**6.3** Using the appropriate table, determine the indicated property. In each case, locate the state by hand on sketches of the $T$–$v$ and $T$–$s$ diagrams.

(a) water at $p = 0.20$ bar, $s = 4.3703$ kJ/kg · K. Find $h$, in kJ/kg.
(b) water at $p = 10$ bar, $u = 3124.4$ kJ/kg. Find $s$, in kJ/kg · K.
(c) Refrigerant 134a at $T = -28°\text{C}$, $x = 0.8$. Find $s$, in kJ/kg · K.
(d) ammonia at $T = 20°\text{C}$, $s = 5.0849$ kJ/kg · K. Find $u$, in kJ/kg.

**6.4** Using the appropriate table, determine the change in specific entropy between the specified states, in Btu/lb · °R.

(a) water, $p_1 = 1000$ lbf/in.$^2$, $T_1 = 800°\text{F}$, $p_2 = 1000$ lbf/in.$^2$, $T_2 = 100°\text{F}$.
(b) Refrigerant 134a, $h_1 = 47.91$ Btu/lb, $T_1 = -40°\text{F}$, saturated vapor at $p_2 = 40$ lbf/in.$^2$
(c) air as an ideal gas, $T_1 = 40°\text{F}$, $p_1 = 2$ atm, $T_2 = 420°\text{F}$, $p_2 = 1$ atm.
(d) carbon dioxide as an ideal gas, $T_1 = 820°\text{F}$, $p_1 = 1$ atm, $T_2 = 77°\text{F}$, $p_2 = 3$ atm.

**6.5** Using *IT*, determine the specific entropy of water at the indicated states. Compare with results obtained from the appropriate table.

(a) Specific entropy, in kJ/kg · K, for the cases of Problem 6.1.
(b) Specific entropy, in Btu/lb · °R, for the cases of Problem 6.2.

**6.6** Using *IT*, repeat Prob. 6.4. Compare the results obtained using *IT* with those obtained using the appropriate table.

**6.7** Using *steam table* data, determine the indicated property data for a process in which there is no change in specific entropy between state 1 and state 2. In each case, locate the states on a sketch of the $T$–$s$ diagram.

(a) $T_1 = 40°\text{C}$, $x_1 = 100\%$, $p_2 = 150$ kPa. Find $T_2$, in °C, and $\Delta h$, in kJ/kg.
(b) $T_1 = 10°\text{C}$, $x_1 = 75\%$, $p_2 = 1$ MPa. Find $T_2$, in °C, and $\Delta u$, in kJ/kg.

**6.8** Using the appropriate table, determine the indicated property for a process in which there is no change in specific entropy between state 1 and state 2.

(a) water, $p_1 = 14.7$ lbf/in.$^2$, $T_1 = 500°\text{F}$, $p_2 = 100$ lbf/in.$^2$ Find $T_2$ in °F.
(b) water, $T_1 = 10°\text{C}$, $x_1 = 0.75$, saturated vapor at state 2. Find $p_2$ in bar.
(c) air as an ideal gas, $T_1 = 27°\text{C}$, $p_1 = 1.5$ bar, $T_2 = 127°\text{C}$. Find $p_2$ in bar.
(d) air as an ideal gas, $T_1 = 100°\text{F}$, $p_1 = 3$ atm, $p_2 = 2$ atm. Find $T_2$ in °F.
(e) Refrigerant 134a, $T_1 = 20°\text{C}$, $p_1 = 5$ bar, $p_2 = 1$ bar. Find $v_2$ in m$^3$/kg.

**6.9** Using *IT*, obtain the property data requested in (a) Problem 6.7, (b) Problem 6.8, and compare with data obtained from the appropriate table.

**6.10** Propane undergoes a process from state 1, where $p_1 = 1.4$ MPa, $T_1 = 60°\text{C}$, to state 2, where $p_2 = 1.0$ MPa, during which the change in specific entropy is $s_2 - s_1 = -0.035$ kJ/kg · K. At state 2, determine the temperature, in °C, and the specific enthalpy, in kJ/kg.

**6.11** Air in a piston–cylinder assembly undergoes a process from state 1, where $T_1 = 300$ K, $p_1 = 100$ kPa, to state 2, where $T_2 = 500$ K, $p_2 = 650$ kPa. Using the ideal gas model for air, determine the change in specific entropy between these states, in kJ/kg · K, if the process occurs (a) without internal irreversibilities, (b) with internal irreversibilities.

**6.12** Water contained in a closed, rigid tank, initially at 100 lbf/in.$^2$, 800°F, is cooled to a final state where the pressure is 20 lbf/in.$^2$ Determine the change in specific entropy, in Btu/lb · °R, and show the process on sketches of the $T$–$v$ and $T$–$s$ diagrams.

**6.13** One-quarter lbmol of nitrogen gas ($N_2$) undergoes a process from $p_1 = 20$ lbf/in.$^2$, $T_1 = 500°\text{R}$ to $p_2 = 150$ lbf/in.$^2$ For the process $W = -500$ Btu and $Q = -125.9$ Btu. Employing the ideal gas model, determine

(a) $T_2$, in °R.
(b) the change in entropy, in Btu/°R.

Show the initial and final states on a $T$–$s$ diagram.

**6.14** One kilogram of water contained in a piston–cylinder assembly, initially at 160°C, 150 kPa, undergoes an isothermal compression process to saturated liquid. For the process, $W = -471.5$ kJ. Determine for the process,

(a) the heat transfer, in kJ.
(b) the change in entropy, in kJ/K.

Show the process on a sketch of the $T$–$s$ diagram.

**6.15** One-tenth kmol of carbon monoxide (CO) in a piston–cylinder assembly undergoes a process from $p_1 = 150$ kPa, $T_1 = 300$ K to $p_2 = 500$ kPa, $T_2 = 370$ K. For the process, $W = -300$ kJ. Employing the ideal gas model, determine

(a) the heat transfer, in kJ.
(b) the change in entropy, in kJ/K.

Show the process on a sketch of the $T$–$s$ diagram.

**6.16** Argon in a piston–cylinder assembly is compressed from state 1, where $T_1 = 300$ K, $V_1 = 1$ m$^3$, to state 2, where $T_2 = 200$ K. If the change in specific entropy is $s_2 - s_1 = -0.27$ kJ/kg · K, determine the final volume, in m$^3$. Assume the ideal gas model with $k = 1.67$.

**6.17** Steam enters a turbine operating at steady state at 1 MPa, 200°C and exits at 40°C with a quality of 83%. Stray heat transfer and kinetic and potential energy effects are negligible. Determine (a) the power developed by the turbine, in kJ per kg of steam flowing, (b) the change in specific entropy from inlet to exit, in kJ/K per kg of steam flowing.

**6.18** Answer the following true or false. Explain.

(a) The change of entropy of a closed system is the same for every process between two specified states.
(b) The entropy of a fixed amount of an ideal gas increases in every isothermal compression.

(c) The specific internal energy and enthalpy of an ideal gas are each functions of temperature alone but its specific entropy depends on two independent intensive properties.
(d) One of the $T\,ds$ equations has the form $T\,ds = du - p\,dv$.
(e) The entropy of a fixed amount of an incompressible substance increases in every process in which temperature decreases.

**6.19** Showing all steps, derive Eqs. 6.43, 6.44, and 6.45.

### Analyzing Internally Reversible Processes

**6.20** One kilogram of water in a piston–cylinder assembly undergoes the two internally reversible processes in series shown in Fig. P6.20. For each process, determine, in kJ, the heat transfer and the work.

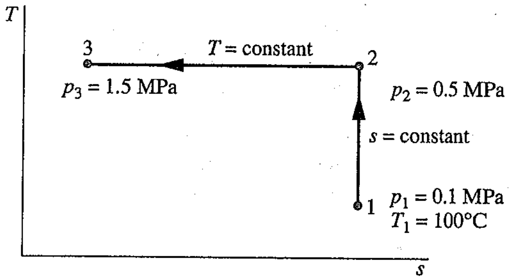

**Fig. P6.20**

**6.21** One kilogram of water in a piston–cylinder assembly undergoes the two internally reversible processes in series shown in Fig. P6.21. For each process, determine, in kJ, the heat transfer and the work.

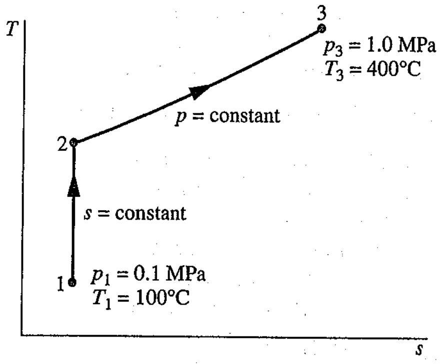

**Fig. P6.21**

**6.22** One kilogram of water in a piston–cylinder assembly, initially at 160°C, 1.5 bar, undergoes an isothermal, internally reversible compression process to the saturated liquid state. Determine the work and heat transfer, each in kJ. Sketch the process on $p$–$v$ and $T$–$s$ coordinates. Associate the work and heat transfer with areas on these diagrams.

**6.23** One pound mass of water in a piston–cylinder assembly, initially a saturated liquid at 1 atm, undergoes a constant-pressure, internally reversible expansion to $x = 90\%$. Determine the work and heat transfer, each in Btu. Sketch the process on $p$–$v$ and $T$–$s$ coordinates. Associate the work and heat transfer with areas on these diagrams.

**6.24** A gas within a piston–cylinder assembly undergoes an isothermal process at 400 K during which the change in entropy is $-0.3$ kJ/K. Assuming the ideal gas model for the gas and negligible kinetic and potential energy effects, evaluate the work, in kJ.

**6.25** Water within a piston–cylinder assembly, initially at 10 lbf/in.$^2$, 500°F, undergoes an internally reversible process to 80 lbf/in.$^2$, 800°F, during which the temperature varies linearly with specific entropy. For the water, determine the work and heat transfer, each in Btu/lb. Neglect kinetic and potential energy effects.

**6.26** Nitrogen ($N_2$) initially occupying 0.1 m$^3$ at 6 bar, 247°C undergoes an internally reversible expansion during which $pV^{1.20} = \textit{constant}$ to a final state where the temperature is 37°C. Assuming the ideal gas model, determine

(a) the pressure at the final state, in bar.
(b) the work and heat transfer, each in kJ.
(c) the entropy change, in kJ/K.

**6.27** Air in a piston–cylinder assembly and modeled as an ideal gas undergoes two internally reversible processes in series from state 1, where $T_1 = 290$ K, $p_1 = 1$ bar.

**Process 1–2:** Compression to $p_2 = 5$ bar during which $pV^{1.19} = \textit{constant}$.

**Process 2–3:** Isentropic expansion to $p_3 = 1$ bar.

(a) Sketch the two processes in series on $T$–$s$ coordinates.
(b) Determine the temperature at state 2, in K.
(c) Determine the net work, in kJ/kg.

**6.28** One lb of oxygen, $O_2$, in a piston–cylinder assembly undergoes a cycle consisting of the following processes:

**Process 1–2:** Constant-pressure expansion from $T_1 = 450$°R, $p_1 = 30$ lbf/in.$^2$ to $T_2 = 1120$°R.

**Process 2–3:** Compression to $T_3 = 800$°R and $p_3 = 53.3$ lbf/in.$^2$ with $Q_{23} = -60$ Btu.

**Process 3–1:** Constant-volume cooling to state 1.

Employing the ideal gas model with $c_p$ evaluated at $T_1$, determine the change in specific entropy, in Btu/lb · °R, for each process. Sketch the cycle on $p$–$v$ and $T$–$s$ coordinates.

**6.29** One-tenth kilogram of a gas in a piston–cylinder assembly undergoes a Carnot power cycle for which the isothermal expansion occurs at 800 K. The change in specific entropy of the gas during the isothermal compression, which occurs at 400 K, is $-25$ kJ/kg · K. Determine (a) the net work developed per cycle, in kJ, and (b) the thermal efficiency.

**6.30** Figure P6.30 provides the $T$–$s$ diagram of a Carnot refrigeration cycle for which the substance is Refrigerant 134a. Determine the coefficient of performance.

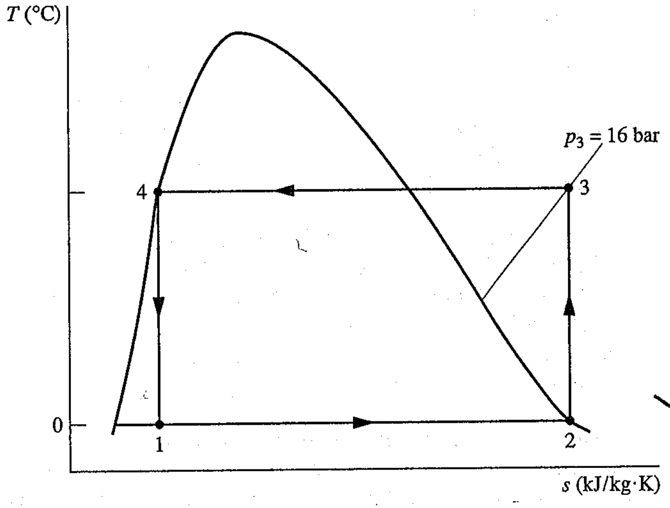

**Fig. P6.30**

**6.31** Figure P6.31 provides the $T$–$s$ diagram of a Carnot heat pump cycle for which the substance is ammonia. Determine the net work input required, in kJ, for 50 cycles of operation and 0.1 kg of substance.

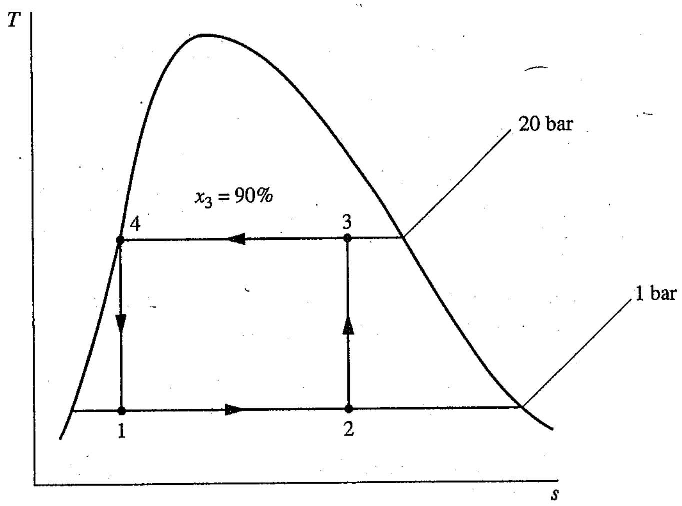

**Fig. P6.31**

**6.32** Air in a piston–cylinder assembly undergoes a Carnot power cycle. The isothermal expansion and compression processes occur at 1400 K and 350 K, respectively. The pressures at the beginning and end of the isothermal compression are 100 kPa and 500 kPa, respectively. Assuming the ideal gas model with $c_p = 1.005$ kJ/kg · K, determine

(a) the pressures at the beginning and end of the isothermal expansion, each in kPa.
(b) the heat transfer and work, in kJ/kg, for each process.
(c) the thermal efficiency.

**6.33** Water in a piston–cylinder assembly undergoes a Carnot power cycle. At the beginning of the isothermal expansion, the temperature is 250°C and the quality is 80%. The isothermal expansion continues until the pressure is 2 MPa. The adiabatic expansion then occurs to a final temperature of 175°C.

(a) Sketch the cycle on $T$–$s$ coordinates.
(b) Determine the heat transfer and work, in kJ/kg, for each process.
(c) Evaluate the thermal efficiency.

**6.34** A Carnot power cycle operates at steady state as shown in Fig. 5.15 with water as the working fluid. The boiler pressure is 200 lbf/in.$^2$, with saturated liquid entering and saturated vapor exiting. The condenser pressure is 20 lbf/in.$^2$
(a) Sketch the cycle on $T$–$s$ coordinates.
(b) Determine the heat transfer and work for each process, in Btu per lb of water flowing.
(c) Evaluate the thermal efficiency.

**6.35** Figure P6.35 shows a Carnot heat pump cycle operating at steady state with ammonia as the working fluid. The condenser temperature is 120°F, with saturated vapor entering and saturated liquid exiting. The evaporator temperature is 10°F.

(a) Determine the heat transfer and work for each process, in Btu per lb of ammonia flowing.
(b) Evaluate the coefficient of performance for the heat pump.
(c) Evaluate the coefficient of performance for a Carnot refrigeration cycle operating as shown in the figure.

## Applying the Entropy Balance: Closed Systems

**6.36** A closed system undergoes a process in which work is done on the system and the heat transfer $Q$ occurs only at temperature $T_b$. For each case, determine whether the entropy change of the system is positive, negative, zero, or indeterminate.

(a) internally reversible process, $Q > 0$.
(b) internally reversible process, $Q = 0$.
(c) internally reversible process, $Q < 0$.
(d) internal irreversibilities present, $Q > 0$.
(e) internal irreversibilities present, $Q = 0$.
(f) internal irreversibilities present, $Q < 0$.

**6.37** Answer the following true or false. Explain.

(a) A process that violates the second law of thermodynamics violates the first law of thermodynamics.
(b) When a net amount of work is done on a closed system undergoing an internally reversible process, a net heat transfer of energy from the system also occurs.
(c) One corollary of the second law of thermodynamics states that the change in entropy of a closed system must be greater than zero or equal to zero.
(d) A closed system can experience an increase in entropy only when irreversibilities are present within the system during the process.
(e) Entropy is produced in every internally reversible process of a closed system.
(f) In an adiabatic and internally reversible process of a closed system, the entropy remains constant.
(g) The energy of an isolated system must remain constant, but the entropy can only decrease.

**6.47** Refrigerant 134a contained in a piston–cylinder assembly rapidly expands from an initial state where $T_1 = 140°F$, $p_1 = 200\ lbf/in.^2$ to a final state where $p_2 = 5\ lbf/in.^2$ and the quality, $x_2$, is (a) 99%, (b) 95%. In each case, determine if the process can occur adiabatically. If yes, determine the work, in Btu/lb, for an adiabatic expansion between these states. If no, determine the direction of the heat transfer.

**6.48** One kg of air contained in a piston–cylinder assembly undergoes a process from an initial state where $T_1 = 300\ K$, $v_1 = 0.8\ m^3/kg$ to a final state where $T_2 = 420\ K$, $v_2 = 0.2\ m^3/kg$. Can this process occur adiabatically? If yes, determine the work, in kJ, for an adiabatic process between these states. If no, determine the direction of the heat transfer. Assume the ideal gas model for air.

**6.49** Air as an ideal gas contained within a piston–cylinder assembly is compressed between two specified states. In each of the following cases, can the process occur adiabatically? If yes, determine the work in appropriate units for an adiabatic process between these states. If no, determine the direction of the heat transfer.

(a) State 1: $p_1 = 0.1\ MPa$, $T_1 = 27°C$. State 2: $p_2 = 0.5\ MPa$, $T_2 = 207°C$. Use Table A-22 data.
(b) State 1: $p_1 = 3\ atm$, $T_1 = 80°F$ State 2: $p_2 = 10\ atm$, $T_2 = 240°F$. Assume $c_p = 0.241\ Btu/lb°R$.

**6.50** One kilogram of propane initially at 8 bar and 50°C undergoes a process to 3 bar, 20°C while being rapidly expanded in a piston–cylinder assembly. Heat transfer between the propane and its surroundings occurs at an average temperature of 35°C. The work done by the propane is measured as 42.4 kJ. Kinetic and potential energy effects can be ignored. Determine whether it is possible for the work measurement to be correct.

**6.51** As shown in Fig. P6.51, a divider separates 1 lb mass of carbon monoxide (CO) from a thermal reservoir at 150°F. The carbon monoxide, initially at 60°F and 150 lbf/in.², expands isothermally to a final pressure of 10 lbf/in.² while receiving heat transfer through the divider from the reservoir. The carbon monoxide can be modeled as an ideal gas.

(a) For the carbon monoxide as the system, evaluate the work and heat transfer, each in Btu, and the amount of entropy produced, in Btu/°R.

(b) Evaluate the entropy production, in Btu/°R, for an enlarged system that includes the carbon monoxide and the divider, assuming the state of the divider remains unchanged. Compare with the entropy production of part (a) and comment on the difference.

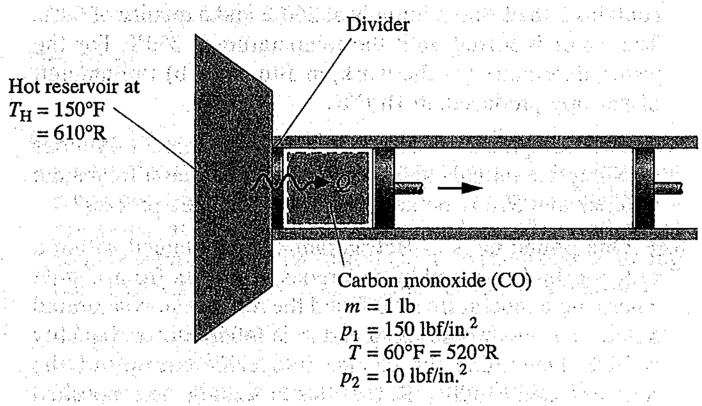

**Fig. P6.51**

**6.52** Three kilograms of Refrigerant 134a initially a saturated vapor at 20°C expand to 3.2 bar, 20°C. During this process, the temperature of the refrigerant departs by no more than 0.01°C from 20°C. Determine the maximum theoretical heat transfer to the refrigerant during the process, in kJ.

**6.53** An inventor claims that the device shown in Fig. P6.53 generates electricity while receiving a heat transfer at the rate of 250 Btu/s at a temperature of 500°R, a second heat transfer at the rate of 350 Btu/s at 700°R, and a third at the rate of 500 Btu/s at 1000°R. For operation at steady state, evaluate this claim.

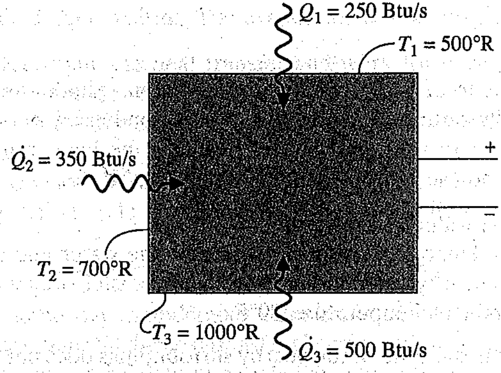

**Fig. P6.53**

**6.54** For the silicon chip of Example 2.5, determine the rate of entropy production, in kW/K. What is the cause of entropy production in this case?

**6.55** At steady state, the 20-W curling iron shown in Fig. P6.55 has an outer surface temperature of 180°F. For the curling iron, determine the rate of heat transfer, in Btu/h, and the rate of entropy production, in Btu/h · °R.

**6.56** A rigid, insulated vessel is divided into two compartments connected by a valve. Initially, one compartment, occupying one-third of the total volume, contains air at 500°R, and the other is evacuated. The valve is opened and the air is allowed to fill the entire volume. Assuming the ideal gas model, determine the final temperature of the air, in °R, and the amount of entropy produced, in Btu/°R per lb of air.

**6.57** A rigid, insulated vessel is divided into two equal-volume compartments connected by a valve. Initially, one compartment contains 1 $m^3$ of water at 20°C, $x = 50\%$, and the other is evacuated. The valve is opened and the water is allowed to fill the entire volume. For the water, determine the final temperature, in °C, and the amount of entropy produced, in kJ/K.

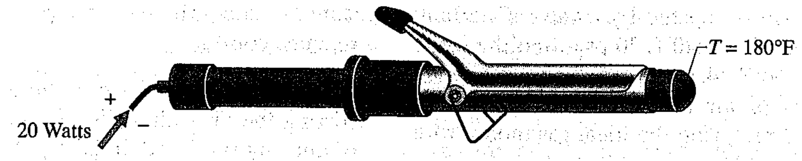

**Fig. P6.55**

**6.58** An electric motor at steady state draws a current of 10 amp with a voltage of 110 V. The output shaft develops a torque of 10.2 N · m and a rotational speed of 1000 RPM.

(a) If the outer surface of the motor is at 42°C, determine the rate of entropy production within the motor, in kW/K.
(b) Evaluate the rate of entropy production, in kW/K, for an enlarged system that includes the motor and enough of the nearby surroundings that heat transfer occurs at the ambient temperature, 22°C.

**6.59** A power plant has a turbogenerator, shown in Fig. P6.59, operating at steady state with an input shaft rotating at 1800 RPM with a torque of 16,700 N · m. The turbogenerator produces current at 230 amp with a voltage of 13,000 V. The rate of heat transfer between the turbogenerator and its surroundings is related to the surface temperature $T_b$ and the lower ambient temperature $T_0$, and is given by $\dot{Q} = -\mathrm{h}A(T_b - T_0)$, where $\mathrm{h} = 110\ \mathrm{W/m^2 \cdot K}$, $A = 32\ \mathrm{m}^2$, and $T_0 = 298$ K.

(a) Determine the temperature $T_b$, in K.
(b) For the turbogenerator as the system, determine the rate of entropy production, in kW/K.
(c) If the system boundary is located to take in enough of the nearby surroundings for heat transfer to take place at temperature $T_0$, determine the rate of entropy production, in kW/K, for the enlarged system.

**6.60** At steady state, work is done by a paddle wheel on a *slurry* contained within a closed, rigid tank whose outer surface temperature is 245°C. Heat transfer from the tank and its contents occurs at a rate of 50 kW to surroundings that, away from the immediate vicinity of the tank, are at 27°C. Determine the rate of entropy production, in kW/K,

(a) for the tank and its contents as the system.
(b) for an enlarged system including the tank and enough of the nearby surroundings for the heat transfer to occur at 27°C.

**6.61** A 33.8-lb aluminum bar, initially at 200°F, is placed in a tank together with 249 lb of liquid water, initially at 70°F, and allowed to achieve thermal equilibrium. The aluminum bar and water can be modeled as incompressible with specific heats 0.216 Btu/lb · °R and 0.998 Btu/lb · °R, respectively. For the aluminum bar and water as the system, determine (a) the final temperature, in °F, and (b) the amount of entropy produced within the tank, in Btu/°R. Ignore heat transfer between the system and its surroundings.

**6.62** In a heat-treating process, a 1-kg metal part, initially at 1075 K, is quenched in a tank containing 100 kg of water, initially at 295 K. There is negligible heat transfer between the contents of the tank and their surroundings. The metal part and water can be modeled as incompressible with specific heats 0.5 kJ/kg · K and 4.2 kJ/kg · K, respectively. Determine (a) the final equilibrium temperature after quenching, in K, and (b) the amount of entropy produced within the tank, in kJ/K.

**6.63** A 50-lb iron casting, initially at 700°F, is quenched in a tank filled with 2121 lb of oil, initially at 80°F. The iron casting and oil can be modeled as incompressible with specific heats 0.10 Btu/lb · °R, and 0.45 Btu/lb · °R, respectively. For the iron casting and oil as the system, determine (a) the final equilibrium temperature, in °F, and (b) the amount of entropy produced within the tank, in Btu/°R. Ignore heat transfer between the system and its surroundings.

**6.64** A 2.64-kg copper part, initially at 400 K, is plunged into a tank containing 4 kg of liquid water, initially at 300 K. The copper part and water can be modeled as incompressible with specific heats 0.385 kJ/kg · K and 4.2 kJ/kg · K, respectively. For the copper part and water as the system, determine (a) the final equilibrium temperature, in K, and (b) the amount of entropy produced within the tank, in kJ/K. Ignore heat transfer between the system and its surroundings.

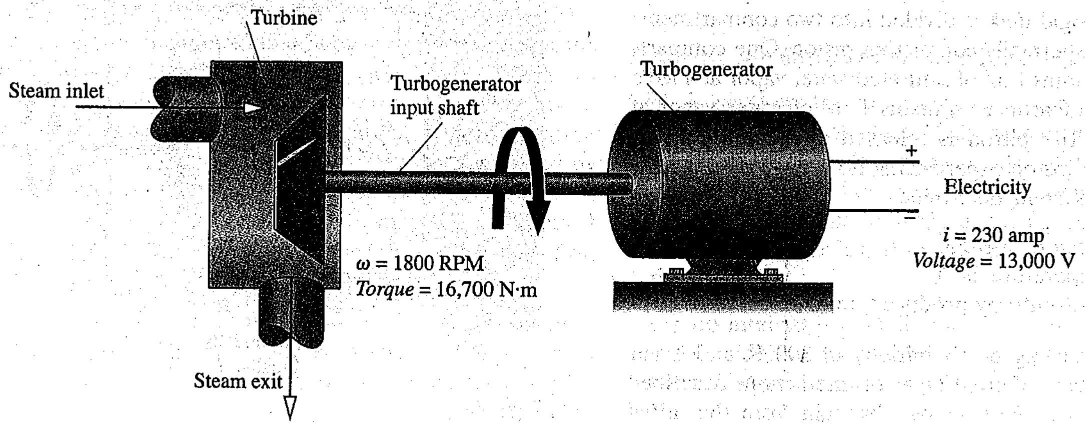

**Fig. P6.59**

**6.65** Two insulated tanks are connected by a valve. One tank initially contains 1.2 lb of air at 240°F, 30 psia, and the other contains 1.5 lb of air at 60°F, 14.7 psia. The valve is opened and the two quantities of air are allowed to mix until equilibrium is attained. Employing the ideal gas model with $c_v = 0.18$ Btu/lb · °R determine

(a) the final temperature, in °F.
(b) the final pressure, in psia.
(c) the amount of entropy produced, in Btu/°R.

**6.66** As shown in Fig. P6.66, an insulated box is initially divided into halves by a frictionless, thermally conducting piston. On one side of the piston is 1.5 $m^3$ of air at 400 K, 4 bar. On the other side is 1.5 $m^3$ of air at 400 K, 2 bar. The piston is released and equilibrium is attained, with the piston experiencing no change of state. Employing the ideal gas model for the air, determine

(a) the final temperature, in K.
(b) the final pressure, in bar.
(c) the amount of entropy produced, in kJ/kg.

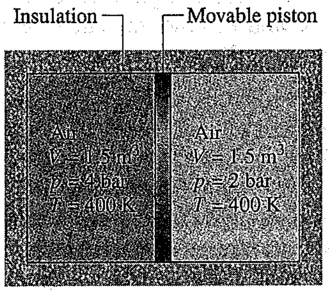

**Fig. P6.66**

**6.67** An insulated vessel is divided into two equal-sized compartments connected by a valve. Initially, one compartment contains steam at 50 lbf/in.$^2$ and 700°F, and the other is evacuated. The valve is opened and the steam is allowed to fill the entire volume. Determine

(a) the final temperature, in °F.
(b) the amount of entropy produced, in Btu/lb · °R.

**6.68** An insulated, rigid tank is divided into two compartments by a frictionless, thermally conducting piston. One compartment initially contains 1 $m^3$ of saturated water vapor at 4 MPa and the other compartment contains 1 $m^3$ of water vapor at 20 MPa, 800°C. The piston is released and equilibrium is attained, with the piston experiencing no change of state. For the water as the system, determine

(a) the final pressure, in MPa.
(b) the final temperature, in °C.
(c) the amount of entropy produced, in kJ/K.

**6.69** A system consisting of air initially at 300 K and 1 bar experiences the two different types of interactions described below. In each case, the system is brought from the initial state to a state where the temperature is 500 K, while volume remains constant.

(a) The temperature rise is brought about adiabatically by stirring the air with a paddle wheel. Determine the amount of entropy produced, in kJ/kg · K.
(b) The temperature rise is brought about by heat transfer from a reservoir at temperature $T$. The temperature at the system boundary where heat transfer occurs is also $T$. Plot the amount of entropy produced, in kJ/kg · K, versus $T$ for $T \geq 500$ K. Compare with the result of (a) and discuss.

**6.70** A cylindrical copper rod of base area A and length $L$ is insulated on its lateral surface. One end of the rod is in contact with a wall at temperature $T_H$. The other end is in contact with a wall at a lower temperature $T_C$. At steady state, the rate at which energy is conducted into the rod from the hot wall is

$$\dot{Q}_H = \frac{\kappa A(T_H - T_C)}{L}$$

where $\kappa$ is the thermal conductivity of the copper rod.

(a) For the rod as the system, obtain an expression for the time rate of entropy production in terms of A, $L$, $T_H$, $T_C$, and $\kappa$.
(b) If $T_H = 327°C$, $T_C = 77°C$, $\kappa = 0.4$ kW/m · K, $A = 0.1\ m^2$, plot the heat transfer rate $\dot{Q}_H$, in kW, and the time rate of entropy production, in kW/K, each versus $L$ ranging from 0.01 to 1.0 m. Discuss.

**6.71** Figure P6.71 shows a system consisting of air in a rigid container fitted with a paddle wheel and in contact with a thermal energy reservoir. By heating and/or stirring, the air can achieve a specified increase in temperature from $T_1$ to $T_2$ in alternative ways. Discuss how the temperature increase of the air might be achieved with (a) minimum entropy production, and (b) maximum entropy production. Assume that the temperature on the boundary where heat transfer to the air occurs, $T_b$, is the same as the reservoir temperature. Let $T_1 < T_b < T_2$. The ideal gas model applies to the air.

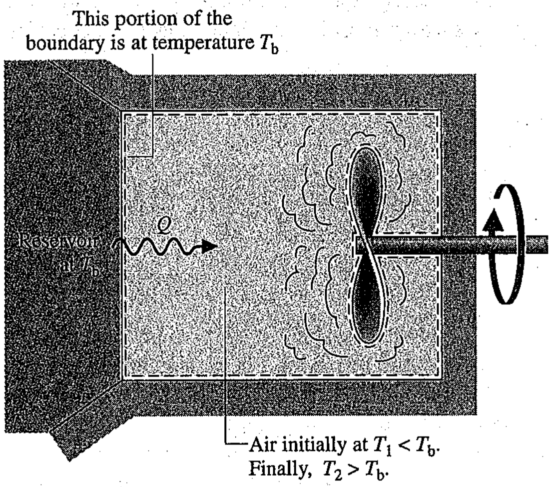

**Fig. P6.71**

**6.81** Steam at 15 bar, 540°C, 60 m/s enters an insulated turbine operating at steady state and exits at 1.5 bar, 89.4 m/s. The work developed per kg of steam flowing is claimed to be (a) 606.0 kJ/kg, (b) 765.9 kJ/kg. Can either claim be correct? Explain.

**6.82** Air enters an insulated turbine operating at steady state at 8 bar, 1127°C and exits at 1.5 bar, 347°C. Neglecting kinetic and potential energy changes and assuming the ideal gas model for the air, determine

(a) the work developed, in kJ per kg of air flowing through the turbine.
(b) whether the expansion is internally reversible, irreversible, or impossible.

**6.83** Water at 20 bar, 400°C enters a turbine operating at steady state and exits at 1.5 bar. Stray heat transfer and kinetic and potential energy effects are negligible. A hard-to-read data sheet indicates that the quality at the turbine exit is 98%. Can this quality value be correct? If no, explain. If yes, determine the power developed by the turbine, in kJ per kg of water flowing.

**6.84** Air enters a compressor operating at steady state at 15 lbf/in.$^2$, 80°F and exits at 400°F. Stray heat transfer and kinetic and potential energy effects are negligible. Assuming the ideal gas model for the air, determine the maximum theoretical pressure at the exit, in lbf/in.$^2$

**6.85** Propane at 0.1 MPa, 20°C enters an insulated compressor operating at steady state and exits at 0.4 MPa, 90°C Neglecting kinetic and potential energy effects, determine

(a) the power required by the compressor, in kJ per kg of propane flowing.
(b) the rate of entropy production within the compressor, in kJ/K per kg of propane flowing.

**6.86** By injecting liquid water into superheated steam, the *desuperheater* shown in Fig. P6.86 has a saturated vapor stream at its exit. Steady-state operating data are provided in the accompanying table. Stray heat transfer and all kinetic and potential energy effects are negligible. (a) Locate states 1, 2, and 3 on a sketch of the *T*–*s* diagram. (b) Determine the rate of entropy production within the desuperheater, in kW/K.

| State | $p$(MPa) | $T$(°C) | $v \times 10^3$(m$^3$/kg) | $u$(kJ/kg) | $h$(kJ/kg) | $s$(kJ/kg · K) |
|---|---|---|---|---|---|---|
| 1 | 2.7 | 40 | 1.0066 | 167.2 | 169.9 | 0.5714 |
| 2 | 2.7 | 300 | 91.01 | 2757.0 | 3002.8 | 6.6001 |
| 3 | 2.5 | sat. vap. | 79.98 | 2603.1 | 2803.1 | 6.2575 |

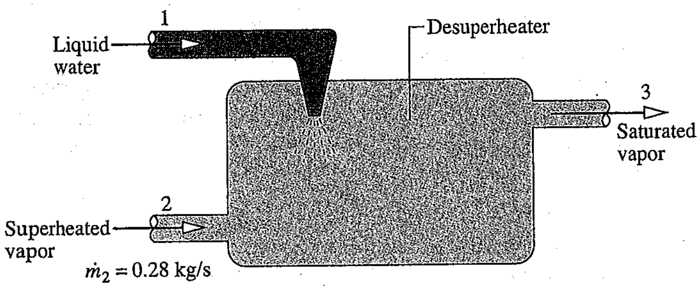

**Fig. P6.86**

**6.87** An inventor claims that at steady state the device shown in Fig. P6.87 develops power from entering and exiting streams of water at a rate of 1174.9 kW. The accompanying table provides data for inlet 1 and exits 3 and 4. The pressure at inlet 2 is 1 bar. Stray heat transfer and kinetic and potential energy effects are negligible. Evaluate the inventor's claim.

| State | $\dot{m}$(kg/s) | $p$(bar) | $T$(°C) | $v$(m$^3$/kg) | $u$(kJ/kg) | $h$(kJ/kg) | $s$(kJ/kg · K) |
|---|---|---|---|---|---|---|---|
| 1 | 4 | 1 | 450 | 3.334 | 3049.0 | 3382.4 | 8.6926 |
| 3 | 5 | 2 | 200 | 1.080 | 2654.4 | 2870.5 | 7.5066 |
| 4 | 3 | 4 | 400 | 0.773 | 2964.4 | 3273.4 | 7.8985 |

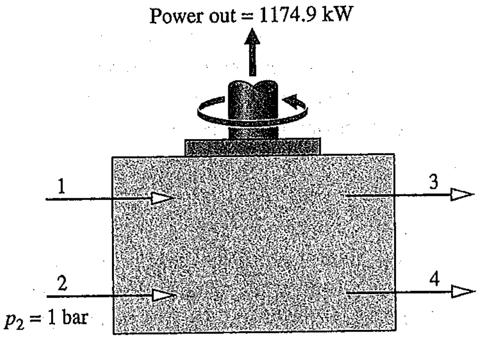

**Fig. P6.87**

**6.88** Figure P6.88 provides steady-state operating data for a well-insulated device having steam entering at one location and exiting at another. Neglecting kinetic and potential energy effects, determine (a) the direction of flow and (b) the power output or input, as appropriate, in kJ per kg of steam flowing.

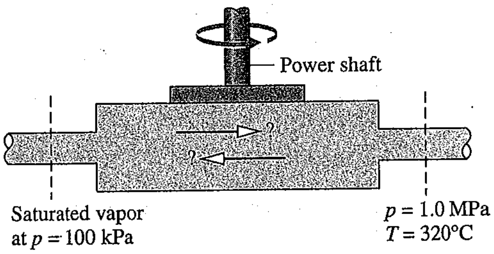

**Fig. P6.88**

**6.89** Steam enters a well-insulated nozzle operating at steady state at 1000°F, 500 lbf/in.$^2$ and a velocity of 10 ft/s. At the nozzle exit, the pressure is 14.7 lbf/in.$^2$ and the velocity is 4055 ft/s. Determine the rate of entropy production, in Btu/°R per lb of steam flowing.

**6.90** Air at 400 kPa, 970 K enters a turbine operating at steady state and exits at 100 kPa, 670 K. Heat transfer from the turbine occurs at an average outer surface temperature of 315 K at the rate of 30 kJ per kg of air flowing. Kinetic and potential energy effects are negligible. For air as an ideal gas with $c_p$ = 1.1 kJ/kg · K, determine (a) the rate power is developed, in kJ per kg of air flowing, and (b) the rate of entropy production within the turbine, in kJ/K per kg of air flowing.

**6.91** Steam at 240°C, 700 kPa enters an open feedwater heater operating at steady state with a mass flow rate of 0.5 kg/s. A separate stream of liquid water enters at 45°C, 700 kPa with a mass flow rate of 4 kg/s. A single mixed stream exits

**6.108** Carbon monoxide (CO) enters a nozzle operating at steady state at 25 bar, 257°C, and 45 m/s. At the nozzle exit, the conditions are 2 bar, 57°C, 560 m/s, respectively. The carbon monoxide can be modeled as an ideal gas.

(a) For a control volume enclosing the nozzle only, determine the heat transfer, in kJ, and the change in specific entropy, in kJ/K, each per kg of carbon monoxide flowing through the nozzle. What additional information would be required to evaluate the rate of entropy production?
(b) Evaluate the rate of entropy production, in kJ/K per kg of carbon monoxide flowing, for an enlarged control volume enclosing the nozzle and a portion of its immediate surroundings so that the heat transfer occurs at the ambient temperature, 27°C.

**6.109** A counterflow heat exchanger operates at steady state with negligible kinetic and potential energy effects. In one stream, liquid water enters at 10°C and exits at 20°C with a negligible change in pressure. In the other stream, Refrigerant 134a enters at 10 bar, 80°C with a mass flow rate of 135 kg/h and exits at 10 bar, 20°C. The liquid water can be modeled as incompressible with $c$ = 4.179 kJ/kg · K. Heat transfer from the outer surface of the heat exchanger can be ignored. Determine

(a) the mass flow rate of the liquid water, in kg/h.
(b) the rate of entropy production within the heat exchanger, in kW/K.

**6.110** Saturated water vapor at 100 kPa enters a counterflow heat exchanger operating at steady state and exits at 20°C with a negligible change in pressure. Ambient air at 275 K, 1 atm enters in a separate stream and exits at 290 K, 1 atm. The air mass flow rate is 170 times that of the water. The air can be modeled as an ideal gas with $c_p$ = 1.005 kJ/kg · K. Kinetic and potential energy effects can be ignored.

(a) For a control volume enclosing the heat exchanger, evaluate the rate of heat transfer, in kJ per kg of water flowing.
(b) For an enlarged control volume that includes the heat exchanger and enough of its immediate surroundings that heat transfer from the control volume occurs at the ambient temperature, 275 K, determine the rate of entropy production, in kJ/K per kg of water flowing.

**6.111** Figure P6.111 shows data for a portion of the ducting in a ventilation system operating at steady state. The ducts are well insulated and the pressure is very nearly 1 atm throughout. Assuming the ideal gas model for air with $c_p$ = 0.24 Btu/lb · °R, and ignoring kinetic and potential energy effects, determine (a) the temperature of the air at the exit, in °F, (b) the exit diameter, in ft, and (c) the rate of entropy production within the duct, in Btu/min · °R.

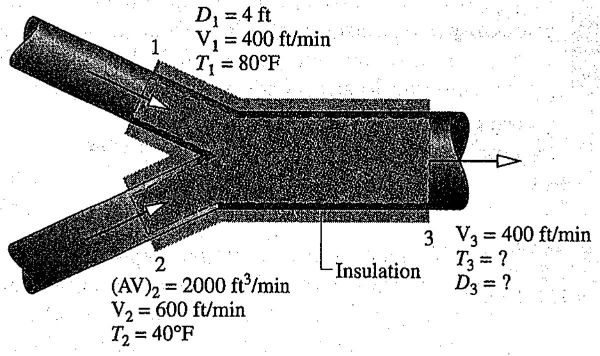

**Fig. P6.111**

**6.112** Air flows through an insulated circular duct having a diameter of 2 cm. Steady-state pressure and temperature data obtained by measurements at two locations, denoted as 1 and 2, are given in the accompanying table. Modeling air as an ideal gas with $c_p$ = 1.005 kJ/kg · K, determine (a) the direction of the flow, (b) the velocity of the air, in m/s, at each of the two locations, and (c) the mass flow rate of the air, in kg/s.

| Measurement location | 1 | 2 |
|---|---|---|
| Pressure (kPa) | 100 | 500 |
| Temperature (°C) | 20 | 50 |

**6.113** Determine the rates of entropy production, in Btu/min · °R, for the steam generator and turbine of Example 4.10. Identify the component that contributes more to inefficient operation of the overall system.

**6.114** Air as an ideal gas flows through the compressor and heat exchanger shown in Fig. P6.114. A separate liquid water stream also flows through the heat exchanger. The data given are for operation at steady state. Stray heat transfer to the surroundings can be neglected, as can all kinetic and potential energy changes. Determine

(a) the compressor power, in kW, and the mass flow rate of the cooling water, in kg/s.
(b) the rates of entropy production, each in kW/K, for the compressor and heat exchanger.

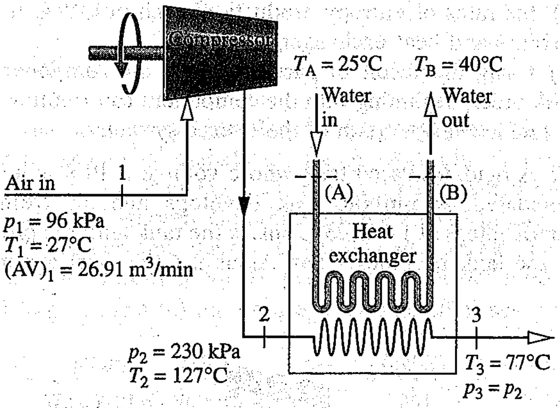

**Fig. P6.114**

**6.115** Figure P6.115 shows several components in series, all operating at steady state. Liquid water enters the boiler at 60 bar. Steam exits the boiler at 60 bar, 540°C and undergoes a throttling process to 40 bar before entering the turbine. Steam expands adiabatically through the turbine to 5 bar, 240°C, and then undergoes a throttling process to 1 bar before entering the condenser. Kinetic and potential energy effects can be ignored.

(a) Locate each of the states 2–5 on a sketch of the $T$–$s$ diagram.

**6.124** Propane undergoes an isentropic expansion from an initial state where $T_1 = 40°C, p_1 = 1$ MPa to a final state where the temperature and pressure are $T_2, p_2$, respectively. Determine

(a) $p_2$, in kPa, when $T_2 = -40°C$.
(b) $T_2$, in °C, when $p_2 = 0.8$ MPa.

**6.125** Argon in a piston–cylinder assembly is compressed isentropically from state 1, where $p_1 = 150$ kPa, $T_1 = 35°C$, to state 2, where $p_2 = 300$ kPa. Assuming the ideal gas model with $k = 1.67$, determine (a) $T_2$, in °C, and (b) the work, in kJ per kg of argon.

**6.126** Air within a piston–cylinder assembly, initially at 12 bar, 620 K, undergoes an isentropic expansion to 1.4 bar. Assuming the ideal gas model for the air, determine the final temperature, in K, and the work, in kJ/kg. Solve two ways: using (a) data from Table A-22 and (b) $k = 1.4$.

**6.127** Air within a piston–cylinder assembly, initially at 30 lbf/in.$^2$, 510°R, and a volume of 6 ft$^3$, is compressed isentropically to a final volume of 1.2 ft$^3$. Assuming the ideal gas model with $k = 1.4$ for the air, determine the (a) mass, in lb, (b) final pressure, in lbf/in.$^2$, (c) final temperature, in °R, and (d) work, in Btu.

**6.128** Air contained in a piston–cylinder assembly, initially at 4 bar, 600 K and a volume of 0.43 m$^3$, expands isentropically to a pressure of 1.5 bar. Assuming the ideal gas model for the air, determine the (a) mass, in kg, (b) final temperature, in K, and (c) work, in kJ.

**6.129** Air in a piston–cylinder assembly is compressed isentropically from an initial state where $T_1 = 340$ K to a final state where the pressure is 90% greater than at state 1. Assuming the ideal gas model, determine (a) $T_2$, in K, and (b) the work, in kJ/kg.

**6.130** A rigid, insulated tank with a volume of 20 m$^3$ is filled initially with air at 10 bar, 500 K. A leak develops, and air slowly escapes until the pressure of the air remaining in the tank is 5 bar. Employing the ideal gas model with $k = 1.4$ for the air, determine the amount of mass remaining in the tank, in kg, and its temperature, in K.

**6.131** A rigid, insulated tank with a volume of 21.61 ft$^3$ is filled initially with air at 110 lbf/in.$^2$, 535°R. A leak develops, and air slowly escapes until the pressure of the air remaining in the tank is 15 lbf/in.$^2$ Employing the ideal gas model with $k = 1.4$ for the air, determine the amount of mass remaining in the tank, in lb, and its temperature, in °R.

**6.132** The accompanying table provides steady-state data for an isentropic expansion of steam through a turbine. For a mass flow rate of 2.55 kg/s, determine the power developed by the turbine, in MW. Ignore the effects of potential energy.

| | *p*(bar) | *T*(°C) | V(m/s) | *h*(kJ/kg) | *s*(kJ/kg · K) |
|---|---|---|---|---|---|
| Inlet | 10 | 300 | 25 | 3051.1 | 7.1214 |
| Exit | 1.5 | — | 100 | | 7.1214 |

**6.133** Water vapor enters a turbine operating at steady state at 1000°F, 140 lbf/in.$^2$, with a volumetric flow rate of 21.6 ft$^3$/s, and expands isentropically to 2 lbf/in.$^2$ Determine the power developed by the turbine, in hp. Ignore kinetic and potential energy effects.

**6.134** Air enters a turbine operating at steady state at 6 bar and 1100 K and expands isentropically to a state where the temperature is 700 K. Employing the ideal gas model with data from Table A-22, and ignoring kinetic and potential energy changes, determine the pressure at the exit, in bar, and the work, in kJ per kg of air flowing.

**6.135** Figure P6.135 shows a simple vapor power cycle operating at steady state with water as the working fluid. Data at key locations are given on the figure. Flow through the turbine and pump occurs isentropically. Flow through the steam generator and condenser occurs at constant pressure. Stray heat transfer and kinetic and potential energy effects are negligible. Sketch the four processes of this cycle in series on a *T–s* diagram. Determine the thermal efficiency.

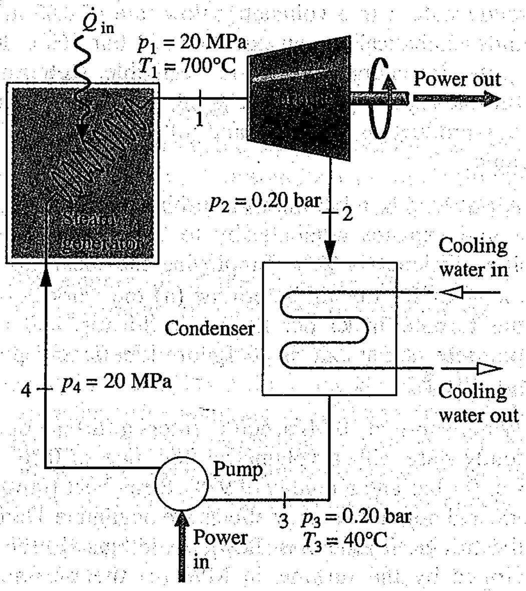

**Fig. P6.135**

**6.136** The accompanying table provides steady-state data for steam expanding adiabatically though a turbine. The states are numbered as in Fig. 6.11. Kinetic and potential energy effects can be ignored. Determine for the turbine (a) the work developed per unit mass of steam flowing, in kJ/kg, (b) the amount of entropy produced per unit mass of steam flowing, in kJ/kg · K, and (c) the isentropic turbine efficiency.

| State | *p*(bar) | *T*(°C) | *x*(%) | *h*(kJ/kg) | *s*(kJ/kg · K) |
|---|---|---|---|---|---|
| 1 | 10 | 300 | — | 3051 | 7.121 |
| 2s | 0.10 | 45.81 | 86.3 | — | 7.121 |
| 2 | 0.10 | 45.81 | 90.0 | — | 7.400 |

**6.137** The accompanying table provides steady-state data for steam expanding adiabatically with a mass flow rate of 4 lb/s through a turbine. Kinetic and potential energy effects can be ignored. Determine for the turbine (a) the power developed, in hp, (b) the rate of entropy production, in hp/°R, and (c) the isentropic turbine efficiency.

| | *p*(lbf/in.$^2$) | *T*(°F) | *u*(Btu/lb) | *h*(Btu/lb) | *s*(Btu/lb · °R) |
|---|---|---|---|---|---|
| Inlet | 140 | 1000 | 1371.0 | 1531.0 | 1.8827 |
| Exit | 2 | 270 | 1101.4 | 1181.7 | 2.0199 |

compressor efficiency and (b) the rate of entropy production, in hp/°R. Ignore kinetic and potential energy effects.

**6.155** Refrigerant 134a at a rate of 0.8 lb/s enters a compressor operating at steady state as saturated vapor at 30 psia and exits at a pressure of 160 psia. There is no significant heat transfer with the surroundings, and kinetic and potential energy effects can be ignored.

(a) Determine the minimum theoretical power input required, in Btu/s, and the corresponding exit temperature, in °F.
(b) If the refrigerant exits at a temperature of 130°F, determine the actual power, in Btu/s, and the isentropic compressor efficiency.

Not assigned

**6.156** Air at 1.3 bar, 423 K and a velocity of 40 m/s enters a nozzle operating at steady state and expands adiabatically to the exit, where the pressure is 0.85 bar and velocity is 307 m/s. For air modeled as an ideal gas with $k = 1.4$, determine for the nozzle (a) the temperature at the exit, in K, and (b) the isentropic nozzle efficiency.

**6.157** Water vapor at 100 $\text{lbf/in.}^2$, 500°F and a velocity of 100 ft/s enters a nozzle operating at steady state and expands adiabatically to the exit, where the pressure is 40 $\text{lbf/in.}^2$ If the isentropic nozzle efficiency is 95%, determine for the nozzle (a) the velocity of the steam at the exit, in ft/s, and (b) the amount of entropy produced, in Btu/°R per lb of steam flowing.

**6.158** Helium gas at 810°R, 45 $\text{lbf/in.}^2$, and a velocity of 10 ft/s enters an insulated nozzle operating at steady state and exits at 670°R, 25 $\text{lbf/in.}^2$ Modeling helium as an ideal gas with $k = 1.67$, determine (a) the velocity at the nozzle exit, in ft/s, (b) the isentropic nozzle efficiency, and (c) the rate of entropy production within the nozzle, in Btu/°R per lb of helium flowing.

**6.159** Air modeled as an ideal gas enters a one-inlet, one-exit control volume operating at steady state at 100 $\text{lbf/in.}^2$, 900°R and expands adiabatically to 25 $\text{lbf/in.}^2$ Kinetic and potential energy effects are negligible. Determine the rate of entropy production, in Btu/°R per lb of air flowing,

(a) if the control volume encloses a turbine having an isentropic turbine efficiency of 89.1%.
(b) if the control volume encloses a throttling valve.

**6.160** Ammonia enters a valve as saturated liquid at 9 bar and undergoes a throttling process to a pressure of 2 bar. Determine the rate of entropy production per unit mass of ammonia flowing, in kJ/kg · K. If the valve were replaced by a power-recovery turbine operating at steady state, determine the maximum theoretical power that could be developed per unit mass of ammonia flowing, in kJ/kg, and comment. In each case, ignore heat transfer with the surroundings and changes in kinetic and potential energy.

**6.161** Figure P6.161 provides the schematic of a heat pump using Refrigerant 134a as the working fluid, together with steady-state data at key points. The mass flow rate of the refrigerant is 7 kg/min, and the power input to the compressor is 5.17 kW. (a) Determine the coefficient of performance for the heat pump. (b) If the valve were replaced by a turbine, power could be produced, thereby reducing the power requirement of the heat pump system. Would you recommend this *power-saving* measure? Explain.

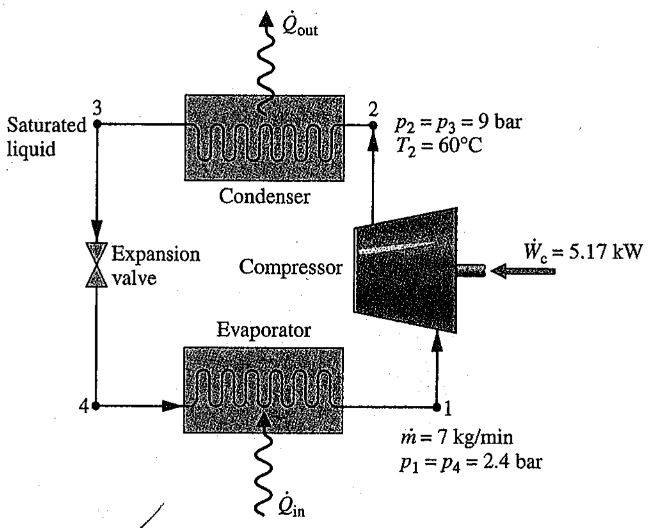

**Fig. P6.161**

← Not assigned

**6.162** Air enters an insulated diffuser operating at steady state at 1 bar, −3°C, and 260 m/s and exits with a velocity of 130 m/s. Employing the ideal gas model and ignoring potential energy, determine

(a) the temperature of the air at the exit, in °C.
(b) The maximum attainable exit pressure, in bar.

**6.163** As shown in Fig. P6.163, air enters the diffuser of a jet engine at 18 kPa, 216 K with a velocity of 265 m/s, all data corresponding to high-altitude flight. The air flows adiabatically through the diffuser, decelerating to a velocity of 50 m/s at the diffuser exit. Assume steady-state operation, the ideal gas model for air, and negligible potential energy effects.

(a) Determine the temperature of the air at the exit of the diffuser, in K.
(b) If the air would undergo an isentropic process as it flows through the diffuser, determine the pressure of the air at the diffuser exit, in kPa.
(c) If friction were present, would the pressure of the air at the diffuser exit be greater than, less than, or equal to the value found in part (b)? Explain.

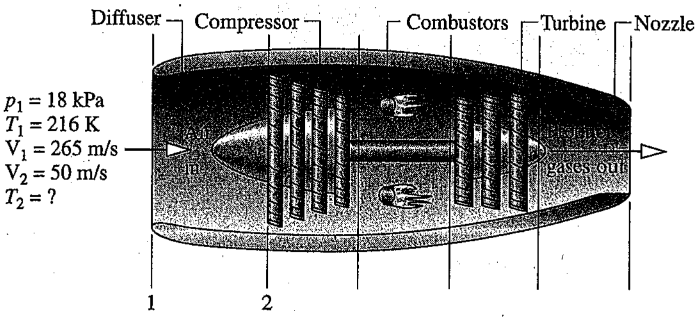

**Fig. P6.163**

**6.164** As shown in Fig. P6.164, a steam turbine having an isentropic turbine efficiency of 90% drives an air compressor having an isentropic compressor efficiency of 85%. Steady-state operating data are provided on the figure. Assume the ideal gas model for air, and ignore stray heat transfer and kinetic and potential energy effects.

(a) Determine the mass flow rate of the steam entering the turbine, in kg of steam per kg of air exiting the compressor.
(b) Repeat part (a) if $\eta_t = \eta_c = 100\%$

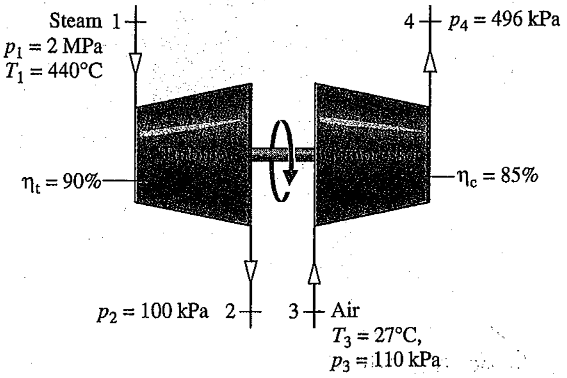

**Fig. P6.164**

**6.165** Figure P6.165 shows a simple vapor power plant operating at steady state with water as the working fluid. Data at key locations are given on the figure. The mass flow rate of the water circulating through the components is 109 kg/s. Stray heat transfer and kinetic and potential energy effects can be ignored. Determine

(a) the net power developed, in MW.
(b) the thermal efficiency.
(c) the isentropic turbine efficiency.
(d) the isentropic pump efficiency.
(e) the mass flow rate of the cooling water, in kg/s.
(f) the rates of entropy production, each in kW/K, for the turbine, condenser, and pump.

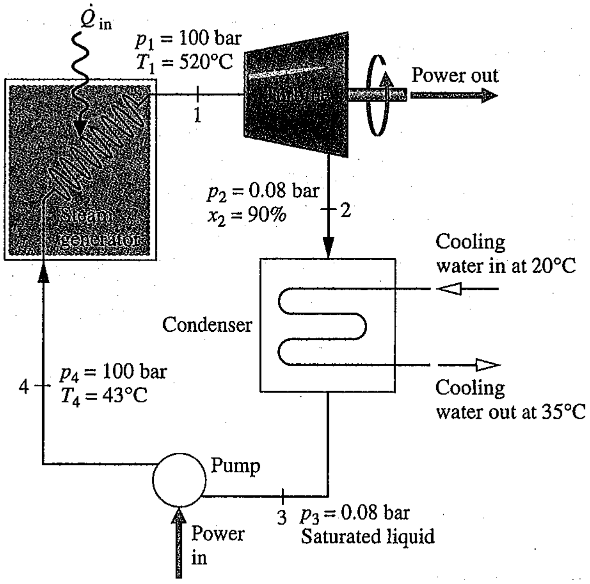

**Fig. P6.165**

**6.166** Figure P6.166 shows a power system operating at steady state consisting of three components in series: an air compressor having an isentropic compressor efficiency of 80%, a heat exchanger, and a turbine having an isentropic turbine efficiency of 90%. Air enters the compressor at 1 bar, 300 K with a mass flow rate of 5.8 kg/s and exits at a pressure of 10 bar. Air enters the turbine at 10 bar, 1400 K and exits at a pressure of 1 bar. Air can be modeled as an ideal gas. Stray heat transfer and kinetic and potential energy effects are negligible. Determine, in kW, (a) the power required by the compressor, (b) the power developed by the turbine, and (c) the *net* power output of the overall power system.

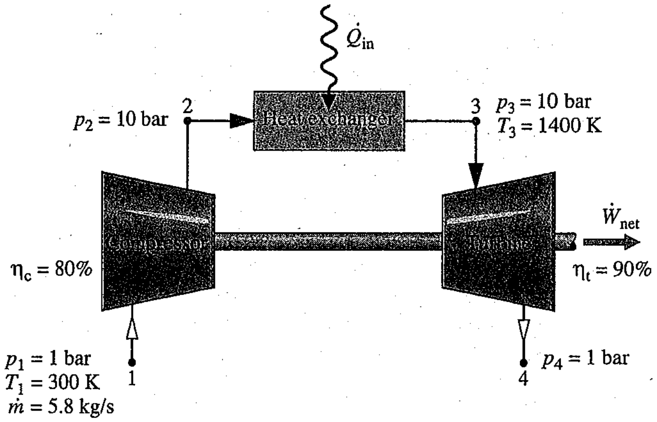

**Fig. P6.166**

**6.167** As shown in Fig. P6.167, a well-insulated turbine operating at steady state has two stages in series. Steam enters the first stage at 800°F, 600 lbf/in.$^2$ and exits at 250 lbf/in.$^2$ The steam then enters the second stage and exits at 14.7 lbf/in.$^2$ The isentropic efficiencies of the stages are 85% and 91%, respectively. Show the principal states on a *T–s* diagram. At the exit of the second stage, determine the temperature, in °F, if superheated vapor exits or the quality if a two-phase liquid–vapor mixture exits. Also determine the work developed by each stage, in Btu per lb of steam flowing.

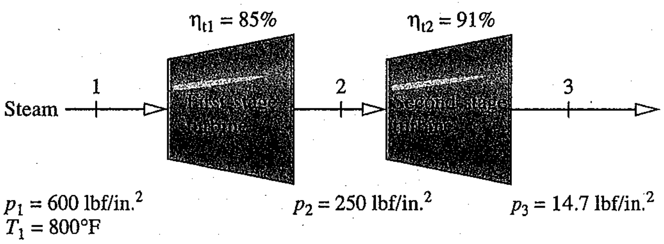

**Fig. P6.167**

**6.168** A rigid tank is filled initially with 5.0 kg of air at a pressure of 0.5 MPa and a temperature of 500 K. The air is allowed to discharge through a turbine into the atmosphere, developing work until the pressure in the tank has fallen to the atmospheric level of 0.1 MPa. Employing the ideal gas model for the air, determine the *maximum* theoretical amount of work that could be developed, in kJ. Ignore heat transfer with the atmosphere and changes in kinetic and potential energy.

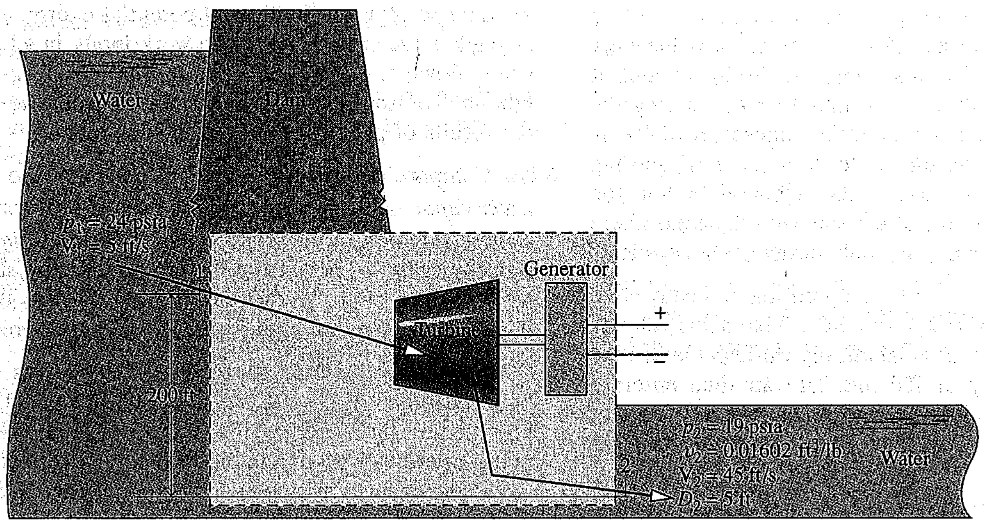

**Fig. P6.183**

volume of 0.01602 $\text{ft}^3$/lb. The diameter of the exit pipe is 5 ft and the local acceleration of gravity is 32.2 $\text{ft/s}^2$. Evaluating the electricity generated at 8.5 cents per kW • h, determine the value of the power produced, in \$/day, for operation at steady state and in the absence of internal irreversibilities.

**6.184** As shown in Figure P6.184, water flows from an elevated reservoir through a hydraulic turbine operating at steady state. Determine the maximum power output, in MW, associated with a mass flow rate of 950 kg/s. The inlet and exit diameters are equal. The water can be modeled as incompressible with $v = 10^{-3}$ $\text{m}^3$/kg. The local acceleration of gravity is 9.8 $\text{m/s}^2$.

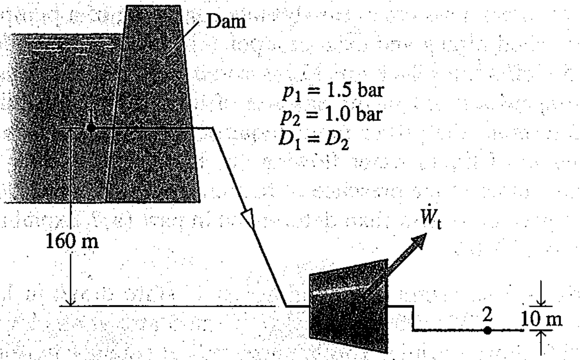

**Fig. P6.184**

**6.185** Nitrogen ($N_2$) enters a nozzle operating at steady state at 0.2 MPa, 550 K with a velocity of 1 m/s and undergoes a polytropic expansion with $n = 1.3$ to 0.15 MPa. Using the ideal gas model with $k = 1.4$, and ignoring potential energy effects, determine (a) the exit velocity, in m/s, and (b) the rate of heat transfer, in kJ per kg of gas flowing.

**6.186** Carbon monoxide enters a nozzle operating at steady state at 5 bar, 200°C with a velocity of 1 m/s and undergoes a polytropic expansion to 1 bar and an exit velocity of 630 m/s. Using the ideal gas model and ignoring potential energy effects, determine

(a) the exit temperature, in °C.
(b) the rate of heat transfer, in kJ per kg of gas flowing.

## Reviewing Concepts

**6.187** Answer the following true or false. Explain.

(a) For closed systems undergoing processes involving internal irreversibilities, both entropy change and entropy production are positive in value.
(b) The *Carnot* cycle is represented on a *Mollier* diagram by a rectangle.
(c) Entropy *change* of a closed system during a process can be greater than, equal to, or less than zero.
(d) For specified inlet state, exit pressure, and mass flow rate, the power *input* required by a compressor operating at steady state is less than that if compression occurred isentropically.
(e) The $T\,dS$ equations are fundamentally important in thermodynamics because of their use in deriving important property relations for pure, simple compressible systems.
(f) At liquid states, the following approximation is reasonable for many engineering applications $s(T, p) = s_f(T)$.

**6.188** Answer the following true or false. Explain

(a) The steady-state form of the control volume entropy balance requires that the total rate at which entropy is transferred out of the control volume be *less* than the total rate at which entropy enters.
(b) In *statistical* thermodynamics, entropy is associated with the notion of microscopic *disorder*.
(c) For a gas modeled as an ideal gas, the specific internal energy, enthalpy, and entropy all depend on temperature only.
(d) The entropy change between two states of water can be read *directly* from the *steam tables*.
(e) The *increase of entropy principle* states that the only processes of an isolated system are those for which its entropy increases.
(f) Equation 6.52, the *Bernoulli* equation, applies generally to one-inlet, one-exit control volumes at steady state, whether internal irreversibilities are present or not.

**6.189** Answer the following true or false. Explain

(a) The only entropy transfer to, or from, control volumes is that accompanying heat transfer.