(b) the temperature at $p = 60$ lbf/in.^{2}, $v = 5.982$ ft^3/lb, in °F.
(c) the specific volume at $T = 110$°F, $p = 58$ lbf/in.^{2}, in ft^3/lb.

3.9 Determine the volume change, in ft^3, when 1 lb of water, initially saturated liquid, is heated to saturated vapor while pressure remains constant at 1.0, 14.7, 100, and 500, each in lbf/in.^{2} Comment.

✓ **3.10** For H_2O, determine the specified property at the indicated state. Locate the state on a sketch of the T–v diagram.

(a) $p = 300$ kPa, $v = 0.5$ m^3/kg. Find T, in °C.
(b) $p = 28$ MPa, $T = 200$°C. Find v, in m^3/kg.
(c) $p = 1$ MPa, $T = 405$°C. Find v, in m^3/kg.
(d) $T = 100$°C, $x = 60\%$. Find v, in m^3/kg.

3.11 For each case, determine the specific volume at the indicated state. Locate the state on a sketch of the T–v diagram.

(a) Water at $p = 14.7$ lbf/in.^{2}, $T = 100$°F. Find v, in ft^3/lb.
(b) Ammonia at $T = -30$°C, $x = 50\%$. Find v, in m^3/kg.
(c) Refrigerant 134a at $p = 1.5$ MPa, $T = 100$°C. Find v, in m^3/kg.

✓ **3.12** For each case, determine the specified property at the indicated state. Locate the state on a sketch of the T–v diagram.

(a) Water at $v = 0.5$ m^3/kg, $p = 3$ bar, determine T, in °C.
(b) Ammonia at $p = 11$ lbf/in.^{2}, $T = -20$°F, determine v, in ft^3/lb.
(c) Propane at $p = 1$ MPa, $T = 85$°C, determine v, in m^3/kg.

3.13 For H_2O, determine the specific volume at the indicated state, in m^3/kg. Locate the states on a sketch of the T–v diagram.

(a) $T = 400$°C, $p = 20$ MPa.
(b) $T = 40$°C, $p = 20$ MPa.
(c) $T = 40$°C, $p = 2$ MPa.

3.14 For H_2O, locate each of the following states on sketches of the p–v, T–v, and phase diagrams.

(a) $T = 120$°C, $p = 5$ bar.
(b) $T = 120$°C, $v = 0.6$ m^3/kg.
(c) $T = 120$°C, $p = 1$ bar.

3.15 Complete the following exercises. In each case locate the state on sketches of the T–v and p–v diagrams.

(a) Four kg of water at 100°C fill a closed container having a volume of 1 m^3. If the water at this state is a vapor, determine the pressure, in bar. If the water is a two-phase liquid–vapor mixture, determine the quality.
(b) Ammonia at a pressure of 40 lbf/in.^{2} has a specific internal energy of 308.75 Btu/lb. Determine the specific volume at the state, in ft^3/lb.

3.16 Two kg of a two-phase, liquid–vapor mixture of carbon dioxide (CO_2) exists at -40°C in a 0.05 m^3 tank. Determine the quality of the mixture, if the values of specific volume for saturated liquid and saturated vapor CO_2 at -40°C are $v_f = 0.896 \times 10^{-3}$ m^3/kg and $v_g = 3.824 \times 10^{-2}$ m^3/kg, respectively.

3.17 Each of the following exercises requires evaluating the quality of a two-phase liquid–vapor mixture:

(a) The quality of a two-phase liquid–vapor mixture of H_2O at 40°C with a specific volume of 10 m^3/kg is
(i) 0, (ii) 0.486 (iii) 0.512, (iv) 1.
(b) The quality of a two-phase liquid–vapor mixture of propane at 20 bar with a specific internal energy of 300 kJ/kg is (i) 0.166, (ii) 0.214, (iii) 0.575, (iv) 0.627.
(c) The quality of a two-phase liquid–vapor mixture of Refrigerant 134a at 90 lbf/in.^{2} with a specific enthalpy of 90 Btu/lb is (i) 0.387, (ii) 0.718, (iii) 0.806, (iv) 0.854.
(d) The quality of a two-phase liquid–vapor mixture of ammonia at -20°F with a specific volume of 11 ft^3/lb is (i) 0, (ii) 0.251, (iii) 0.537, (iv) 0.749.

3.18 Determine the quality of a two-phase liquid–vapor mixture of

(a) H_2O at 10 lbf/in.^{2} with a specific volume of 15 ft^3/lb.
(b) Refrigerant 134a at 60°F with a specific internal energy of 50.5 Btu/lb.
(c) ammonia at 80 lbf/in.^{2} with a specific enthalpy of 350 Btu/lb.
(d) propane at -20°F with a specific volume of 1 ft^3/lb.

3.19 A two-phase liquid–vapor mixture of ammonia has a specific volume of 1.0 ft^3/lb. Determine the quality if the temperature is (a) 100°F, (b) 0°F. Locate the states on a sketch of the T–v diagram.

3.20 A two-phase liquid–vapor mixture of a substance has a pressure of 150 bar and occupies a volume of 0.2 m^3. The masses of saturated liquid and vapor present are 3.8 kg and 4.2 kg, respectively. Determine the specific volume of the mixture, in m^3/kg.

✓ **3.21** As shown in Fig. P3.21, a closed, rigid cylinder contains different volumes of saturated liquid water and saturated water vapor at a temperature of 150°C. Determine the quality of the mixture, expressed as a percent.

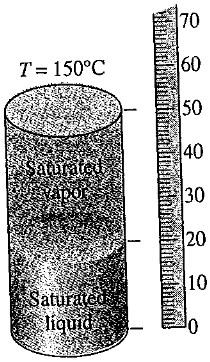


Fig. P3.21

3.22 As shown in Fig. P3.22, 0.1 kg of water is contained within a piston–cylinder assembly at 100°C. The piston is free to move smoothly in the cylinder. The local atmospheric pressure and acceleration of gravity are 100 kPa and 9.81 m/s^2, respectively. For the water, determine the pressure, in kPa, and volume, in cm^3.

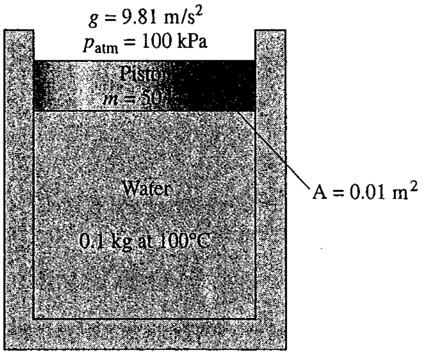


Fig. P3.22

3.23 Ammonia, initially saturated vapor at −4°C, undergoes a constant-specific volume process to 200 kPa. At the final state, determine the temperature, in °C, and the quality. Locate each state on a sketch of the T–v diagram.

3.24 Water contained in a closed, rigid tank, initially saturated vapor at 200°C, is cooled to 100°C. Determine the initial and final pressures, each in bar. Locate the initial and final states on sketches of the p–v and T–v diagrams.

3.25 A closed, rigid tank whose volume is 1.5 m^3 contains Refrigerant 134a, initially a two-phase liquid–vapor mixture at 10°C. The refrigerant is heated to a final state where temperature is 50°C and quality is 100%. Locate the initial and final states on a sketch of the T–v diagram. Determine the mass of vapor present at the initial and final states, each in kg.

3.26 In each of the following cases, ammonia contained in a closed, rigid tank is heated from an initial saturated vapor state at temperature T_1 to the final temperature, T_2:

(a) T_1 = 20°C, T_2 = 40°C. Using *IT*, determine the final pressure, in bar.
(b) T_1 = 70°F, T_2 = 120°F. Using *IT*, determine the final pressure, in lbf/in.^{2}

Compare the pressure values determined using *IT* with those obtained using the appropriate Appendix tables for ammonia.

3.27 Propane is contained in a closed, rigid container with a volume of 10 m^3. Initially the pressure and temperature of the propane are 8 bar and 80°C, respectively. The temperature drops as a result of energy rejected by heat transfer to the surroundings. Determine the temperature at which condensation first occurs, in °C, and the fraction of the total mass that has condensed when the pressure reaches 5 bar. What is the volume, in m^3, occupied by saturated liquid at the final state?

✓ **3.28** Water vapor is cooled in a closed, rigid tank from 520°C and 100 bar to a final temperature of 270°C. Determine the final pressure, in bar, and sketch the process on T–v and p–v diagrams.

3.29 Ammonia contained in a piston–cylinder assembly, initially saturated vapor at 0°F, undergoes an isothermal process during which its volume (a) doubles, (b) reduces by a half. For each case, fix the final state by giving the quality or pressure, in lbf/in.^{2}, as appropriate. Locate the initial and final states on sketches of the p–v and T–v diagrams.

3.30 One kg of water initially is at the critical point.

(a) If the water is cooled at constant-specific volume to a pressure of 30 bar, determine the quality at the final state.
(b) If the water undergoes a constant-temperature expansion to a pressure of 30 bar, determine the specific volume at the final state, in m^3/kg.

Show each process on a sketch of the T–v diagram.

✓ **3.31** As shown in Fig. P3.31, a cylinder fitted with a piston is filled with 600 lb of saturated liquid ammonia at 45°F. The piston weighs 1 ton and has a diameter of 2.5 ft. What is the volume occupied by the ammonia, in ft^3? Ignoring friction, is it necessary to provide mechanical attachments, such as stops, to hold the piston in place? Explain.

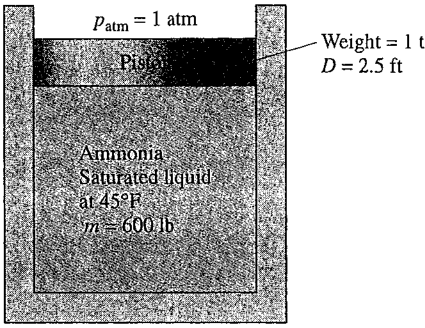


Fig. P3.31

3.32 Two lb of water vapor in a piston–cylinder assembly is compressed at a constant pressure of 250 lbf/in.^{2} from a volume of 6.88 ft^3 to a saturated vapor state. Determine the temperatures at the initial and final states, each in °F, and the work for the process, in Btu.

3.33 Seven lb of propane in a piston–cylinder assembly, initially at p_1 = 200 lbf/in.^{2} and T_1 = 200°F, undergoes a constant-pressure process to a final state. The work for the process is −88.84 Btu. At the final state, determine the temperature, in °F, if superheated, or the quality if saturated.

3.34 Ammonia in a piston–cylinder assembly undergoes a constant-pressure process at 2.5 bar from T_1 = 30°C to saturated vapor. Determine the work for the process, in kJ per kg of refrigerant.

3.35 From an initial state where the pressure is p_1, the temperature is T_1, and the volume is V_1, water vapor contained in a piston–cylinder assembly undergoes each of the following processes:

Process 1–2: Constant-temperature to $p_2 = 2p_1$.
Process 1–3: Constant-volume to $p_3 = 2p_1$.
Process 1–4: Constant-pressure to $V_4 = 2V_1$
Process 1–5: Constant-temperature to $V_5 = 2V_1$

On a p–V diagram, sketch each process, identify the work by an area on the diagram, and indicate whether the work is done by, or on, the water vapor.

3.36 Three kilograms of Refrigerant 22 undergo a process for which the pressure–specific volume relation is $pv^{-0.8} = constant$. The initial state of the refrigerant is 12 bar and 60°C, and the final pressure is 8 bar. Kinetic and potential energy effects are negligible. Determine the work, in kJ, for the process.

√ **3.37** As shown in Fig. P3.37, Refrigerant 134a is contained in a piston–cylinder assembly, initially as saturated vapor. The refrigerant is slowly heated until its temperature is 160°C. During the process, the piston moves smoothly in the cylinder. For the refrigerant, evaluate the work, in kJ/kg.

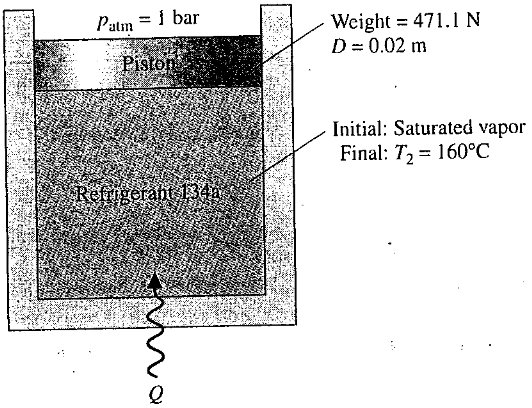


Fig. P3.37

3.38 A piston–cylinder assembly contains 0.1 lb of propane. The propane expands from an initial state where p_1 = 60 lbf/in.^{2} and T_1 = 30°F to a final state where p_2 = 10 lbf/in.^{2} During the process, the pressure and specific volume are related by $pv^2 = constant$. Determine the energy transfer by work, in Btu.

Using *u–h* Data

3.39 Determine the values of the specified properties at each of the following conditions.

(a) For Refrigerant 134a at T = 60°C and v = 0.072 m^3/kg, determine p in kPa and h in kJ/kg.
(b) For ammonia at p = 8 bar and v = 0.005 m^3/kg, determine T in °C and u in kJ/kg.
(c) For Refrigerant 22 at T = −10°C and u = 200 kJ/kg, determine p in bar and v in m^3/kg.

3.40 Determine the values of the specified properties at each of the following conditions.

(a) For Refrigerant 134a at p = 140 lbf/in.^{2} and h = 100 Btu/lb, determine T in °F and v in ft^3/lb.
(b) For ammonia at T = 0°F and v = 15 ft^3/lb, determine p in lbf/in.^{2} and h in Btu/lb.
(c) For Refrigerant 22 at T = 30°F and v = 1.2 ft^3/lb, determine p in lbf/in.^{2} and h in Btu/lb.

3.41 Using *IT*, determine the specified property data at the indicated states. Compare with results from the appropriate table.

(a) Cases (a), (b), and (c) of Problem 3.39.
(b) Cases (a), (b), and (c) of Problem 3.40.

√ **3.42** Using the tables for water, determine the specified property data at the indicated states. In each case, locate the state by hand on sketches of the $p–v$ and $T–v$ diagrams.

(a) At p = 2 MPa, T = 300°C. Find u, in kJ/kg.
(b) At p = 2.5 MPa, T = 200°C. Find u, in kJ/kg.
(c) At T = 170 F, x = 50%. Find u, in Btu/lb.
(d) At p = 100 lbf/in.^{2}, T = 300°F. Find h, in Btu/lb
(e) At p = 1.5 MPa, v = 0.2095 m^3/kg. Find h, in kJ/kg.

3.43 For each case, determine the specified property value and locate the state by hand on sketches of the $p–v$ and $T–v$ diagrams.

(a) For Refrigerant 134a at T = 160°F, h = 127.7 Btu/lb. Find v, in ft^3/lb.
(b) For Refrigerant 134a at T = 90°F, u = 72.71 Btu/lb. Find h, in Btu/lb.
(c) For ammonia at T = 160°F, p = 60 lbf/in.^{2} Find u, in Btu/lb.
(d) For ammonia at T = 0°F, p = 35 lbf/in.^{2} Find u, in Btu/lb.
(e) For Refrigerant 22 at p = 350 lbf/in.^{2}, T = 350°F. Find u, in Btu/lb.

3.44 Using the tables for water, determine the specified property data at the indicated states. In each case, locate the state by hand on sketches of the $p–v$ and $T–v$ diagrams.

(a) At p = 3 bar, v = 0.5 m^3/kg, find T in °C and u in kJ/kg.
(b) At T = 320°C, v = 0.03 m^3/kg, find p in MPa and u in kJ/kg.
(c) At p = 28 MPa, T = 520°C, find v in m^3/kg and h in kJ/kg.
(d) At T = 10°C, v = 100 m^3/kg, find p in kPa and h in kJ/kg.
(e) At p = 4 MPa, T = 160°C, find v in m^3/kg and u in kJ/kg.

√ **3.45** Using the tables for water, determine the specified property data at the indicated states. In each case, locate the state by hand on sketches of the $p–v$ and $T–v$ diagrams.

(a) At p = 20 lbf/in.^{2}, v = 16 ft^3/lb, find T in °F and u in Btu/lb.
(b) At T = 900°F, p = 170 lbf/in.^{2}, find v in ft^3/lb and h in Btu/lb.
(c) At T = 600°F, v = 0.6 ft^3/lb, find p in lbf/in.^{2} and u in Btu/lb.
(d) At T = 40°F, v = 1950 ft^3/lb, find p in lbf/in.^{2} and h in Btu/lb.
(e) At p = 600 lbf/in.^{2}, T = 320°F, find v in ft^3/lb and u in Btu/lb.

3.46 For each case, determine the specified property data and locate the state by hand on a sketch of the $T–v$ diagram.

(a) Evaluate the specific volume, in ft^3/lb, and the specific enthalpy, in Btu/lb, of water at 400°F and a pressure of 3000 lbf/in.^{2}
(b) Evaluate the specific volume, in ft^3/lb, and the specific enthalpy, in Btu/lb, of Refrigerant 134a at 95°F and 150 lbf/in.^{2}
(c) Evaluate the specific volume, in m^3/kg, and the specific enthalpy, in kJ/kg, of ammonia at 20°C and 1.0 MPa.
(d) Evaluate the specific volume, in m^3/kg, and the specific enthalpy, in kJ/kg, of propane at 800 kPa and 0°C.

Applying the Energy Balance

3.47 Water, initially saturated vapor at 4 bar, fills a closed, rigid container. The water is heated until its temperature is 400°C. For the water, determine the heat transfer, in kJ/kg. Kinetic and potential energy effects can be ignored.

3.48 A closed, rigid tank contains Refrigerant 134a, initially at 100°C. The refrigerant is cooled until it becomes saturated vapor at 20°C. For the refrigerant, determine the initial and final pressures, each in bar, and the heat transfer, in kJ/kg. Kinetic and potential energy effects can be ignored.

3.49 A closed, rigid tank is filled with water. Initially, the tank holds 9.9 ft^3 saturated vapor and 0.1 ft^3 saturated liquid, each at 212°F. The water is heated until the tank contains only saturated vapor. For the water, determine (a) the quality at the initial state, (b) the temperature at the final state, in °F, and (c) the heat transfer, in Btu. Kinetic and potential energy effects can be ignored.

3.50 A closed, rigid tank is filled with water, initially at the critical point. The water is cooled until it attains a temperature of 400°F. For the water, show the process on a sketch of the T–v diagram and determine the heat transfer, in Btu/lb.

3.51 Propane within a piston–cylinder assembly undergoes a constant-pressure process from saturated vapor at 400 kPa to a temperature of 40°C. Kinetic and potential energy effects are negligible. For the propane, (a) show the process on a p–v diagram, (b) evaluate the work, in kJ/kg, and (c) evaluate the heat transfer, in kJ/kg.

3.52 Refrigerant 134a expands in a piston–cylinder assembly from 180 lbf/in.^{2} and 140°F to 30 lbf/in.^{2} The mass of refrigerant is 0.5 lb. During the process, heat transfer to the refrigerant from its surroundings is 1.2 Btu while the work done by the refrigerant is 4.32 Btu. Determine the final temperature of the refrigerant, in °F. Kinetic and potential energy effects are negligible.

3.53 Ammonia vapor in a piston–cylinder assembly undergoes a constant-pressure process from saturated vapor at 10 bar. The work is +16.5 kJ/kg. Changes in kinetic and potential energy are negligible. Determine (a) the final temperature of the ammonia, in °C, and (b) the heat transfer, in kJ/kg.

3.54 Water in a piston–cylinder assembly, initially at a temperature of 99.63°C and a quality of 65%, is heated at constant pressure to a temperature of 200°C. If the work during the process is +300 kJ, determine (a) the mass of water, in kg, and (b) the heat transfer, in kJ. Changes in kinetic and potential energy are negligible.

3.55 A piston–cylinder assembly containing water, initially a liquid at 50°F, undergoes a process at a constant pressure of 20 lbf/in.^{2} to a final state where the water is a vapor at 300°F. Kinetic and potential energy effects are negligible. Determine the work and heat transfer, in Btu per lb, for each of three parts of the overall process: (a) from the initial liquid state to the saturated liquid state, (b) from saturated liquid to saturated vapor, and (c) from saturated vapor to the final vapor state, all at 20 lbf/in.^{2}

3.56 As shown in Fig. P3.56, 0.1 kg of propane is contained within a piston-cylinder assembly at a constant pressure of 0.2 MPa. Energy transfer by heat occurs slowly to the propane, and the volume of the propane increases from 0.0277 m^3 to 0.0307 m^3. Friction between the piston and cylinder is negligible. The local atmospheric pressure and acceleration of gravity are 100 kPa and 9.81 m/s^2, respectively. The propane experiences no significant kinetic and potential energy effects. For the propane, determine (a) the initial and final temperatures, in °C, (b) the work, in kJ, and (c) the heat transfer, in kJ.

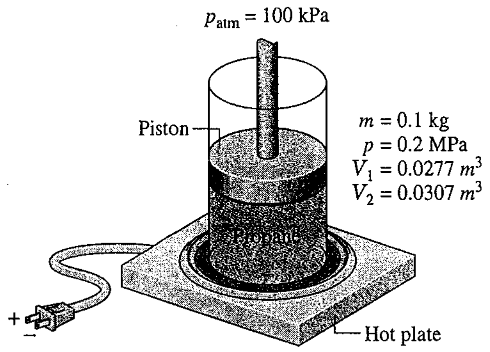


Fig. P3.56

3.57 A piston–cylinder assembly contains water, initially saturated liquid at 150°C. The water is heated at constant temperature to saturated vapor.

(a) If the rate of heat transfer to the water is 2.28 kW, determine the rate at which work is done by the water on the piston, in kW.
(b) If in addition to the heat transfer rate given in part (a) the total mass of water is 0.1 kg, determine the time, in s, required to execute the process.

3.58 A closed, rigid tank contains 2 kg of water, initially a two-phase liquid–vapor mixture at 80°C. Heat transfer occurs until the tank contains only saturated vapor with v = 2.045 m^3/kg. For the water, locate the initial and final states on a sketch of the T–v diagram and determine the heat transfer, in kJ.

√**3.59** As shown in Fig. P3.59, a rigid, closed tank having a volume of 20 ft^3 and filled with 75 lb of Refrigerant 134a is exposed to the sun. At 9:00 a.m., the refrigerant is at a pressure of 100 lbf/in.^{2} By 3:00 p.m., owing to solar radiation, the refrigerant is a saturated vapor at a pressure greater than 100 lbf/in.^{2} For the refrigerant, determine (a) the initial

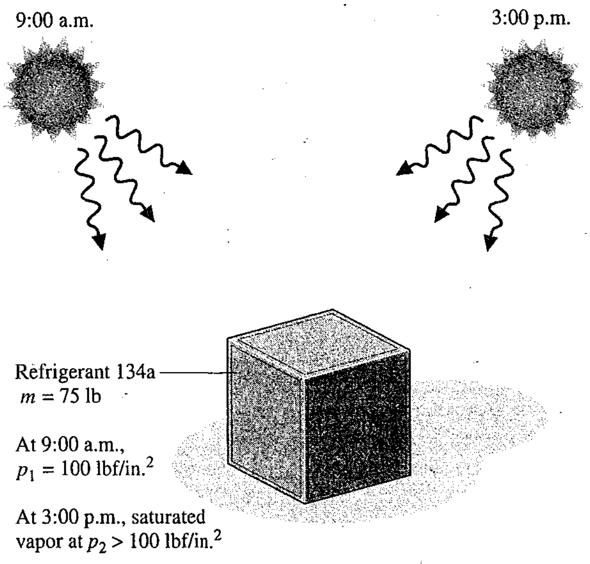


Fig. P3.59

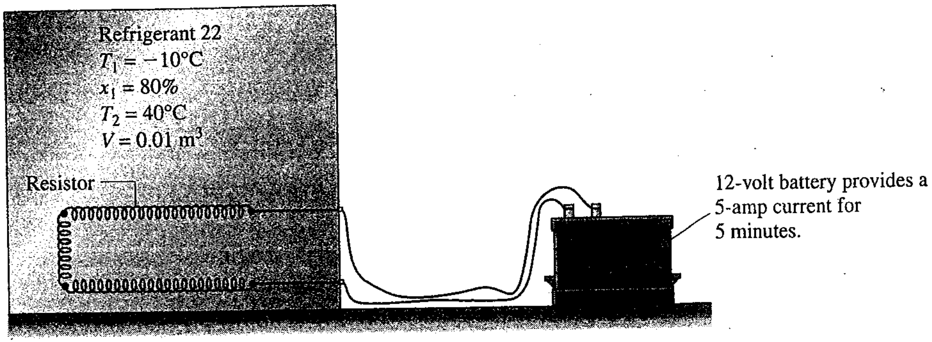


Fig. P3.63

temperature, in °F, (b) the final pressure, in lbf/in.^{2}, and (c) the heat transfer, in Btu.

3.60 A rigid, insulated tank fitted with a paddle wheel is filled with water, initially a two-phase liquid–vapor mixture at 20 lbf/in.^{2}, consisting of 0.07 lb of saturated liquid and 0.07 lb of saturated vapor. The tank contents are stirred by the paddle wheel until all of the water is saturated vapor at a pressure greater than 20 lbf/in.^{2} Kinetic and potential energy effects are negligible. For the water, determine the

(a) volume occupied, in ft^3.
(b) initial temperature, in °F.
(c) final pressure, in lbf/in.^{2}
(d) work, in Btu.

3.61 If the hot plate of Example 3.2 transfers energy at a rate of 0.1 kW to the two-phase mixture, determine the time required, in h, to bring the mixture from (a) state 1 to state 2, (b) state 1 to state 3.

✓**3.62** A closed, rigid tank filled with water, initially at 20 bar, a quality of 80%, and a volume of 0.5 m^3, is cooled until the pressure is 4 bar. Show the process of the water on a sketch of the T–v diagram and evaluate the heat transfer, in kJ.

✓**3.63** As shown in Fig. P3.63, a closed, rigid tank fitted with a fine-wire electric resistor is filled with Refrigerant 22, initially at −10°C, a quality of 80%, and a volume of 0.01 m^3. A 12-volt battery provides a 5-amp current to the resistor for 5 minutes. If the final temperature of the refrigerant is 40°C, determine the heat transfer, in kJ, from the refrigerant.

3.64 A rigid, well-insulated tank contains a two-phase mixture of ammonia with 0.0025 ft^3 of saturated liquid and 1.5 ft^3 of saturated vapor, initially at 40 lbf/in.^{2} A paddle wheel stirs the mixture until only saturated vapor at higher pressure remains in the tank. Kinetic and potential energy effects are negligible. For the ammonia, determine the amount of energy transfer by work, in Btu.

3.65 A closed, rigid tank is filled with 0.02 lb of water, initially at 120°F and a quality of 50%. The water receives 8 Btu by heat transfer. Determine the temperature, in °F, pressure, in lbf/in.^{2}, and quality of the water at its final state.

3.66 A piston–cylinder assembly contains ammonia, initially at a temperature of −20°C and a quality of 50%. The ammonia is slowly heated to a final state where the pressure is 6 bar and the temperature is 180°C. While the ammonia is heated, its pressure varies linearly with specific volume. Show the process of the ammonia on a sketch of the p–v diagram. For the ammonia, determine the work and heat transfer, each in kJ/kg.

3.67 A rigid, well-insulated container with a volume of 2 ft^3 holds 0.12 lb of ammonia initially at a pressure of 20 lbf/in.^{2} The ammonia is stirred by a paddle wheel, resulting in an energy transfer to the ammonia with a magnitude of 1 Btu. For the ammonia, determine the initial and final temperatures, each in °R, and the final pressure, in lbf/in.^{2} Neglect kinetic and potential energy effects.

3.68 Water contained in a piston–cylinder assembly, initially at 300°F, a quality of 90%, and a volume of 6 ft^3, is heated at constant temperature to saturated vapor. If the rate of heat transfer is 0.3 Btu/s, determine the time, in min, for this process of the water to occur. Kinetic and potential energy effects are negligible.

3.69 Five kg of water is contained in a piston–cylinder assembly, initially at 5 bar and 240°C. The water is slowly heated at constant pressure to a final state. If the heat transfer for the process is 2960 kJ, determine the temperature at the final state, in °C, and the work, in kJ. Kinetic and potential energy effects are negligible.

3.70 Referring to Fig. P3.70, water contained in a piston–cylinder assembly, initially at 1.5 bar and a quality of 20%, is heated at constant pressure until the piston hits the stops. Heating then continues until the water is saturated vapor. Show the processes of the water in series on a sketch of the T–v diagram. For the overall process of the water, evaluate the work and heat transfer, each in kJ/kg. Kinetic and potential effects are negligible.

3.71 A piston–cylinder assembly contains 2 lb of water, initially at 300°F. The water undergoes two processes in series: constant-volume heating followed by a constant-pressure process. At the end of the constant-volume process, the pressure is 100 lbf/in.^{2} and the water is a two-phase, liquid–vapor mixture with a quality of 80%. At the end of the constant-pressure process, the temperature is 400°F. Neglect kinetic and potential energy effects.

(a) Sketch T–v and p–v diagrams showing key states and the processes.
(b) Determine the work and heat transfer for each of the two processes, all in Btu.

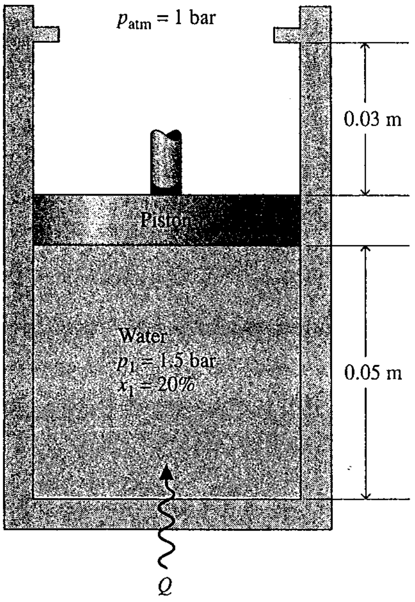


Fig. P3.70

3.72 A system consisting of 3 lb of water vapor in a piston–cylinder assembly, initially at 350°F and a volume of 71.7 ft^3, is expanded in a constant-pressure process to a volume of 85.38 ft^3. The system then is compressed isothermally to a final volume of 28.2 ft^3. During the isothermal compression, energy transfer by work into the system is 72 Btu. Kinetic and potential energy effects are negligible. Determine the heat transfer, in Btu, for each process.

3.73 Ammonia in a piston–cylinder assembly undergoes two processes in series. Initially, the ammonia is saturated vapor at p_1 = 100 lbf/in.^{2} Process 1–2 involves cooling at constant pressure until x_2 = 75%. The second process, from state 2 to state 3, involves heating at constant volume until x_3 = 100%. Kinetic and potential energy effects are negligible. For 1.2 lb of ammonia, determine (a) the heat transfer and work for Process 1–2 and (b) the heat transfer for Process 2–3, all in Btu.

3.74 Three lb of water is contained in a piston–cylinder assembly, initially occupying a volume V_1 = 30 ft^3 at T_1 = 300°F. The water undergoes two processes in series:

Process 1–2: Constant-temperature compression to V_2 = 11.19 ft^3, during which there is an energy transfer by heat *from* the water of 1275 Btu.

Process 2–3: Constant-volume heating to p_3 = 120 lbf/in.^{2}

Sketch the two processes in series on a T–v diagram. Neglecting kinetic and potential energy effects, determine the work in Process 1–2 and the heat transfer in Process 2–3, each in Btu.

3.75 As shown in Fig. P3.75, a piston-cylinder assembly fitted with stops contains 0.1 kg of water, initially at 1 MPa, 500°C. The water undergoes two processes in series:

Process 1–2: Constant-pressure cooling until the piston face rests against the stops. The volume occupied by the water is then one-half its initial volume.

Process 2–3: With the piston face resting against the stops, the water cools to 25°C.

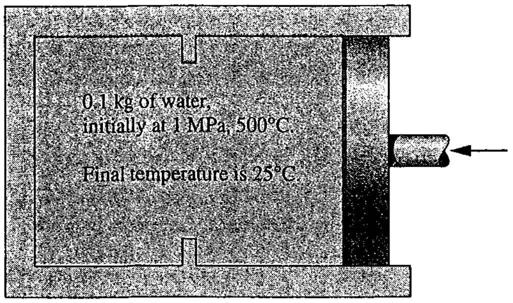


Fig. P3.75

Sketch the two processes in series on a p–v diagram. Neglecting kinetic and potential energy effects, evaluate for each process the work and heat transfer, each in kJ.

✓**3.76** A two-phase, liquid–vapor mixture of H_2O, initially at x = 30% and a pressure of 100 kPa, is contained in a piston–cylinder assembly, as shown in Fig P3.76. The mass of the piston is 10 kg, and its diameter is 15 cm. The pressure of the surroundings is 100 kPa. As the water is heated, the pressure inside the cylinder remains constant until the piston hits the stops. Heat transfer to the water continues at constant volume until the pressure is 150 kPa. Friction between the piston and the cylinder wall and kinetic and potential energy effects are negligible. For the overall process of the water, determine the work and heat transfer, each in kJ.

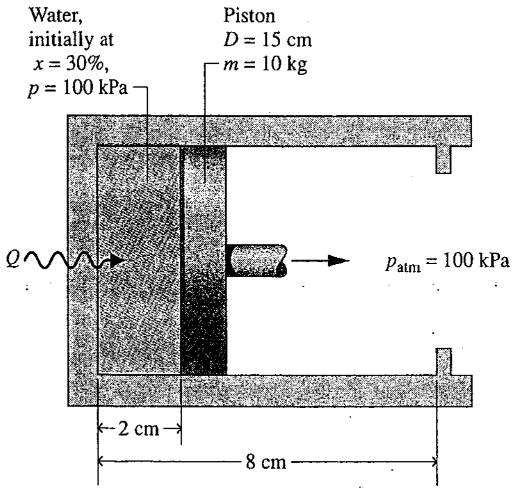


Fig. P3.76

3.77 A system consisting of 1 kg of H_2O undergoes a power cycle composed of the following processes:

Process 1–2: Constant-pressure heating at 10 bar from saturated vapor.

Process 2–3: Constant-volume cooling to p_3 = 5 bar, T_3 = 160°C.

Process 3–4: Isothermal compression with Q_{34} = −815.8 kJ.

Process 4–1: Constant-volume heating.

Sketch the cycle on T–v and p–v diagrams. Neglecting kinetic and potential energy effects, determine the thermal efficiency.

Working with the Ideal Gas Model

3.100 A tank contains 0.5 m^3 of nitrogen (N_2) at −71°C and 1356 kPa. Determine the mass of nitrogen, in kg, using

(a) the ideal gas model.
(b) data from the compressibility chart.

Comment on the applicability of the ideal gas model for nitrogen at this state.

✓ **3.101** Determine the percent error in using the ideal gas model to determine the specific volume of

(a) water vapor at 4000 $lbf/in.^2$, 1000°F.
(b) water vapor at 5 $lbf/in.^2$, 250°F.
(c) ammonia at 40 $lbf/in.^2$, 60°F.
(d) air at 1 atm, 560°R.
(e) Refrigerant 134a at 300 $lbf/in.^2$, 180°F.

3.102 Check the applicability of the ideal gas model

(a) for water at 700°F and pressures of 1600 $lbf/in.^2$ and 160 $lbf/in.^2$
(b) for carbon dioxide at 865 K and pressures of 75 bar and 3 bar.

3.103 Determine the specific volume, in m^3/kg, of Refrigerant 134a at 16 bar, 100°C, using

(a) Table A-12.
(b) Figure A-1.
(c) the ideal gas equation of state.

Compare the values obtained in parts (b) and (c) with that of part (a).

3.104 Determine the specific volume, in m^3/kg, of ammonia at 50°C, 10 bar, using

(a) Table A-15.
(b) Figure A-1.
(c) the ideal gas equation of state.

Compare the values obtained in parts (b) and (c) with that of part (a).

3.105 A closed, rigid tank is filled with a gas modeled as an ideal gas, initially at 27°C and a gage pressure of 300 kPa. If the gas is heated to 77°C, determine the final pressure, expressed as a gage pressure, in kPa. The local atmospheric pressure is 1 atm.

3.106 The air in a room measuring 8 ft × 9 ft × 12 ft is at 80°F and 1 atm. Determine the mass of the air, in lb, and its weight, in lbf, if $g = 32.0\ ft/s^2$.

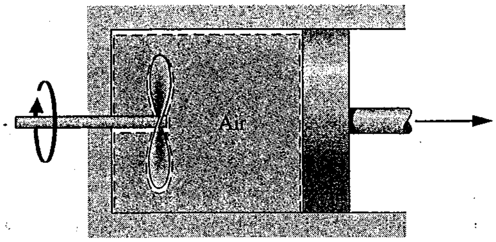
3.107 Determine the total mass of nitrogen (N_2), in kg, required to inflate all four tires of a vehicle, each to a gage pressure of 180 kPa at a temperature of 25°C. The volume of each tire is 0.6 m^3, and the atmospheric pressure is 1 atm.

3.108 Using Table A-18, determine the temperature, in K and °C, of propane at a state where the pressure is 2 bar and the specific volume is 0.307 m^3/kg. Compare with the temperature, in K and °C, respectively, obtained using Fig. A-1. Comment.

3.109 A balloon filled with helium, initially at 27°C, 1 bar, is released and rises in the atmosphere until the helium is at 17°C, 0.9 bar. Determine, as a percent, the change in volume of the helium from its initial volume.

Using Energy Concepts and the Ideal Gas Model

3.110 As shown in Fig. P3.110, a piston–cylinder assembly fitted with a paddle wheel contains air, initially at $p_1 = 30\ lbf/in.^2$, $T_1 = 540°F$, and $V_1 = 4\ ft^3$. The air undergoes a process to a final state where $p_2 = 20\ lbf/in.^2$, $V_2 = 4.5\ ft^3$. During the process, the paddle wheel transfers energy *to* the air by work in the amount 1 Btu, while the air transfers energy by work *to* the piston in the amount 3.31 Btu. Assuming ideal gas behavior, determine for the air (a) the temperature at state 2, in °R, and (b) the heat transfer, in Btu.



Initially, $p_1 = 30\ lbf/in.^2$, $T_1 = 540°F$, $V_1 = 4\ ft^3$.
Finally, $p_2 = 20\ lbf/in.^2$, $V_2 = 4.5\ ft^3$.

Fig. P3.110

3.111 A piston–cylinder assembly contains air, initially at 2 bar, 300 K, and a volume of 2 m^3. The air undergoes a process to a state where the pressure is 1 bar, during which the pressure–volume relationship is $pV = constant$. Assuming ideal gas behavior for the air, determine the mass of the air, in kg, and the work and heat transfer, each in kJ.

3.112 Air contained in a piston–cylinder assembly, initially at 2 bar, 200 K, and a volume of 1 L, undergoes a process to a final state where the pressure is 8 bar and the volume is 2 L. During the process, the pressure–volume relationship is linear. Assuming the ideal gas model for the air, determine the work and heat transfer, each in kJ.

3.113 Carbon dioxide (CO_2) contained in a piston–cylinder arrangement, initially at 6 bar and 400 K, undergoes an expansion to a final temperature of 298 K, during which the pressure–volume relationship is $pV^{1.2} = constant$. Assuming the ideal gas model for the CO_2, determine the final pressure, in bar, and the work and heat transfer, each in kJ/kg.

3.114 Water vapor contained in a piston–cylinder assembly undergoes an isothermal expansion at 240°C from a pressure of 7 bar to a pressure of 3 bar. Evaluate the work, in kJ/kg. Solve two ways: using (a) the ideal gas model, (b) *IT* with *water/steam* data. Comment.

✓ **3.115** One kilogram of nitrogen fills the cylinder of a piston–cylinder assembly, as shown in Fig. P3.115. There is no friction between the piston and the cylinder walls, and the surroundings are at 1 atm. The initial volume and pressure in the cylinder are 1 m^3 and 1 atm, respectively. Heat transfer to the nitrogen occurs until the volume is doubled. Determine the heat transfer for the process, in kJ, assuming the specific heat ratio is constant, $k = 1.4$.

occurs *from* the nitrogen *to* its surroundings. Assuming ideal gas behavior, determine the nitrogen's final temperature, in °C, and final pressure, in MPa.

3.126 A closed, rigid tank fitted with a paddle wheel contains 0.1 kg of air, initially at 300 K, 0.1 MPa. The paddle wheel stirs the air for 20 minutes, with the power input varying with time according to $\dot{W} = -10t$, where $\dot{W}$ is in watts and t is time, in minutes. The final temperature of the air is 1060 K. Assuming ideal gas behavior and no change in kinetic or potential energy, determine for the air (a) the final pressure, in MPa, (b) the work, in kJ, and (c) the heat transfer, in kJ.

3.127 As shown in Fig. P3.127, one side of a rigid, insulated container initially holds 2 m^3 of air at 27°C, 0.3 MPa. The air is separated by a thin membrane from an evacuated volume of 3 m^3. Owing to the pressure of the air, the membrane stretches and eventually bursts, allowing the air to occupy the full volume. Assuming the ideal gas model for the air, determine (a) the mass of the air, in kg, (b) the final temperature of the air, in K, and (c) the final pressure of the air, in MPa.

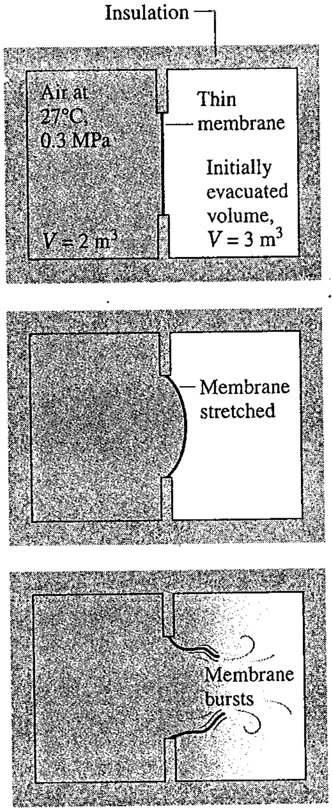


Fig. P3.127

3.128 Air is confined to one side of a rigid container divided by a partition, as shown in Fig. P3.128. The other side is initially evacuated. The air is initially at $p_1 = 5$ bar, $T_1 = 500$ K, and $V_1 = 0.2$ m^3. When the partition is removed, the air expands to fill the entire chamber. Measurements show that $V_2 = 2\ V_1$ and $p_2 = p_1/4$. Assuming the air behaves as an ideal gas, determine (a) the final temperature, in K, and (b) the heat transfer, kJ.

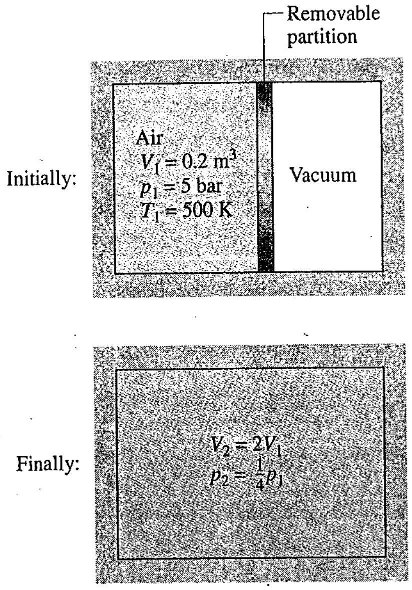


Fig. P3.128

3.129 Two kilograms of air, initially at 5 bar, 350 K and 4 kg of carbon monoxide (CO) initially at 2 bar, 450 K are confined to opposite sides of a rigid, well-insulated container by a partition, as shown in Fig. P3.129. The partition is free to move and allows conduction from one gas to the other without energy storage in the partition itself. The air and CO each behave as ideal gases with constant specific heat ratio, $k = 1.395$. Determine at equilibrium (a) the temperature, in K, (b) the pressure, in bar, and (c) the volume occupied by each gas, in m^3.

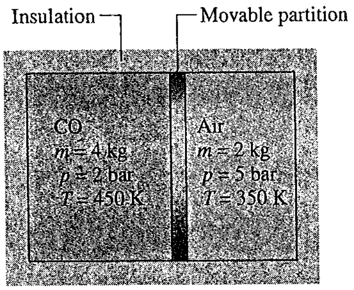


Fig. P3.129

3.130 As shown in Fig. P3.130, a piston–cylinder assembly contains 5 g of air holding the piston against the stops. The air, initially at 3 bar, 600 K, is slowly cooled until the piston just begins to move downward in the cylinder. The air behaves as an ideal gas, $g = 9.81$ m/s^2, and friction is negligible. Sketch the process of the air on a p–V diagram labeled with the temperature and pressure at the end states. Also determine the heat transfer, in kJ, between the air and its surroundings.

3.131 Five kilograms of a gas with molecular weight of 32 kg/kmol and a temperature of 110°C is contained in a closed, rigid tank fitted with an electric resistor whose mass is negligible. The resistor draws a constant current of 12 amps

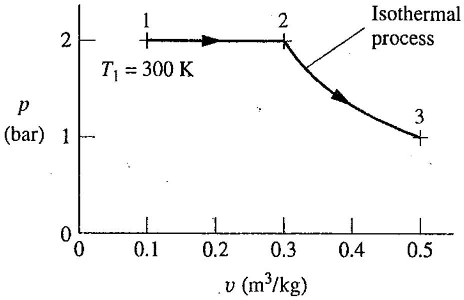


Fig. P3.137

3.139 One kilogram of air in a piston-cylinder assembly undergoes two processes in series from an initial state where p_1 = 0.5 MPa, T_1 = 227°C:

Process 1–2: Constant-temperature expansion until the volume is twice the initial volume.

Process 2–3: Constant-volume heating until the pressure is again 0.5 MPa.

Sketch the two processes in series on a p–v diagram. Assuming ideal gas behavior, determine (a) the pressure at state 2, in MPa, (b) the temperature at state 3, in °C, and for each of the processes (c) the work and heat transfer, each in kJ.

✓ **3.140** Air contained in a piston–cylinder assembly undergoes the power cycle shown in Fig. P3.140. Assuming ideal gas behavior for the air, evaluate the thermal efficiency of the cycle.

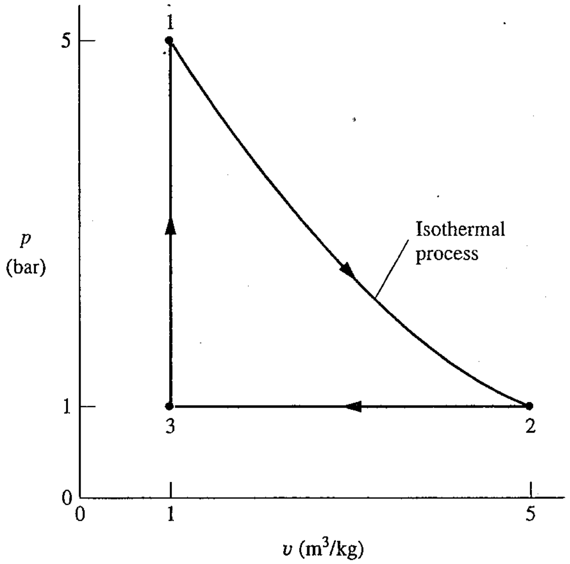


Fig. P3.140

3.141 A piston–cylinder assembly contains air modeled as an ideal gas with a constant specific heat ratio, k = 1.4. The air undergoes a power cycle consisting of four processes in series:

Process 1–2: Constant-temperature expansion at 600 K from p_1 = 0.5 MPa to p_2 = 0.4 MPa.

Process 2–3: Polytropic expansion with $n = k$ to p_3 = 0.3 MPa.

Process 3–4: Constant-pressure compression to $V_4 = V_1$.

Process 4–1: Constant-volume heating.

Sketch the cycle on a p–v diagram. Determine (a) the work and heat transfer for each process, in kJ/kg, and (d) the thermal efficiency.

3.142 One lb of oxygen, O_2, undergoes a power cycle consisting of the following processes:

Process 1–2: Constant-volume from p_1 = 20 lbf/in.², T_1 = 500°R to T_2 = 820°R.

Process 2–3: Adiabatic expansion to $v_3 = 1.432v_2$.

Process 3–1: Constant-pressure compression to state 1.

Sketch the cycle on a p–v diagram. Assuming ideal gas behavior, determine

(a) the pressure at state 2, in lbf/in.²
(b) the temperature at state 3, in °R.
(c) the heat transfer and work, each in Btu, for all processes.
(d) the thermal efficiency of the cycle.

3.143 A system consists of 2 kg of carbon dioxide gas initially at state 1, where p_1 = 1 bar, T_1 = 300 K. The system undergoes a power cycle consisting of the following processes:

Process 1–2: Constant volume to $p_2, p_2 > p_1$

Process 2–3: Expansion with $pv^{1.28}$ = *constant*

Process 3–1: Constant-pressure compression

Assuming the ideal gas model and neglecting kinetic and potential energy effects,

(a) sketch the cycle on a p–v diagram.
(b) plot the thermal efficiency versus p_2/p_1 ranging from 1.05 to 4.

3.144 Air undergoes a polytropic process in a piston–cylinder assembly from p_1 = 14.7 lbf/in.², T_1 = 70°F to p_2 = 100 lbf/in.² Using *IT*, plot the work and heat transfer, each in Btu per lb of air, for polytropic exponents ranging from 1.0 to 1.6. Investigate the error in the heat transfer introduced by assuming constant c_v evaluated at 70°F. Discuss.

3.145 Steam, initially at 5 MPa, 280°C undergoes a polytropic process in a piston–cylinder assembly to a final pressure of 20 MPa. Using *IT*, plot the heat transfer, in kJ per kg of steam, for polytropic exponents ranging from 1.0 to 1.6. Investigate the error in the heat transfer introduced by assuming ideal gas behavior for the steam. Discuss.

Reviewing Concepts

3.146 Answer the following true or false. Explain.

(a) For a gas modeled as an ideal gas, $c_p = c_v + R$, where R is the gas constant for the gas.
(b) Air always can be regarded as a *pure substance.*
(c) Water at p = 100 lbf/in.² and v = 0.0169 ft³/lb is a *compressed* liquid.
(d) Atmospheric air is normally not modeled as an ideal gas.
(e) For liquid water, the following approximation is reasonable for many engineering calculations: $v(T, p) = v_f(T)$.