3.3 A system consists of liquid water in equilibrium with a gaseous mixture of air and water vapor. How many phases are present? Does the system consist of a pure substance? Explain. Repeat for a system consisting of ice and liquid water in equilibrium with a gaseous mixture of air and water vapor.

3.4 An open container of pure ethanol (ethyl alcohol) liquid is placed on a table in a room. Evaporation occurs until all of the ethanol is gone. Where did the ethanol go? If the ethanol and the room air are taken to be a closed system, can the system be regarded as a pure substance during the process? How many phases are present initially and finally? Explain.

Using p–v–T Data

3.5 Determine the phase or phases in a system consisting of H_2O at the following conditions and sketch p–v and T–v diagrams showing the location of each state.

(a) p = 100 lbf/in.², T = 327.86°F.
(b) p = 100 lbf/in.², T = 240°F.
(c) T = 212°F, p = 10 lbf/in.²
(d) T = 70°F, p = 20 lbf/in.²
(e) p = 14.7 lbf/in.², T = 20°F.

3.6 Determine the phase or phases in a system consisting of H_2O at the following conditions and sketch p–v and T–v diagrams showing the location of each state.

(a) p = 10 bar, T = 179.9°C.
(b) p = 10 bar, T = 150°C.
(c) T = 100°C, p = 0.5 bar.
(d) T = 20°C, p = 50 bar.
(e) p = 1 bar, T = −6°C.

3.7 The following table lists temperatures and specific volumes of water vapor at two pressures:

p = 1.0 MPa		p = 1.5 MPa	
T (°C)	v(m³/kg)	T (°C)	v(m³/kg)
200	0.2060	200	0.1325
240	0.2275	240	0.1483
280	0.2480	280	0.1627

Data encountered in solving problems often do not fall exactly on the grid of values provided by property tables, and *linear interpolation* between adjacent table entries becomes necessary. Using the data provided here, estimate

(a) the specific volume at T = 240°C, p = 1.25 MPa, in m³/kg.
(b) the temperature at p = 1.5 MPa, v = 0.1555 m³/kg, in °C.
(c) the specific volume at T = 220°C, p = 1.4 MPa, in m³/kg.

3.8 The following table lists temperatures and specific volumes of ammonia vapor at two pressures:

p = 50 lbf/in.²		p = 60 lbf/in.²	
T (°F)	v(ft³/lb)	T (°F)	v(ft³/lb)
100	6.836	100	5.659
120	7.110	120	5.891
140	7.380	140	6.120

Data encountered in solving problems often do not fall exactly on the grid of values provided by property tables, and *linear interpolation* between adjacent table entries becomes necessary. Using the data provided here, estimate

(a) the specific volume at T = 120°F, p = 54 lbf/in.², in ft³/lb.
(b) the temperature at p = 60 lbf/in.², v = 5.982 ft³/lb, in °F.
(c) the specific volume at T = 110°F, p = 58 lbf/in.², in ft³/lb.

3.9 Determine the volume change, in ft³, 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) T = 140°C, v = 0.5 m³/kg. Find T, in °C.
(b) p = 30 MPa, T = 100°C. Find v, in m³/kg.
(c) p = 10 MPa, T = 485°C. Find v, in m³/kg.
(d) T = 80°C, x = 0.75. Find p, in bar, and v, in m³/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 = 1 bar, T = 20°C. Find v, in m³/kg.
(b) Refrigerant 22 at p = 40 lbf/in.², x = 0.6. Find v, in ft³/lb.
(c) Ammonia at p = 200 lbf/in.², T = 195°F. Find v, in ft³/lb.

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 m³/kg, p = 3 bar, determine T, in °C.
(b) Ammonia at p = 11 lbf/in.², T = −20°F, determine v, in ft³/lb.
(c) Propane at p = 1 MPa, T = 85°C, determine v, in m³/kg.

3.13 For H_2O, determine the specific volume at the indicated state, in m³/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 sketche[s] of the p–v, T–v, and phase diagrams.

(a) T = 120°C, p = 5 bar.
(b) T = 120°C, v = 0.6 m³/kg.
(c) T = 120°C, p = 1 bar.

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

(a) Four kg of water at 100°C fills a closed container havi[ng] a volume of 1 m³. If the water at this state is a vap[or] determine the pressure, in bar. If the water is a two-ph[ase] liquid–vapor mixture, determine the quality.
(b) Ammonia at a pressure of 40 lbf/in.² has a spec[ific] internal energy of 308.75 Btu/lb. Determine the spec[ific] volume at the state, in ft³/lb.

3.16 A 1-m³ tank holds a two-phase liquid–vapor mixtur[e] carbon dioxide at −17°C. The quality of the mixture is 7[...] For saturated carbon dioxide at −17°C, v_f = 0.9827 × [...] m³/kg and v_g = 1.756 × 10⁻² m³/kg. Determine the m[...]

of saturated liquid and saturated vapor, each in kg. What is the percent of the total volume occupied by saturated liquid?

3.17 Determine the volume, in ft^3, of 2 lb of a two-phase liquid–vapor mixture of Refrigerant 134A at 40°F with a quality of 20%. What is the pressure, in $lbf/in.^2$?

3.18 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.

3.19 A tank contains a two-phase liquid–vapor mixture of Refrigerant 22 at 10 bar. The mass of saturated liquid in the tank is 25 kg and the quality is 60%. Determine the volume of the tank, in m^3, and the fraction of the total volume occupied by saturated vapor.

3.20 As shown in Fig. P3.20, 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. P3.20

3.21 As shown in Fig. P3.21 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.

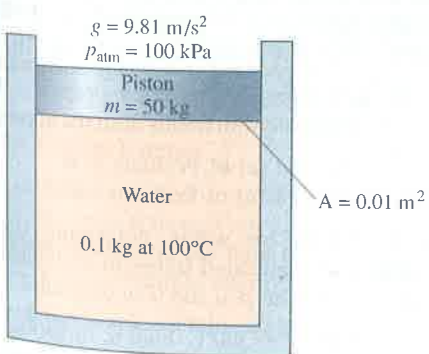


Fig. P3.21

3.22 Ammonia, initially at 6 bar, 40°C undergoes a constant-specific volume process to a final pressure of 3 bar. At the final state, determine the temperature, in °C, and the quality. Locate each state on a sketch of the T–v diagram.

3.23 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.

3.24 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.

3.25 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.

3.26 A closed, rigid tank contains a two-phase liquid–vapor mixture of Refrigerant 22 initially at −20°C with a quality of 50.36%. Energy transfer by heat into the tank occurs until the refrigerant is at a final pressure of 6 bar. Determine the final temperature, in °C. If the final state is in the superheated vapor region, at what temperature, in °C, does the tank contain only saturated vapor?

3.27 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.

3.28 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 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.

3.29 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.

3.30 As shown in Fig. P3.30, 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.

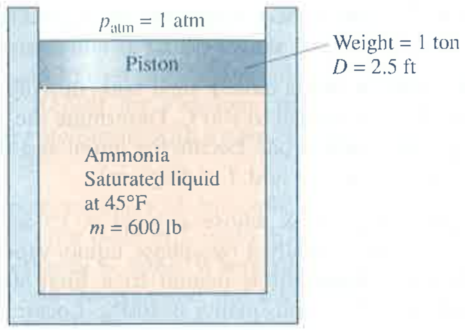


Fig. P3.30

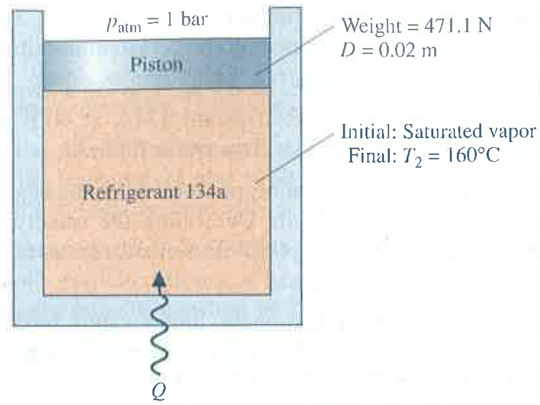


Fig. P3.36

3.31 A piston–cylinder assembly contains a two-phase liquid–vapor mixture of H_2O at 200 lbf/in.^{2} with a quality of 80%. The mixture is heated and expands at constant pressure until a final temperature of 480°F is reached. Determine the work for the process, in Btu per lb of H_2O present.

3.32 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.

3.33 Two kg of Refrigerant 134A undergoes a polytropic process in a piston–cylinder assembly from an initial state of saturated vapor at 2 bar to a final state of 12 bar, 80°C. Determine the work for the process, in kJ.

3.34 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.

3.35 Three kg of Refrigerant 22 undergoes 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.

3.36 As shown in Fig. P3.36, 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.

3.37 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

3.38 For each of the following cases, determine the specified properties and show the states on a sketch of the T–v diagram.

(a) For Refrigerant 22 at p = 3 bar and v = 0.05 m^3/kg, determine T in °C and u in kJ/kg.
(b) For water at T = 200°C and v = 0.2429 m^3/kg, determine p in bar and h in kJ/kg.
(c) For ammonia at p = 5 bar and u = 1400 kJ/kg, determine T in °C and v in m^3/kg.

3.39 Determine the values of the specified properties at each of the following conditions and show the states on a sketch of the T–v diagram.

(a) For Refrigerant 22 at p = 60 lbf/in.^{2} and u = 50 Btu/lb, determine T in °F and v in ft^3/lb.
(b) For Refrigerant 134a at T = 120°F and u = 114 Btu/lb, determine p in lbf/in.^{2} and v in ft^3/lb.
(c) For water vapor at p = 100 lbf/in.^{2} and h = 1240 Btu/lb, determine T in °F, v in ft^3/lb, and u in Btu/lb.

3.40 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 3.38.
(b) Cases (a), (b), and (c) of Problem 3.39.

3.41 Using the tables for water, determine the specified property data at the indicated states. In each case, locate the state 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.

3.42 For each case, determine the specified property value and locate the state 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.

3.43 Using the tables for water, determine the specified property data at the indicated states. In each case, locate the state 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.

3.44 Using the tables for water, determine the specified property data at the indicated states. In each case, locate the state by 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.

3.45 For each case, determine the specified property data and locate the state 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

3.46 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 per kg of water. Kinetic and potential energy effects can be ignored.

3.47 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.

3.48 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.

3.49 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 per lb of water.

3.50 Refrigerant 22 undergoes a constant-pressure process within a piston–cylinder assembly from saturated vapor at 4 bar to a final temperature of 30°C. Kinetic and potential energy effects are negligible. For the refrigerant, show the process on a p–v diagram. Evaluate the work and the heat transfer, each in kJ per kg of refrigerant.

3.51 For the system of Problem 3.26, determine the amount of energy transfer by heat, in kJ per kg of refrigerant.

3.52 For the system of Problem 3.31, determine the amount of energy transfer by heat, in Btu, if the mass is 2 lb. Kinetic and potential energy effects can be neglected.

3.53 For the system of Problem 3.33, determine the amount of energy transfer by heat, in kJ. Kinetic and potential energy effects can be neglected.

3.54 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.

3.55 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.

3.56 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}

3.57 As shown in Fig. P3.57, 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.

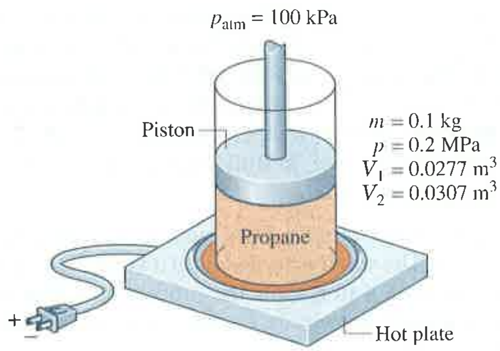


Fig. P3.57

3.58 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.

3.59 A well-insulated, rigid tank contains 1.5 kg of Refrigerant 134A, initially a two-phase liquid–vapor mixture with a quality of 60% and a temperature of 0°C. An electrical resistor transfers energy *to* the contents of the tank at a rate of 2 kW until the tank contains only saturated vapor. For the refrigerant, locate the initial and final states on a T–v diagram and determine the time it takes, in *s*, for the process.

3.60 As shown in Fig. P3.60, a rigid, closed tank having a volume of 20 ft³ 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 temperature, in °F, (b) the final pressure, in lbf/in.², and (c) the heat transfer, in Btu.

3.61 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 ft³.
(b) initial temperature, in °F.
(c) final pressure, in lbf/in.²
(d) work, in Btu.

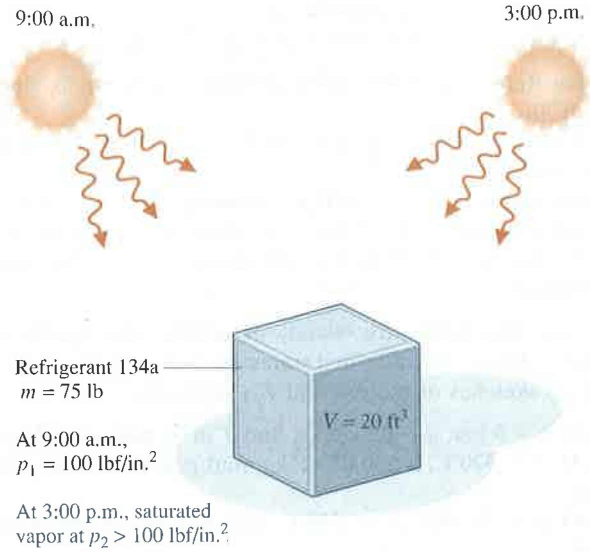


Fig. P3.60

3.62 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.

3.63 A closed, rigid tank filled with water, initially at 20 bar, a quality of 80%, and a volume of 0.5 m³, 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.

3.64 As shown in Fig. P3.64, 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 m³. 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.

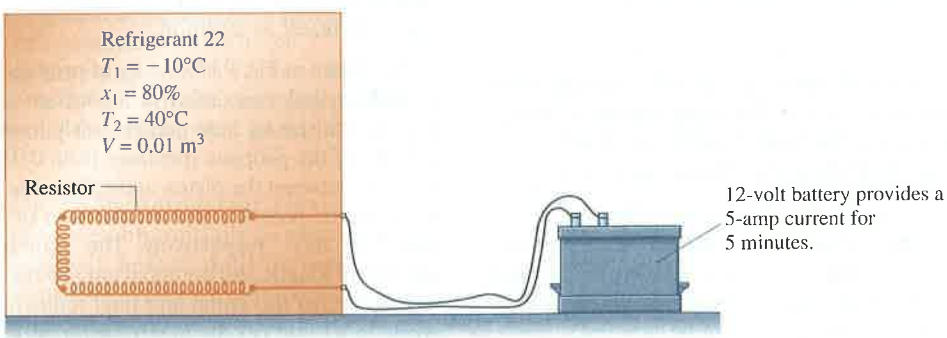


Fig. P3.64

3.65 Five lb of propane is contained in a closed, rigid tank initially at 80 lbf/in.^{2}, 110°F. Heat transfer occurs until the final temperature in the tank is 0°F. Kinetic and potential energy effects are negligible. Show the initial and final states on a T–v diagram and determine the amount of energy transfer by heat, in Btu.

3.66 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.

3.67 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.

3.68 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.

3.69 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.

3.70 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.

3.71 Referring to Fig. P3.71, 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.

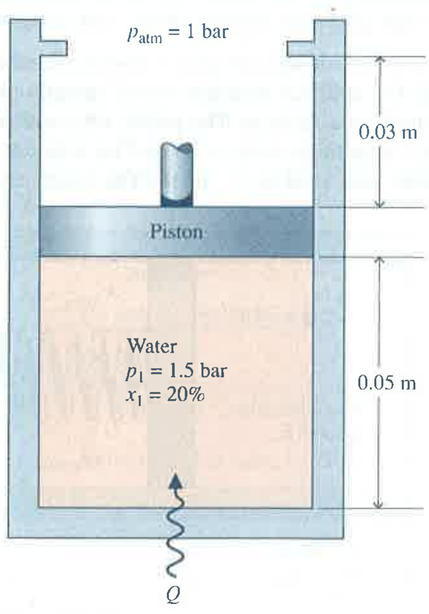


Fig. P3.71

3.72 A piston–cylinder assembly contains 2 lb of water, initially at 100 lbf/in.^{2} and 400°F. The water undergoes two processes in series: a constant-pressure process followed by a constant-volume process. At the end of the constant-volume process, the temperature is 300°F and the water is a two-phase liquid–vapor mixture with a quality of 60%. Neglect kinetic and potential energy effects.

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

3.73 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.

3.74 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.

3.75 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.

3.76 As shown in Fig. P3.76, 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.

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.

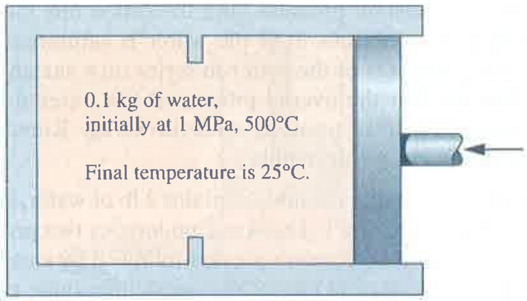


Fig. P3.76

3.77 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 P3.77. 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.

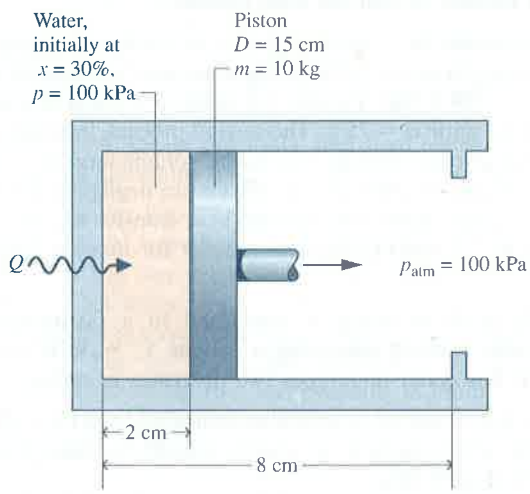


Fig. P3.77

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

Process 1–2: Constant-volume heating from p_1 = 5 bar, T_1 = 160°C to p_2 = 10 bar.

Process 2–3: Constant-pressure cooling to saturated vapor.

Process 3–4: Constant-volume cooling to T_4 = 160°C.

Process 4–1: Isothermal expansion with Q_{41} = 815.8 kJ.

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

3.79 One lb of water contained in a piston–cylinder assembly undergoes the power cycle shown in Fig. P3.79. For each of the four processes, evaluate the work and heat transfer, each in Btu. For the overall cycle, evaluate the thermal efficiency.

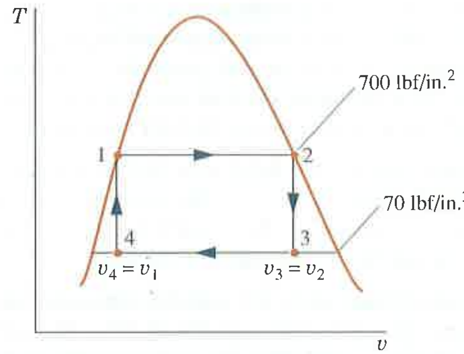


Fig. P3.79

3.80 One-half kg of Refrigerant 22 is contained in a piston–cylinder assembly, initially saturated vapor at 5 bar. The refrigerant undergoes a process for which the pressure-specific volume relation is pv = *constant* to a final pressure of 20 bar. Kinetic and potential energy effects can be neglected. Determine the work and heat transfer for the process, each in kJ.

3.81 Ten kg of Refrigerant 22 contained in a piston–cylinder assembly undergoes a process for which the pressure-specific volume relationship is pv^n = *constant*. The initial and final states of the refrigerant are fixed by p_1 = 400 kPa, T_1 = −5°C, and p_2 = 2000 kPa, T_2 = 70°C, respectively. Determine the work and heat transfer for the process, each in kJ.

3.82 A piston–cylinder assembly contains ammonia, initially at 0.8 bar and −10°C. The ammonia is compressed to a pressure of 5.5 bar. During the process, the pressure and specific volume are related by pv = *constant*. For 20 kg of ammonia, determine the work and heat transfer, each in kJ.

3.83 A piston–cylinder assembly contains propane, initially at 27°C, 1 bar, and a volume of 0.2 m^3. The propane undergoes a process to a final pressure of 4 bar, during which the pressure–volume relationship is $pV^{1.1}$ = *constant*. For the propane, evaluate the work and heat transfer, each in kJ. Kinetic and potential energy effects can be ignored.

3.84 Figure P3.84 shows a piston–cylinder assembly fitted with a spring. The cylinder contains water, initially at 1000°F, and the spring is in a vacuum. The piston face, which has an area of 20 in.², is initially at x_1 = 20 in. The water is cooled until the piston face is at x_2 = 16 in. The force exerted by the

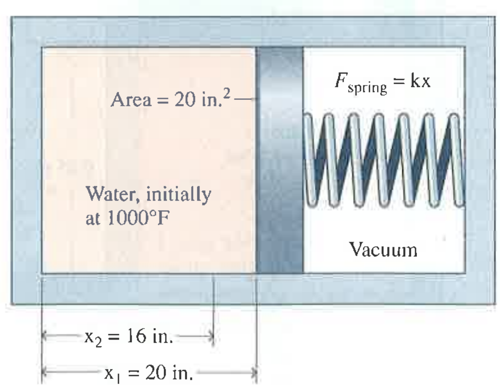


Fig. P3.84

spring varies linearly with x according to F_{spring} = kx, where k = 200 lbf/in. Friction between the piston and cylinder is negligible. For the water, determine

(a) the initial and final pressures, each in lbf/in.^{2}
(b) the amount of water present, in lb.
(c) the work, in Btu.
(d) the heat transfer, in Btu.

3.85 As shown in Fig. P3.85, 0.5 kg of ammonia is contained in a piston–cylinder assembly, initially at T_1 = −20°C and a quality of 25%. As the ammonia is slowly heated to a final state, where T_2 = 20°C, p_2 = 0.6 MPa, its pressure varies linearly with specific volume. There are no significant kinetic and potential energy effects. For the ammonia, (a) show the process on a sketch of the p–v diagram and (b) evaluate the work and heat transfer, each in kJ.

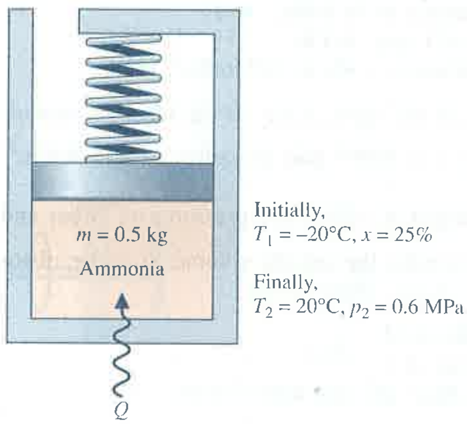


Fig. P3.85

3.86 A gallon of milk at 68°F is placed in a refrigerator. If energy is removed from the milk by heat transfer at a constant rate of 0.08 Btu/s, how long would it take, in minutes, for the milk to cool to 40°F? The specific heat and density of the milk are 0.94 Btu/lb · °R and 64 lb/ft^3, respectively.

3.87 Shown in Fig. P3.87 is an insulated copper block that receives energy at a rate of 100 W from an embedded resistor. If the block has a volume of 10^{-3} m^3 and an initial temperature of 20°C, how long would it take, in minutes, for the temperature to reach 60°C? Data for copper are provided in Table A-19.

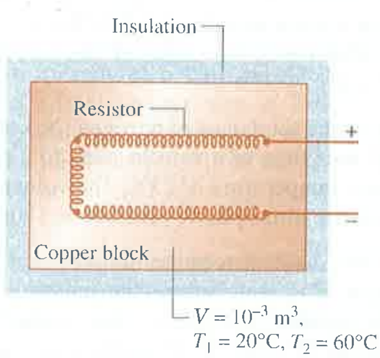


Fig. P3.87

3.88 In a heat-treating process, a 1-kg metal part, initially at 1075 K, is quenched in a closed tank containing 100 kg of water, initially at 295 K. There is negligible heat transfer between the contents of the tank and their surroundings. Modeling the metal part and water as incompressible with constant specific heats 0.5 kJ/kg · K and 4.4 kJ/kg · K, respectively, determine the final equilibrium temperature after quenching, in K.

3.89 As shown in Fig. P3.89, a tank open to the atmosphere initially contains 2 lb of liquid water at 80°F and 0.4 lb of ice at 32°F. All of the ice melts as the tank contents attain equilibrium. If no significant heat transfer occurs between the tank contents and their surroundings, determine the final equilibrium temperature, in °F. For water, the specific enthalpy change for a phase change from solid to liquid at 32°F and 1 atm is 144 Btu/lb.

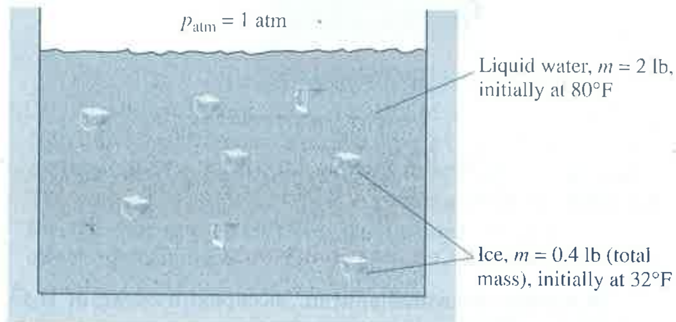


Fig. P3.89

3.90 As shown in Fig. P3.90, a system consists of a copper tank whose mass is 13 kg, 4 kg of liquid water, and an electrical resistor of negligible mass. The system is insulated on its outer surface. Initially, the temperature of the copper is 27°C and the temperature of the water is 50°C. The electrical resistor transfers 100 kJ of energy to the system. Eventually the system comes to equilibrium. Determine the final equilibrium temperature, in °C.

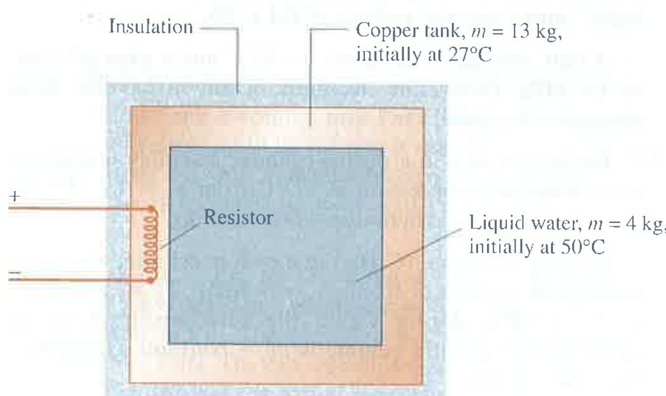


Fig. P3.90

3.91 As shown in Fig. P3.91, a closed, insulated tank contains 0.15 kg of liquid water and has a 0.25-kg copper base. The thin walls of the container have negligible mass. Initially, the tank and its contents are all at 30°C. A heating element embedded in the copper base is energized with an electrical current of 10 amps at 12 volts for 100 seconds. Determine the final temperature, in °C, of the tank and its contents. Data for copper and liquid water are provided in Table A-19.

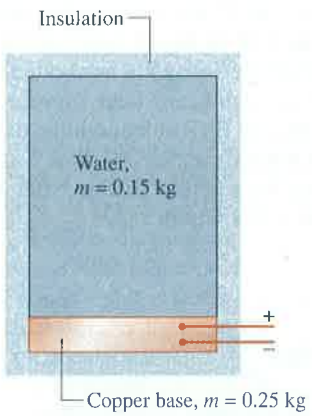


Fig. P3.91

Using Generalized Compressibility Data

3.92 Determine the volume, in m^3, occupied by 2 kg of H_2O at 100 bar, 400°C, using

(a) data from the compressibility chart.
(b) data from the steam tables.

Compare the results of parts (a) and (b) and discuss.

3.93 Five kmol of oxygen (O_2) gas undergoes a process in a closed system from $p_1 = 50$ bar, $T_1 = 170$ K to $p_2 = 25$ bar, $T_2 = 200$ K. Determine the change in volume, in m^3.

3.94 Carbon monoxide (CO) with mass of 150 lb occupies a volume at 500°R and 3500 lbf/in.^{2} Determine the volume, in ft^3.

3.95 Determine the temperature, in °F, of ethane (C_2H_6) at 500 lbf/in.^{2} and a specific volume of 0.4 ft^3/lb.

3.96 A tank contains 2 m^3 of air at −93°C and a gage pressure of 1.4 MPa. Determine the mass of air, in kg. The local atmospheric pressure is 1 atm.

3.97 Butane (C_4H_{10}) in a piston–cylinder assembly undergoes an isothermal compression at 173°C from $p_1 = 1.9$ MPa to $p_2 = 2.5$ MPa. Determine the work, in kJ/kg.

3.98 Five kg of butane (C_4H_{10}) in a piston–cylinder assembly undergoes a process from $p_1 = 5$ MPa, $T_1 = 500$ K to $p_2 = 3$ MPa, during which the relationship between pressure and specific volume is $pv = constant$. Determine the work, in kJ.

3.99 In a cryogenic application, carbon monoxide (CO) gas undergoes a constant-pressure process at 1000 lbf/in.^{2} in a piston–cylinder assembly from $T_1 = -100$°F to $T_2 = -30$°F. Determine the work for the process, in Btu per lb of carbon monoxide present.

Working with the Ideal Gas Model

3.100 For what ranges of pressure and temperature can air be considered an ideal gas? Explain your reasoning. Repeat for H_2O.

3.101 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.

3.102 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.

3.103 Check the applicability of the ideal gas model for

(a) water at 600°F and pressures of 900 lbf/in.^{2} and 100 lbf/in.^{2}
(b) nitrogen at −20°C and pressures of 75 bar and 1 bar.

3.104 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).

3.105 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).

3.106 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. The gas is heated, and the gage pressure at the final state is 367 kPa. Determine the final temperature, in °C. The local atmospheric pressure is 1 atm.

3.107 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.

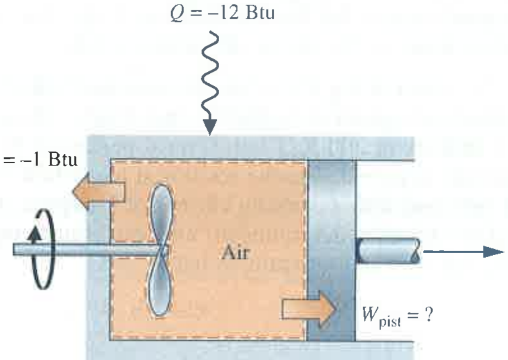
3.108 Determine the total mass of nitrogen (N_2), in kg, required to inflate all four tires of a vehicle, each to a gage pressure of 180 kPa at a temperature of 25°C. The volume of each tire is 0.6 m^3, and the atmospheric pressure is 1 atm.

3.109 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.

3.110 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

3.111 As shown in Fig. 3.111, 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 of 1 Btu, and there is energy transfer *to* the air by heat in the amount of 12 Btu. Assuming ideal gas behavior, and neglecting kinetic and potential energy effects, determine for the air (a) the temperature at state 2, in °R, and (b) the energy transfer by work from the air *to* the piston, 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. P3.111

3.112 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.

3.113 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.

3.114 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.

3.115 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.

3.116 Two kg of oxygen fills the cylinder of a piston–cylinder assembly. The initial volume and pressure are 2 m^3 and 1 bar, respectively. Heat transfer to the oxygen occurs at constant pressure until the volume is doubled. Determine the heat transfer for the process, in kJ, assuming the specific heat ratio is constant, $k = 1.35$. Kinetic and potential energy effects can be ignored.

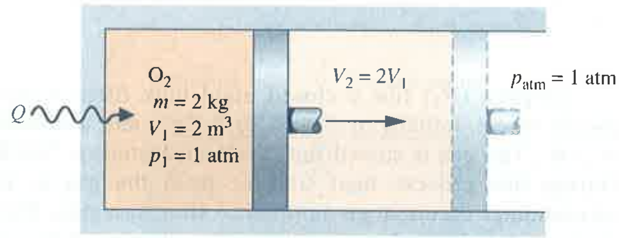


Fig. P3.116

3.117 As shown in Fig. P3.117, 20 ft^3 of air at $T_1 = 600$°R, 100 lbf/in.^{2} undergoes a polytropic expansion to a final pressure of 51.4 lbf/in.^{2} The process follows $pV^{1.2} = constant$. The work is $W = 194.34$ Btu. Assuming ideal gas behavior for the air, and neglecting kinetic and potential energy effects, determine

(a) the mass of air, in lb, and the final temperature, in °R.
(b) the heat transfer, in Btu.

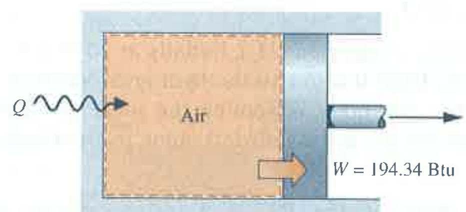


Fig. P3.117

3.118 A piston–cylinder assembly contains air at a pressure of 30 lbf/in.^{2} and a volume of 0.75 ft^3. The air is heated at constant pressure until its volume is doubled. Assuming the ideal gas model with constant specific heat ratio, $k = 1.4$, for the air, determine the work and heat transfer, each in Btu.

3.119 As shown in Fig. P3.119, a fan drawing electricity at a rate of 1.5 kW is located within a rigid enclosure, measuring 3 m × 4 m × 5 m. The enclosure is filled with air, initially at 27°C, 0.1 MPa. The fan operates steadily for 30 minutes. Assuming the ideal gas model, determine for the air (a) the mass, in kg, (b) the final temperature, in °C, and (c) the final pressure, in MPa. There is no heat transfer between the enclosure and the surroundings. Ignore the volume occupied by the fan itself and assume there is no overall change in internal energy for the fan.

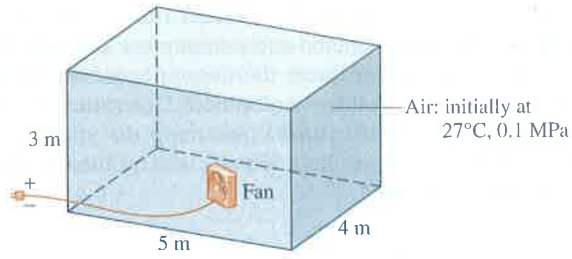


Fig. P3.119

3.120 Nitrogen (N_2) fills a closed, rigid tank fitted with a paddle wheel, initially at 540°R, 20 lbf/in.^{2}, and a volume of 2 ft^3. The gas is stirred until its temperature is 760°R. During this process, heat transfer from the gas to its surroundings occurs in an amount 1.6 Btu. Assuming ideal gas behavior, determine the mass of the nitrogen, in lb, and the work, in Btu. Kinetic and potential energy effects can be ignored.

3.121 Four-tenth lb of air, initially at 540°R, is contained in a closed, rigid tank fitted with a paddle wheel that stirs the air until its temperature is 740°R. The driveshaft of the paddle wheel rotates for 60 s at 100 RPM with an applied torque of 20 ft · lbf. Assuming ideal gas behavior for the air, determine the work and heat transfer, each in Btu. There are no overall changes in kinetic or potential energy.

3.122 Argon contained in a closed, rigid tank, initially at 50°C, 2 bar, and a volume of 2 m^3, is heated to a final pressure of 8 bar. Assuming the ideal gas model with $k = 1.67$ for the argon, determine the final temperature, in °C, and the heat transfer, in kJ.

3.123 Ten kg of hydrogen (H_2), initially at 20°C, fills a closed, rigid tank. Heat transfer to the hydrogen occurs at the rate 400 W for one hour. Assuming the ideal gas model with $k = 1.405$ for the hydrogen, determine its final temperature, in °C.

3.124 As shown in Fig. P3.124, a piston–cylinder assembly whose piston is resting on a set of stops contains 0.5 kg of helium gas, initially at 100 kPa and 25°C. The mass of the piston and the effect of the atmospheric pressure acting on the piston are such that a gas pressure of 500 kPa is required to raise it. How much energy must be transferred by heat to the helium, in kJ, before the piston starts rising? For the helium, assume ideal gas behavior with $c_p = \frac{5}{2} R$.

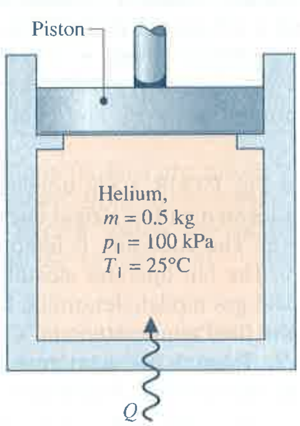


Fig. P3.124

3.125 A piston–cylinder assembly fitted with a slowly rotating paddle wheel contains 0.13 kg of air, initially at 300 K. The air undergoes a constant-pressure process to a final temperature of 400 K. During the process, energy is gradually transferred to the air by heat transfer in the amount 12 kJ. Assuming the ideal gas model with $k = 1.4$ and negligible changes in kinetic and potential energy for the air, determine the work done (a) by the paddle wheel on the air and (b) by the air to displace the piston, each in kJ.

3.126 A piston–cylinder assembly contains air. The air undergoes a constant-pressure process, during which the rate of heat transfer to the air is 0.7 kW. Assuming ideal gas behavior with $k = 1.4$ and negligible effects of kinetic and potential energy for the air, determine the rate at which work is done by the air on the piston, in kW.

3.127 As shown in Fig. P3.127, a well-insulated tank fitted with an electrical resistor of negligible mass holds 2 kg of nitrogen (N_2), initially at 300 K, 1 bar. Over a period of 10 minutes, electricity is provided to the resistor at a constant voltage of 120 volts and with a constant current of 1 ampere. Assuming ideal gas behavior, determine the nitrogen's final temperature, in K, and the final pressure, in bar.

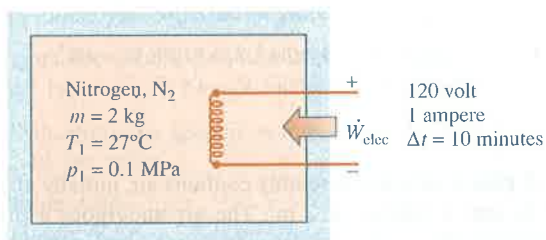


Fig. P3.127

3.128 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.

3.129 As shown in Fig. P3.129, 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.

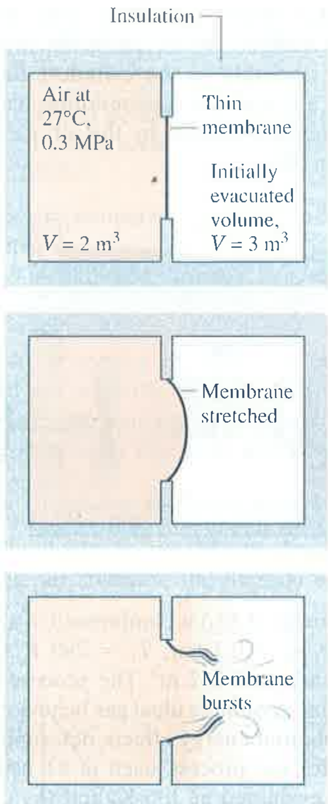


Fig. P3.129

3.130 Air is confined to one side of a rigid container divided by a partition, as shown in Fig. P3.130. 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 $V_2 = 2V_1$ 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.

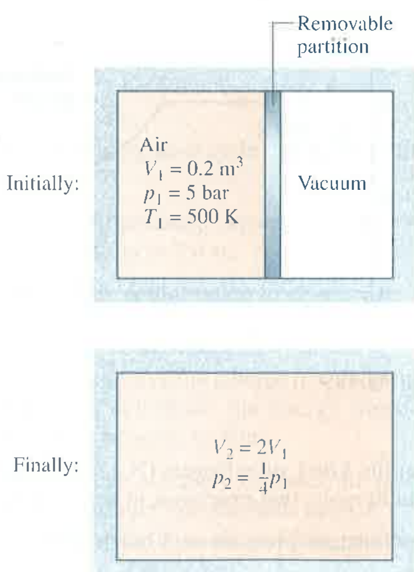


Fig. P3.130

3.131 Two kg 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. P3.131. 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.

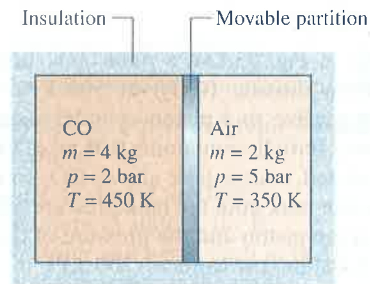


Fig. P3.131

3.132 As shown in Fig. P3.132, 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.

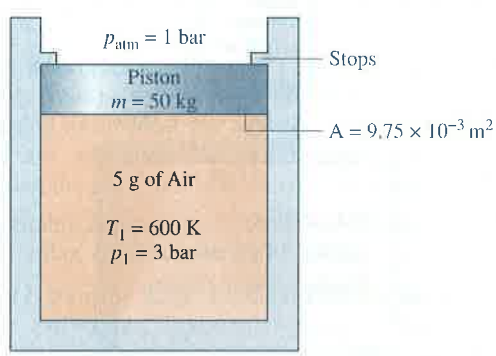


Fig. P3.132

3.133 Two kg of nitrogen (N_2) gas is contained in a closed, rigid tank surrounded by a 10-kg water bath, as shown in Fig. P3.133. Data for the initial states of the nitrogen and water are shown on the figure. The entire unit is well insulated, and the nitrogen and water interact until thermal equilibrium is achieved. The measured final temperature is 34.1°C. The water can be modeled as an incompressible substance, with $c = 4.179$ kJ/kg · K, and the nitrogen is an ideal gas with constant c_v. From the measured data, determine the average value of the specific heat c_v, in kJ/kg · K.

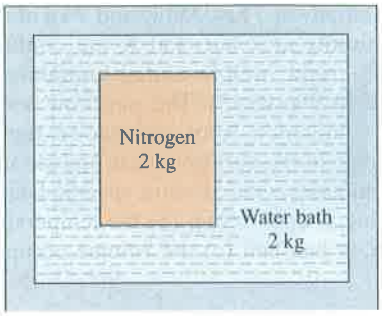


Fig. P3.133

3.134 As shown in Fig. P3.134, a rigid tank initially contains 3 kg of carbon dioxide (CO_2) at 500 kPa. The tank is connected by a valve to a piston–cylinder assembly located vertically above, initially containing 0.05 m^3 of CO_2. Although the valve is closed, a slow leak allows CO_2 to flow into the cylinder from the tank until the tank pressure falls to 200 kPa. The weight of the piston and the pressure of the atmosphere maintain a constant pressure of 200 kPa in the cylinder. Owing to heat transfer, the temperature of the CO_2 throughout the tank and cylinder stays constant at 290 K. Assuming ideal gas behavior, determine for the CO_2 the work and heat transfer, each in kJ.

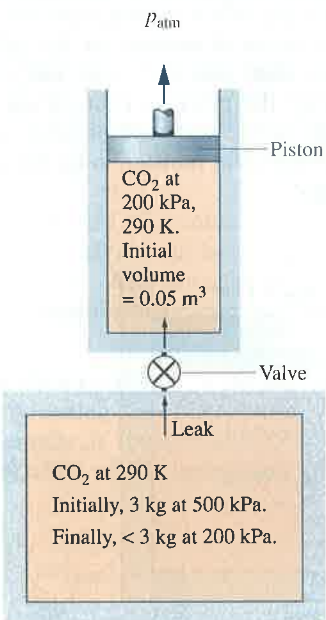


Fig. P3.134

3.135 A closed, rigid tank fitted with a paddle wheel contains 2 kg of air, initially at 300 K. During an interval of 5 minutes, the paddle wheel transfers energy to the air at a rate of 1 kW. During this interval, the air also receives energy by heat transfer at a rate of 0.5 kW. These are the only energy transfers. Assuming the ideal gas model for the air, and no overall changes in kinetic or potential energy, determine the final temperature of the air, in K.

3.136 As shown in Fig. P3.136, a piston–cylinder assembly fitted with a paddle wheel contains air, initially at 560°R, 18 lbf/in.^{2}, and a volume of 0.29 ft^3. Energy in the amount of 1.7 Btu is transferred to the air by the paddle wheel. The piston moves smoothly in the cylinder, and heat transfer between the air and its surroundings can be ignored. Assuming ideal gas behavior by the air, determine its final temperature, in °R.

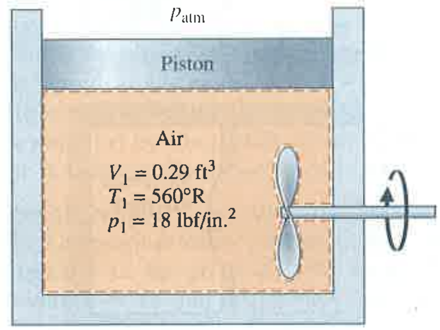


Fig. P3.136

3.137 Carbon dioxide (CO_2) is compressed in a piston–cylinder assembly from p_1 = 0.7 bar, T_1 = 280 K to p_2 = 11 bar. The initial volume is 0.262 m^3. The process is described by $pV^{1.25} = constant$. Assuming ideal gas behavior and neglecting kinetic and potential energy effects, determine the work and heat transfer for the process, each in kJ, using (a) constant specific heats evaluated at 300 K, and (b) data from Table A-23. Compare the results and discuss.

3.138 Air is contained in a piston–cylinder assembly, initially at 40 lbf/in.^{2} and 600°R. The air expands in a polytropic process with $n = k = 1.4$ until the volume is doubled. Modeling the air as an ideal gas with constant specific heats, determine (a) the final temperature, in °R, and pressure, in lbf/in.^{2}, and (b) the work and heat transfer, each in Btu per lb of air.

3.139 Air contained in a piston–cylinder assembly undergoes two processes in series, as shown in Fig. P3.139. Assuming ideal gas behavior for the air, determine the work and heat transfer for the overall process, each in kJ/kg.

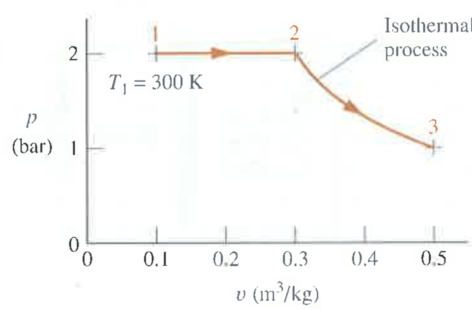


Fig. P3.139

3.140 Two-tenths kmol of nitrogen (N_2) in a piston–cylinder assembly undergoes two processes in series as follows:

Process 1–2: Constant pressure at 5 bar from V_1 = 1.33 m^3 to V_2 = 1 m^3.

Process 2–3: Constant volume to p_3 = 4 bar.

Assuming ideal gas behavior and neglecting kinetic and potential energy effects, determine the work and heat transfer for each process, in kJ.

3.141 One kg 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.

3.142 Air contained in a piston–cylinder assembly undergoes the power cycle shown in Fig. P3.142. Assuming ideal gas behavior for the air, evaluate the thermal efficiency of the cycle.

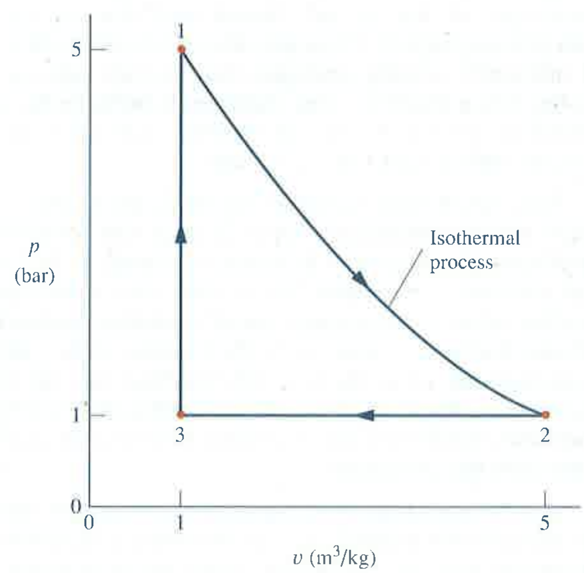


Fig. P3.142

3.143 One lb of air undergoes a cycle consisting of the following processes:

Process 1–2: Constant-pressure expansion with p = 20 lbf/in.^{2} from T_1 = 500°R to $v_2 = 1.4\ v_1$.

Process 2–3: Adiabatic compression to $v_3 = v_1$ and T_3 = 820°R.

Process 3–1: Constant-volume process.

Sketch the cycle on a carefully labeled p–v diagram. Assuming ideal gas behavior, determine the energy transfers by heat and work for each process, in Btu.

3.144 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.

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

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

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

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.

3.146 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 = 4 bar.

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 and calculate thermal efficiency.
(b) plot the thermal efficiency versus p_2/p_1 ranging from 1.05 to 4.

3.147 Air undergoes a polytropic process in a piston–cylinder assembly from p_1 = 1 bar, T_1 = 295 K to p_2 = 7 bar. The air is modeled as an ideal gas and kinetic and potential energy effects are negligible. For a polytropic exponent of 1.6, determine the work and heat transfer, each in kJ per kg of air,

(a) assuming constant c_v evaluated at 300 K.
(b) assuming variable specific heats.

Using *IT*, plot the work and heat transfer per unit mass 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.

3.148 Steam, initially at 700 lbf/in.^{2}, 550°F undergoes a polytropic process in a piston–cylinder assembly to a final pressure of 3000 lbf/in.^{2} Kinetic and potential energy effects are negligible. Determine the heat transfer, in Btu per lb of steam, for a polytropic exponent of 1.6,

(a) using data from the steam tables.
(b) assuming ideal gas behavior.

Using *IT*, plot the heat transfer per unit mass 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.