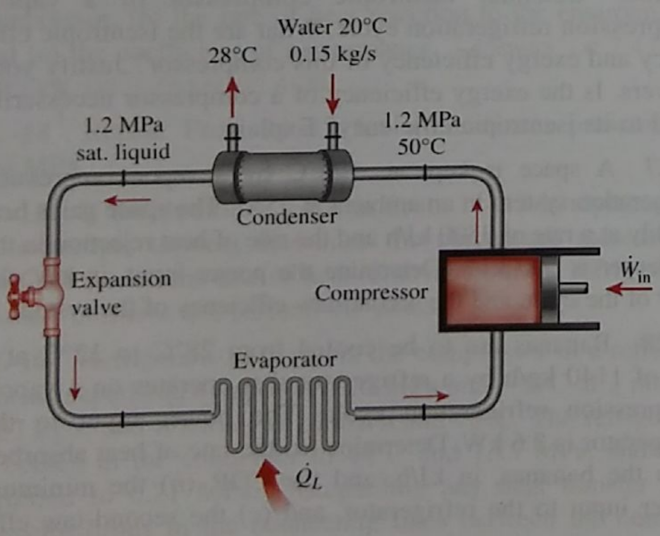

FIGURE P11–31

11–32 A refrigerator operates on the ideal vapor-compression refrigeration cycle with refrigerant-134a as the working fluid. The refrigerant evaporates at −10°C and condenses at 57.9°C. The refrigerant absorbs heat from a space at 5°C and rejects heat to ambient air at 25°C. Determine (*a*) the cooling load, in kJ/kg, and the COP, (*b*) the exergy destruction in each component of the cycle and the total exergy destruction in the cycle, and (*c*) the second-law efficiency of the compressor, evaporator, and the cycle.

11–33 A refrigeration system operates on the ideal vapor-compression refrigeration cycle with ammonia as the refrigerant. The evaporator and condenser pressures are 200 kPa and 2000 kPa, respectively. The temperatures of the low-temperature and high-temperature mediums are −9°C and 27°C, respectively. If the rate of heat rejected in the condenser is 18.0 kW, determine (*a*) the volume flow rate of ammonia at the compressor inlet, in L/s, (*b*) the power input and the COP, and (*c*) the second-law efficiency of the cycle and the total exergy destruction in the cycle. The properties of ammonia at various states are given as follows: h_1 = 1439.3 kJ/kg, s_1= 5.8865 kJ/kg·K, v_1 = 0.5946 m³/kg, h_2 = 1798.3 kJ/kg, h_3 = 437.4 kJ/kg, s_3 = 1.7892 kJ/kg·K, s_4 = 1.9469 kJ/kg·K. Note: state 1: compressor inlet, state 2: compressor exit, state 3: condenser exit, state 4: evaporator inlet.

11–34 EES Using EES (or other) software, repeat the previous problem if ammonia, R-134a, and R-22 is used as the refrigerant. Also, for the case of ammonia, investigate the effects of evaporator and condenser pressures on the COP, the second-law efficiency, and the total exergy destruction. Vary the evaporator pressure between 100 and 400 kPa and the condenser pressure between 1000 and 2000 kPa.

Selecting the Right Refrigerant

11–35C When selecting a refrigerant for a certain application, what qualities would you look for in the refrigerant?

11–36C Consider a refrigeration system using refrigerant-134a as the working fluid. If this refrigerator is to operate in an environment at 30°C, what is the minimum pressure to which the refrigerant should be compressed? Why?

11–37C A refrigerant-134a refrigerator is to maintain the refrigerated space at −10°C. Would you recommend an evaporator pressure of 0.12 or 0.14 MPa for this system? Why?

11–38 A refrigerator that operates on the ideal vapor-compression cycle with refrigerant-134a is to maintain the refrigerated space at −10°C while rejecting heat to the environment at 25°C. Select reasonable pressures for the evaporator and the condenser, and explain why you chose those values.

11–39 A heat pump that operates on the ideal vapor-compression cycle with refrigerant-134a is used to heat a house and maintain it at 26°C by using underground water at 14°C as the heat source. Select reasonable pressures for the

11–47 Refrigerant-134a enters the condenser of a residential heat pump at 800 kPa and 55°C at a rate of 0.018 kg/s and leaves at 750 kPa subcooled by 3°C. The refrigerant enters the compressor at 200 kPa superheated by 4°C. Determine (*a*) the isentropic efficiency of the compressor, (*b*) the rate of heat supplied to the heated room, and (*c*) the COP of the heat pump. Also, determine (*d*) the COP and the rate of heat supplied to the heated room if this heat pump operated on the ideal vapor-compression cycle between the pressure limits of 200 and 800 kPa.

Innovative Refrigeration Systems

11–48C What is cascade refrigeration? What are the advantages and disadvantages of cascade refrigeration?

11–49C How does the COP of a cascade refrigeration system compare to the COP of a simple vapor-compression cycle operating between the same pressure limits?

11–50C A certain application requires maintaining the refrigerated space at −32°C. Would you recommend a simple refrigeration cycle with refrigerant-134a or a two-stage cascade refrigeration cycle with a different refrigerant at the bottoming cycle? Why?

11–51C Consider a two-stage cascade refrigeration cycle and a two-stage compression refrigeration cycle with a flash chamber. Both cycles operate between the same pressure limits and use the same refrigerant. Which system would you favor? Why?

11–52C Can a vapor-compression refrigeration system with a single compressor handle several evaporators operating at different pressures? How?

11–53C In the liquefaction process, why are gases compressed to very high pressures?

11–54 A two-stage compression refrigeration system operates with refrigerant-134a between the pressure limits of 1.4 and 0.10 MPa. The refrigerant leaves the condenser as a saturated liquid and is throttled to a flash chamber operating at 0.4 MPa. The refrigerant leaving the low-pressure compressor at 0.4 MPa is also routed to the flash chamber. The vapor in the flash chamber is then compressed to the condenser pressure by the high-pressure compressor, and the liquid is throttled to the evaporator pressure. Assuming the refrigerant leaves the evaporator as saturated vapor and both compressors are isentropic, determine (*a*) the fraction of the refrigerant that evaporates as it is throttled to the flash chamber, (*b*) the rate of heat removed from the refrigerated space for a mass flow rate of 0.25 kg/s through the condenser, and (*c*) the coefficient of performance.

11–55 Repeat Prob. 11–54 for a flash chamber pressure of 0.6 MPa.

11–56 Reconsider Prob. 11–54. Using EES (or other) software, investigate the effect of the various refrigerants for compressor efficiencies of 80, 90, and 100 percent. Compare the performance of the refrigeration system with different refrigerants.

11–57 Consider a two-stage cascade refrigeration system operating between the pressure limits of 1.2 MPa and 200 kPa with refrigerant-134a as the working fluid. Heat rejection from the lower cycle to the upper cycle takes place in an adiabatic counterflow heat exchanger where the pressure in the upper and lower cycles are 0.4 and 0.5 MPa, respectively. In both cycles, the refrigerant is a saturated liquid at the condenser exit and a saturated vapor at the compressor inlet, and the isentropic efficiency of the compressor is 80 percent. If the mass flow rate of the refrigerant through the lower cycle is 0.15 kg/s, determine (*a*) the mass flow rate of the refriger-

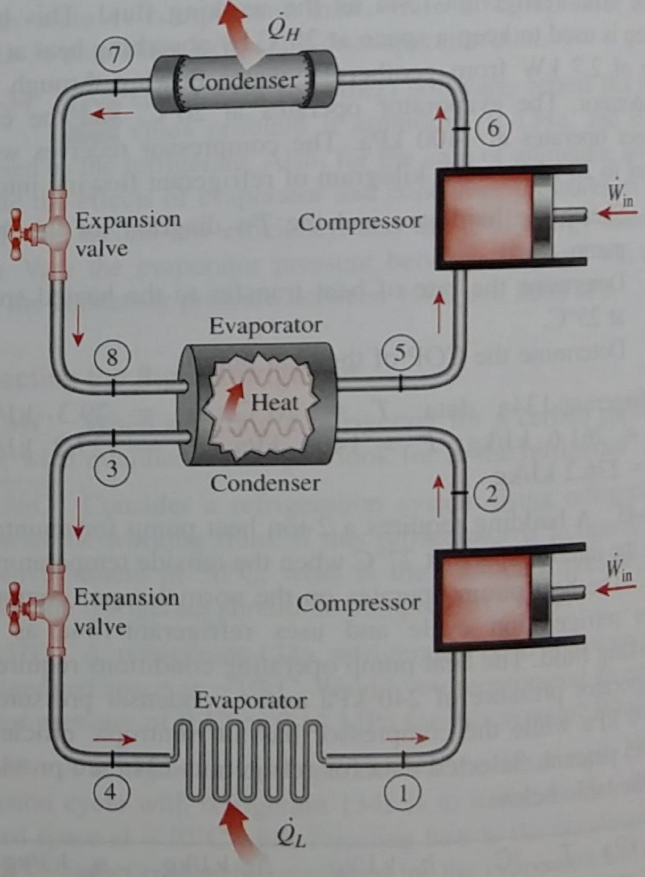

FIGURE P11–57

ant through the upper cycle, (*b*) the rate of heat removal from the refrigerated space, and (*c*) the COP of this refrigerator. *Answers:* (*a*) 0.212 kg/s, (*b*) 25.7 kW, (*c*) 2.68

11–58 A two-evaporator compression refrigeration system as shown in the figure uses refrigerant-134a as the working fluid. The system operates evaporator 1 at 0°C, evaporator 2 at −26.4°C, and the condenser at 800 kPa. The refrigerant is circulated through the compressor at a rate of 0.1 kg/s and the low-temperature evaporator serves a cooling load of 8 kW. Determine the cooling rate of the high-temperature evaporator, the power required by the compressor, and the COP of the system. The refrigerant is saturated liquid at the exit

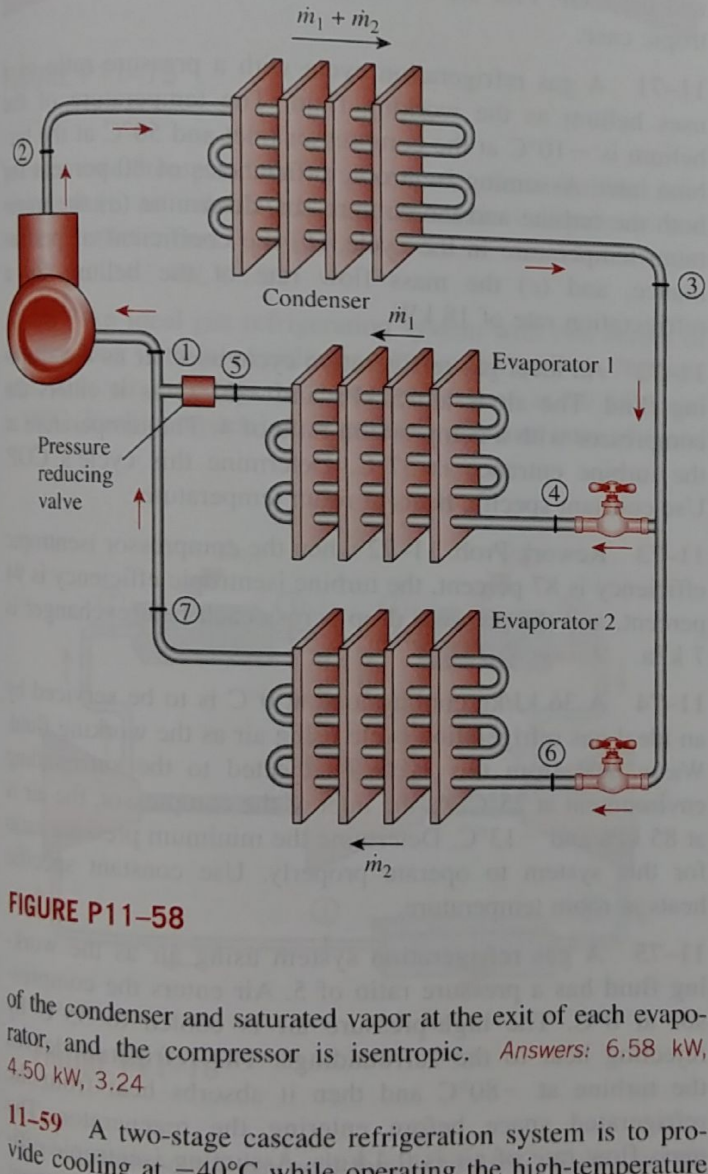

FIGURE P11–58

of the condenser and saturated vapor at the exit of each evaporator, and the compressor is isentropic. *Answers:* 6.58 kW, 4.50 kW, 3.24

11–59 A two-stage cascade refrigeration system is to provide cooling at −40°C while operating the high-temperature condenser at 1.6 MPa. Each stage operates on the ideal vapor-compression refrigeration cycle. The upper vapor compression refrigeration system (VCRS) uses water as its working fluid and operates its evaporator at 5°C. The lower cycle uses refrigerant-134a as its working fluid and operates its condenser at 400 kPa. This system produces a cooling effect

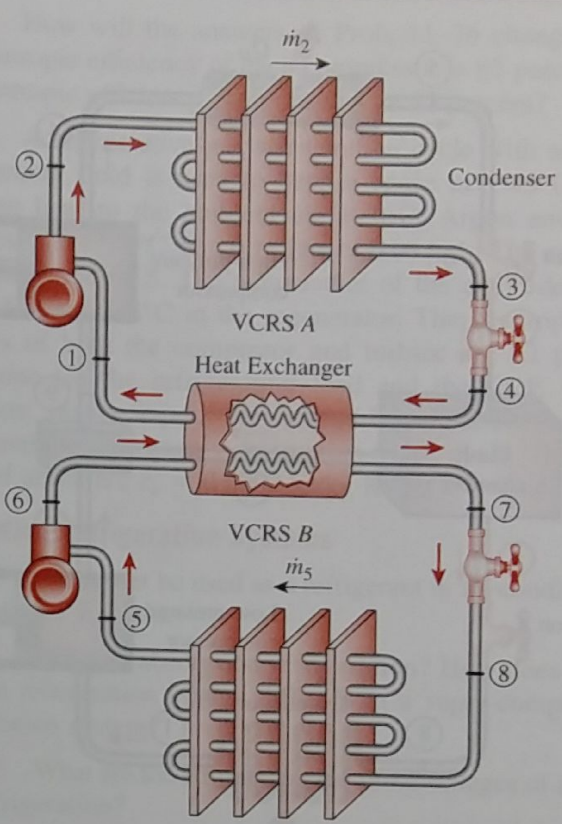

FIGURE P11–59

of 20 kJ/s. Determine the mass flow rate of R-134a and water in their respective cycles, and the overall COP of this cascaded system.

11–60 Perform a second-law analysis of the cascaded system of Prob. 11–59 when the low-temperature reservoir is at −30°C and the high-temperature reservoir is at 30°C. Where does the largest exergy destruction occur?

11–61 Consider a two-stage cascade refrigeration cycle with a flash chamber as shown in the figure with refrigerant-134a as the working fluid. The evaporator temperature is −10°C and the condenser pressure is 1600 kPa. The refrigerant leaves the condenser as a saturated liquid and is throttled to a flash chamber operating at 0.45 MPa. Part of the refrigerant evaporates during this flashing process, and this vapor is mixed with the refrigerant leaving the low-pressure compressor. The mixture is then compressed to the condenser pressure by the high-pressure compressor. The liquid in the flash chamber is throttled to the evaporator pressure and cools the refrigerated space as it vaporizes in the evaporator. The mass flow rate of the refrigerant through the low-pressure compressor is 0.11 kg/s. Assuming the refrigerant leaves the evaporator as a saturated vapor and the isentropic efficiency is 86 percent for both compressors, determine (*a*) the mass flow rate of the refrigerant through the high-pressure compressor, (*b*) the rate of refrigeration supplied by the system, and (*c*) the COP of this refrigerator. Also, determine (*d*) the rate of refrigeration and the COP

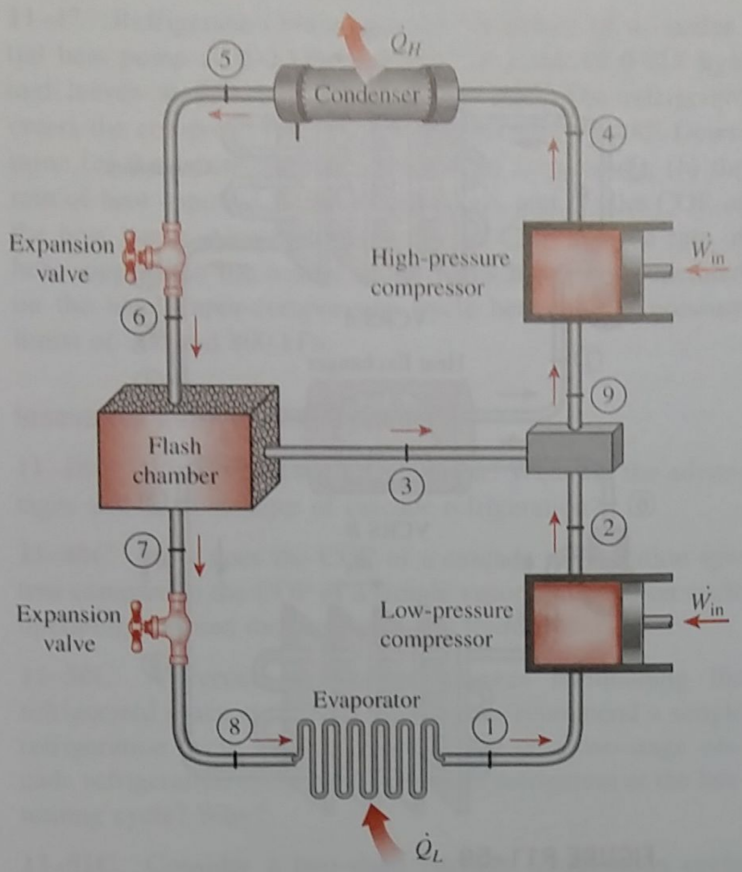

FIGURE P11–61

if this refrigerator operated on a single-stage vapor-compression cycle between the same evaporating temperature and condenser pressure with the same compressor efficiency and the same flow rate as calculated in part (*a*).

Gas Refrigeration Cycle

11–62C How does the ideal-gas refrigeration cycle differ from the Brayton cycle?

11–63C How does the ideal-gas refrigeration cycle differ from the Carnot refrigeration cycle?

11–64C Devise a refrigeration cycle that works on the reversed Stirling cycle. Also, determine the COP for this cycle.

11–65C How is the ideal-gas refrigeration cycle modified for aircraft cooling?

11–66C In gas refrigeration cycles, can we replace the turbine by an expansion valve as we did in vapor-compression refrigeration cycles? Why?

11–67C How do we achieve very low temperatures with gas refrigeration cycles?

11–68 Air enters the compressor of an ideal gas refrigeration cycle at 7°C and 35 kPa and the turbine at 37°C and 160 kPa. The mass flow rate of air through the cycle is 0.2 kg/s. Assuming variable specific heats for air, determine (*a*) the rate of refrigeration, (*b*) the net power input, and (*c*) the coefficient of performance. *Answers:* (a) 15.9 kW, (b) 8.64 kW, (c) 1.84

11–69 Repeat Prob. 11–68 for a compressor isentropic efficiency of 80 percent and a turbine isentropic efficiency of 85 percent.

11–70 Reconsider Prob. 11–69. Using EES (or other) software, study the effects of compressor and turbine isentropic efficiencies as they are varied from 70 to 100 percent on the rate of refrigeration, the net power input, and the COP. Plot the *T-s* diagram of the cycle for the isentropic case.

11–71 A gas refrigeration cycle with a pressure ratio of 3 uses helium as the working fluid. The temperature of the helium is −10°C at the compressor inlet and 50°C at the turbine inlet. Assuming isentropic efficiencies of 80 percent for both the turbine and the compressor, determine (*a*) the minimum temperature in the cycle, (*b*) the coefficient of performance, and (*c*) the mass flow rate of the helium for a refrigeration rate of 18 kW.

11–72 An ideal gas refrigeration cycle uses air as the working fluid. The air is at 35 kPa and −23°C as it enters the compressor with a compression ratio of 4. The temperature at the turbine entrance is 37°C. Determine this cycle's COP. Use constant specific heats at room temperature.

11–73 Rework Prob. 11–72 when the compressor isentropic efficiency is 87 percent, the turbine isentropic efficiency is 94 percent, and the pressure drop across each heat exchanger is 7 kPa. *Answer:* 0.377

11–74 A 36 kJ/kg cooling load at 0°C is to be serviced by an ideal gas refrigeration cycle using air as the working fluid. Waste heat from this cycle is rejected to the surrounding environment at 25°C. At the inlet of the compressor, the air is at 85 kPa and −13°C. Determine the minimum pressure ratio for this system to operate properly. Use constant specific heats at room temperature.

11–75 A gas refrigeration system using air as the working fluid has a pressure ratio of 5. Air enters the compressor at 0°C. The high-pressure air is cooled to 35°C by rejecting heat to the surroundings. The refrigerant leaves the turbine at −80°C and then it absorbs heat from the refrigerated space before entering the regenerator. The mass flow rate of air is 0.4 kg/s. Assuming isentropic efficiencies of 80 percent for the compressor and 85 percent for the turbine and using constant specific heats at room temperature, determine (*a*) the effectiveness of the regenerator, (*b*) the rate of heat removal from the refrigerated space, and (*c*) the COP of the cycle. Also, determine (*d*) the refrigeration load and the COP if this system operated on the simple gas refrigeration cycle. Use the same com-