11-11E An ice-making machine operates on the ideal vapor-compression cycle, using refrigerant-134a. The refrigerant enters the compressor as saturated vapor at 20 psia and leaves the condenser as saturated liquid at 80 psia. Water enters the ice machine at 55°F and leaves as ice at 25°F. For an ice production rate of 15 lbm/h, determine the power input to the ice machine (169 Btu of heat needs to be removed from each lbm of water at 55°F to turn it into ice at 25°F).

11-12E A refrigerator operates on the ideal vapor-compression refrigeration cycle and uses refrigerant-134a as the working fluid. The condenser operates at 300 psia and the evaporator at 20°F. If an adiabatic, reversible expansion device were available and used to expand the liquid leaving the condenser, how much would the COP improve by using this device instead of the throttle device?  

*Answer: 16.5 percent*
An ideal vapor-compression refrigeration cycle that uses refrigerant-134a as its working fluid maintains a condenser at 800 kPa and the evaporator at \(-12^\circ\text{C}\). Determine this system’s COP and the amount of power required to service a 150 kW cooling load.  

*Answers: 4.87, 30.8 kW*
11–17 Refrigerant-134a enters the compressor of a refrigerator as superheated vapor at 0.20 MPa and –5°C at a rate of 0.07 kg/s, and it leaves at 1.2 MPa and 70°C. The refrigerant is cooled in the condenser to 44°C and 1.15 MPa, and it is throttled to 0.21 MPa. Disregarding any heat transfer and pressure drops in the connecting lines between the components, show the cycle on a T-s diagram with respect to saturation lines, and determine (a) the rate of heat removal from the refrigerated space and the power input to the compressor, (b) the isentropic efficiency of the compressor, and (c) the COP of the refrigerator. Answers: (a) 9.42 kW, 3.63 kW, (b) 74.1 percent, (c) 2.60
A commercial refrigerator with refrigerant-134a as the working fluid is used to keep the refrigerated space at $-30^\circ$C by rejecting its waste heat to cooling water that enters the condenser at $18^\circ$C at a rate of 0.25 kg/s and leaves at $26^\circ$C. The refrigerant enters the condenser at 1.2 MPa and $65^\circ$C and leaves at $42^\circ$C. The inlet state of the compressor is 60 kPa and $-34^\circ$C and the compressor is estimated to gain a net heat of 450 W from the surroundings. Determine (a) the quality of the refrigerant at the evaporator inlet, (b) the refrigeration load, (c) the COP of the refrigerator, and (d) the theoretical maximum refrigeration load for the same power input to the compressor.
11–19 Refrigerant-134a enters the compressor of a refrigerator at 100 kPa and −20°C at a rate of 0.5 m³/min and leaves at 0.8 MPa. The isentropic efficiency of the compressor is 78 percent. The refrigerant enters the throttling valve at 0.75 MPa and 26°C and leaves the evaporator as saturated vapor at −26°C. Show the cycle on a T-s diagram with respect to saturation lines, and determine (a) the power input to the compressor, (b) the rate of heat removal from the refrigerated space, and (c) the pressure drop and rate of heat gain in the line between the evaporator and the compressor. Answers: (a) 2.40 kW, (b) 6.17 kW, (c) 1.73 kPa, 0.203 kW
11–21 A refrigerator uses refrigerant-134a as the working fluid and operates on the ideal vapor-compression refrigeration cycle except for the compression process. The refrigerant enters the evaporator at 120 kPa with a quality of 34 percent and leaves the compressor at 70°C. If the compressor consumes 450 W of power, determine (a) the mass flow rate of the refrigerant, (b) the condenser pressure, and (c) the COP of the refrigerator.  

Answers: (a) 0.00644 kg/s, (b) 800 kPa, (c) 2.03

FIGURE P11–21

11–42 A heat pump that operates on the ideal vapor-compression cycle with refrigerant-134a is used to heat water from 15 to 45°C at a rate of 0.12 kg/s. The condenser and evaporator pressures are 1.4 and 0.32 MPa, respectively. Determine the power input to the heat pump.
A heat pump with refrigerant-134a as the working fluid is used to keep a space at 25°C by absorbing heat from geothermal water that enters the evaporator at 50°C at a rate of 0.065 kg/s and leaves at 40°C. The refrigerant enters the evaporator at 20°C with a quality of 23 percent and leaves at the inlet pressure as saturated vapor. The refrigerant loses 300 W of heat to the surroundings as it flows through the compressor and the refrigerant leaves the compressor at 1.4 MPa at the same entropy as the inlet. Determine (a) the degrees of subcooling of the refrigerant in the condenser, (b) the mass flow rate of the refrigerant, (c) the heating load and the COP of the heat pump, and (d) the theoretical minimum power input to the compressor for the same heating load. Answers: (a) 3.8°C, (b) 0.0194 kg/s, (c) 3.07 kW, 4.68, (d) 0.238 kW

**FIGURE P11–43**
11-44 Refrigerant-134a enters the condenser of a residential heat pump at 800 kPa and 50°C at a rate of 0.022 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.

**FIGURE P11-44**

11-45E A heat pump that operates on the ideal vapor-compression cycle with refrigerant-134a is used to heat a house and maintain it at 75°F by using underground water at 50°F as the heat source. The house is losing heat at a rate of 60,000 Btu/h. The evaporator and condenser pressures are 50 and 120 psia, respectively. Determine the power input to the heat pump and the electric power saved by using a heat pump instead of a resistance heater.  

_Ans.: 2.46 hp, 21.1 hp_
11–46 A heat pump using refrigerant-134a heats a house by using underground water at 8°C as the heat source. The house is losing heat at a rate of 60,000 kJ/h. The refrigerant enters the compressor at 280 kPa and 0°C, and it leaves at 1 MPa and 60°C. The refrigerant exits the condenser at 30°C. Determine (a) the power input to the heat pump, (b) the rate of heat absorption from the water, and (c) the increase in electric power input if an electric resistance heater is used instead of a heat pump. Answers: (a) 3.55 kW, (b) 13.12 kW, (c) 13.12 kW

11–56 Consider a two-stage cascade refrigeration system operating between the pressure limits of 0.8 and 0.14 MPa. Each stage operates on the ideal vapor-compression refrigeration cycle 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 both streams enter at about 0.4 MPa. If the mass flow rate of the refrigerant through the upper cycle is 0.24 kg/s, determine (a) the mass flow rate of the refrigerant through the lower cycle, (b) the rate of heat removal from the refrigerated space and the power input to the compressor, and (c) the coefficient of performance of this cascade refrigerator. Answers: (a) 0.195 kg/s, (b) 34.2 kW, 7.63 kW, (c) 4.49
Consider a two-stage cascade refrigeration system operating between the pressure limits of 1.4 MPa and 160 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 0.11 kg/s, determine (a) the mass flow rate of the refrigerant through the upper cycle, (b) the rate of heat removal from the refrigerated space, and (c) the COP of this refrigerator. 

Answers: (a) 0.169 kg/s, (b) 18.5 kW, (c) 2.12
FIGURE P11-58
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. 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 0.15 kg/s. Assuming the refrigerant leaves the evaporator as a saturated vapor and the isentropic efficiency is 80 percent for both compressors, determine (a) the mass flow rate of the refrigerant through the high-pressure compressor, (b) the rate of heat removal from the refrigerated space, and (c) the COP of this refrigerator. Also, determine (d) the rate of heat removal and the COP if this refrigerator operated on a single-stage cycle between the same pressure limits with the same compressor efficiency and the same flow rate as in part (a).
A two-evaporator compression refrigeration system as shown in Fig. P11-60 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 of the condenser and saturated vapor at the exit of each evaporator, and the compressor is isentropic. *Answers: 6.58 kW, 4.51 kW, 3.24*
11-68E Air enters the compressor of an ideal gas refrigeration cycle at 40°F and 10 psia and the turbine at 120°F and 30 psia. The mass flow rate of air through the cycle is 0.5 lbm/s. Determine (a) the rate of refrigeration, (b) the net power input, and (c) the coefficient of performance.

11-69 An ideal gas refrigeration cycle using air as the working fluid is to maintain a refrigerated space at −23°C while rejecting heat to the surrounding medium at 27°C. If the pressure ratio of the compressor is 3, determine (a) the maximum and minimum temperatures in the cycle, (b) the coefficient of performance, and (c) the rate of refrigeration for a mass flow rate of 0.08 kg/s.

11-73 A gas refrigeration cycle with a pressure ratio of 4 uses helium as the working fluid. The temperature of the helium is −6°C at the compressor inlet and 50°C at the turbine inlet. Assuming isentropic efficiencies of 85 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 25 kW.
11–74 A gas refrigeration system using air as the working fluid has a pressure ratio of 4. Air enters the compressor at \(-7^\circ\text{C}\). The high-pressure air is cooled to \(27^\circ\text{C}\) by rejecting heat to the surroundings. It is further cooled to \(-15^\circ\text{C}\) by regenerative cooling before it enters the turbine. Assuming both the turbine and the compressor to be isentropic and using constant specific heats at room temperature, determine (a) the lowest temperature that can be obtained by this cycle, (b) the coefficient of performance of the cycle, and (c) the mass flow rate of air for a refrigeration rate of 12 kW. Answers: (a) \(-99.4^\circ\text{C}\), (b) 1.12, (c) 0.237 kg/s

11–75 Repeat Prob. 11–74 assuming isentropic efficiencies of 75 percent for the compressor and 80 percent for the turbine.
11–77 An ideal gas refrigeration system with two stages of compression with intercooling as shown in Fig. P11–77 operates with air entering the first compressor at 90 kPa and $-24^\circ$C. Each compression stage has a pressure ratio of 3 and the two intercoolers can cool the air to $5^\circ$C. Calculate the coefficient of performance of this system and the rate at which air must be circulated through this system to service a 45,000 kJ/h cooling load. Use constant specific heats at room temperature. *Answers: 1.56, 0.124 kg/s*

![Diagram of the refrigeration system](image)

**FIGURE P11–77**

11–78 How will the answers of Prob. 11–77 change when the isentropic efficiency of each compressor is 85 percent and the isentropic efficiency of the turbine is 95 percent?