


Problem Set 3 2nd Law of Thermodynamics and Entropy

- 6-44**  When a man returns to his well-sealed house on a summer day, he finds that the house is at 32°C . He turns on the air conditioner, which cools the entire house to 20°C in 15 min. If the COP of the air-conditioning system is 2.5, determine the power drawn by the air conditioner. Assume the entire mass within the house is equivalent to 800 kg of air for which $c_v = 0.72 \text{ kJ/kg} \cdot ^\circ\text{C}$ and $c_p = 1.0 \text{ kJ/kg} \cdot ^\circ\text{C}$.

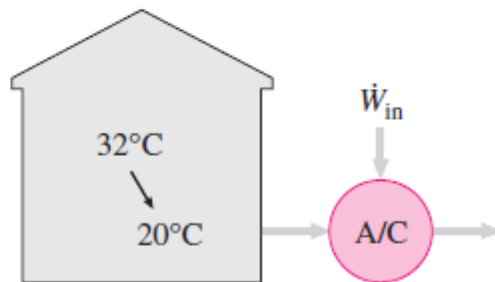


FIGURE P6-44

- 6-51** A heat pump is used to maintain a house at a constant temperature of 23°C . The house is losing heat to the outside air through the walls and the windows at a rate of $60,000 \text{ kJ/h}$ while the energy generated within the house from people, lights, and appliances amounts to 4000 kJ/h . For a COP of 2.5, determine the required power input to the heat pump.

Answer: 6.22 kW

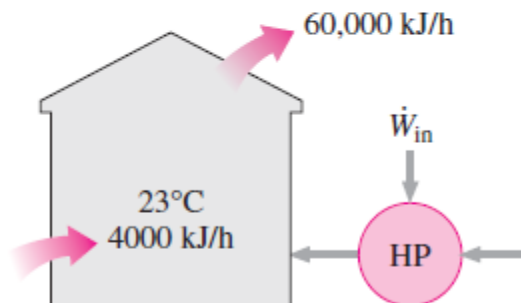


FIGURE P6-51

6-71 A Carnot heat engine operates between a source at 1000 K and a sink at 300 K. If the heat engine is supplied with heat at a rate of 800 kJ/min, determine (a) the thermal efficiency and (b) the power output of this heat engine.
Answers: (a) 70 percent, (b) 9.33 kW

6-77 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*

6-100 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 the same ambient air at 27°C. Determine (a) the maximum rate of heat removal from the refrigerated space and (b) the total rate of heat rejection to the ambient air. *Answers: (a) 4982 kJ/min, (b) 5782 kJ*

6–150 A heat pump receives heat from a lake that has an average winter time temperature of 6°C and supplies heat into a house having an average temperature of 27°C .

(a) If the house loses heat to the atmosphere at the rate of $64,000\text{ kJ/h}$, determine the minimum power supplied to the heat pump, in kW.

(b) A heat exchanger is used to transfer the energy from the lake water to the heat pump. If the lake water temperature decreases by 5°C as it flows through the lake water-to-heat pump heat exchanger, determine the minimum mass flow rate of lake water, in kg/s. Neglect the effect of the lake water pump.

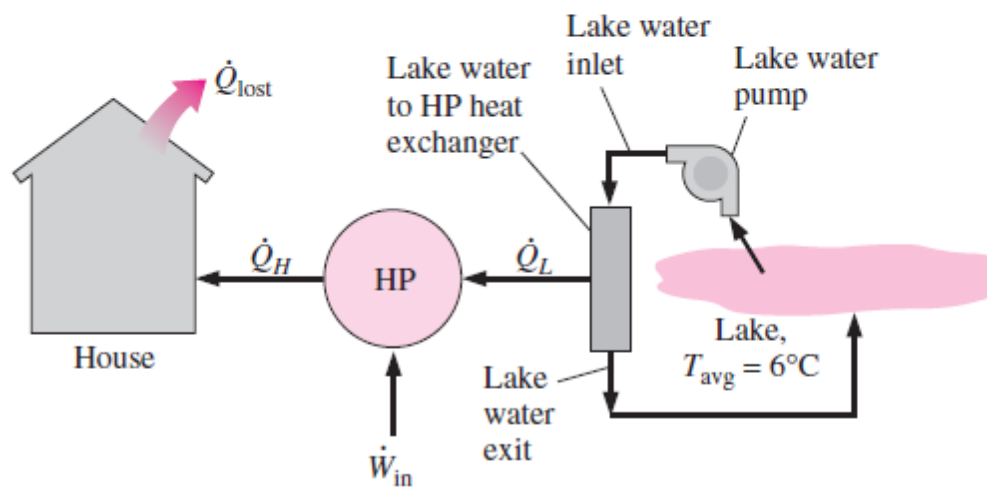


FIGURE P6–150

7–25 Air is compressed by a 12-kW compressor from P_1 to P_2 . The air temperature is maintained constant at 25°C during this process as a result of heat transfer to the surrounding medium at 10°C . Determine the rate of entropy change of the air. State the assumptions made in solving this problem.

Answer: -0.0403 kW/K

7-34 A well-insulated rigid tank contains 2 kg of a saturated liquid–vapor mixture of water at 100 kPa. Initially, three-quarters of the mass is in the liquid phase. An electric resistance heater placed in the tank is now turned on and kept on until all the liquid in the tank is vaporized. Determine the entropy change of the steam during this process. *Answer:* 8.10 kJ/K

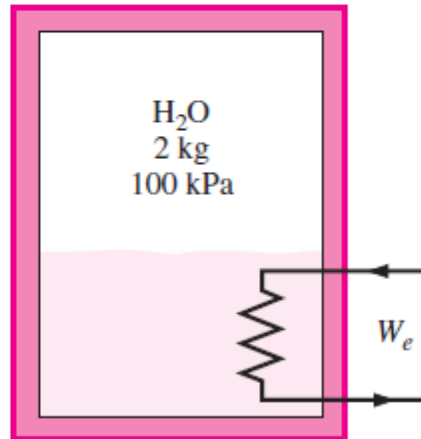



FIGURE P7-34

- 7-35**  A rigid tank is divided into two equal parts by a partition. One part of the tank contains 1.5 kg of compressed liquid water at 300 kPa and 60°C while the other part is evacuated. The partition is now removed, and the water expands to fill the entire tank. Determine the entropy change of water during this process, if the final pressure in the tank is 15 kPa. *Answer: -0.114 kJ/K*

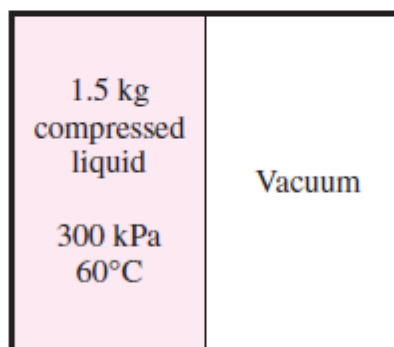


FIGURE P7-35

- 7-50** Steam at 6000 kPa and 500°C enters a steady-flow turbine. The steam expands in the turbine while doing work until the pressure is 1000 kPa. When the pressure is 1000 kPa, 10 percent of the steam is removed from the turbine for other uses. The remaining 90 percent of the steam continues to expand through the turbine while doing work and leaves the turbine at 10 kPa. The entire expansion process by the steam through the turbine is reversible and adiabatic.

- (a) Sketch the process on a T - s diagram with respect to the saturation lines. Be sure to label the data states and the lines of constant pressure.
- (b) If the turbine has an isentropic efficiency of 85 percent, what is the work done by the steam as it flows through the turbine per unit mass of steam flowing into the turbine, in kJ/kg?

7–57 A 50-kg iron block and a 20-kg copper block, both initially at 80°C , are dropped into a large lake at 15°C . Thermal equilibrium is established after a while as a result of heat transfer between the blocks and the lake water. Determine the total entropy change for this process.

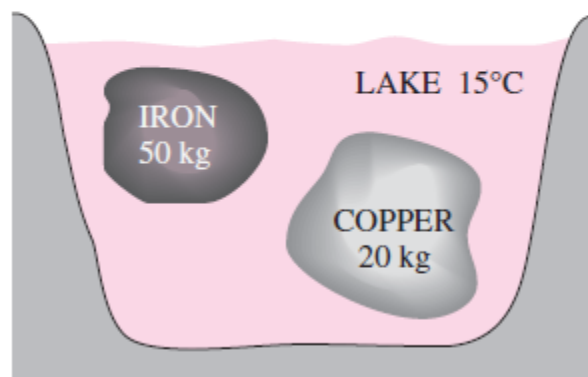


FIGURE P7–57

7–67 A 1.5-m^3 insulated rigid tank contains 2.7 kg of carbon dioxide at 100 kPa. Now paddle-wheel work is done on the system until the pressure in the tank rises to 150 kPa. Determine the entropy change of carbon dioxide during this process. Assume constant specific heats. *Answer: 0.719 kJ/K*

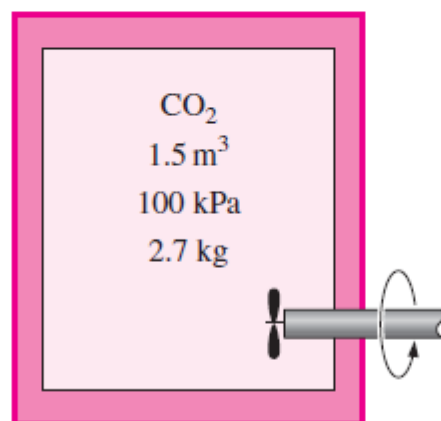


FIGURE P7–67

7-73 Air is compressed steadily by a 5-kW compressor from 100 kPa and 17°C to 600 kPa and 167°C at a rate of 1.6 kg/min. During this process, some heat transfer takes place between the compressor and the surrounding medium at 17°C . Determine the rate of entropy change of air during this process. *Answer: -0.0025 kW/K*

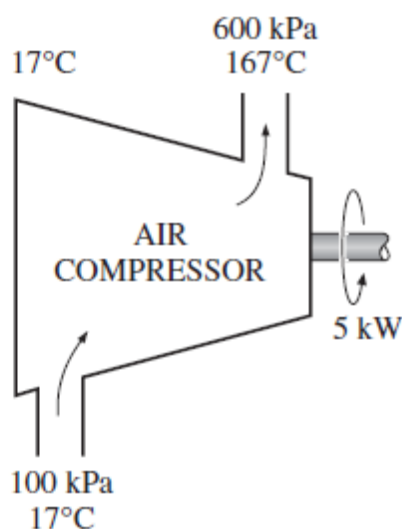


FIGURE P7-73

7-74 An insulated rigid tank is divided into two equal parts by a partition. Initially, one part contains 5 kmol of an ideal gas at 250 kPa and 40°C , and the other side is evacuated. The partition is now removed, and the gas fills the entire tank. Determine the total entropy change during this process. *Answer: 28.81 kJ/K*

7-86 A constant-volume tank contains 5 kg of air at 100 kPa and 327°C . The air is cooled to the surroundings temperature of 27°C . Assume constant specific heats at 300 K. (a) Determine the entropy change of the air in the tank during the process, in kJ/K, (b) determine the net entropy change of the universe due to this process, in kJ/K, and (c) sketch the processes for the air in the tank and the surroundings on a single T - s diagram. Be sure to label the initial and final states for both processes.

7-90 Water enters the pump of a steam power plant as saturated liquid at 20 kPa at a rate of 45 kg/s and exits at 6 MPa. Neglecting the changes in kinetic and potential energies and assuming the process to be reversible, determine the power input to the pump.

7-91 Liquid water enters a 25-kW pump at 100-kPa pressure at a rate of 5 kg/s. Determine the highest pressure the liquid water can have at the exit of the pump. Neglect the kinetic and potential energy changes of water, and take the specific volume of water to be $0.001 \text{ m}^3/\text{kg}$. *Answer: 5100 kPa*

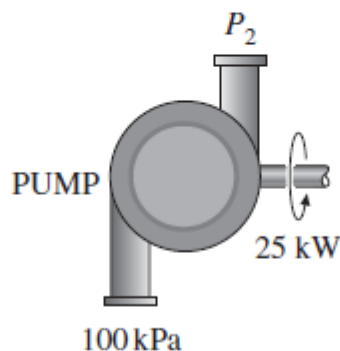


FIGURE P7-91

7-112 Air is compressed by an adiabatic compressor from 95 kPa and 27°C to 600 kPa and 277°C . Assuming variable specific heats and neglecting the changes in kinetic and potential energies, determine (a) the isentropic efficiency of the compressor and (b) the exit temperature of air if the process were reversible. *Answers: (a) 81.9 percent, (b) 505.5 K*

7-106 Steam enters an adiabatic turbine at 7 MPa, 600°C , and 80 m/s and leaves at 50 kPa, 150°C , and 140 m/s. If the power output of the turbine is 6 MW, determine (a) the mass flow rate of the steam flowing through the turbine and (b) the isentropic efficiency of the turbine. *Answers: (a) 6.95 kg/s, (b) 73.4 percent*

7-117 Hot combustion gases enter the nozzle of a turbojet engine at 260 kPa, 747°C, and 80 m/s, and they exit at a pressure of 85 kPa. Assuming an isentropic efficiency of 92 percent and treating the combustion gases as air, determine (a) the exit velocity and (b) the exit temperature. *Answers: (a) 728.2 m/s, (b) 786.3 K*

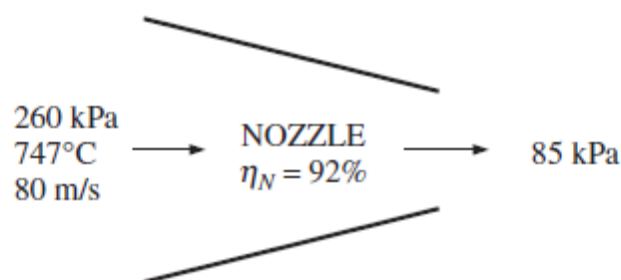


FIGURE P7-117

7-119 Steam enters an adiabatic turbine steadily at 7 MPa, 500°C, and 45 m/s, and leaves at 100 kPa and 75 m/s. If the power output of the turbine is 5 MW and the isentropic efficiency is 77 percent, determine (a) the mass flow rate of steam through the turbine, (b) the temperature at the turbine exit, and (c) the rate of entropy generation during this process.

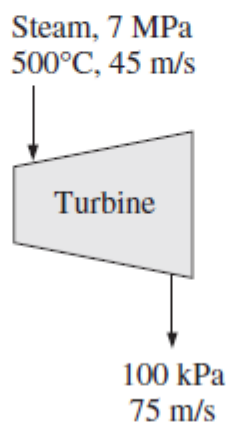


FIGURE P7-119

7-124 A well-insulated heat exchanger is to heat water ($c_p = 4.18 \text{ kJ/kg} \cdot ^\circ\text{C}$) from 25 to 60°C at a rate of 0.50 kg/s . The heating is to be accomplished by geothermal water ($c_p = 4.31 \text{ kJ/kg} \cdot ^\circ\text{C}$) available at 140°C at a mass flow rate of 0.75 kg/s . Determine (a) the rate of heat transfer and (b) the rate of entropy generation in the heat exchanger.

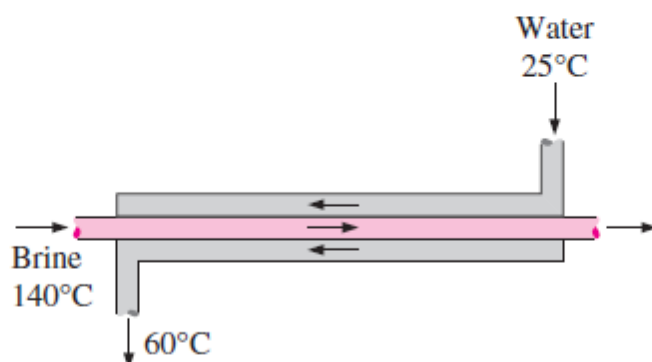


FIGURE P7-124

7-122 Consider a family of four, with each person taking a 5-min shower every morning. The average flow rate through the shower head is 12 L/min . City water at 15°C is heated to 55°C in an electric water heater and tempered to 42°C by cold water at the T-elbow of the shower before being routed to the shower head. Determine the amount of entropy generated by this family per year as a result of taking daily showers.

7-143 Steam expands in a turbine steadily at a rate of 25,000 kg/h, entering at 6 MPa and 450°C and leaving at 20 kPa as saturated vapor. If the power generated by the turbine is 4 MW, determine the rate of entropy generation for this process. Assume the surrounding medium is at 25°C.

Answer: 11.0 kW/K

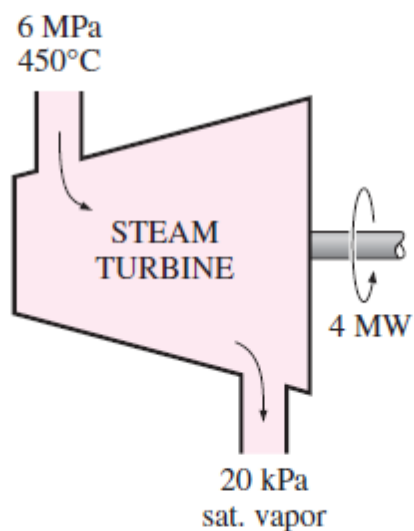


FIGURE P7-143

7-145 Liquid water at 200 kPa and 20°C is heated in a chamber by mixing it with superheated steam at 200 kPa and 150°C. Liquid water enters the mixing chamber at a rate of 2.5 kg/s, and the chamber is estimated to lose heat to the surrounding air at 25°C at a rate of 1200 kJ/min. If the mixture leaves the mixing chamber at 200 kPa and 60°C, determine (a) the mass flow rate of the superheated steam and (b) the rate of entropy generation during this mixing process.

Answers: (a) 0.166 kg/s, (b) 0.333 kW/K

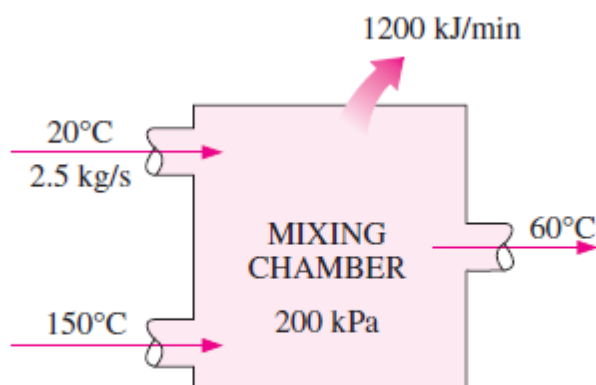


FIGURE P7-145

7-169 An insulated tank containing 0.4 m^3 of saturated water vapor at 500 kPa is connected to an initially evacuated, insulated piston–cylinder device. The mass of the piston is such that a pressure of 150 kPa is required to raise it. Now the valve is opened slightly, and part of the steam flows to the cylinder, raising the piston. This process continues until the pressure in the tank drops to 150 kPa . Assuming the steam that remains in the tank to have undergone a reversible adiabatic process, determine the final temperature (*a*) in the rigid tank and (*b*) in the cylinder.

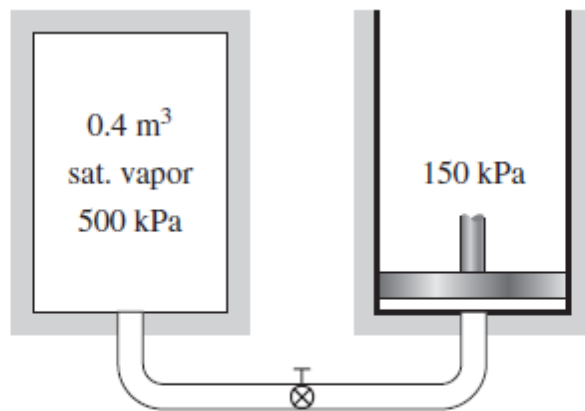


FIGURE P7-169

7-173 Air enters a two-stage compressor at 100 kPa and 27°C and is compressed to 900 kPa. The pressure ratio across each stage is the same, and the air is cooled to the initial temperature between the two stages. Assuming the compression process to be isentropic, determine the power input to the compressor for a mass flow rate of 0.02 kg/s. What would your answer be if only one stage of compression were used?

Answers: 4.44 kW, 5.26 kW

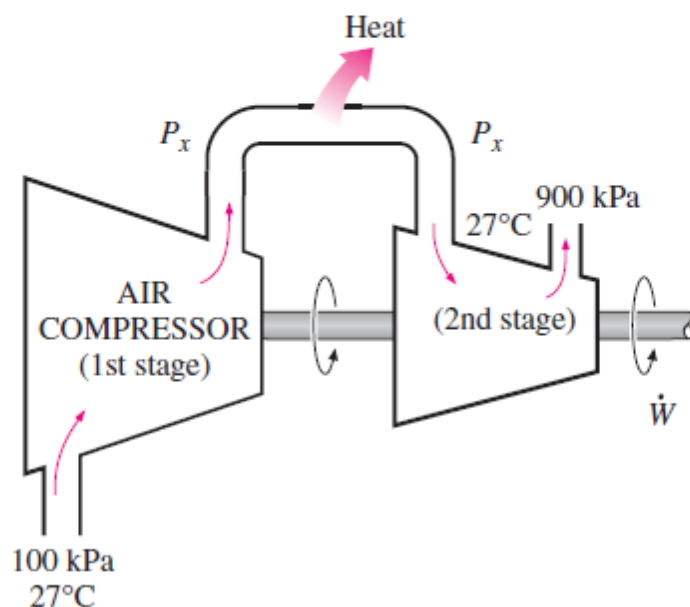


FIGURE P7-173

7-194 The inner and outer glasses of a $2\text{-m} \times 2\text{-m}$ double-pane window are at 18°C and 6°C , respectively. If the glasses are very nearly isothermal and the rate of heat transfer through the window is 110 W , determine the rates of entropy transfer through both sides of the window and the rate of entropy generation within the window, in W/K .

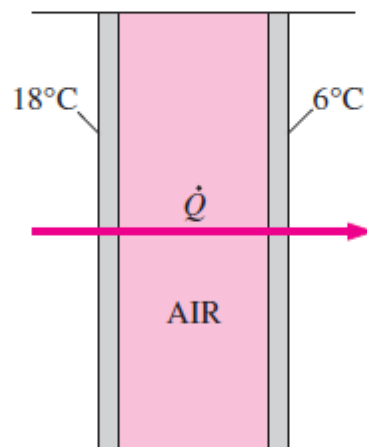


FIGURE P7-194

7-198 Air enters the evaporator section of a window air conditioner at 100 kPa and 27°C with a volume flow rate of $6\text{ m}^3/\text{min}$. The refrigerant-134a at 120 kPa with a quality of 0.3 enters the evaporator at a rate of $2\text{ kg}/\text{min}$ and leaves as saturated vapor at the same pressure. Determine the exit temperature of the air and the rate of entropy generation for this process, assuming (a) the outer surfaces of the air conditioner are insulated and (b) heat is transferred to the evaporator of the air conditioner from the surrounding medium at 32°C at a rate of $30\text{ kJ}/\text{min}$. *Answers: (a) -15.9°C , $0.00193\text{ kW}/\text{K}$, (b) -11.6°C , $0.00223\text{ kW}/\text{K}$*

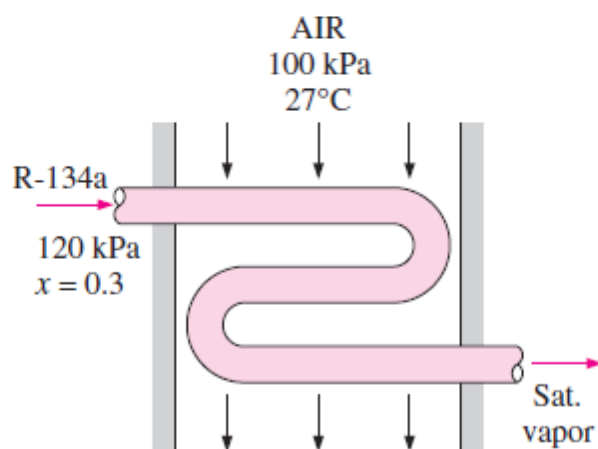


FIGURE P7-198

7-212 A 0.25-m^3 insulated piston–cylinder device initially contains 0.7 kg of air at 20°C . At this state, the piston is free to move. Now air at 500 kPa and 70°C is allowed to enter the cylinder from a supply line until the volume increases by 50 percent. Using constant specific heats at room temperature, determine (a) the final temperature, (b) the amount of mass that has entered, (c) the work done, and (d) the entropy generation.

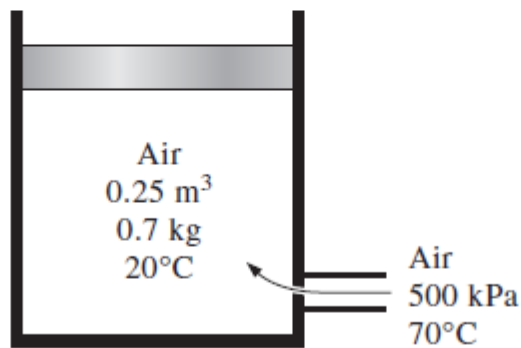


FIGURE P7-212