volumetric flow rate and mass flow rate at the exit, evaluate them. If not, explain.

4.19 A water storage tank initially contains 100,000 gal of water. The average daily usage is 10,000 gal. If water is added to the tank at an average rate of 5000[exp($-t/20$)] gallons per day, where t is time in days, for how many days will the tank contain water?

4.20 A pipe carrying an incompressible liquid contains an expansion chamber as illustrated in Fig. P4.20.

(a) Develop an expression for the time rate of change of liquid level in the chamber, dL/dt, in terms of the diameters D_1, D_2, and D, and the velocities V_1 and V_2.
(b) Compare the relative magnitudes of the mass flow rates $\dot{m}_1$ and $\dot{m}_2$ when $dL/dt > 0$, $dL/dt = 0$, and $dL/dt < 0$, respectively.

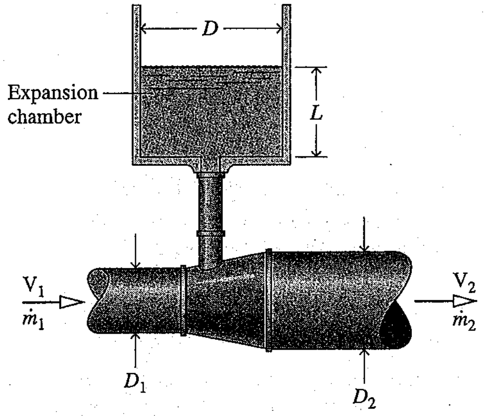

Fig. P4.20

4.21 Velocity distributions for *laminar* and *turbulent* flow in a circular pipe of radius R carrying an incompressible liquid of density ρ are given, respectively, by

$$V/V_0 = [1 - (r/R)^2]$$
$$V/V_0 = [1 - (r/R)]^{1/7}$$

where r is the radial distance from the pipe centerline and V_0 is the centerline velocity. For each velocity distribution

(a) plot V/V_0 versus r/R.
(b) derive expressions for the mass flow rate and the average velocity of the flow, V_{ave}, in terms of V_0, R, and ρ, as required.
(c) derive an expression for the *specific* kinetic energy carried through an area normal to the flow. What is the percent error if the specific kinetic energy is evaluated in terms of the average velocity as $(V_{ave})^2/2$?

Which velocity distribution adheres most closely to the idealizations of one-dimensional flow? Discuss.

4.22 Figure P4.22 shows a cylindrical tank being drained through a duct whose cross-sectional area is 3×10^{-4} m^2. The velocity of the water at the exit varies according to $(2gz)^{1/2}$, where z is the water level, in m, and g is the acceleration of gravity, 9.81 m/s^2. The tank initially contains 2500 kg of liquid water. Taking the density of the water as 10^3 kg/m^3, determine the time, in minutes, when the tank contains 900 kg of water.

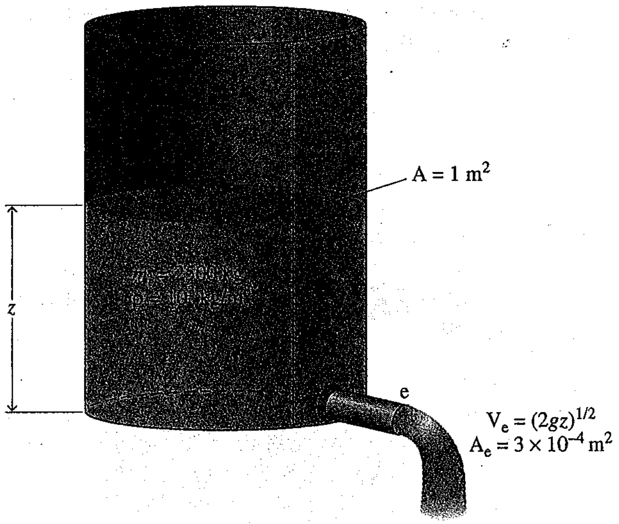

Fig. P4.22

Energy Analysis of Control Volumes at Steady State

4.23 Steam enters a horizontal pipe operating at steady state with a specific enthalpy of 3000 kJ/kg and a mass flow rate of 0.5 kg/s. At the exit, the specific enthalpy is 1700 kJ/kg. If there is no significant change in kinetic energy from inlet to exit, determine the rate of heat transfer between the pipe and its surroundings, in kW.

4.24 Refrigerant 134a enters a horizontal pipe operating at steady state at 40°C, 300 kPa and a velocity of 40 m/s. At the exit, the temperature is 50°C and the pressure is 240 kPa. The pipe diameter is 0.04 m. Determine (a) the mass flow rate of the refrigerant, in kg/s, (b) the velocity at the exit, in m/s, and (c) the rate of heat transfer between the pipe and its surroundings, in kW.

4.25 As shown in Fig. P4.25, air enters a pipe at 25°C, 100 kPa with a volumetric flow rate of 23 m^3/h. On the outer pipe surface is an electrical resistor covered with insulation. With a voltage of 120 V, the resistor draws a current of 4 amps. Assuming the ideal gas model with $c_p = 1.005$ kJ/kg · K for air and ignoring kinetic and potential energy effects, determine (a) the mass flow rate of the air, in kg/h, and (b) the temperature of the air at the exit, in °C.

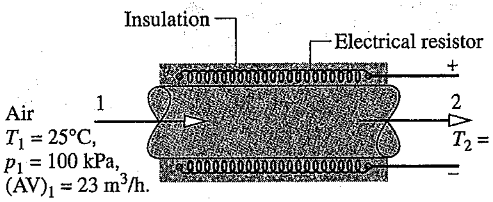

Fig. P4.25

4.26 Air enters a horizontal, constant-diameter heating duct operating at steady state at 290 K, 1 bar, with a volumetric flow rate of 0.25 m^3/s, and exits at 325 K, 0.95 bar. The flow area is 0.04 m^2. Assuming the ideal gas model with $k = 1.4$ for the air, determine (a) the mass flow rate, in kg/s, (b) the velocity at the inlet and exit, each in m/s, and (c) the rate of heat transfer, in kW.

4.27 Air at 600 kPa, 330 K enters a well-insulated, horizontal pipe having a diameter of 1.2 cm and exits at 120 kPa, 300 K. Applying the ideal gas model for air, determine at steady state (a) the inlet and exit velocities, each in m/s, and (b) the mass flow rate, in kg/s.

4.28 At steady state, air at 200 kPa, 52°C and a mass flow rate of 0.5 kg/s enters an insulated duct having differing inlet and exit cross-sectional areas. At the duct exit, the pressure of the air is 100 kPa, the velocity is 255 m/s, and the cross-sectional area is 2×10^{-3} m^2. Assuming the ideal gas model, determine

(a) the temperature of the air at the exit, in °C.
(b) the velocity of the air at the inlet, in m/s.
(c) the inlet cross-sectional area, in m^2.

4.29 Refrigerant 134a flows at steady state through a horizontal pipe having an inside diameter of 4 cm, entering as saturated vapor at −8°C with a mass flow rate of 17 kg/min. Refrigerant vapor exits at a pressure of 2 bar. If the heat transfer rate to the refrigerant is 3.4 kW, determine the exit temperature, in °C, and the velocities at the inlet and exit, each in m/s.

4.30 Water vapor enters an insulated nozzle operating at steady state at 500°C, 40 bar, with a velocity of 100 m/s, and exits at 300°C, 10 bar. The velocity at the exit, in m/s, is approximately

(a) 104, (c) 888,
(b) 636, (d) 894.

4.31 Steam enters a nozzle operating at steady state at 20 bar, 280°C, with a velocity of 80 m/s. The exit pressure and temperature are 7 bar and 180°C, respectively. The mass flow rate is 1.5 kg/s. Neglecting heat transfer and potential energy, determine

(a) the exit velocity, in m/s.
(b) the inlet and exit flow areas, in cm^2.

4.32 Refrigerant 134a enters a well-insulated nozzle at 200 lbf/in.^{2}, 220°F, with a velocity of 120 ft/s and exits at 20 lbf/in.^{2} with a velocity of 1500 ft/s. For steady-state operation, and neglecting potential energy effects, determine the exit temperature, in °F.

4.33 Air enters a nozzle operating at steady state at 720°R with negligible velocity and exits the nozzle at 500°R with a velocity of 1450 ft/s. Assuming ideal gas behavior and neglecting potential energy effects, determine the heat transfer in Btu per lb of air flowing.

4.34 Air with a mass flow rate of 5 lb/s enters a horizontal nozzle operating at steady state at 800°R, 50 lbf/in.^{2} and a velocity of 10 ft/s. At the exit, the temperature is 570°R and the velocity is 1510 ft/s. Using the ideal gas model for air, determine (a) the area at the inlet, in ft^2, and (b) the heat transfer between the nozzle and its surroundings, in Btu per lb of air flowing.

4.35 Helium gas flows through a well-insulated nozzle at steady state. The temperature and velocity at the inlet are 550°R and 150 ft/s, respectively. At the exit, the temperature is 400°R and the pressure is 40 lbf/in.^{2} The area of the exit is 0.0085 ft^2. Using the ideal gas model with $k = 1.67$, and neglecting potential energy effects, determine the mass flow rate, in lb/s, through the nozzle.

4.36 Methane (CH_4) gas enters a horizontal, well-insulated nozzle operating at steady state at 80°C and a velocity of 10 m/s. Assuming ideal gas behavior for the methane, plot the temperature of the gas exiting the nozzle, in °C, versus the exit velocity ranging from 500 to 600 m/s.

4.37 As shown in Fig. P4.37, air enters the diffuser of a jet engine operating at steady state at 18 kPa, 216 K and a velocity of 265 m/s, all data corresponding to high-altitude flight. The air flows adiabatically through the diffuser and achieves a temperature of 250 K at the diffuser exit. Using the ideal gas model for air, determine the velocity of the air at the diffuser exit, in m/s.

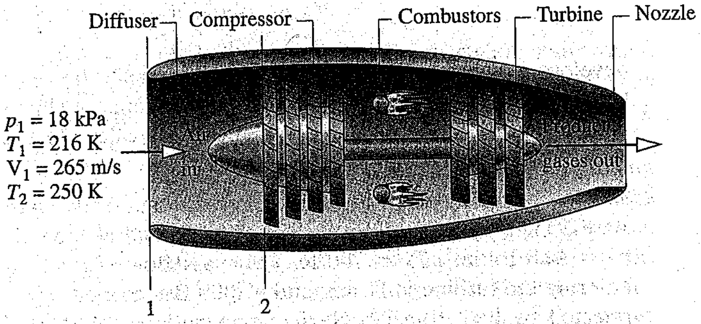

Fig. P4.37

4.38 Air enters a diffuser operating at steady state at 540°R, 15 lbf/in.^{2}, with a velocity of 600 ft/s, and exits with a velocity of 60 ft/s. The ratio of the exit area to the inlet area is 8. Assuming the ideal gas model for the air and ignoring heat transfer, determine the temperature, in °R, and pressure, in lbf/in.^{2}, at the exit.

4.39 Refrigerant 134a enters an insulated diffuser as a saturated vapor at 80°F with a velocity of 1453.4 ft/s. At the exit, the temperature is 280°F and the velocity is negligible. The diffuser operates at steady state and potential energy effects can be neglected. Determine the exit pressure, in lbf/in.^{2}

4.40 Oxygen gas enters a well-insulated diffuser at 30 lbf/in.^{2}, 440°R, with a velocity of 950 ft/s through a flow area of 2.0 in.^{2} At the exit, the flow area is 15 times the inlet area, and the velocity is 25 ft/s. The potential energy change from inlet to exit is negligible. Assuming ideal gas behavior for the oxygen and steady-state operation of the nozzle, determine the exit temperature, in °R, the exit pressure, in lbf/in.^{2}, and the mass flow rate, in lb/s.

4.41 Steam enters a well-insulated turbine operating at steady state at 4 MPa with a specific enthalpy of 3015.4 kJ/kg and a velocity of 10 m/s. The steam expands to the turbine exit where the pressure is 0.07 MPa, specific enthalpy is 2431.7 kJ/kg, and the velocity is 90 m/s. The mass flow rate is 11.95 kg/s. Neglecting potential energy effects, determine the power developed by the turbine, in kW.

4.42 Hot combustion gases, modeled as air behaving as an ideal gas, enter a turbine at 145 lbf/in.^{2}, 2700°R with a mass flow rate of 0.22 lb/s and exit at 29 lbf/in.^{2} and 1620°R. If heat transfer from the turbine to its surroundings occurs at a rate of 14 Btu/s, determine the power output of the turbine, in hp.

4.43 Air expands through a turbine from 8 bar, 960 K to 1 bar, 450 K. The inlet velocity is small compared to the exit velocity of 90 m/s. The turbine operates at steady state and

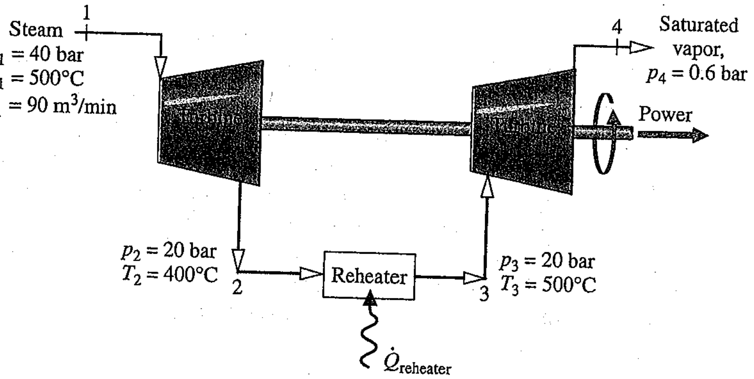

Fig. P4.50

develops a power output of 2500 kW. Heat transfer between the turbine and its surroundings and potential energy effects are negligible. Modeling air as an ideal gas, calculate the mass flow rate of air, in kg/s, and the exit area, in m^2.

4.44 Air expands through a turbine operating at steady state. At the inlet, p_1 = 150 lbf/in.^{2}, T_1 = 1400°R, and at the exit, p_2 = 14.8 lbf/in.^{2}, T_2 = 700°R. The mass flow rate of air entering the turbine is 11 lb/s, and 65,000 Btu/h of energy is rejected by heat transfer. Neglecting kinetic and potential energy effects, determine the power developed, in hp.

4.45 Steam enters a turbine operating at steady state at 700°F and 450 lbf/in.^{2} and leaves as a saturated vapor at 1.2 lbf/in.^{2} The turbine develops 12,000 hp, and heat transfer from the turbine to the surroundings occurs at a rate of 2×10^6 Btu/h. Neglecting kinetic and potential energy changes from inlet to exit, determine the volumetric flow rate of the steam at the inlet, in ft^3/s.

4.46 A well-insulated turbine operating at steady state develops 28.75 MW of power for a steam flow rate of 50 kg/s. The steam enters at 25 bar with a velocity of 61 m/s and exits as saturated vapor at 0.06 bar with a velocity of 130 m/s. Neglecting potential energy effects, determine the inlet temperature, in °C.

4.47 Steam enters a turbine operating at steady state with a mass flow of 10 kg/min, a specific enthalpy of 3100 kJ/kg, and a velocity of 30 m/s. At the exit, the specific enthalpy is 2300 kJ/kg and the velocity is 45 m/s. The elevation of the inlet is 3 m higher than at the exit. Heat transfer from the turbine to its surroundings occurs at a rate of 1.1 kJ per kg of steam flowing. Let g = 9.81 m/s^2. Determine the power developed by the turbine, in kW.

4.48 Steam enters a turbine operating at steady state at 2 MPa, 360°C with a velocity of 100 m/s. Saturated vapor exits at 0.1 MPa and a velocity of 50 m/s. The elevation of the inlet is 3 m higher than at the exit. The mass flow rate of the steam is 15 kg/s, and the power developed is 7 MW. Let g = 9.81 m/s^2. Determine (a) the area at the inlet, in m^2, and (b) the rate of heat transfer between the turbine and its surroundings, in kW.

4.49 Water vapor enters a turbine operating at steady state at 500°C, 40 bar, with a velocity of 200 m/s, and expands adiabatically to the exit, where it is saturated vapor at 0.8 bar, with a velocity of 150 m/s and a volumetric flow rate of 9.48 m^3/s. The power developed by the turbine, in kW, is approximately

(a) 3500, (c) 3580,
(b) 3540, (d) 7470.

4.50 Steam enters the first-stage turbine shown in Fig. P4.50 at 40 bar and 500°C with a volumetric flow rate of 90 m^3/min. Steam exits the turbine at 20 bar and 400°C. The steam is then reheated at constant pressure to 500°C before entering the second-stage turbine. Steam leaves the second stage as saturated vapor at 0.6 bar. For operation at steady state, and ignoring stray heat transfer and kinetic and potential energy effects, determine the

(a) mass flow rate of the steam, in kg/h.

(b) total power produced by the two stages of the turbine, in kW.

(c) rate of heat transfer to the steam flowing through the reheater, in kW.

✓ **4.51** Steam at 1800 lbf/in.^{2} and 1100°F enters a turbine operating at steady state. As shown in Fig. P4.51, 20% of the entering mass flow is extracted at 600 lbf/in.^{2} and 500°F. The rest of the steam exits as a saturated vapor at 1 lbf/in.^{2} The turbine develops a power output of 6.8×10^6 Btu/h. Heat transfer from the turbine to the surroundings occurs at a rate of 5×10^4 Btu/h. Neglecting kinetic and potential energy effects, determine the mass flow rate of the steam entering the turbine, in lb/s.

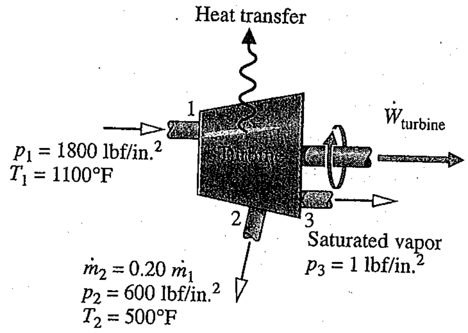

Fig. P4.51

4.52 Air enters a compressor operating at steady state at 1 atm with a specific enthalpy of 290 kJ/kg and exits at a higher pressure with a specific enthalpy of 1023 kJ/kg. The mass flow rate is 0.1 kg/s. If the compressor power input is 77 kW, determine the rate of heat transfer between the compressor and its surroundings, in kW. Neglect kinetic and potential energy effects and assume the ideal gas model.

4.53 Air enters a compressor operating at steady state at 1.05 bar, 300 K, with a volumetric flow rate of 12 m^3/min and exits at 12 bar, 400 K. Heat transfer occurs at a rate of 2 kW from the compressor to its surroundings. Assuming the ideal gas model for air and neglecting kinetic and potential energy effects, determine the power input, in kW.

4.54 Nitrogen is compressed in an axial-flow compressor operating at steady state from a pressure of 15 lbf/in.^{2} and a temperature of 50°F to a pressure 60 lbf/in.^{2} The gas enters the compressor through a 6-in.-diameter duct with a velocity of 30 ft/s and exits at 198°F with a velocity of 80 ft/s. Using the ideal gas model, and neglecting stray heat transfer and potential energy effects, determine the compressor power input, in hp.

4.55 Refrigerant 134a enters a compressor operating at steady state as saturated vapor at 0.12 MPa and exits at 1.2 MPa and 70°C at a mass flow rate of 0.108 kg/s. As the refrigerant passes through the compressor, heat transfer to the surroundings occurs at a rate of 0.32 kJ/s. Determine at steady state the power input to the compressor, in kW.

4.56 Carbon dioxide gas is compressed at steady state from a pressure of 20 lbf/in.^{2} and a temperature of 32°F to a pressure of 50 lbf/in.^{2} and a temperature of 120°F. The gas enters the compressor with a velocity of 30 ft/s and exits with a velocity of 80 ft/s. The mass flow rate is 0.98 lb/s. The magnitude of the heat transfer rate from the compressor to its surroundings is 5% of the compressor power input. Using the ideal gas model with $c_p = 0.21$ Btu/lb · °R and neglecting potential energy effects, determine the compressor power input, in horsepower.

4.57 At steady state, a well-insulated compressor takes in nitrogen at 60°F, 14.2 lbf/in.^{2}, with a volumetric flow rate of 1200 ft^3/min. Compressed nitrogen exits at 500°F, 120 lbf/in.^{2} Kinetic and potential energy changes from inlet to exit can be neglected. Determine the compressor power, in hp, and the volumetric flow rate at the exit, in ft^3/min.

✓ **4.58** Air enters a compressor operating at steady state with a pressure of 14.7 lbf/in.^{2}, a temperature of 80°F, and a volumetric flow rate of 18 ft^3/s. The air exits the compressor at a pressure of 90 lbf/in.^{2} Heat transfer from the compressor to its surroundings occurs at a rate of 9.7 Btu per lb of air flowing. The compressor power input is 90 hp. Neglecting kinetic and potential energy effects and modeling air as an ideal gas, determine the exit temperature, in °F.

4.59 Refrigerant 134a enters an air conditioner compressor at 4 bar, 20°C, and is compressed at steady state to 12 bar, 80°C. The volumetric flow rate of the refrigerant entering is 4 m^3/min. The power input to the compressor is 60 kJ per kg of refrigerant flowing. Neglecting kinetic and potential energy effects, determine the heat transfer rate, in kW.

4.60 Refrigerant 134a enters an insulated compressor operating at steady state as saturated vapor at −20°C with a mass flow rate of 1.2 kg/s. Refrigerant exits at 7 bar, 70°C. Changes in kinetic and potential energy from inlet to exit can be ignored. Determine (a) the volumetric flow rates at the inlet and exit, each in m^3/s, and (b) the power input to the compressor, in kW.

4.61 Refrigerant 134a enters a water-jacketed compressor operating at steady state at −10°C, 1.4 bar, with a mass flow rate of 4.2 kg/s, and exits at 50°C, 12 bar. The compressor power required is 150 kW. Neglecting kinetic and potential energy effects, determine the rate of heat transfer to the cooling water circulating through the water jacket.

4.62 Air is compressed at steady state from 1 bar, 300 K, to 6 bar with a mass flow rate of 4 kg/s. Each unit of mass passing from inlet to exit undergoes a process described by $pv^{1.27} =$ *constant*. Heat transfer occurs at a rate of 46.95 kJ per kg of air flowing to cooling water circulating in a water jacket enclosing the compressor. If kinetic and potential energy changes of the air from inlet to exit are negligible, determine the compressor power, in kW.

4.63 Air enters a compressor operating at steady state with a pressure of 14.7 lbf/in.^{2} and a temperature of 70°F. The volumetric flow rate at the inlet is 16.6 ft^3/s, and the flow area is 0.26 ft^2. At the exit, the pressure is 35 lbf/in.^{2}, the temperature is 280°F, and the velocity is 50 ft/s. Heat transfer from the compressor to its surroundings occurs at a rate of 1.0 Btu per lb of air flowing. Potential energy effects are negligible, and the ideal gas model can be assumed for the air. Determine (a) the velocity of the air at the inlet, in ft/s, (b) the mass flow rate, in lb/s, and (c) the compressor power, in Btu/s and hp.

4.64 Air enters a compressor operating at steady state at 14.7 lbf/in.^{2} and 60°F and is compressed to a pressure of 150 lbf/in.^{2} As the air passes through the compressor, it is cooled at a rate of 10 Btu per lb of air flowing by water circulated through the compressor casing. The volumetric flow rate of the air at the inlet is 5000 ft^3/min, and the power input to the compressor is 700 hp. The air behaves as an ideal gas, there is no stray heat transfer, and kinetic and potential effects are negligible. Determine (a) the mass flow rate of the air, lb/s, and (b) the temperature of the air at the compressor exit, in °F.

4.65 As shown in Fig. P4.65, a pump operating at steady state draws water from a pond and delivers it though a pipe whose exit is 90 ft above the inlet. At the exit, the mass flow rate is 10 lb/s. There is no significant change in water temperature, pressure, or kinetic energy from inlet to exit. If the power required by the pump is 1.68 hp, determine the rate of heat transfer between the pump and its surroundings, in hp and Btu/min. Let $g = 32.0$ ft/s^2.

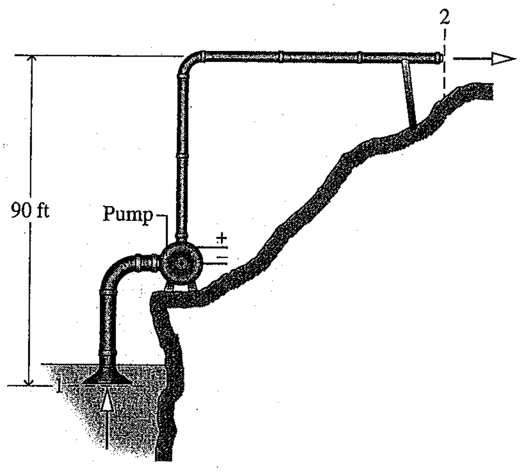

Fig. P4.65

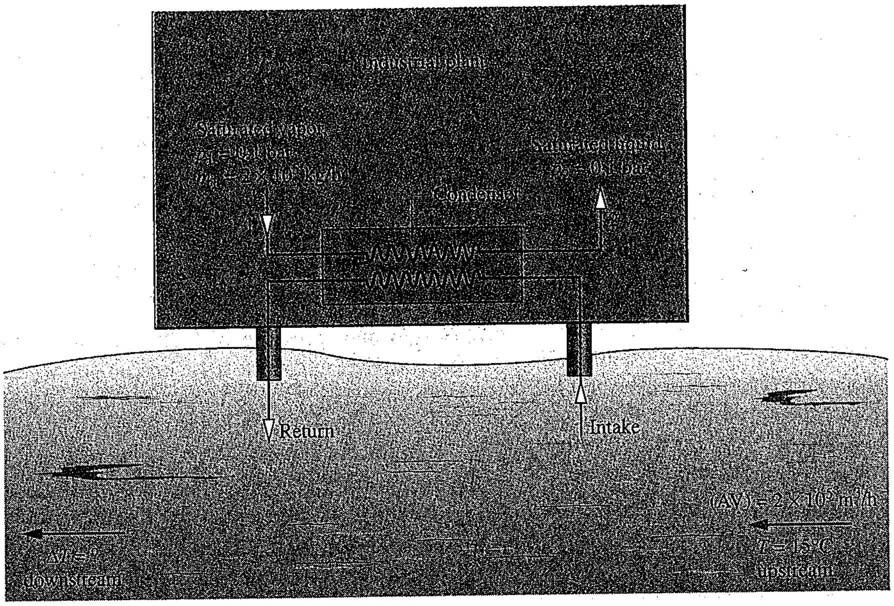

Fig. P4.78

of 188 kg/min and exits at 17°C. Assuming the ideal gas model for air and ignoring kinetic and potential energy effects, determine (a) the mass flow rate of the Refrigerant 134a, in kg/min, and (b) the heat transfer between the heat exchanger and its surroundings, in kJ/min.

4.78 As sketched in Fig. P4.78, a condenser using river water to condense steam with a mass flow rate of 2 × 10^5 kg/h from saturated vapor to saturated liquid at a pressure of 0.1 bar is proposed for an industrial plant. Measurements indicate that several hundred meters upstream of the plant, the river has a volumetric flow rate of 2 × 10^5 m^3/h and a temperature of 15°C. For operation at steady state and ignoring changes in kinetic and potential energy, determine the river-water temperature rise, in °C, downstream of the plant traceable to use of such a condenser, and comment.

✓ **4.79** Figure P4.79 shows a solar collector panel embedded in a roof. The panel, which has a surface area of 24 ft^2, receives energy from the sun at a rate of 200 Btu/h per ft^2 of collector surface. Twenty-five percent of the incoming energy is lost to the surroundings. The remaining energy is used to heat domestic hot water from 90 to 120°F. The water passes through the solar collector with a negligible pressure drop. Neglecting kinetic and potential effects, determine at steady state how many gallons of water at 120°F the collector generates per hour.

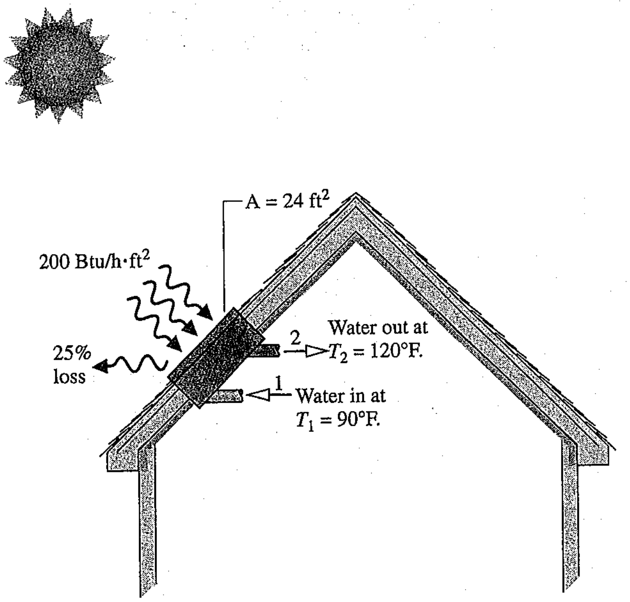

Fig. P4.79

4.80 A feedwater heater in a vapor power plant operates at steady state with liquid entering at inlet 1 with T_1 = 45°C and p_1 = 3.0 bar. Water vapor at T_2 = 320°C and p_2 = 3.0 bar enters at inlet 2. Saturated liquid water exits with a pressure of p_3 = 3.0 bar. Ignore heat transfer with the surroundings and all kinetic and potential energy effects. If the mass flow rate of the liquid entering at inlet 1 is $\dot{m}_1$ = 3.2 × 10^5 kg/h, determine the mass flow rate at inlet 2, $\dot{m}_2$, in kg/h.

4.81 An open feedwater heater operates at steady state with liquid water entering inlet 1 at 10 bar, 50°C, and a mass flow rate of 60 kg/s. A separate stream of steam enters inlet 2 at 10 bar and 200°C. Saturated liquid at 10 bar exits the feedwater heater at exit 3. Ignoring heat transfer with the surroundings and neglecting kinetic and potential energy effects, determine the mass flow rate, in kg/s, of the steam at inlet 2.

4.82 For the *desuperheater* shown in Fig. P4.82, liquid water at state 1 is injected into a stream of superheated vapor entering at state 2. As a result, saturated vapor exits at state 3. Data for steady state operation are shown on the figure. Ignoring stray heat transfer and kinetic and potential energy effects,

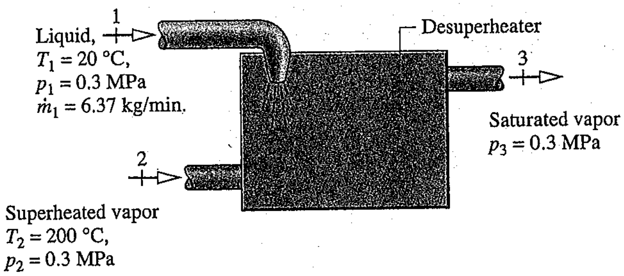

Fig. P4.82

determine the mass flow rate of the incoming superheated vapor, in kg/min.

4.83 As shown in Fig. P4.83, 15 kg/s of steam enters a *desuperheater* operating at steady state at 30 bar, 320°C, where it is mixed with liquid water at 25 bar and temperature T_2 to produce saturated vapor at 20 bar. Heat transfer between the device and its surroundings and kinetic and potential energy effects can be neglected.

(a) If T_2 = 200°C, determine the mass flow rate of liquid, $\dot{m}_2$, in kg/s.
(b) Plot $\dot{m}_2$, in kg/s, versus T_2 ranging from 20 to 220°C.

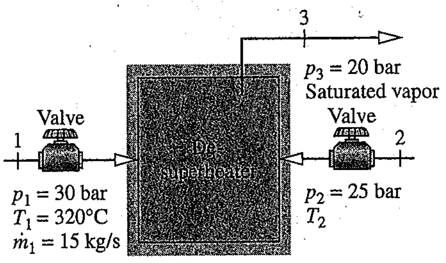

Fig. P4.83

4.84 Figure P4.84 provides steady-state data for the ducting ahead of the chiller coils in an air conditioning system. Outside air at 90°F is mixed with return air at 75°F. Stray heat transfer is negligible, kinetic and potential energy effects can be ignored, and the pressure throughout is 1 atm. Modeling the air as an ideal gas with c_p = 0.24 Btu/lb · R, determine (a) the mixed-air temperature, in °F, and (b) the diameter of the mixed-air duct, in ft.

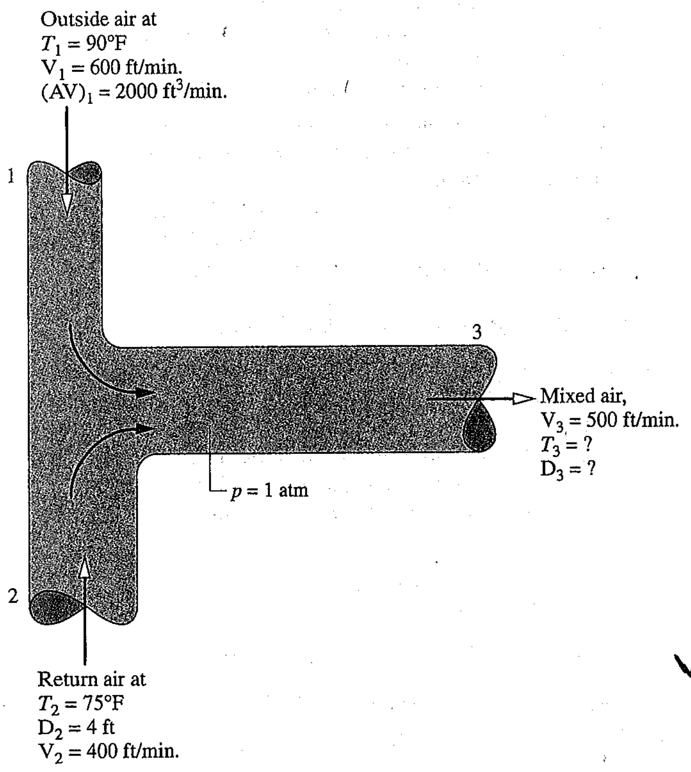

Fig. P4.84

4.85 Figure P4.85 provides steady-state operating data for a *parallel flow* heat exchanger in which there are separate streams of air and water. Each stream experiences no significant change in pressure. Stray heat transfer with the surroundings of the heat exchanger and kinetic and potential energy effects can be ignored. The ideal gas model applies to the air. If each stream exits at the same temperature, determine the value of that temperature, in K.

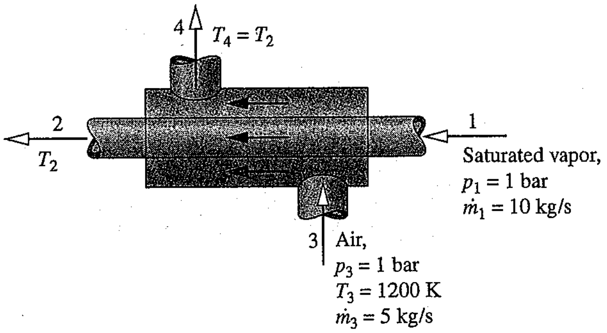

Fig. P4.85

4.86 Figure P4.86 provides steady-state operating data for a *parallel flow* heat exchanger in which there are separate streams of air and carbon dioxide (CO_2). Stray heat transfer with the surroundings of the heat exchanger and kinetic and potential energy effects can be ignored. The ideal gas model applies to each gas. A constraint on heat exchanger size requires the temperature of the exiting air to be 20 degrees greater than the temperature of the exiting CO_2. Determine the exit temperature of each stream, in °R.

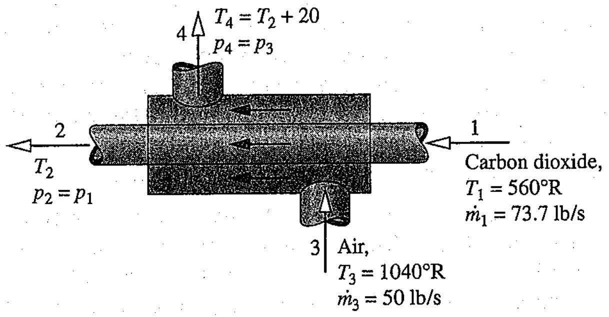

Fig. P4.86

4.87 Ten kg/min of cooling water circulates through a water jacket enclosing a housing filled with electronic components. At steady state, water enters the water jacket at 22°C and exits with a negligible change in pressure at a temperature that cannot exceed 26°C. There is no significant energy transfer by heat from the outer surface of the water jacket to the surroundings, and kinetic and potential energy effects can be ignored. Determine the maximum electric power the electronic components can receive, in kW, for which the limit on the temperature of the exiting water is met.

✓**4.88** As shown in Fig. P4.88, electronic components mounted on a flat plate are cooled by convection to the surroundings and by liquid water circulating through a U-tube bonded to the plate. At steady state, water enters the tube at 20°C and a velocity of 0.4 m/s and exits at 24°C with a negligible

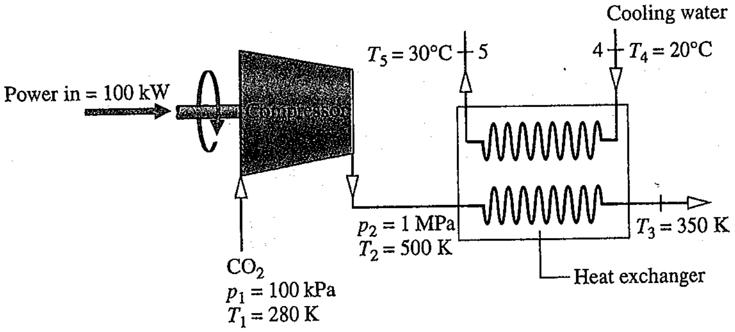

Fig. P4.100

the surroundings and kinetic and potential energy effects can be ignored.

(a) Determine the mass flow rates of the exiting streams, each in kg/h, if $p = 4$ bar.

(b) Plot the mass flow rates of the exiting streams, each in kg/h, versus p ranging from 1 to 9 bar.

4.100 Carbon dioxide (CO_2) modeled as an ideal gas flows through the compressor and heat exchanger shown in Fig. P4.100. The power input to the compressor is 100 kW. A separate liquid cooling water stream flows through the heat exchanger. All data are for operation at steady state. Stray heat transfer with the surroundings can be neglected, as can all kinetic and potential energy changes. Determine (a) the mass flow rate of the CO_2, in kg/s, and (b) the mass flow rate of the cooling water, in kg/s.

✓**4.101** Figure P4.101 shows a *pumped-hydro* energy storage system delivering water at steady state from a lower reservoir to an upper reservoir using *off-peak* electricity (see Sec. 4.8.3). Water is delivered to the upper reservoir at a volumetric flow rate of 150 m^3/s with an increase in elevation of 20 m. There is no significant change in temperature, pressure, or kinetic energy from inlet to exit. Heat transfer from the pump to its surroundings occurs at a rate of 0.6 MW and $g = 9.81$ m/s^2. Determine the pump power required, in MW. Assuming the same volumetric flow rate when the system generates *on-peak* electricity using this water, will the power be greater, less, or the same as the pump power? Explain.

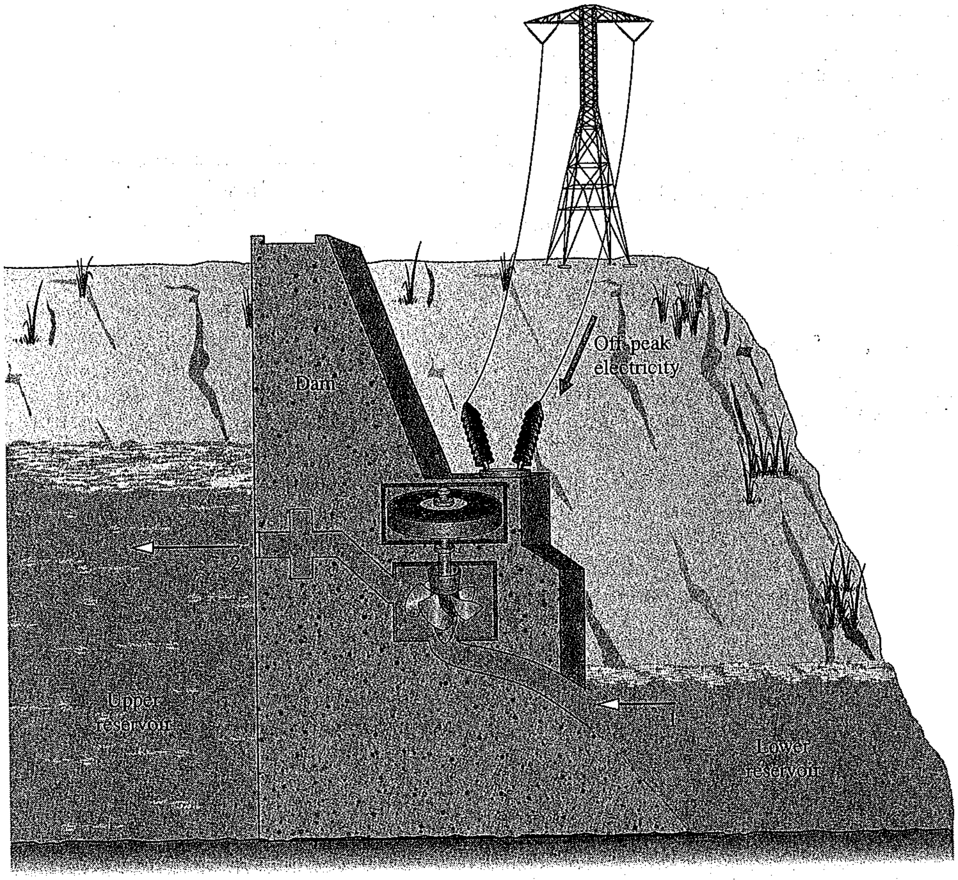

Fig. P4.101

4.102 Steady-state operating data for a simple steam power plant are provided in Fig. P4.102. Stray heat transfer and kinetic and potential energy effects can be ignored. Determine the (a) thermal efficiency and (b) the mass flow rate of the cooling water, in kg per kg of steam flowing.

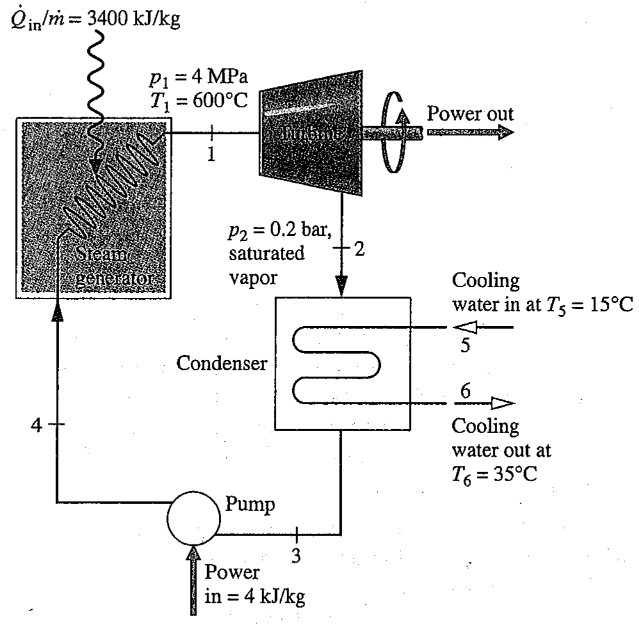

Fig. P4.102

4.103 Steady-state operating data are provided for a compressor and heat exchanger in Fig. P4.103. The power input to the compressor is 50 kW. As shown in the figure, nitrogen (N_2) flows through the compressor and heat exchanger with a mass flow rate of 0.25 kg/s. The nitrogen is modeled as an ideal gas. A separate cooling stream of helium, modeled as an ideal gas with $k = 1.67$, also flows through the heat exchanger. Stray heat transfer and kinetic and potential energy effects are negligible. Determine the mass flow rate of the helium, in kg/s.

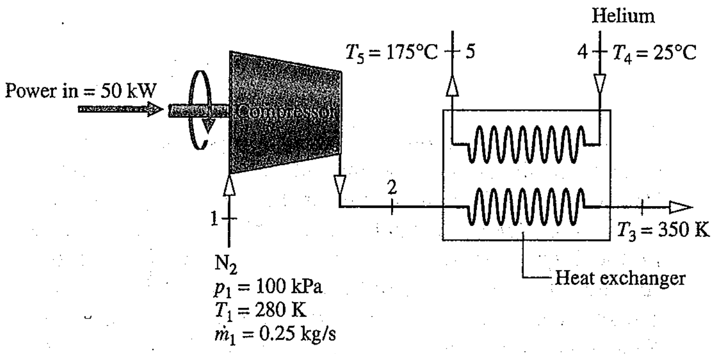

Fig. P4.103

4.104 Figure P4.104 provides steady-state operating data for a *cogeneration system* with water vapor at 20 bar, 360°C entering at location 1. Power is developed by the system at a rate of 2.2 MW. Process steam leaves at location 2, and hot water for other process uses leaves at location 3. Evaluate the rate of heat transfer, in MW, between the system and its surroundings. Let $g = 9.81$ m/s^2.

4.105 As shown in Fig. P4.105, hot industrial waste water at 15 bar, 180°C with a mass flow rate of 5 kg/s enters a *flash chamber* via a valve. Saturated vapor and saturated liquid streams, each at 4 bar, exit the flash chamber. The saturated vapor enters the turbine and expands to 0.08 bar, $x = 90\%$. Stray heat transfer and kinetic and potential energy effects are negligible. For operation at steady state, determine the power, in hp, developed by the turbine.

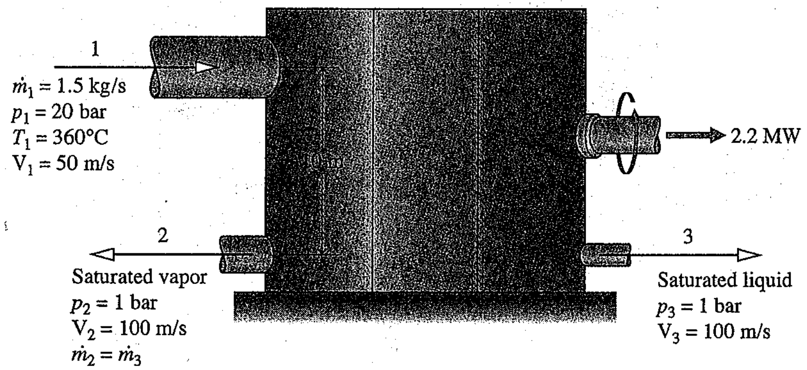

Fig. P4.104

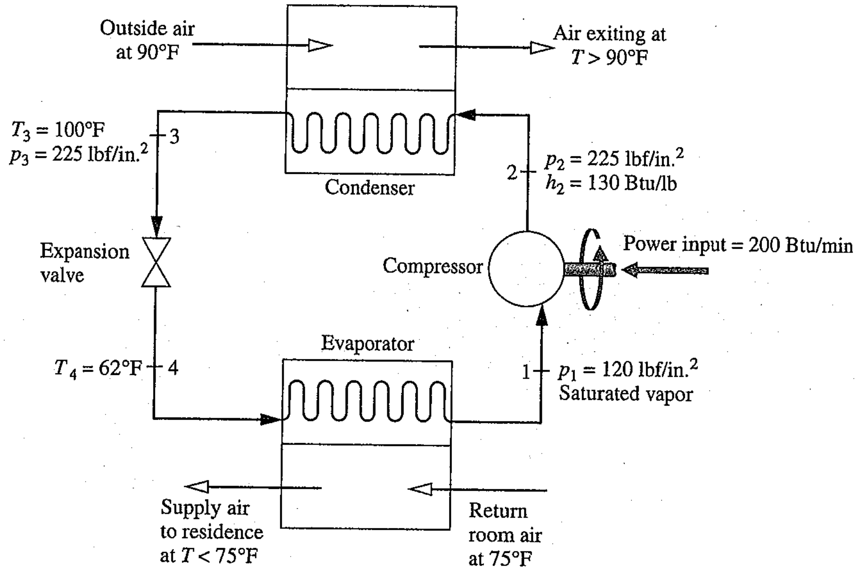

Fig. P4.107

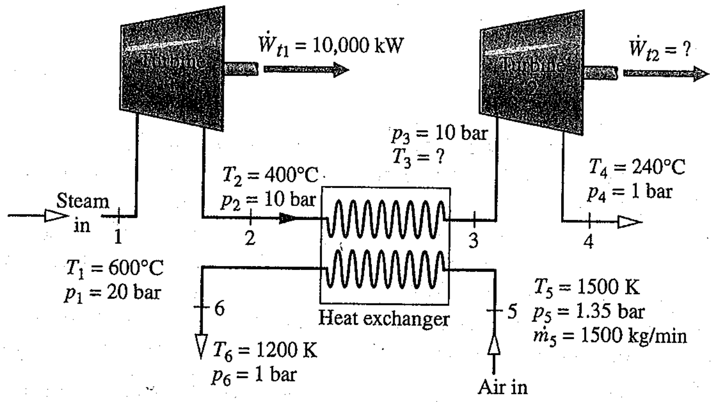

Fig. P4.108

Transient Analysis

4.109 A rigid tank whose volume is 10 L is initially evacuated. A pinhole develops in the wall, and air from the surroundings at 1 bar, 25°C enters until the pressure in the tank becomes 1 bar. No significant heat transfer between the contents of the tank and the surroundings occurs. Assuming the ideal gas model with $k = 1.4$ for the air, determine (a) the final temperature in the tank, in °C, and (b) the amount of air that leaks into the tank, in g.

4.110 A tank whose volume is 0.01 m^3 is initially evacuated. A pinhole develops in the wall, and air from the surroundings at 21°C, 1 bar enters until the pressure in the tank is 1 bar. If the final temperature of the air in the tank is 21°C, determine (a) the final mass in the tank, in g, and (b) the heat transfer between the tank contents and the surroundings, in kJ.

4.111 A rigid tank whose volume is 2 m^3, initially containing air at 1 bar, 295 K, is connected by a valve to a large vessel holding air at 6 bar, 295 K. The valve is opened only as long as required to fill the tank with air to a pressure of 6 bar and a temperature of 350 K. Assuming the ideal gas model for the air, determine the heat transfer between the tank contents and the surroundings, in kJ.

4.112 An insulated, rigid tank whose volume is 0.5 m^3 is connected by a valve to a large vessel holding steam at 40 bar, 500°C. The tank is initially evacuated. The valve is opened only as long as required to fill the tank with steam to a pressure of 20 bar. Determine the final temperature of the steam in the tank, in °C, and the final mass of the steam in the tank, in kg.

4.113 An insulated, rigid tank whose volume is 10 ft^3 is connected by a valve to a large steam line through which steam flows at 500 lbf/in.^{2}, 800°F. The tank is initially evacuated. The valve is opened only as long as required to fill the tank with steam to a pressure of 500 lbf/in.^{2} Determine the final temperature of the steam in the tank, in °F, and the final mass of steam in the tank, in lb.

✓**4.114** Figure P4.114 provides operating data for a *compressed-air* energy storage system using *off-peak* electricity to power a compressor that fills a cavern with pressurized air (see Sec. 4.8.3). The cavern shown in the figure has a volume of 10^5 m^3 and initially holds air at 290 K, 1 bar, which corresponds to ambient air. After filling, the air in the cavern is at 790 K, 21 bar. Assuming ideal gas behavior for the air, determine (a) the initial and final mass of air in the cavern, each in kg, and (b) the work required by the compressor, in GJ. Ignore heat transfer and kinetic and potential energy effects.

face is located at $x = 0$ and the spring exerts no force on the piston. The atmospheric pressure is 14.7 lbf/in.^{2}, and the area of the piston face is 0.22 ft^2. The valve is opened, and air is admitted slowly until the volume of the air inside the cylinder is 0.4 ft^3. During the process, the spring exerts a force on the piston that varies according to $F = kx$. The ideal gas model applies for the air, and there is no friction between the piston and the cylinder wall. For the air within the cylinder, plot the final pressure, in lbf/in.^{2}, and the final temperature, in °F, versus k ranging from 650 to 750 lbf/ft.

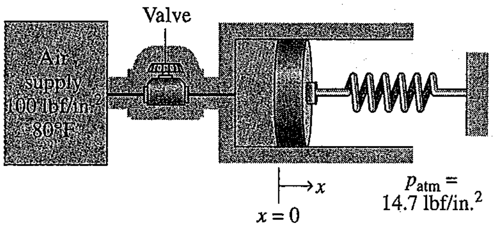

Fig. P4.121

4.122 A rigid tank having a volume of 0.1 m^3 initially contains water as a two-phase liquid–vapor mixture at 1 bar and a quality of 1%. The water is heated in two stages:

Stage 1: Constant-volume heating until the pressure is 20 bar.
Stage 2: Continued heating while saturated water vapor is slowly withdrawn from the tank at a constant pressure of 20 bar. Heating ceases when all the water remaining in the tank is saturated vapor at 20 bar.

For the water, evaluate the heat transfer, in kJ, for each stage of heating. Ignore kinetic and potential energy effects.

4.123 A rigid, insulated tank having a volume of 50 ft^3 initially contains a two-phase liquid–vapor mixture of ammonia at 100°F and a quality of 1.9%. Saturated vapor is slowly withdrawn from the tank until a two-phase liquid–vapor mixture at 80°F remains. Determine the mass of ammonia in the tank initially and finally, each in lb.

✓**4.124** The rigid tank illustrated in Fig. P4.124 has a volume of 0.06 m^3 and initially contains a two-phase liquid–vapor mixture of H_2O at a pressure of 15 bar and a quality of 20%. As the tank contents are heated, a pressure-regulating valve keeps the pressure constant in the tank by allowing saturated vapor to escape. Neglecting kinetic and potential energy effects

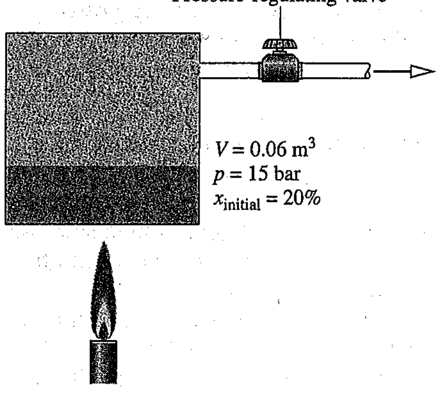

Fig. P4.124

(a) determine the total mass in the tank, in kg, and the amount of heat transfer, in kJ, if heating continues until the final quality is $x = 0.5$.
(b) plot the total mass in the tank, in kg, and the amount of heat transfer, in kJ, versus the final quality x ranging from 0.2 to 1.0.

4.125 A well-insulated rigid tank of volume 7 ft^3 initially contains helium at 160°F and 30 lbf/in.^{2} A valve connected to the tank is opened, and helium is withdrawn slowly until the pressure within the tank drops to p. An electrical resistor inside the tank maintains the temperature at 160°F.

(a) Determine the mass of helium withdrawn, in lb, and the energy input to the resistor, in Btu, when $p = 18$ lbf/in.^{2}
(b) Plot the quantities of part (a) versus p ranging from 15 to 30 lbf/in.^{2}

4.126 A tank of volume 1 m^3 initially contains steam at 6 MPa and 320°C. Steam is withdrawn slowly from the tank until the pressure drops to p. Heat transfer to the tank contents maintains the temperature constant at 320°C. Neglecting all kinetic and potential energy effects,

(a) determine the heat transfer, in kJ, if $p = 1.5$ MPa.
(b) plot the heat transfer, in kJ, versus p ranging from 0.5 to 6 MPa.

4.127 A 1 m^3 tank initially contains air at 300 kPa, 300 K. Air slowly escapes from the tank until the pressure drops to 100 kPa. The air that remains in the tank undergoes a process described by $pv^{1.2} = constant$. For a control volume enclosing the tank, determine the heat transfer, in kJ. Assume ideal gas behavior with constant specific heats.

4.128 Nitrogen gas is contained in a rigid 1-m tank, initially at 10 bar, 300 K. Heat transfer to the contents of the tank occurs until the temperature has increased to 400 K. During the process, a pressure-relief valve allows nitrogen to escape, maintaining constant pressure in the tank. Neglecting kinetic and potential energy effects, and using the ideal gas model with constant specific heats evaluated at 350 K, determine the mass of nitrogen that escapes, in kg, and the amount of energy transfer by heat, in kJ.

4.129 The air supply to a 2000-ft^3 office has been shut off overnight to conserve utilities, and the room temperature has dropped to 40°F. In the morning, a worker resets the thermostat to 70°F, and 200 ft^3/min of air at 120°F begins to flow in through a supply duct. The air is well mixed within the room, and an equal mass flow of air at room temperature is withdrawn through a return duct. The air pressure is nearly 1 atm everywhere. Ignoring heat transfer with the surroundings and kinetic and potential energy effects, estimate how long it takes for the room temperature to reach 70°F. Plot the room temperature as a function of time.

4.130 A well-insulated chamber of volume 1 ft^3 is shown in Fig. P4.130. Initially, the chamber contains air at 14.7 lbf/in.^{2} and 100°F. Connected to the chamber are supply and discharge pipes equipped with valves that control the flow rates into and out of the chamber. The supply air is at 30 lbf/in.^{2}, 200°F. Both valves are opened simultaneously,