·29E A rigid tank with a volume of 30 ft^3 contains 1.5 lbm of saturated quid–vapor mixture of water at 190°F. Now the water is slowly heated.)etermine the temperature at which the liquid in the tank is completely aporized. Also show the process on a *T-v* diagram with respect to aturation lines. *Answer:* 228.4°F

-30 A 0.5-m^3 vessel contains 10 kg of refrigerant-134a at −20°C.)etermine (*a*) the pressure, (*b*) the total internal energy, and (*c*) the olume occupied by the liquid phase.
Answers: (*a*) 132.99 kPa, (*b*) 889.5 kJ, (*c*) 0.00487 m^3

:-31 A piston–cylinder device initially contains 50 L of liquid water at :5°C and 300 kPa. Heat is added to the water at constant pressure until he entire liquid is vaporized.

(*a*) What is the mass of the water?
(*b*) What is the final temperature?
(*c*) Determine the total enthalpy change.
(*d*) Show the process on a *T-v* diagram with respect to saturation lines.

Answers: (*a*) 49.85 kg, (*b*) 133.55°*C*, (*c*) 130,627 kJ

2-31E A piston–cylinder device initially contains 2 ft^3 of liquid water at 70°F and 50 psia. Heat is transferred to the water at constant pressure until the entire liquid is vaporized.

(*a*) What is the mass of the water?
(*b*) What is the final temperature?
(*c*) Determine the total enthalpy change.
(*d*) Show the process on a *T-v* diagram with respect to saturation lines.

2-32 A 0.5-m^3 rigid vessel initially contains saturated liquid–vapor mixture of water at 100°C. The water is now heated until it reaches the critical state. Determine the mass of the liquid water and the volume occupied by the liquid at the initial state.
Answers: 158.28 kg, 0.165 m^3

2-32E A 5-ft^3 rigid vessel initially contains saturated liquid–vapor mixture of water at 212°F. The water is now heated until it reaches the critical state. Determine the mass of the liquid water and the volume occupied by the liquid at the initial state. *Answers:* 98.8 lbm, 1.65 ft^3

2-33 A 0.5-m^3 rigid tank contains saturated mixture of refrigerant-134a at 200 kPa. If the saturated liquid occupies 10 percent of the volume, determine the quality and the total mass of the refrigerant in the tank.

2-33E A 15-ft^3 rigid tank contains saturated mixture of refrigerant-134a at 30 psia. If the saturated liquid occupies 10 percent of the volume, determine the quality and the total mass of the refrigerant in the tank.

3-71 A 4 m × 5 m × 7 m room is heated by the radiator of a steam-heating system. The steam radiator transfers heat at a rate of 10,000 kJ/h, and a 100-W fan is used to distribute the warm air in the room. The rate of heat loss from the room is estimated to be about 5000 kJ/h. If the initial temperature of the room air is 10°C, determine how long it will take for the air temperature to rise to 20°C. Assume constant specific heats at room temperature.

3-71E A 12 ft × 15 ft × 20 ft room is heated by the radiator of a steam-heating system. The steam radiator transfers heat at a rate of 10,000 Btu/h, and a 100-W fan is used to distribute the warm air in the room. The heat losses from the room are estimated to be at a rate of about 5000 Btu/h. If the initial temperature of the room air is 45°F, determine how long it will take for the air temperature to rise to 75°F. Assume constant specific heats at room temperature. *Answer:* 978 s

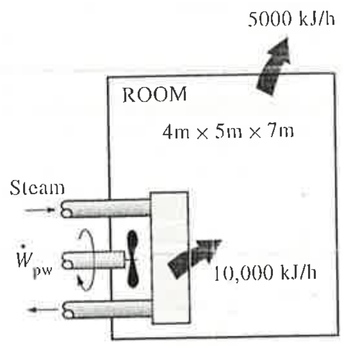

FIGURE P3-71

3-72 A student living in a 4 m × 6 m × 6 m dormitory room turns on her 150-W fan before she leaves the room on a summer day, hoping that the room will be cooler when she comes back in the evening. Assuming all the doors and windows are tightly closed and disregarding any heat transfer through the walls and the windows, determine the temperature in the room when she comes back 10 h later. Use specific heat values at room temperature, and assume the room to be at 100 kPa and 15°C in the morning when she leaves. *Answer:* 58.2°C

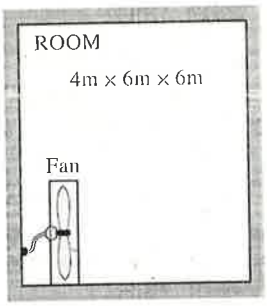

FIGURE P3-72

3-73 A 0.3-m^3 tank contains oxygen initially at 100 kPa and 27°C. A paddle wheel within the tank is rotated until the pressure inside rises to 150 kPa. During the process 2 kJ of heat is lost to the surroundings. Determine the paddle-wheel work done. Neglect the energy stored in the paddle wheel. *Answer:* −40.94 kJ

3-73E A 10-ft^3 tank contains oxygen initially at 14.7 psia and 80°F. A paddle wheel within the tank is rotated until the pressure inside rises to 20 psia. During the process 20 Btu of heat is lost to the surroundings. Determine the paddle-wheel work done. Neglect the energy stored in the paddle wheel.

3-74 An insulated rigid tank is divided into two equal parts by a partition. Initially, one part contains 3 kg of an ideal gas at 800 kPa and 50°C, and the other part is evacuated. The partition is now removed, and the gas expands into the entire tank. Determine the final temperature and pressure in the tank.

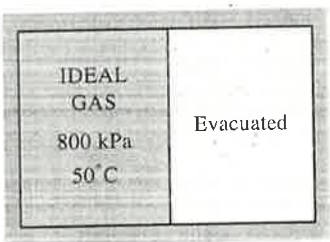

FIGURE P3-74

3-74E An insulated rigid tank is divided into two equal parts by a partition. Initially, one part contains 8 lbm of an ideal gas at 80 psia and 200°F, and the other part is evacuated. The partition is now removed, and the gas expands into the entire tank. Determine the final temperature and pressure in the tank.

3-75 A piston–cylinder device, whose piston is resting on top of a set of stops, initially contains 0.5 kg of helium gas at 100 kPa and 25°C. The mass of the piston is such that 500 kPa of pressure is required to raise it. How much heat must be transferred to the helium before the piston starts rising? *Answer:* 1857 kJ

3-76 An insulated piston–cylinder device contains 100 L of air at 400 kPa and 25°C. A paddle wheel within the cylinder is rotated until 15 kJ of work is done on the air while the pressure is held constant. Determine the final temperature of the air. Neglect the energy stored in the paddle wheel.

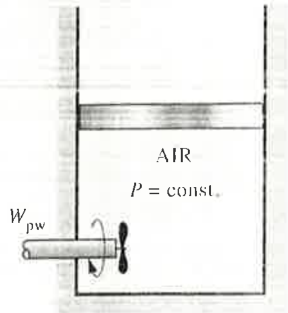

FIGURE P3-76

3-77 A piston–cylinder device contains 0.8 m^3 of nitrogen at 300 kPa and 327°C. The nitrogen is now allowed to cool at constant pressure until the temperature drops to 77°C. Determine the heat transfer.
Answer: −355.2 kJ

3-77E A piston–cylinder device contains 25 ft^3 of nitrogen at 50 psia and 700°F. Nitrogen is now allowed to cool at constant pressure until the temperature drops to 140°F. Determine the heat transfer.

3-78 A mass of 15 kg of air in a piston–cylinder device is heated from 25 to 77°C by passing current through a resistance heater inside the cylinder. The pressure inside the cylinder is held constant at 300 kPa during the process, and a heat loss of 60 kJ occurs. Determine the electric energy supplied, in kWh. *Answer:* 0.235 kWh

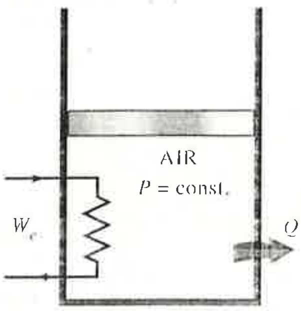

FIGURE P3-78

3-79 An insulated piston–cylinder device initially contains 0.3 m^3 of carbon dioxide at 200 kPa and 27°C. An electric switch is turned on, and a 110-V source supplies current to a resistance heater inside the cylinder for a period of 10 min. The pressure is held constant during the process, while the volume is doubled. Determine the current that passes through the resistance heater.

3-79E An insulated piston–cylinder device initially contains 10 ft^3 of carbon dioxide at 30 psia and 80°F. An electric switch is turned on, and a 110-V source supplies current to a resistance heater inside the cylinder for 10 min. The pressure is held constant during the process, while the volume is doubled. Determine the current that passes through the resistance heater. *Answer:* 4.6 A

3-80 A piston–cylinder device contains 0.8 kg of nitrogen initially at 100 kPa and 27°C. The nitrogen is now compressed slowly in a polytropic process during which $PV^{1.3}$ = constant until the volume is reduced by one-half. Determine the work done and the heat transfer for this process.

3-81 A room is heated by a baseboard resistance heater. When the heat losses from the room on a winter day amount to 8000 kJ/h, the air temperature in the room remains constant even though the heater operates continuously. Determine the power rating of the heater, in kW.

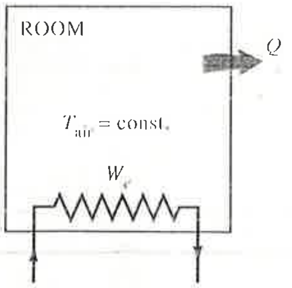

FIGURE P3-81

3-82 A piston–cylinder device contains 0.1 m^3 of air at 400 kPa and 50°C. Heat is transferred to the air in the amount of 40 kJ as the air expands isothermally. Determine the amount of boundary work done during this process. *Answer:* 40 kJ

3-82E A piston–cylinder device contains 3 ft^3 of air at 60 psia and 150°F. Heat is transferred to the air in the amount of 40 Btu as the air expands isothermally. Determine the amount of boundary work done during this process.

3-83 A piston–cylinder device contains 5 kg of argon at 400 kPa and 30°C. During a quasi-equilibrium, isothermal expansion process, 15 kJ of boundary work is done by the system, and 3 kJ of paddle-wheel work is done on the system. Determine the heat transfer for this process.
Answer: 12 kJ

3-83E A piston–cylinder device contains 8 lbm of argon at 75 psia and 70°F. During a quasi-equilibrium, isothermal expansion process, 15 Btu of boundary work is done by the system, and 3 Btu of paddle-wheel work is done on the system. Determine the heat transfer for this process.

3-84 A piston–cylinder device, whose piston is resting on a set of stops, initially contains 3 kg of air at 200 kPa and 27°C. The mass of the piston is such that a pressure of 400 kPa is required to move it. Heat is now transferred to the air until its volume doubles. Determine the work done by the air and the total heat transferred to the air during this process. Also show the process on a *P-v* diagram. *Answers:* 516 kJ, 2674 kJ

3-85 A piston–cylinder device, with a set of stops on the top, initially contains 3 kg of air at 200 kPa and 27°C. Heat is now transferred to the air, and the piston rises until it hits the stops, at which point the volume is twice the initial volume. More heat is transferred until the pressure inside the cylinder also doubles. Determine the work done and the amount of heat transfer for this process. Also show the process on a *P-v* diagram.

3-85E A piston–cylinder device, with a set of stops on the top, initially contains 5 lbm of air at 30 psia and 80°F. Heat is now transferred to the air, and the piston rises until it hits the stops, at which point the volume is twice the initial volume. More heat is transferred until the pressure inside the cylinder also doubles. Determine the work done and the amount of heat transfer for this process. Also show the process on a *P-v* diagram.
Answers: 184.9 Btu, 1731 Btu

3-86 A rigid tank containing 0.4 m^3 of air at 400 kPa and 30°C is connected by a valve to a piston–cylinder device with zero clearance. The mass of the piston is such that a pressure of 200 kPa is required to raise the piston. The valve is now opened slightly, and air is allowed to flow into the cylinder until the pressure in the tank drops to 200 kPa. During this process, heat is exchanged with the surroundings such that the entire air remains at 30°C at all times. Determine the heat transfer for this process.

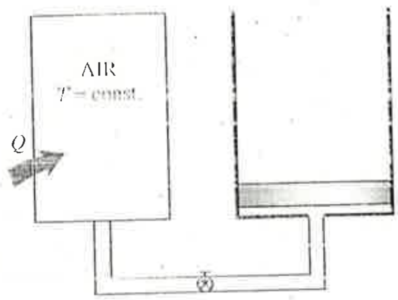

FIGURE P3-86

Nozzles and Diffusers

4-11C A diffuser is an adiabatic device that decreases the kinetic energy of the fluid by slowing it down. What happens to this *lost* kinetic energy?

4-12C The kinetic energy of a fluid increases as it is accelerated in an adiabatic nozzle. Where does this energy come from?

4-13C Is heat transfer to or from the fluid desirable as it flows through a nozzle? How will heat transfer affect the fluid velocity at the nozzle exit?

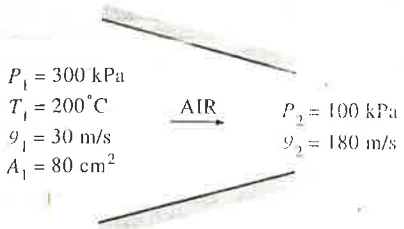

FIGURE P4-14

4-14 Air enters an adiabatic nozzle steadily at 300 kPa, 200°C, and 30 m/s and leaves at 100 kPa and 180 m/s. The inlet area of the nozzle is 80 cm². Determine (*a*) the mass flow rate through the nozzle, (*b*) the exit temperature of the air, and (*c*) the exit area of the nozzle.
Answers: (*a*) 0.5304 kg/s, (*b*) 184.60°C, (*c*) 38.7 cm²

4-14E Air enters an adiabatic nozzle steadily at 75 psia, 400°F, and 100 ft/s and leaves at 15 psia and 500 ft/s. The inlet area of the nozzle is 20 in². Determine (*a*) the mass flow rate through the nozzle, (*b*) the exit temperature of the air and (*c*) the exit area of the nozzle.

4-15 Carbon dioxide enters an adiabatic nozzle steadily at 1 MPa and 500°C with a mass flow rate of 6000 kg/h and leaves at 100 kPa and 450 m/s. The inlet area of the nozzle is 40 cm². Determine (*a*) the inlet velocity and (*b*) the exit temperature.
Answers: (*a*) 60.8 m/s, (*b*) 685.8 K

4-16 Air enters a nozzle steadily at 300 kPa, 77°C, and 50 m/s and leaves at 100 kPa and 320 m/s. The heat loss from the nozzle is estimated to be 3.2 kJ/kg of air flowing. The inlet area of the nozzle is 100 cm². Determine (*a*) the exit temperature of air and (*b*) the exit area of the nozzle. *Answers:* (*a*) 24.2°C, (*b*) 39.7 cm²

4-16E Air enters a nozzle steadily at 50 psia, 140°F, and 150 ft/s and leaves at 14.7 psia and 900 ft/s. The heat loss from the nozzle is estimated to be 6.5 Btu/lbm of air flowing. The inlet area of the nozzle is 0.1 ft². Determine (*a*) the exit temperature of air and (*b*) the exit area of the nozzle. *Answers:* (*a*) 507.4 R, (*b*) 0.0479 ft²

4-17 Air at 600 kPa and 500 K enters an adiabatic nozzle that has an inlet-to-exit area ratio of 2:1 with a velocity of 120 m/s and leaves with a velocity of 380 m/s. Determine (*a*) the exit temperature and (*b*) the exit pressure of the air. *Answers:* (*a*) 436.5 K, (*b*) 330.8 kPa

4-18 Air at 80 kPa and 127°C enters an adiabatic diffuser steadily at a rate of 6000 kg/h and leaves at 100 kPa. The velocity of the airstream is decreased from 230 to 30 m/s as it passes through the diffuser. Find (*a*) the exit temperature of the air and (*b*) the exit area of the diffuser.

4-29 Air flows steadily through an adiabatic turbine, entering at 1 MPa, 500°C, and 120 m/s and leaving at 150 kPa, 150°C, and 250 m/s. The inlet area of the turbine is 80 cm². Determine (*a*) the mass flow rate of the air and (*b*) the power output of the turbine.

4-29E Air flows steadily through an adiabatic turbine, entering at 150 psia, 900°F, and 350 ft/s and leaving at 20 psia, 300°F, and 700 ft/s. The inlet area of the turbine is 0.1 ft². Determine (*a*) the mass flow rate of the air and (*b*) the power output of the turbine.

4-30 Air enters the compressor of a gas-turbine plant at ambient conditions of 100 kPa and 25°C with a low velocity and exits at 1 MPa and 347°C with a velocity of 90 m/s. The compressor is cooled at a rate of 1500 kJ/min, and the power input to the compressor is 250 kW. Determine the mass flow rate of air through the compressor.
Answer: 0.675 kg/s

4-31 Air is compressed from 100 kPa and 22°C to a pressure of 1 MPa while being cooled at a rate of 16 kJ/kg by circulating water through the compressor casing. The volume flow rate of the air at the inlet conditions is 150 m³/min, and the power input to the compressor is 500 kW. Determine (*a*) the mass flow rate of the air and (*b*) the temperature at the compressor exit. *Answers:* (*a*) 2.95 kg/s, (*b*) 174°C

4-31E Air is compressed from 14.7 psia and 60°F to a pressure of 150 psia while being cooled at a rate of 10 Btu/lbm by circulating water through the compressor casing. The volume flow rate of the air at the inlet conditions is 5000 ft³/min, and the power input to the compressor is 700 hp. Determine (*a*) the mass flow rate of the air and (*b*) the temperature at the compressor exit.
Answers: (*a*) 6.36 lbm/s, (*b*) 801 R

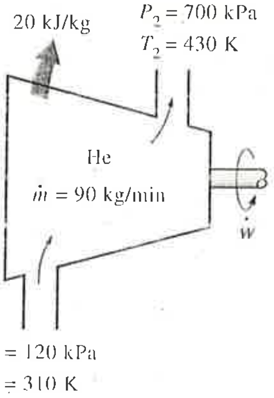

FIGURE P4-32

4-32 Helium is to be compressed from 120 kPa and 310 K to 700 kPa and 430 K. A heat loss of 20 kJ/kg occurs during the compression process. Neglecting kinetic energy changes, determine the power input required for a mass flow rate of 90 kg/min.

4-33 Carbon dioxide enters an adiabatic compressor at 100 kPa and 300 K at a rate of 0.5 kg/s and leaves at 600 kPa and 450 K. Neglecting kinetic energy changes, determine (*a*) the volume flow rate of the carbon dioxide at the compressor inlet and (*b*) the power input to the compressor. *Answers:* (*a*) 0.28 m³/s, (*b*) 68.8 kW

Throttling Valves

4-34C Why are throttling devices commonly used in refrigeration and air-conditioning applications?

4-35C During a throttling process, the temperature of a fluid drops from 30 to −20°C. Can this process occur adiabatically?

4-36C Would you expect the temperature of air to drop as it undergoes a steady-flow throttling process?

4-37C Would you expect the temperature of a liquid to change as it is throttled? How?

4-38 Refrigerant-134a is throttled from the saturated liquid state at 800 kPa to a pressure of 140 kPa. Determine the temperature drop during this process. *Answer:* 50.13°C

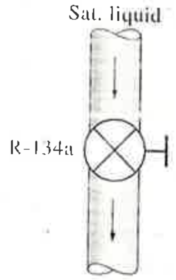

FIGURE P4-38

4-39 Refrigerant-134a is throttled from the saturated liquid state at 800 kPa to a temperature of −20°C. Determine the pressure of the refrigerant at the final state. *Answer:* 133 kPa

4-40 Air at 2 MPa and 30°C is throttled to the atmospheric pressure of 100 kPa. Determine the final temperature of the air.

4-40E Air at 200 psia and 90°F is throttled to the atmospheric pressure of 14.7 psia. Determine the final temperature of the air.

Mixing Chambers and Heat Exchangers

4-41C When two fluid streams are mixed in a mixing chamber, can the mixture temperature be lower than the temperature of both streams? How?

4-42C Consider a steady-flow mixing process. Under what conditions will the energy transported into the control volume by the incoming streams be equal to the energy transported out of it by the outgoing stream?

4-43C Consider a steady-flow heat exchanger involving two different fluid streams. Under what conditions will the amount of heat lost by one fluid be equal to the amount of heat gained by the other?

4-44 A hot-water stream at 80°C enters a mixing chamber with a mass flow rate of 0.5 kg/s where it is mixed with a stream of cold water at 20°C. If it is desired that the mixture leave the chamber at 42°C, determine the mass flow rate of the cold-water stream. Assume all the streams are at a pressure of 250 kPa. *Answer:* 0.864 kg/s

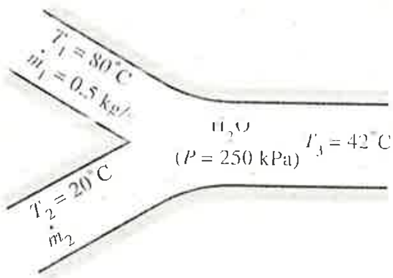

FIGURE P4-44

4-44E A hot-water stream at 180°F enters a mixing chamber with a mass flow rate of 2 lbm/s, where it is mixed with a stream of cold water at 60°F. If it is desired that the mixture leave the chamber at 110°F, determine the mass flow rate of the cold-water stream. Assume all the streams are at a pressure of 50 psia. *Answer:* 2.80 lbm/s

4-45 Liquid water at 300 kPa and 20°C is heated in a chamber by mixing it with hot water at 300 kPa and 90°C. Cold water enters the chamber at a rate of 1.8 kg/s. If the mixture leaves the mixing chamber at 60°C, determine the mass flow rate of the hot water required.

4-46 Water at 25°C and 300 kPa is heated in a chamber by mixing it with hot water at 80°C and 300 kPa. If both streams enter the mixing chamber at the same mass flow rate, determine the temperature of the exiting stream.

4-51E Steam enters the condenser of a steam power plant at 3 psia as saturated vapor with a mass flow rate of 40,000 lbm/h. It is to be cooled by water from a nearby river by circulating the water through the tubes within the condenser. To prevent thermal pollution, the river water is not allowed to experience a temperature rise above 18°F. If the steam is to leave the condenser as saturated liquid at 3 psia, determine the mass flow rate of the cooling water required.

Pipe and Duct Flow

4-52 A 5 m × 6 m × 8 m room is to be heated by an electric resistance heater placed in a short duct in the room. Initially, the room is at 15°C, and the local atmospheric pressure is 98 kPa. The room is losing heat steadily to the outside at a rate of 200 kJ/min. A 200-W fan circulates the air steadily through the duct and the electric heater at an average mass flow rate of 50 kg/min. The duct can be assumed to be adiabatic, and there is no air leaking in or out of the room. If it takes 15 min for the room air to reach an average temperature of 25°C, find (*a*) the power rating of the electric heater and (*b*) the temperature rise that the air experiences each time it passes through the heater.

4-53 A house has an electric heating system that consists of a 300-W fan and an electric resistance heating element placed in a duct. Air flows steadily through the duct at a rate of 0.6 kg/s and experiences a temperature rise of 5°C. The rate of heat loss from the air in the duct is estimated to be 400 W. Determine the power rating of the electric resistance heating element. *Answer:* 3.12 kW

4-53E A house has an electric heating system that consists of a 300-W fan and an electric resistance heating element placed in a duct. Air flows through the duct at a rate of 1 lbm/s and experiences a temperature rise of 10°F. The rate of heat loss from the air in the duct is estimated to be 0.2 Btu/s. Determine the power rating of the electric heating element.

4-54 A hair dryer is basically a duct in which a few layers of electric resistors are placed. A small fan pulls the air in and forces it through the resistors where it is heated. Air enters a 1200-W hair dryer at 100 kPa and 22°C and leaves at 47°C. The cross-sectional area of the hair dryer at the exit is 60 cm². Neglecting the power consumed by the fan and the heat losses through the walls of the hair dryer, determine (*a*) the volume flow rate of air at the inlet and (*b*) the velocity of the air at the exit. *Answers:* (*a*) 0.0404 m³/s, (*b*) 7.31 m/s

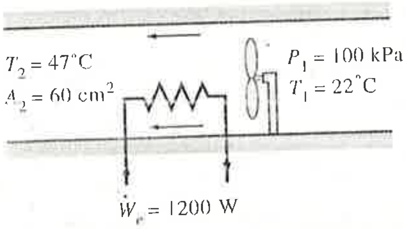

FIGURE P4-54

4-55 The ducts of an air heating system pass through an unheated area. As a result of heat losses, the temperature of the air in the duct drops by 4°C. If the mass flow rate of air is 120 kg/min, determine the rate of heat loss from the air to the cold environment.

NO **4-56** Air enters the duct of an air-conditioning system at 105 kPa and 12°C at a volume flow rate of 12 m³/min. The diameter of the duct is 20 cm, and heat is transferred to the air in the duct from the surroundings

5-74 A heat engine is operating on Carnot cycle and has a thermal efficiency of 55 percent. The waste heat from this engine is rejected to a nearby lake at 15°C at a rate of 800 kJ/min. Determine (*a*) the power output of the engine and (*b*) the temperature of the source. *Answers:* (*a*) 16.3 kW, (*b*) 640 K

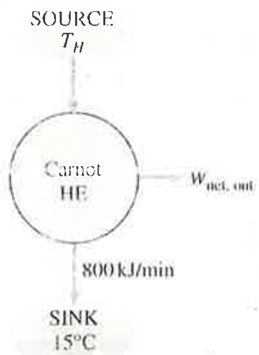

FIGURE P5-74

5-74E A heat engine is operating on Carnot cycle and has a thermal efficiency of 55 percent. The waste heat from this engine is rejected to a nearby lake at 60°F at a rate of 800 Btu/min. Determine (*a*) the power output of the engine and (*b*) the temperature of the source. *Answers:* (*a*) 23.1 hp, (*b*) 1155.6 R

5-75 In tropical climates, the water near the surface of the ocean remains warm throughout the year as a result of solar energy absorption. In the deeper parts of the ocean, however, the water remains at a relatively low temperature since the sun's rays cannot penetrate very far. It is proposed to take advantage of this temperature difference and construct a power plant that will absorb heat from the warm water near the surface and reject the waste heat to the cold water a few hundred meters below. Determine the maximum thermal efficiency of such a plant if the water temperatures at the two respective locations are 24 and 4°C.

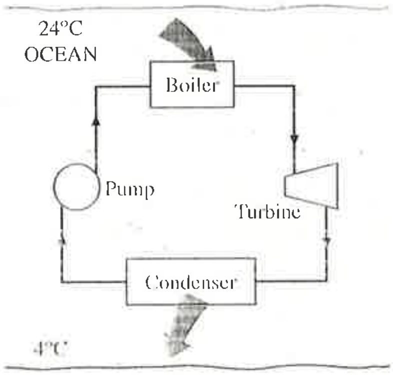

FIGURE P5-75

5-76 An innovative way of power generation involves the utilization of geothermal energy—the energy of hot water that exists naturally underground—as the heat source. If a supply of hot water at 140°C is discovered at a location where the environmental temperature is 20°C, determine the maximum thermal efficiency a geothermal power plant built at that location can have. *Answer:* 29.1 percent

5-77 An inventor claims to have developed a heat engine that receives 800 kJ of heat from a source at 400 K and produces 250 kJ of net work while rejecting the waste heat to a sink at 300 K. Is this a reasonable claim? Why?

5-77E An inventor claims to have developed a heat engine that receives 600 Btu of heat from a source at 750 R and produces 200 Btu of net work while rejecting the waste heat to a sink at 550 R. Is this a reasonable claim? Why?

5-78 An experimentalist claims that, based on his measurements, a heat engine receives 320 kJ of heat from a source at 500 K, converts 180 kJ of it to work, and rejects the rest as waste heat to a sink at 300 K. Are these measurements reasonable? Why?

5-78E An experimentalist claims that, based on his measurements, a heat engine receives 300 Btu of heat from a source of 900 R, converts 160 Btu of it to work, and rejects the rest as waste heat to a sink at 540 R. Are these measurements reasonable? Why?

Carnot Refrigerators and Heat Pumps

5-79C How can we increase the COP of a Carnot refrigerator?

5-80C What is the highest COP that a refrigerator operating between temperature levels T_L and T_H can have?

5-81C What is the highest COP that a heat pump operating between temperature levels T_L and T_H can have?

5-82C In an effort to conserve energy in a heat-engine cycle, somebody suggests incorporating a refrigerator that will absorb some of the waste energy Q_L and transfer it to the energy source of the heat engine. Is this a smart idea? Explain.

5-83C It is well established that the thermal efficiency of a heat engine increases as the temperature at which heat is rejected from the heat engine T_L decreases. In an effort to increase the efficiency of a power plant, somebody suggests refrigerating the cooling water before it enters the condenser, where heat rejection takes place. Would you be in favor of this idea? Why?

5-84C It is well known that the thermal efficiency of heat engines increases as the temperature of the energy source increases. In an attempt to improve the efficiency of a power plant, somebody suggests transferring heat from the available energy source to a higher temperature medium by a heat pump before energy is supplied to the power plant. What do you think of this suggestion? Explain.

5-85 A Carnot refrigerator operates in a room in which the temperature is 25°C and consumes 2 kW of power when operating. If the food compartment of the refrigerator is to be maintained at 3°C, determine the rate of heat removal from the food compartment.

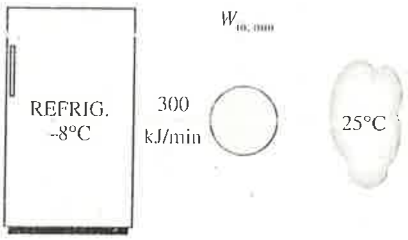

FIGURE P5-86

5-86 A refrigerator is to remove heat from the cooled space at a rate of 300 kJ/min to maintain its temperature at −8°C. If the air surrounding the refrigerator is at 25°C, determine the minimum power input required for this refrigerator. *Answer:* 0.623 kW

5-86E A refrigerator is to remove heat from the cooled space at a rate of 150 Btu/min to keep its temperature at 25°F. If the air surrounding the refrigerator is at 80°F, determine the minimum power input required for this refrigerator. *Answer:* 0.4 hp

5-87 An air conditioning system operating on the reversed Carnot cycle is required to transfer heat from a house at a rate of 750 kJ/min, to maintain its temperature at 20°C. If the outdoor air temperature is 35°C, determine the power required to operate this air conditioning system. *Answer:* 0.64 kW

5-88 An air conditioning system is used to maintain a house at 20°C when the temperature outside is 35°C. If this air conditioning system draws 5 kW of power when operating, determine the maximum rate of heat removal from the house that it can provide.

5-88E An air conditioning system is used to maintain a house at 70°F when the temperature outside is 90°F. If this air conditioning system draws 5 hp of power when operating, determine the maximum rate of heat removal from the house that it can provide.

5-89 A Carnot refrigerator operates in a room in which the temperature is 25°C. The refrigerator consumes 500 W of power when operating and had a COP of 4.5. Determine (*a*) the rate of heat removal from the refrigerated space and (*b*) the temperature of the refrigerated space. *Answers:* (*a*) 135 kJ/min, (*b*) −29.2°C

5-90 An inventor claims to have developed a refrigeration system that removes heat from the closed region at −5°C and transfers it to the surrounding air at 22°C while maintaining a COP of 8.2. Is this claim reasonable? Why?

5-90E An inventor claims to have developed a refrigeration system that removes heat from the cooled region at 20°F and transfers it to the surrounding air at 75°F while maintaining a COP of 6.7. Is this claim reasonable? Why?

5-91 During an experiment conducted in a room at 25°C, a laboratory assistant measures that a refrigerator that draws 2 kW of power has removed 30,000 kJ of heat from the refrigerated space, which is maintained at −30°C. The running time of the refrigerator during the experiment was 20 min. Determine if these measurements are reasonable.

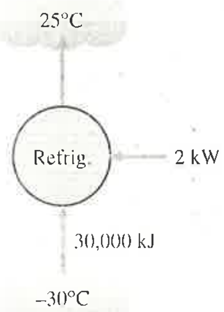

FIGURE P5-91

5-92 An air conditioning system is used to maintain a house at 22°C when the temperature outside is 33°C. The house is gaining heat through the walls and the windows at a rate of 600 kJ/min, and the heat generation rate within the house from people, lights, and appliances amounts to 120 kJ/min. Determine the minimum power input required for this air conditioning system. *Answer:* 0.45 kW

5-92E An air conditioning system is used to maintain a house at 75°F when the temperature outside is 95°F. The house is gaining heat through the walls and the windows at a rate of 750 Btu/min, and the heat generation rate within the house from people, lights, and appliances amounts to 150 Btu/min. Determine the minimum power input required for this air conditioning system. *Answer:* 0.79 hp

5-93 A heat pump is used to heat a house and maintain it at 20°C. On a winter day when the outdoor air temperature is −5°C, the house is estimated to lose heat at a rate of 75,000 kJ/h. Determine the minimum power required to operate this heat pump.

5-93E A heat pump is used to heat a house and maintain it at 70°F. On a winter day when the outdoor air temperature is 20°F, the house is estimated to lose heat at a rate of 55,000 Btu/h. Determine the minimum power required to operate this heat pump.

5-94 A heat pump is used to maintain a house at 22°C by extracting heat from the outside air on a day when the outside air temperature is 2°C. The house is estimated to lose heat at a rate of 110,000 kJ/h, and the heat pump consumes 8 kW of electric power when operating. Is this heat pump powerful enough to do the job?

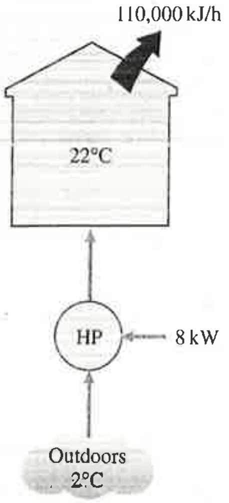

FIGURE P5-94

5-95 The structure of a house is such that it loses heat at a rate of 5400 kJ/h per °C difference between the indoors and outdoors. A heat pump that requires a power input of 6 kW is used to maintain this house at 21°C. Determine the lowest outdoors temperature for which the heat pump can meet the heating requirements of this house.
Answer: −13.3°C

5-96 The performance of a heat pump degrades (i.e., its COP decreases) as the temperature of the heat source decreases. This makes using heat pumps at locations with severe weather conditions unattractive. Consider a house that is heated and maintained at 20°C by a heat pump during the winter. What is the maximum COP for this heat pump if heat is extracted from the outdoor air at (*a*) 10°C, (*b*) −5°C, and (*c*) −30°C?

5-97 A heat pump is to be used for heating a house in winter. The house is to be maintained at 21°C at all times. When the temperature outdoors drops to −2°C, the heat losses from the house are estimated to be 80,000 kJ/h. Determine the minimum power required to run this heat pump if heat is extracted from (*a*) the outdoor air at −2°C and (*b*) the well water at 12°C.

5-97E A heat pump is to be used for heating a house in the winter. The house is to be maintained at 78°F at all times. When the temperature outdoors drops to 25°F, the heat losses from the house are estimated to be 80,000 Btu/h. Determine the minimum power required to run this heat pump if heat is extracted from (*a*) the outdoor air at 25°F and (*b*) the well water at 50°F.

5-98 A Carnot heat pump is to be used for heating a house and maintaining it at 20°C during the winter. On a day when the average outdoor temperature remains at about 2°C, the house is estimated to lose heat at a steady rate of 82,000 kJ/h. If the heat pump consumes 8 kW of power while operating, determine (*a*) how long the heat pump ran on that day; (*b*) the total heating costs, assuming an average price of 8.5¢/kWh for electricity; and (*c*) the heating cost for the same day if resistance heating is used instead of a heat pump.
Answers: (*a*) 4.19 h, (*b*) $2.85, (*c*) $46.47

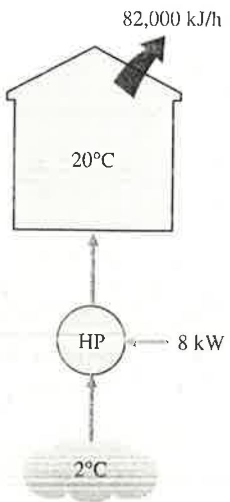

FIGURE P5-98

5-99 A Carnot heat engine receives heat from a reservoir at 900°C at a rate of 800 kJ/min and rejects the waste heat to the ambient air at 27°C. The entire work output of the heat engine is used to drive a refrigerator that removes heat from the refrigerated space at −5°C and transfers it to

7-33E An ideal Otto cycle has a compression ratio of 8. At the beginning of the compression process, air is at 14.5 psia and 80°F, and 450 Btu/lbm of heat is transferred to the air during the constant-volume heat addition process. Using constant specific heats at room temperature, determine (*a*) the pressure and temperature at the end of the heat addition process, (*b*) the net work output, (*c*) the thermal efficiency, and (*d*) the mean effective pressure for the cycle.

7-34 The compression ratio of an air-standard Otto cycle is 9.5. Prior to the isentropic compression process, the air is at 100 kPa, 17°C, and 600 cm^3. The temperature at the end of the isentropic expansion process is 800 K. Using specific heat values at room temperature, determine (*a*) the highest temperature and pressure in the cycle, (*b*) the amount of heat transferred during heat addition, in kJ, (*c*) the thermal efficiency, and (*d*) the mean effective pressure.
Answers: (*a*) 1969 K, 6449 kPa; (*b*) 0.65 kJ; (*c*) 59.4 percent; (*d*) 719 kPa

7-34E The compression ratio of an air-standard Otto cycle is 9.5. Prior to the isentropic compression process, the air is at 14.7 psia, 60°F, and 35 in^3. The temperature at the end of the isentropic expansion process is 1400 R. Using specific heat values at room temperature, determine (*a*) the highest temperature and pressure in the cycle, (*b*) the amount of heat transferred during heat addition, in Btu, (*c*) the thermal efficiency, and (*d*) the mean effective pressure.

7-35 Repeat Prob. 7-34, but replace the isentropic expansion process by a polytropic expansion process with the polytropic exponent $n = 1.35$.

7-36 An ideal Otto cycle with air as the working fluid has a compression ratio of 8. The minimum and maximum temperatures in the cycle are 310 and 1600 K. Using constant specific heats at room temperature, determine (*a*) the amount of heat transferred to air during the heat addition process, (*b*) the thermal efficiency, and (*c*) the thermal efficiency of a Carnot cycle operating between the same temperature limits.
Answers: (*a*) 637 kJ/kg, (*b*) 60 percent, (*c*) 80.6 percent

7-36E An ideal Otto cycle with air as the working fluid has a compression ratio of 8. The minimum and maximum temperatures in the cycle are 540 and 2200 R. Using constant specific heats at room temperature, determine (*a*) the amount of heat transferred to the air during the heat addition process, (*b*) the thermal efficiency, and (*c*) the thermal efficiency of a Carnot cycle operating between the same temperature limits.
Answers: (*a*) 164 Btu/lbm, (*b*) 56.5 percent, (*c*) 75.5 percent

7-37 Repeat Prob. 7-36 using argon as the working fluid.

Diesel Cycle

7-38C What is the dual cycle? How does it differ from the Otto and Diesel cycles?

7-39C How does a diesel engine differ from a gasoline engine?

7-40C How does the ideal Diesel cycle differ from the ideal Otto cycle?

7-41C For a specified compression ratio, is a diesel or gasoline engine more efficient?

7-42C Do diesel or gasoline engines operate at higher compression ratios? Why?

7-43C What is the cutoff ratio? How does it affect the thermal efficiency of a Diesel cycle?

7-44 An air-standard Diesel cycle has a compression ratio of 16 and a cutoff ratio of 2. At the beginning of the compression process, air is at 95 kPa and 27°C. Using constant specific heats at room temperature, determine (*a*) the temperature after the heat addition process, (*b*) the thermal efficiency, and (*c*) the mean effective pressure.
Answers: (*a*) 1819 K, (*b*) 61.4 percent, (*c*) 660.5 kPa

7-44E An air-standard Diesel cycle has a compression ratio of 16 and a cutoff ratio of 2. At the beginning of the compression process, air is at 14.5 psia and 80°F. Using constant specific heats at room temperature, determine (*a*) the temperature after the heat addition process, (*b*) the thermal efficiency, and (*c*) the mean effective pressure.

7-45 An air-standard Diesel cycle has a compression ratio of 18.2. Air is at 27°C and 0.1 MPa at the beginning of the compression process and at 2000 K at the end of the heat addition process. Using constant specific heats at room temperature, determine (*a*) the cutoff ratio, (*b*) the heat rejection per unit mass, and (*c*) the thermal efficiency.

7-45E An air-standard Diesel cycle has a compression ratio of 18.2. Air is at 80°F and 14.7 psia at the beginning of the compression process and at 3400 R at the end of the heat addition process. Using constant specific heats at room temperature, determine (*a*) the cutoff ratio, (*b*) the heat rejection per unit mass, and (*c*) the thermal efficiency.
Answers: (*a*) 1.97, (*b*) 147 Btu/lbm, (*c*) 63.4 percent

7-46 An ideal diesel engine has a compression ratio of 20 and uses air as the working fluid. The state of air at the beginning of the compression process is 95 kPa and 20°C. If the maximum temperature in the cycle is not to exceed 2200 K, determine (*a*) the thermal efficiency and (*b*) the mean effective pressure. Assume constant specific heats for air at room temperature. *Answers:* (*a*) 63.5 percent, (*b*) 933 kPa

7-47 Repeat Prob. 7-46, but replace the isentropic expansion process by polytropic expansion process with the polytropic exponent $n = 1.35$.

7-48 A four-cylinder 4.5-L diesel engine that operates on an ideal Diesel cycle has a compression ratio of 17 and a cutoff ratio of 2.2. Air is at 27°C and 97 kPa at the beginning of the compression process. Using the

7-96E Consider a 150-MW steam power plant that operates on a simple ideal Rankine cycle. Steam enters the turbine at 1000 psia and 1000°F and is cooled in the condenser at a pressure of 2 psia. Show the cycle on a T-s diagram with respect to saturation lines, and determine (*a*) the quality of the steam at the turbine exit, (*b*) the thermal efficiency of the cycle, and (*c*) the mass flow rate of the steam.

7-97 A steam power plant operates on a simple ideal Rankine cycle between the pressure limits of 9 MPa and 10 kPa. The mass flow rate of steam through the cycle is 60 kg/s. The moisture content of the steam at the turbine exit is not to exceed 10 percent. Show the cycle on a T-s diagram with respect to saturation lines, and determine (*a*) the minimum turbine inlet temperature, (*b*) the rate of heat input in the boiler, and (*c*) the thermal efficiency of the cycle.

7-97E A steam power plant operates on a simple ideal Rankine cycle between the pressure limits of 1250 and 2 psia. The mass flow rate of steam through the cycle is 75 lbm/s. The moisture content of the steam at the turbine exit is not to exceed 10 percent. Show the cycle on a T-s diagram with respect to saturation lines, and determine (*a*) the minimum turbine inlet temperature, (*b*) the rate of heat input in the boiler, and (*c*) the thermal efficiency of the cycle.

7-98 Consider a coal-fired steam power plant that produces 300 MW of electric power. The power plant operates on a simple ideal Rankine cycle with turbine inlet conditions of 5 MPa and 450°C and a condenser pressure of 25 kPa. The coal used has a heating value (energy released when the fuel is burned) of 29,300 kJ/kg. Assuming that 75 percent of this energy is transferred to the steam in the boiler and that electric generator has an efficiency of 96 percent, determine (*a*) the overall plant efficiency (the ratio of net electric power output to the energy input as fuel) and (*b*) the required rate of coal supply, in t/h [1 metric ton (t) = 1000 kg]. *Answers:* (*a*) 24.6 percent, (*b*) 150.1 t/h

7-98E Consider a coal-fired steam power plant that produces 300 MW of electric power. The power plant operates on a simple ideal Rankine cycle with turbine inlet conditions of 700 psia and 800°F and a condenser pressure of 3 psia. The coal used has a heating value (energy released when the fuel is burned) of 12,600 Btu/lbm. Assuming that 75 percent of this energy is transferred to the steam in the boiler and that the electric generator has an efficiency of 96 percent, determine (*a*) the overall plant efficiency (the ratio of net electric power output to the energy input as fuel) and (*b*) the required rate of coal supply, in tons/h (1 ton = 2000 lbm). *Answers:* (*a*) 24.6 percent, (*b*) 183.8 tons/h

7-99 Consider a solar-pond power plant that operates on a simple ideal Rankine cycle with refrigerant-134a as the working fluid. The refrigerant enters the turbine as a saturated vapor at 1.6 MPa and leaves at 0.7 MPa. The mass flow rate of the refrigerant is 6 kg/s. Show the cycle on a T-s

diagram with respect to saturation lines, and determine (*a*) the thermal efficiency of the cycle and (*b*) the power output of this plant.

7-100 Consider a steam power plant that operates on a simple ideal Rankine cycle and has a net power output of 30 MW. Steam enters the turbine at 7 MPa and 500°C and is cooled in the condenser at a pressure of 10 kPa by running cooling water from a lake through the tubes of the condenser at a rate of 2000 kg/s. Show the cycle on a *T-s* diagram with respect to saturation lines, and determine (*a*) the thermal efficiency of the cycle, (*b*) the mass flow rate of the steam, and (*c*) the temperature rise of the cooling water. *Answers:* (*a*) 38.9 percent, (*b*) 24.0 kg/s, (*c*) 5.63°C

7-100E Consider a steam power plant that operates on a simple Rankine cycle and has a net power output of 50 MW. Steam enters the turbine at 1000 psia and 1000°F and is cooled in the condenser at a pressure of 2 psia by running cooling water from a lake through the tubes of the condenser at a rate of 7000 lbm/s. The turbine and the pump have adiabatic efficiencies of 84 percent. Show the cycle on a *T*-s diagram with respect to saturation lines, and determine (*a*) the thermal efficiency of the cycle, (*b*) the mass flow rate of the steam, and (*c*) the temperature rise of the cooling water.

The Reheat Rankine Cycle

7-101C How do the following quantities change when a simple ideal Rankine cycle is modified with reheating? Assume the mass flow rate is maintained the same.

Pump work input:	(*a*) increases, (*b*) decreases, (*c*) remains the same
Turbine work output:	(*a*) increases, (*b*) decreases, (*c*) remains the same
Heat added:	(*a*) increases, (*b*) decreases, (*c*) remains the same
Heat rejected:	(*a*) increases, (*b*) decreases, (*c*) remains the same
Moisture content at turbine exit:	(*a*) increases, (*b*) decreases, (*c*) remains the same

7-102C Show the ideal Rankine cycle with three stages of reheating on a *T-s* diagram. Assume the turbine inlet temperature is the same for all stages. How does the cycle efficiency vary with the number of reheat stages?

7-103C Consider a simple Rankine cycle and an ideal Rankine cycle with three reheat stages. Both cycles operate between the same pressure limits. The maximum temperature is 700°C in the simple cycle and 500°C in the reheat cycle. Which cycle do you think will have a higher thermal efficiency?

7-104 A steam power plant operates on the ideal reheat Rankine cycle. Steam enters the high-pressure turbine at 8 MPa and 500°C and leaves at 3 MPa. Steam is then reheated at constant pressure to 500°C before it expands to 20 kPa in the low-pressure turbine. Determine the turbine the boiler, and (c) the thermal efficiency of the cycle. Also show the cycle on a T-s diagram with respect to saturation lines.

Vapor-Compression Refrigeration Cycles

7-108C Draw the T-s diagrams of a reversed Carnot cycle and a Carnot cycle operating between the same temperature limits. How do they differ?

7-109C Why is the reversed Carnot cycle executed within the saturation dome not a realistic model for refrigeration cycles?

7-110C What is the difference between a refrigerator and a heat pump?

7-111C Does the ideal vapor-compression refrigeration cycle involve any internal irreversibilities?

7-112C Why is the throttling valve not replaced by an isentropic turbine in the ideal vapor-compression refrigeration cycle?

7-113C It is proposed to use water instead of refrigerant-134a as the working fluid in air conditioning applications, where the minimum temperature never falls below the freezing point. Would you support this proposal? Explain.

7-114C In a refrigeration system, would you recommend condensing the refrigerant-12 at a pressure of 0.7 or 1.0 MPa if heat is to be rejected to a cooling medium at 15°C? Why?

7-115C Does the area enclosed by the cycle on a T-s diagram represent the net work input for the reversed Carnot cycle? How about for the ideal vapor-compression refrigeration cycle?

7-116C Consider two vapor-compression refrigeration cycles. The refrigerant enters the throttling valve as a saturated liquid at 30°C in one cycle and as subcooled liquid at 30°C in the other one. The evaporator pressure for both cycles is the same. Which cycle do you think will have a higher COP?

7-117 A refrigerator uses refrigerant-134a as the working fluid and operates on an ideal vapor-compression refrigeration cycle between 0.12 and 0.7 MPa. The mass flow rate of the refrigerant is 0.05 kg/s. Show the cycle on a T-s diagram with respect to saturation lines. Determine (a) the rate of heat removal from the refrigerated space and the power input to the compressor, (b) the rate of heat rejection to the environment, and (c) the coefficient of performance.
Answers: (a) 7.35 kW, 1.85 kW; (b) 9.20 kW; (c) 3.97

7-118 Consider a 300 kJ/min refrigeration system that operates on an ideal vapor-compression refrigeration cycle with refrigerant-134a as the working fluid. The refrigerant enters the compressor as saturated vapor at 140 kPa and is compressed to 800 kPa. Show the cycle on a T-s diagram with respect to saturation lines, and determine (a) the quality of the refrigerant at the end of the throttling process, (*b*) the coefficient of performance, and (*c*) the power input to the compressor.

7-118E Consider a 3-ton refrigeration system that operates on an ideal vapor-compression refrigeration cycle with refrigerant-134a as the working fluid. The refrigerant enters the compressor as saturated vapor at 20 psia and is compressed to a pressure of 140 psia. Show the cycle on a *T-s* diagram with respect to saturation lines, and determine (*a*) the quality of the refrigerant at the end of the throttling process, (*b*) coefficient of performance, and (*c*) the power input to the compressor. *Answers:* (*a*) 0.371, (*b*) 3.29, (*c*) 4.30 hp

7-119 An ice-making machine operates on the ideal vapor-compression cycle, using refrigerant-134a. The refrigerant enters the compressor as saturated vapor at 160 kPa and leaves the condenser as saturated liquid at 700 kPa. Water enters the ice machine at 15°C and leaves as ice at −5°C. For an ice production rate of 12 kg/h, determine the power input to the ice maker (384 kJ of heat needs to be removed from each kilogram of water at 15°C to turn it into ice at −5°C). *Answer:* 0.258 kW

7-119E 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 100 psia. Water enters the ice machine at 55°F and leaves as ice at 25°F. For an ice production rate of 20 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).

Selecting the Right Refrigerant

7-120C When selecting a refrigerant for a certain application, what qualities would you look for in the refrigerant?

7-121C Consider a refrigeration system using refrigerant-12 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?

7-122C A refrigerant-12 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?

7-123 A refrigerator that operates on the ideal vapor-compression cycle with refrigerant-12 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.

7-124 A heat pump that operates on the ideal vapor-compression cycle with refrigerant-12 is used to heat a house and maintain it at 20°C by using underground water at 10°C as the heat source. Select reasonable pressures for the evaporator and the condenser, and explain why you chose those values.

Heat Pump Systems

7-125C What are the advantages and disadvantages of heat pumps? How do they compare with other heating systems?

7-126C Do you think a heat pump system will be more cost-effective in New York or in Miami? Why?

7-127C What is a water-source heat pump? How does the COP of a water-source heat pump system compare with that of an air-source system?

7-128 A heat pump that operates on the ideal vapor-compression cycle with refrigerant-134a is used to heat a house and maintain it at 20°C, using underground water at 10°C as the heat source. The house is losing heat at a rate of 75,000 kJ/h. The evaporator and condenser pressures are 320 and 800 kPa, respectively. Determine the power input to the heat pump and the electric power saved by using a heat pump instead of a resistance heater. *Answers:* 2.27 kW, 18.56 kW

7-128E 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 90,000 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. *Answers:* 3.68 hp, 31.7 hp

7-129 A heat pump that operates on the ideal vapor-compression cycle with refrigerant-134a is used to heat water from 15 to 54°C at a rate of 0.18 kg/s. The condenser and evaporator pressures are 1.4 and 0.32 MPa, respectively. Determine the power input to the heat pump.

7-130 A heat pump using refrigerant-12 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 leaves 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*) 3.65 kW, (*b*) 13.0 kW, (*c*) 13.0 kW

7-130E A heat pump using refrigerant-134a heats a house by using underground water at 45°F as the heat source. The house is losing heat at a rate of 70,000 Btu/h. The refrigerant enters the compressor at 30 psia and 20°F and leaves at 120 psia and 140°F. The refrigerant leaves the condenser at 90°F. Determine (*a*) the power input to the heat pump, (*b*) the rate of heat absorption from the water, and (*c*) the increase in

Simple Heating and Cooling

13-41C How do relative and specific humidities change during a simple heating process? Answer the same question for a simple cooling process.

13-42C Why does a simple heating or cooling process appear as a horizontal line on the psychrometric chart?

13-43 Air enters a heating section at 95 kPa, 15°C, and 30 percent relative humidity at a rate of 6 m^3/min, and it leaves at 25°C. Determine (*a*) the rate of heat transfer in the heating section and (*b*) the relative humidity of the air at the exit.
Answers: (*a*) 69.3 kJ/min, (*b*) 16.1 percent

13-44 A heating section consists of a 35-cm-diameter duct which houses a 4-kW electric resistance heater. Air enters the heating section at 1 atm, 13°C, and 40 percent relative humidity at a velocity of 7.5 m/s. Determine (*a*) the exit temperature, (*b*) the exit relative humidity of the air, and (*c*) the exit velocity.

13-44E A heating section consists of a 15-in-diameter duct which houses a 4-kW electric resistance heater. Air enters the heating section at 14.7 psia, 50°F, and 40 percent relative humidity at a velocity of 25 ft/s. Determine (*a*) the exit temperature, (*b*) the exit relative humidity of the air, and (*c*) the exit velocity.
Answers: (*a*) 56.8°F, (*b*) 30.8 percent, (*c*) 25.4 ft/s

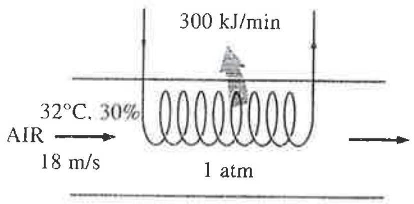

FIGURE P13-45

13-45 Air enters a 40-cm-diameter cooling section at 1 atm, 32°C, and 30 percent relative humidity at 18 m/s. Heat is removed from the air at a rate of 1200 kJ/min. Determine (*a*) the exit temperature, (*b*) the exit relative humidity of the air, and (*c*) the exit velocity.
Answers: (*a*) 24.4°C, (*b*) 46.6 percent, (*c*) 17.6 m/s

13-45E Air enters a 15-in-diameter cooling section at 1 atm, 90°F, and 30 percent relative humidity at 55 ft/s. Heat is removed from the air at a rate of 2400 Btu/min. Determine (*a*) the exit temperature, (*b*) the exit relative humidity of the air, and (*c*) the exit velocity.

Heating with Humidification

13-46C Why is heated air sometimes humidified?

13-47 Air at 1 atm, 15°C, and 60 percent relative humidity is first heated to 20°C in a heating section and then humidified by introducing water vapor. The air leaves the humidifying section at 25°C and 65 percent relative humidity. Determine (*a*) the amount of steam added to the air, in kg H_2O/kg dry air, and (*b*) the amount of heat transfer to the air in the heating section, in kJ/kg dry air.
Answers: (*a*) 0.0065 kg H_2O/kg dry air, (*b*) 5.1 kJ/kg dry air

13-47E Air at 14.7 psia, 55°F, and 60 percent relative humidity is first heated to 72°F in a heating section and then humidified by introducing water vapor. The air leaves the humidifying section at 75°F and 65 percent relative humidity. Determine (*a*) the amount of steam added to the air, in lbm H_2O/lbm dry air, and (*b*) the amount of heat transfer to the air in the heating section, in Btu/lbm dry air.

13-48 An air conditioning system operates at a total pressure of 1 atm and consists of a heating section and a humidifier which supplies wet steam (saturated water vapor) at 100°C. Air enters the heating section at 10°C and 70 percent relative humidity at a rate of 70 m^3/min, and it leaves the humidifying section at 20°C and 60 percent relative humidity. Determine (*a*) the temperature and relative humidity of air when it leaves the heating section, (*b*) the rate of heat transfer in the heating section, and (*c*) the rate at which water is added to the air in the humidifying section.

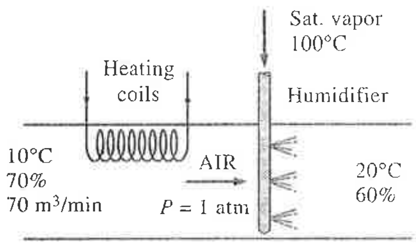

FIGURE P13-48

13-48E An air conditioning system operates at a total pressure of 1 atm and consists of a heating section and a humidifier which supplies wet steam (saturated water vapor) at 212°F. Air enters the heating section at 50°F and 70 percent relative humidity at a rate of 2500 ft^3/min, and it leaves the humidifying section at 70°F and 60 percent relative humidity. Determine (*a*) the temperature and relative humidity of air when it leaves the heating section, (*b*) the rate of heat transfer in the heating section, and (*c*) the rate at which water is added to the air in the humidifying section.
Answers: (*a*) 69.2°F, 35.0 percent; (*b*) 885 Btu/min; (*c*) 0.79 lbm/min

13-49 Repeat Prob. 13-48 for a total pressure of 95 kPa for the airstream.
Answers: (*a*) 19.5°C, 37.7 percent; (*b*) 782 kJ/min; (*c*) 0.29 kg/min

Cooling with Dehumidification

13-50C Why is cooled air sometimes reheated in summer before it is discharged to a room?

13-51 Air enters a window air conditioner at 1 atm, 32°C, and 70 percent relative humidity at a rate of 8 m^3/min, and it leaves as saturated air at 12°C. Part of the moisture in the air which condenses during the process is also removed at 12°C. Determine the rates of heat and moisture removal from the air. *Answers:* 462.4 kJ/min, 0.112 kg/min

13-52 An air conditioning system is to take in air at 1 atm, 34°C, and 70 percent relative humidity and deliver it at 22°C and 50 percent relative humidity. The air flows first over the cooling coils, where it is cooled and dehumidified, and then over the resistance heating wires, where it is heated to the desired temperature. Assuming that the condensate is removed from the cooling section at 10°C, determine (*a*) the temperature of air before it enters the heating section, (*b*) the amount of heat removed in the cooling section, and (*c*) the amount of heat transferred in the heating section, both in kJ/kg dry air.