

Using Eq. (a), the work is then

$$\frac{W}{m} = \frac{R(T_2 - T_1)}{1 - n} = \left(\frac{1.986 \text{ Btu}}{28.97 \text{ lb} \cdot ^\circ\text{R}} \right) \left(\frac{768^\circ\text{R} - 530^\circ\text{R}}{1 - 1.3} \right) = -54.39 \text{ Btu/lb}$$

At 70°F, Table A-20E gives $k = 1.401$ and $c_v = 0.171 \text{ Btu/lb} \cdot ^\circ\text{R}$. Alternatively, c_v can be found using Eq. 3.47b, as follows:

$$\begin{aligned} c_v &= \frac{R}{k - 1} \\ &= \frac{(1.986/28.97) \text{ Btu/lb} \cdot ^\circ\text{R}}{(1.401 - 1)} = 0.171 \frac{\text{Btu}}{\text{lb} \cdot ^\circ\text{R}} \end{aligned} \quad (c)$$


Substituting values into Eq. (b), we get

$$\begin{aligned} \frac{Q}{m} &= -54.39 \frac{\text{Btu}}{\text{lb}} + \left(0.171 \frac{\text{Btu}}{\text{lb} \cdot ^\circ\text{R}} \right) (768^\circ\text{R} - 530^\circ\text{R}) \\ &= -13.69 \frac{\text{Btu}}{\text{lb}} \end{aligned}$$

(b) For $n = k$, substituting Eqs. (a) and (c) into Eq. (b) gives

$$\frac{Q}{m} = \frac{R(T_2 - T_1)}{1 - k} + \frac{R(T_2 - T_1)}{k - 1} = 0$$

That is, no heat transfer occurs in the polytropic process of an ideal gas for which $n = k$.

 **Skills Developed**
 Ability to...

- ☐ evaluate work using Eq. 2.17.
- ☐ apply the energy balance using the ideal gas model.
- ☐ apply the polytropic process concept.

- 1 The states visited in a polytropic compression process are shown by the curve on the accompanying p - v diagram. The magnitude of the work per unit of mass is represented by the shaded area *below* the curve.

QuickQUIZ

For $n = k$, evaluate the temperature at the final state, in °R and °F. **Ans.** 840°R(380°F)

► CHAPTER SUMMARY AND STUDY GUIDE

In this chapter, we have considered property relations for a broad range of substances in tabular, graphical, and equation form. Primary emphasis has been placed on the use of tabular data, but computer retrieval also has been considered.

A key aspect of thermodynamic analysis is fixing states. This is guided by the state principle for pure, simple compressible systems, which indicates that the intensive state is fixed by the values of *any two* independent, intensive properties.

Another important aspect of thermodynamic analysis is locating principal states of processes on appropriate diagrams: p - v , T - v , and p - T diagrams. The skills of fixing states and using property diagrams are particularly important when solving problems involving the energy balance.

The ideal gas model is introduced in the second part of this chapter, using the compressibility factor as a point of departure. This arrangement emphasizes the limitations of the ideal gas

model. When it is appropriate to use the ideal gas model, we stress that specific heats generally vary with temperature, and feature the use of the ideal gas tables in problem solving.

The following checklist provides a study guide for this chapter. When your study of the text and end-of-chapter exercises has been completed you should be able to

- write out the meanings of the terms listed in the margins throughout the chapter and understand each of the related concepts. The subset of key concepts listed on the next page is particularly important in subsequent chapters.
- retrieve property data from Tables A-1 through A-23, using the state principle to fix states and linear interpolation when required.
- sketch T - v , p - v , and p - T diagrams, and locate principal states on such diagrams.

- ▶ apply the closed system energy balance with property data.
- ▶ evaluate the properties of two-phase, liquid–vapor mixtures using Eqs. 3.1, 3.2, 3.6, and 3.7.
- ▶ estimate the properties of liquids using Eqs. 3.11–3.14.
- ▶ apply the incompressible substance model.
- ▶ use the generalized compressibility chart to relate p – v – T data of gases.
- ▶ apply the ideal gas model for thermodynamic analysis, including determining when use of the ideal gas model is warranted, and appropriately using ideal gas table data or constant specific heat data to determine Δu and Δh .

▶ KEY ENGINEERING CONCEPTS

phase p. 92

pure substance p. 92

state principle p. 92

simple compressible system p. 92

p – v – T surface p. 94

phase diagram p. 96

saturation temperature p. 96

saturation pressure p. 96

p – v diagram p. 96

T – v diagram p. 96

compressed liquid p. 97

two-phase, liquid–vapor mixture p. 98

quality p. 98

superheated vapor p. 98

enthalpy p. 106

specific heats p. 117

incompressible substance model p. 119

universal gas constant p. 122

compressibility factor p. 122

ideal gas model p. 128

▶ KEY EQUATIONS

$x = \frac{m_{\text{vapor}}}{m_{\text{liquid}} + m_{\text{vapor}}}$	(3.1) p. 98	Quality, x , of a two-phase, liquid–vapor mixture.
$v = (1 - x)v_{\text{f}} + xv_{\text{g}} = v_{\text{f}} + x(v_{\text{g}} - v_{\text{f}})$	(3.2) p. 103	Specific volume, internal energy and enthalpy of a two-phase, liquid–vapor mixture.
$u = (1 - x)u_{\text{f}} + xu_{\text{g}} = u_{\text{f}} + x(u_{\text{g}} - u_{\text{f}})$	(3.6) p. 107	
$h = (1 - x)h_{\text{f}} + xh_{\text{g}} = h_{\text{f}} + x(h_{\text{g}} - h_{\text{f}})$	(3.7) p. 107	
$v(T, p) \approx v_{\text{f}}(T)$	(3.11) p. 118	Specific volume, internal energy, and enthalpy of liquids, approximated by saturated liquid values, respectively.
$u(T, p) \approx u_{\text{f}}(T)$	(3.12) p. 118	
$h(T, p) \approx h_{\text{f}}(T)$	(3.14) p. 119	
Ideal Gas Model Relations		
$pv = RT$	(3.32) p. 127	Ideal gas model.
$u = u(T)$	(3.36) p. 128	
$h = h(T) = u(T) + RT$	(3.37) p. 128	
$u(T_2) - u(T_1) = \int_{T_1}^{T_2} c_v(T) dT$	(3.40) p. 131	Change in specific internal energy.
$u(T_2) - u(T_1) = c_v(T_2 - T_1)$	(3.50) p. 135	For constant c_v .
$h(T_2) - h(T_1) = \int_{T_1}^{T_2} c_p(T) dT$	(3.43) p. 131	Change in specific enthalpy.
$h(T_2) - h(T_1) = c_p(T_2 - T_1)$	(3.51) p. 135	For constant c_p .

► EXERCISES: THINGS ENGINEERS THINK ABOUT

1. Why does popcorn *pop*?
2. A plastic milk jug filled with water and stored within a freezer ruptures. Why?
3. Apart from keeping food and beverages cool, what are other uses for *dry ice*?
4. What are several actions you can take to reduce *your* CO₂ emissions?
5. What is the price of tap water, per liter, where you live and how does this compare to the average price of tap water in the United States?
6. When should Table A-5 be used for liquid water v , u , and h values? When should Eqs. 3.11–3.14 be used?
7. A traffic sign states, “Bridge Ices Before Road.” Explain.
8. Home canning of fruits and vegetables can be accomplished with either a boiling water canner or a pressure canner. How does each type of canner operate?
9. An automobile’s radiator cap is labeled “Never open when hot.” Why not?
10. Why are the tires of airplanes and race cars inflated with nitrogen instead of air?
11. If pressure and specific internal energy are known at a state of water vapor, how is the specific volume at that state determined using *IT*? Using the *steam tables*? Repeat if temperature and specific internal energy are known.
12. What is a *molten salt*?
13. How many minutes do you have to exercise to *burn* the calories in a helping of your favorite dessert?

► PROBLEMS: DEVELOPING ENGINEERING SKILLS

Exploring Concepts: Phase and Pure Substance

- 3.1 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.
- 3.2 A system consists of liquid oxygen in equilibrium with oxygen vapor. How many phases are present? The system undergoes a process during which some of the liquid is vaporized. Can the system be viewed as being a pure substance during the process? Explain.
- 3.3 A system consisting of liquid water undergoes a process. At the end of the process, some of the liquid water has frozen, and the system contains liquid water and ice. Can the system be viewed as being a pure substance during the process? Explain.
- 3.4 A dish of liquid water is placed on a table in a room. After a while, all of the water evaporates. Taking the water and the air in the room to be a closed system, can the system be regarded as a pure substance *during* the process? *After* the process is completed? Discuss.

Using p – v – T Data

- 3.5 Determine the phase or phases in a system consisting of H₂O at the following conditions and sketch p – v and T – v diagrams showing the location of each state.
 - (a) $p = 80 \text{ lbf/in.}^2$, $T = 312.07^\circ\text{F}$.
 - (b) $p = 80 \text{ lbf/in.}^2$, $T = 400^\circ\text{F}$.
 - (c) $T = 400^\circ\text{F}$, $p = 360 \text{ lbf/in.}^2$.
 - (d) $T = 320^\circ\text{F}$, $p = 70 \text{ lbf/in.}^2$.
 - (e) $T = 10^\circ\text{F}$, $p = 14.7 \text{ lbf/in.}^2$.
- 3.6 Determine the phase or phases in a system consisting of H₂O at the following conditions and sketch p – v and T – v diagrams showing the location of each state.

- (a) $p = 5 \text{ bar}$, $T = 151.9^\circ\text{C}$.
- (b) $p = 5 \text{ bar}$, $T = 200^\circ\text{C}$.
- (c) $T = 200^\circ\text{C}$, $p = 2.5 \text{ MPa}$.
- (d) $T = 160^\circ\text{C}$, $p = 4.8 \text{ bar}$.
- (e) $T = -12^\circ\text{C}$, $p = 1 \text{ bar}$.

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

$p = 1.0 \text{ MPa}$		$p = 1.5 \text{ MPa}$	
$T (^{\circ}\text{C})$	$v (\text{m}^3/\text{kg})$	$T (^{\circ}\text{C})$	$v (\text{m}^3/\text{kg})$
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 $T = 240^\circ\text{C}$, $p = 1.25 \text{ MPa}$, in m^3/kg .
- (b) the temperature at $p = 1.5 \text{ MPa}$, $v = 0.1555 \text{ m}^3/\text{kg}$, in $^\circ\text{C}$.
- (c) the specific volume at $T = 220^\circ\text{C}$, $p = 1.4 \text{ MPa}$, in m^3/kg .

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

$p = 50 \text{ lbf/in.}^2$		$p = 60 \text{ lbf/in.}^2$	
$T (^{\circ}\text{F})$	$v (\text{ft}^3/\text{lb})$	$T (^{\circ}\text{F})$	$v (\text{ft}^3/\text{lb})$
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 $T = 120^\circ\text{F}$, $p = 54 \text{ lbf/in.}^2$, in ft^3/lb .

- (b) the temperature at $p = 60 \text{ lbf/in.}^2$, $v = 5.982 \text{ ft}^3/\text{lb}$, in $^{\circ}\text{F}$.
 (c) the specific volume at $T = 110^{\circ}\text{F}$, $p = 58 \text{ lbf/in.}^2$, 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) $p = 300 \text{ kPa}$, $v = 0.5 \text{ m}^3/\text{kg}$. Find T , in $^{\circ}\text{C}$.
 (b) $p = 28 \text{ MPa}$, $T = 200^{\circ}\text{C}$. Find v , in m^3/kg .
 (c) $p = 1 \text{ MPa}$, $T = 405^{\circ}\text{C}$. Find v , in m^3/kg .
 (d) $T = 100^{\circ}\text{C}$, $x = 60\%$. 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 $p = 14.7 \text{ lbf/in.}^2$, $T = 100^{\circ}\text{F}$. Find v , in ft^3/lb .
 (b) Ammonia at $T = -30^{\circ}\text{C}$, $x = 50\%$. Find v , in m^3/kg .
 (c) Refrigerant 134a at $p = 1.5 \text{ MPa}$, $T = 100^{\circ}\text{C}$. 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 $v = 0.5 \text{ m}^3/\text{kg}$, $p = 3 \text{ bar}$, determine T , in $^{\circ}\text{C}$.
 (b) Ammonia at $p = 11 \text{ lbf/in.}^2$, $T = -20^{\circ}\text{F}$, determine v , in ft^3/lb .
 (c) Propane at $p = 1 \text{ MPa}$, $T = 85^{\circ}\text{C}$, 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) $T = 400^{\circ}\text{C}$, $p = 20 \text{ MPa}$.
 (b) $T = 40^{\circ}\text{C}$, $p = 20 \text{ MPa}$.
 (c) $T = 40^{\circ}\text{C}$, $p = 2 \text{ MPa}$.

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

- (a) $T = 120^{\circ}\text{C}$, $p = 5 \text{ bar}$.
 (b) $T = 120^{\circ}\text{C}$, $v = 0.6 \text{ m}^3/\text{kg}$.
 (c) $T = 120^{\circ}\text{C}$, $p = 1 \text{ bar}$.

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 $v_f = 0.896 \times 10^{-3} \text{ m}^3/\text{kg}$ and $v_g = 3.824 \times 10^{-2} \text{ m}^3/\text{kg}$, 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 $10 \text{ m}^3/\text{kg}$ 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 $11 \text{ ft}^3/\text{lb}$ 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 $15 \text{ ft}^3/\text{lb}$.
 (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 $1 \text{ ft}^3/\text{lb}$.

3.19 A two-phase liquid-vapor mixture of ammonia has a specific volume of $1.0 \text{ ft}^3/\text{lb}$. 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.

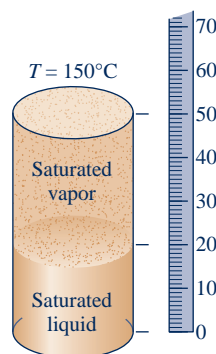


Fig. P3.21

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 .

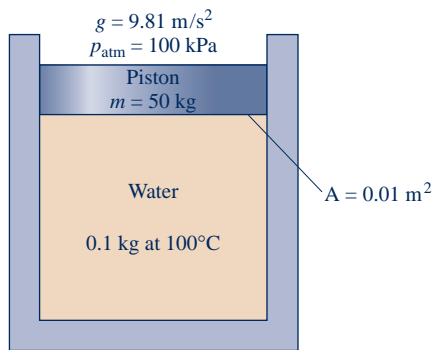


Fig. P3.22

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 $^{\circ}\text{C}$, 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) $T_1 = 20^{\circ}\text{C}$, $T_2 = 40^{\circ}\text{C}$. Using IT , determine the final pressure, in bar.

(b) $T_1 = 70^{\circ}\text{F}$, $T_2 = 120^{\circ}\text{F}$. 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 $^{\circ}\text{C}$, 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.

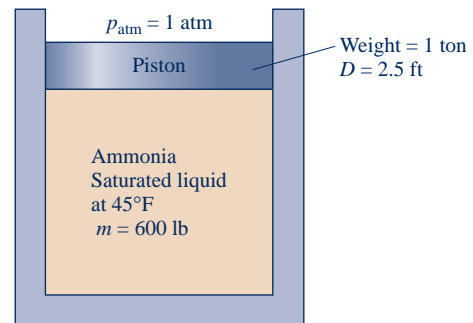


Fig. P3.31

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 $^{\circ}\text{F}$, and the work for the process, in Btu.

3.33 Seven lb of propane in a piston-cylinder assembly, initially at $p_1 = 200\text{ lbf/in.}^2$ and $T_1 = 200^{\circ}\text{F}$, 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 $^{\circ}\text{F}$, 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 $T_1 = 30^{\circ}\text{C}$ 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 $pv^{-0.8} = \text{constant}$. 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.

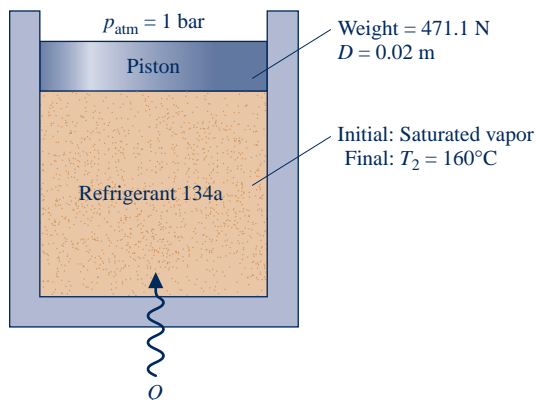


Fig. P3.37

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

- For Refrigerant 134a at $T = 60^\circ\text{C}$ and $v = 0.072 \text{ m}^3/\text{kg}$, determine p in kPa and h in kJ/kg.
- For ammonia at $p = 8 \text{ bar}$ and $v = 0.005 \text{ m}^3/\text{kg}$, determine T in $^\circ\text{C}$ and u in kJ/kg.
- For Refrigerant 22 at $T = -10^\circ\text{C}$ and $u = 200 \text{ kJ/kg}$, 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.

- For Refrigerant 134a at $p = 140 \text{ lbf/in.}^2$ and $h = 100 \text{ Btu/lb}$, determine T in $^\circ\text{F}$ and v in ft^3/lb .
- For ammonia at $T = 0^\circ\text{F}$ and $v = 15 \text{ ft}^3/\text{lb}$, determine p in lbf/in.^2 and h in Btu/lb.
- For Refrigerant 22 at $T = 30^\circ\text{F}$ and $v = 1.2 \text{ ft}^3/\text{lb}$, 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.

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

- At $p = 2 \text{ MPa}$, $T = 300^\circ\text{C}$. Find u , in kJ/kg.
- At $p = 2.5 \text{ MPa}$, $T = 200^\circ\text{C}$. Find u , in kJ/kg.
- At $T = 170^\circ\text{F}$, $x = 50\%$. Find u , in Btu/lb.
- At $p = 100 \text{ lbf/in.}^2$, $T = 300^\circ\text{F}$. Find h , in Btu/lb.
- At $p = 1.5 \text{ MPa}$, $v = 0.2095 \text{ m}^3/\text{kg}$. 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.

- For Refrigerant 134a at $T = 160^\circ\text{F}$, $h = 127.7 \text{ Btu/lb}$. Find v , in ft^3/lb .
- For Refrigerant 134a at $T = 90^\circ\text{F}$, $u = 72.71 \text{ Btu/lb}$. Find h , in Btu/lb.
- For ammonia at $T = 160^\circ\text{F}$, $p = 60 \text{ lbf/in.}^2$. Find u , in Btu/lb.
- For ammonia at $T = 0^\circ\text{F}$, $p = 35 \text{ lbf/in.}^2$. Find u , in Btu/lb.
- For Refrigerant 22 at $p = 350 \text{ lbf/in.}^2$, $T = 350^\circ\text{F}$. 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.

- At $p = 3 \text{ bar}$, $v = 0.5 \text{ m}^3/\text{kg}$, find T in $^\circ\text{C}$ and u in kJ/kg.
- At $T = 320^\circ\text{C}$, $v = 0.03 \text{ m}^3/\text{kg}$, find p in MPa and u in kJ/kg.
- At $p = 28 \text{ MPa}$, $T = 520^\circ\text{C}$, find v in m^3/kg and h in kJ/kg.
- At $T = 10^\circ\text{C}$, $v = 100 \text{ m}^3/\text{kg}$, find p in kPa and h in kJ/kg.
- At $p = 4 \text{ MPa}$, $T = 160^\circ\text{C}$, 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.

- At $p = 20 \text{ lbf/in.}^2$, $v = 16 \text{ ft}^3/\text{lb}$, find T in $^\circ\text{F}$ and u in Btu/lb.
- At $T = 900^\circ\text{F}$, $p = 170 \text{ lbf/in.}^2$, find v in ft^3/lb and h in Btu/lb.
- At $T = 600^\circ\text{F}$, $v = 0.6 \text{ ft}^3/\text{lb}$, find p in lbf/in.^2 and u in Btu/lb.
- At $T = 40^\circ\text{F}$, $v = 1950 \text{ ft}^3/\text{lb}$, find p in lbf/in.^2 and h in Btu/lb.
- At $p = 600 \text{ lbf/in.}^2$, $T = 320^\circ\text{F}$, 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.

- 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 .
- 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 .
- Evaluate the specific volume, in m^3/kg , and the specific enthalpy, in kJ/kg, of ammonia at 20°C and 1.0 MPa .
- 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 ft³ saturated vapor and 0.1 ft³ 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 m³ to 0.0307 m³. Friction between the piston and cylinder is negligible. The local atmospheric pressure and acceleration of gravity are 100 kPa and 9.81 m/s², 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.

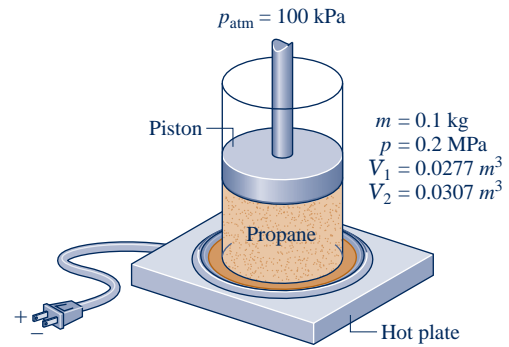


Fig. P3.56

- 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 $v = 2.045$ m³/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 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

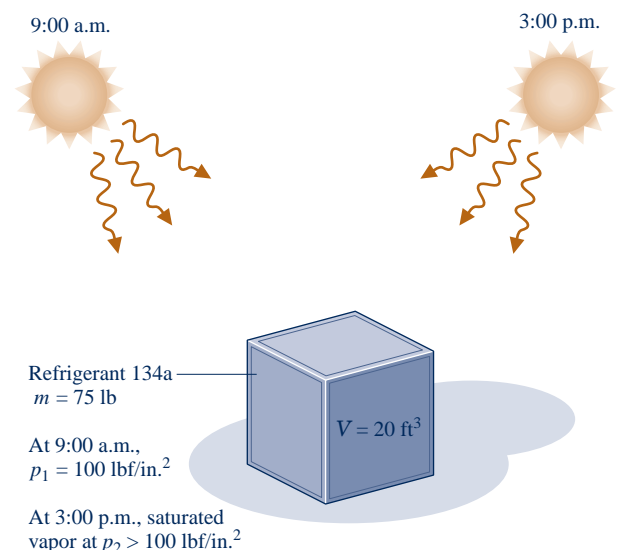


Fig. P3.59

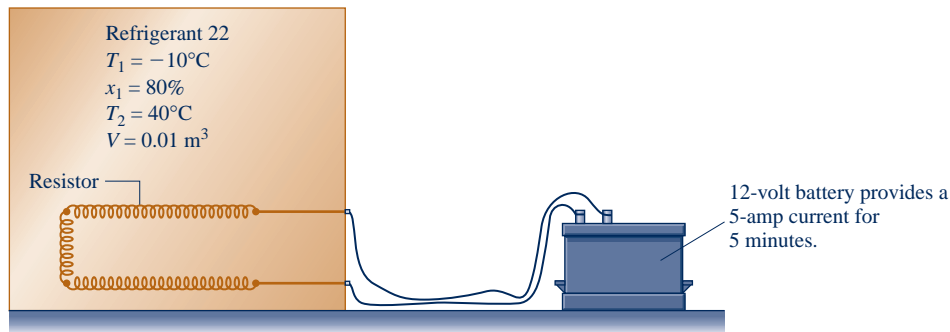


Fig. P3.63

temperature, in $^\circ\text{F}$, (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 $^\circ\text{F}$.
- (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 $^\circ\text{F}$, 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 $^\circ\text{R}$, 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 $^\circ\text{C}$, 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.

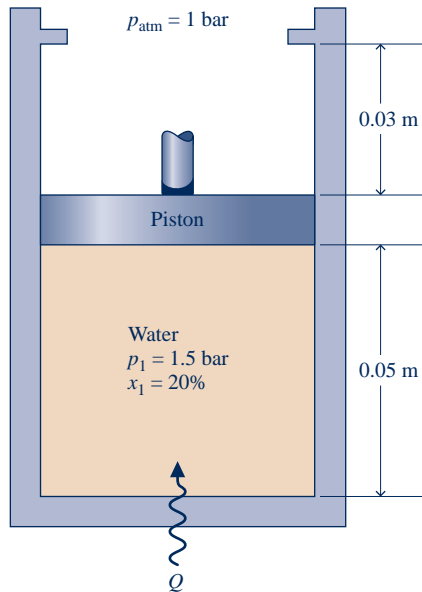


Fig. P3.70

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 ft³, is expanded in a constant-pressure process to a volume of 85.38 ft³. The system then is compressed isothermally to a final volume of 28.2 ft³. 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 $p_1 = 100 \text{ lbf/in.}^2$. 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 $V_1 = 30 \text{ ft}^3$ at $T_1 = 300^\circ\text{F}$. The water undergoes two processes in series:

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

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

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.

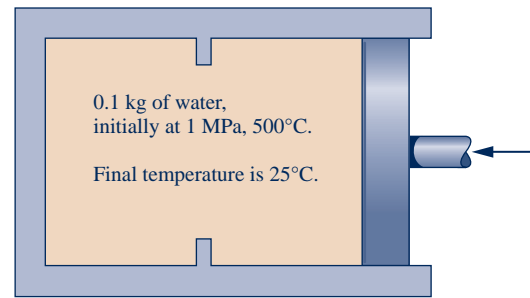


Fig. P3.75

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 H₂O, 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.

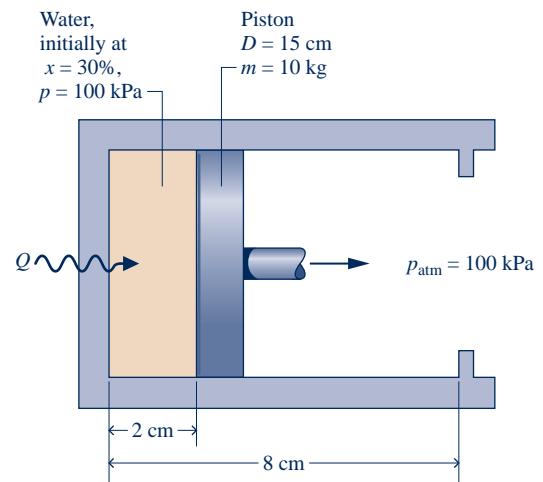


Fig. P3.76

3.77 A system consisting of 1 kg of H₂O 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 $p_3 = 5 \text{ bar}$, $T_3 = 160^\circ\text{C}$.

Process 3–4: Isothermal compression with $Q_{34} = -815.8 \text{ kJ}$.

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.

3.78 One lb of water contained in a piston–cylinder assembly undergoes the power cycle shown in Fig. P3.78. For each of the four processes, evaluate the work and heat transfer, each in Btu. For the overall cycle, evaluate the thermal efficiency.

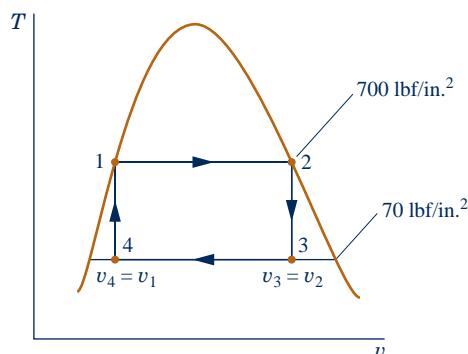


Fig. P3.78

3.79 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 $pv = \text{constant}$ 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.

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

3.81 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 $pv = \text{constant}$. For 20 kg of ammonia, determine the work and heat transfer, each in kJ.

3.82 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 $pV^{1.1} = \text{constant}$. For the propane, evaluate the work and heat transfer, each in kJ. Kinetic and potential energy effects can be ignored.

3.83 Figure P3.83 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 $x_1 = 20 \text{ in.}$ The water is cooled until the piston face is at $x_2 = 16 \text{ in.}$ The force exerted by the spring varies linearly with x according to $F_{\text{spring}} = kx$, where $k = 200 \text{ lbf/in.}$ Friction between the piston and cylinder is negligible. For the water, determine

- the initial and final pressures, each in lbf/in.^2
- the amount of water present, in lb.
- the work, in Btu.
- the heat transfer, in Btu.

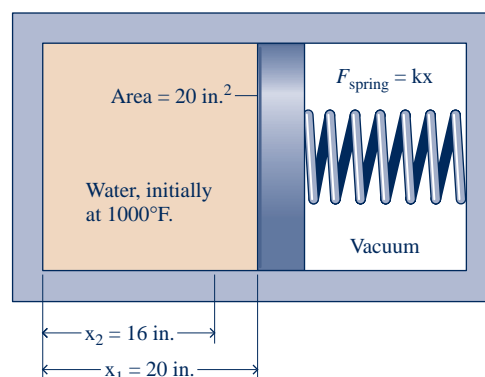


Fig. P3.83

3.84 As shown in Fig. P3.84, 0.5 kg of ammonia is contained in a piston–cylinder assembly, initially at $T_1 = -20^\circ\text{C}$ and a quality of 25%. As the ammonia is slowly heated to a final state, where $T_2 = 20^\circ\text{C}$, $p_2 = 0.6 \text{ MPa}$, 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.

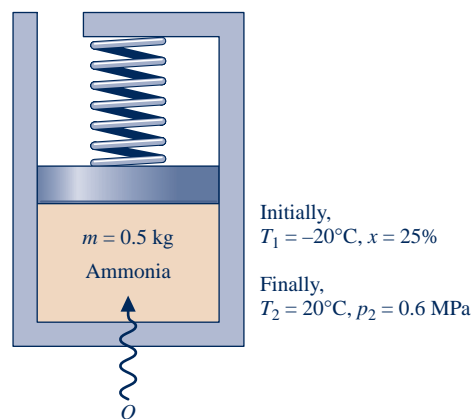


Fig. P3.84

3.85 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 $0.94 \text{ Btu/lb} \cdot ^\circ\text{R}$ and 64 lb/ft^3 , respectively.

3.86 Shown in Fig. P3.86 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.

3.87 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 $0.5 \text{ kJ/kg} \cdot \text{K}$ and $4.4 \text{ kJ/kg} \cdot \text{K}$, respectively, determine the final equilibrium temperature after quenching, in K.

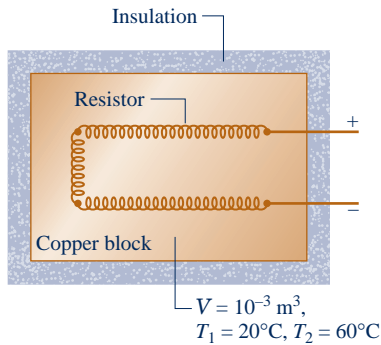


Fig. P3.86

3.88 As shown in Fig. P3.88, 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.

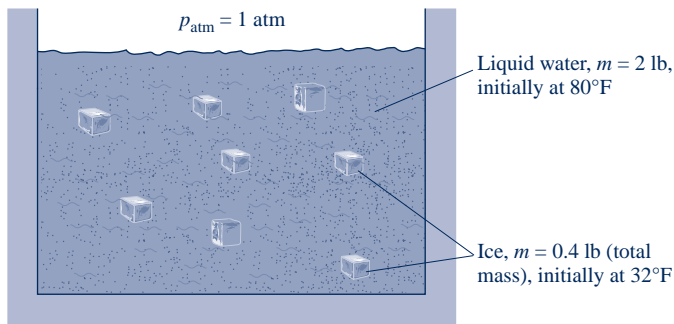


Fig. P3.88

3.89 As shown in Fig. P3.89, 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.

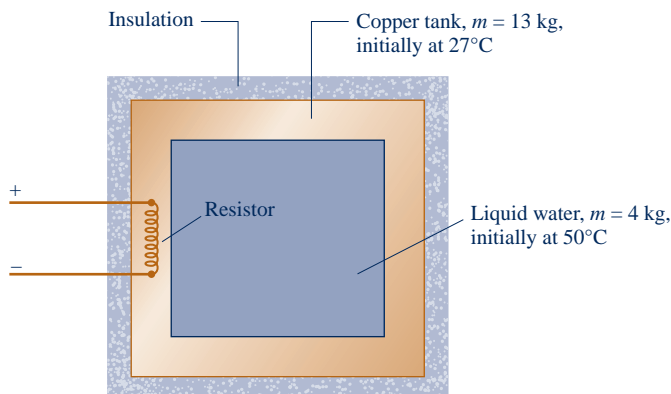


Fig. P3.89

3.90 As shown in Fig. P3.90, 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.

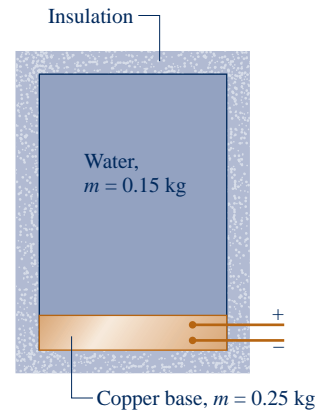


Fig. P3.90

Using Generalized Compressibility Data

3.91 Determine the compressibility factor for water vapor at 120 bar and 520°C using

- data from the compressibility chart.
- data from the steam tables.

Compare the values obtained in parts (a) and (b) and comment.

3.92 Determine the volume, in m^3 , occupied by 20 kg of hydrogen (H_2) at 1170 kPa, -220°C .

3.93 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 .

3.94 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 .

3.95 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.

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

3.97 Five kg of butane (C_4H_{10}) in a piston-cylinder assembly undergo a process from $p_1 = 5 \text{ MPa}$, $T_1 = 500 \text{ K}$ to $p_2 = 3 \text{ MPa}$, $T_2 = 450 \text{ K}$ during which the relationship between pressure and specific volume is $pv^n = \text{constant}$. Determine the work, in kJ.

3.98 Five lbmol of carbon dioxide (CO_2), initially at 320 lbf/in.², 660°R, is compressed at constant pressure in a piston-cylinder assembly. For the gas, $W = -2000 \text{ Btu}$. Determine the final temperature, in °R.

3.99 For what ranges of pressure and temperature can air be considered an ideal gas? Explain your reasoning.

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

- the ideal gas model.
- 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

- water vapor at 4000 lbf/in.^2 , 1000°F .
- water vapor at 5 lbf/in.^2 , 250°F .
- ammonia at 40 lbf/in.^2 , 60°F .
- air at 1 atm , 560°R .
- Refrigerant 134a at 300 lbf/in.^2 , 180°F .

3.102 Check the applicability of the ideal gas model

- for water at 700°F and pressures of 1600 lbf/in.^2 and 160 lbf/in.^2
- 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

- Table A-12.
- Figure A-1.
- 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

- Table A-15.
- Figure A-1.
- 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 $8 \text{ ft} \times 9 \text{ ft} \times 12 \text{ ft}$ is at 80°F and 1 atm . Determine the mass of the air, in lb, and its weight, in lbf, if $g = 32.0 \text{ ft/s}^2$.

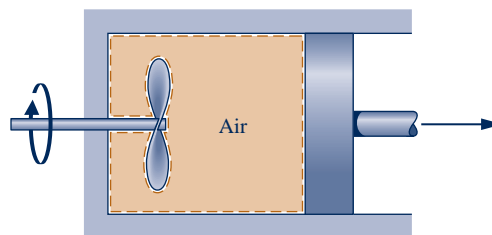
3.107 Determine the total mass of nitrogen (N_2), in kg, required to inflate all four tires of a vehicle, each to a gage pressure of 180 kPa at a temperature of 25°C . The volume of each tire is 0.6 m^3 , and the atmospheric pressure is 1 atm .

3.108 Using Table A-18, determine the temperature, in K and $^\circ\text{C}$, of propane at a state where the pressure is 2 bar and the specific volume is $0.307 \text{ m}^3/\text{kg}$. Compare with the temperature, in K and $^\circ\text{C}$, 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 $p_1 = 30 \text{ lbf/in.}^2$, $T_1 = 540^\circ\text{F}$, and $V_1 = 4 \text{ ft}^3$. The air undergoes a process to a final state where $p_2 = 20 \text{ lbf/in.}^2$, $V_2 = 4.5 \text{ ft}^3$. 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 $^\circ\text{R}$, and (b) the heat transfer, in Btu.



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

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 $pV = \text{constant}$. 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 $pV^{1.2} = \text{constant}$. 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, $k = 1.4$.

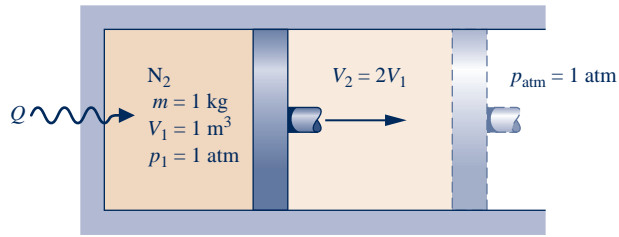


Fig. P3.115

- 3.116** A piston–cylinder assembly contains air at a pressure of 30 lbf/in.² and a volume of 0.75 ft³. 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.
- 3.117** As shown in Fig. P3.117, 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.

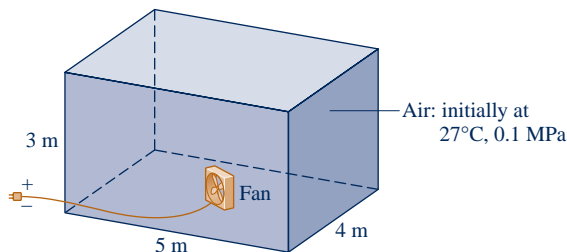


Fig. P3.117

- 3.118** 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 ft³. 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.
- 3.119** 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 seconds 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.
- 3.120** Argon contained in a closed, rigid tank, initially at 50°C, 2 bar, and a volume of 2 m³, 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.
- 3.121** 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.

- 3.122** As shown in Fig. P3.122, 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 $c_p = \frac{5}{2} R$.

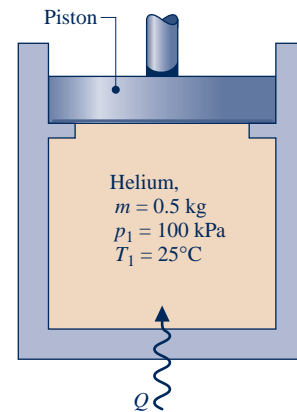


Fig. P3.122

- 3.123** 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.
- 3.124** 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.
- 3.125** As shown in Fig. P3.125, a tank fitted with an electrical resistor of negligible mass holds 2 kg of nitrogen (N_2), initially at 27°C, 0.1 MPa. Over a period of 10 minutes, electricity is provided to the resistor at a rate of 0.12 kW. During this same period, a heat transfer of magnitude 12.59 kJ

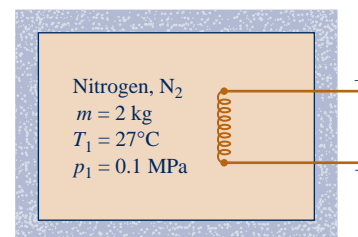


Fig. P3.125

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 m³ of air at 27°C, 0.3 MPa. The air is separated by a thin membrane from an evacuated volume of 3 m³. 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.

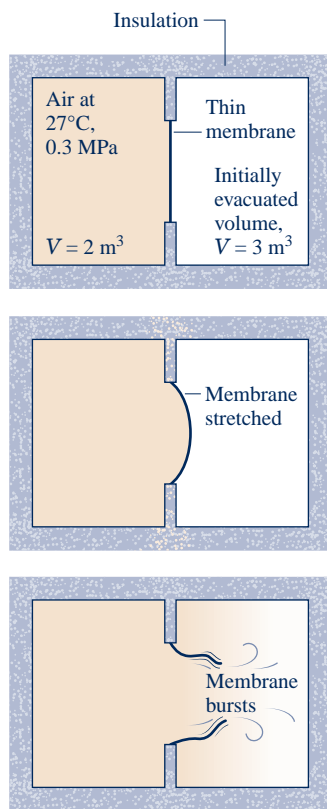


Fig. P3.127

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 $V_1 = 0.2$ m³. 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.

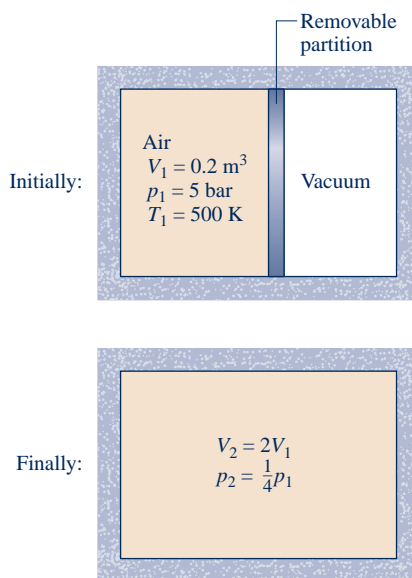


Fig. P3.128

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 m³.

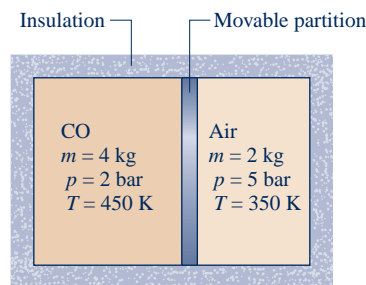


Fig. P3.129

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/s², 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

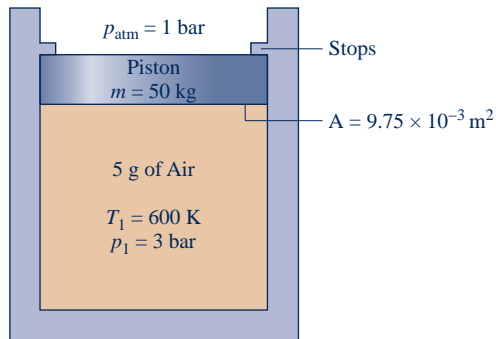


Fig. P3.130

at a voltage of 125 V for 5 minutes. Measurements indicate that when equilibrium is reached, the temperature of the gas has increased by 44.1°C . Heat transfer from the gas is estimated to occur at a constant rate of 1 kW. Assuming ideal gas behavior and negligible kinetic and potential energy effects, determine an average value of the specific heat, c_p , in $\text{kJ/kg} \cdot \text{K}$, of the gas in this temperature interval based on the measured data.

- 3.132** As shown in Fig. P3.132, 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.

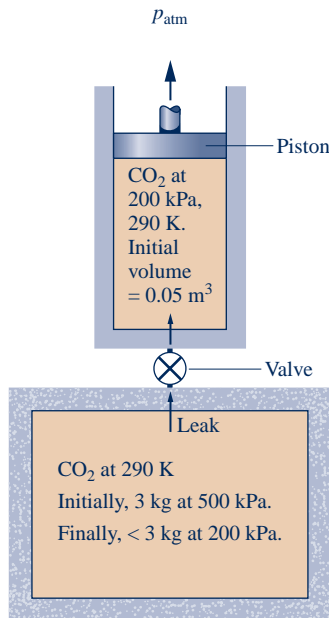


Fig. P3.132

- 3.133** 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.

- 3.134** As shown in Fig. P3.134, 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 $^\circ\text{R}$.

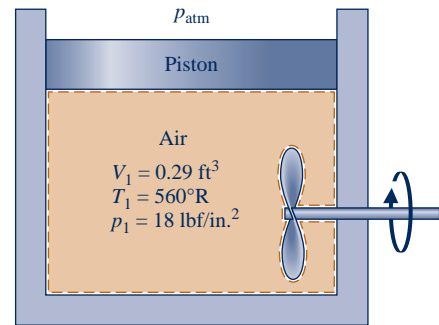


Fig. P3.134

- 3.135** Air is compressed in a piston-cylinder assembly from $p_1 = 10 \text{ lbf/in.}^2$, $T_1 = 500^\circ\text{R}$ to a final volume of $V_2 = 1 \text{ ft}^3$ in a process described by $pv^{1.25} = \text{constant}$. The mass of air is 0.5 lb. Assuming ideal gas behavior and neglecting kinetic and potential energy effects, determine the work and the heat transfer, each in Btu, using (a) constant specific heats evaluated at 500°R , and (b) data from Table A-22E. Compare the results and discuss.
- 3.136** A piston-cylinder assembly contains carbon monoxide modeled as an ideal gas with constant specific heat ratio, $k = 1.4$. The carbon monoxide undergoes a polytropic expansion with $n = k$ from an initial state, where $T_1 = 200^\circ\text{F}$ and $p_1 = 40 \text{ lbf/in.}^2$, to a final state, where the volume is twice the initial volume. Determine (a) the final temperature, in $^\circ\text{F}$, and final pressure, in lbf/in.^2 , and (b) the work and heat transfer, each in Btu/lb.

- 3.137** Air contained in a piston-cylinder assembly undergoes two processes in series, as shown in Fig. P3.137. Assuming ideal gas behavior for the air, determine the work and heat transfer for the overall process, each in kJ/kg.

- 3.138** 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 $V_1 = 1.33 \text{ m}^3$ to $V_2 = 1 \text{ m}^3$.

Process 2–3: Constant volume to $p_3 = 4 \text{ bar}$.

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

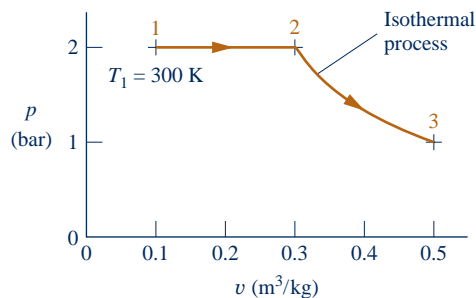


Fig. P3.137

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, $T_1 = 227^\circ\text{C}$:

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 $^\circ\text{C}$, 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.

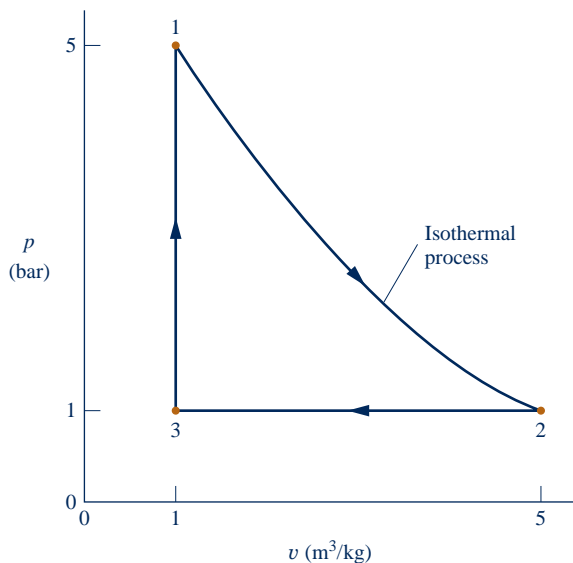


Fig. P3.140

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, $T_1 = 500^\circ\text{R}$ to $T_2 = 820^\circ\text{R}$.

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

- the pressure at state 2, in lbf/in.²
- the temperature at state 3, in $^\circ\text{R}$.
- the heat transfer and work, each in Btu, for all processes.
- 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 $pv^{1.28} = \text{constant}$

Process 3–1: Constant-pressure compression

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

- sketch the cycle on a p - v diagram.
- 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, $T_1 = 70^\circ\text{F}$ 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.

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

3.147 Answer the following true or false. Explain.

- (a) If water, initially a superheated vapor at 30 MPa, is cooled at *constant pressure*, the water eventually will become saturated vapor, and then with sufficient additional cooling condensation to saturated liquid will occur.
- (b) A quasiequilibrium process for which the pressure–volume relation is described by $p/V^n = \text{constant}$, where n is a constant, is called a *polytropic process*.
- (c) For *simple compressible systems*, the state principle indicates that the number of independent intensive thermodynamic properties required to fix an intensive state is two.
- (d) For ammonia at 0.45 MPa and 50°C, the specific enthalpy is 1564.32 kJ/kg.
- (e) For gases modeled as ideal gases, the value of the specific heat ratio c_v/c_p is greater than 1.

3.148 Answer the following true or false. Explain

- (a) The change in specific volume from saturated liquid to saturated vapor, $(v_g - v_f)$, at a specified saturation pressure increases as the pressure decreases.
- (b) A two-phase liquid–vapor mixture with equal volumes of saturated liquid and saturated vapor has a quality of 50%.
- (c) The following assumptions apply for a liquid modeled as *incompressible*: The specific volume (density) is constant and the specific internal energy is a function only of temperature.
- (d) Carbon dioxide (CO₂) at 320 K and 55 bar can be modeled as an ideal gas.
- (e) When an ideal gas undergoes a *polytropic* process with $n = 1$, the gas temperature remains constant.

► DESIGN & OPEN-ENDED PROBLEMS: EXPLORING ENGINEERING PRACTICE

3.1D Dermatologists remove skin blemishes from patients by applying sprays from canisters filled with liquid nitrogen (N₂). Investigate how liquid nitrogen is produced and delivered to physicians, and how physicians manage liquid nitrogen in their practices. Also investigate the advantages and disadvantages of this approach for removing blemishes compared to alternative approaches used today. Write a report including at least three references.

3.2D The EPA (Environmental Protection Agency) has developed an online *Personal Emissions Calculator* that helps individuals and families reduce greenhouse emissions. Use the EPA calculator to estimate, in the home and on the road, your personal greenhouse emissions or your family's greenhouse emissions. Also use the calculator to explore steps you as an individual or your family can take to cut emissions by at least 20%. In a memorandum, summarize your findings and present your program for lowering emissions.

3.3D Methane-laden gas generated by the decomposition of landfill trash has economic value. Research literature on the possible uses of landfill gas. Contact the manager of a large landfill in your locale concerning the capture and use, if any, of landfill gas generated by the facility. Write a report including at least three references.

3.4D Use of the *constant-volume* calorimeter to measure the calorie value of foods and other substances, as illustrated in Example 3.6, is one of three general types of biological calorimetry. Two others are *differential scanning calorimetry* and *isothermal titration calorimetry*. For these two, investigate the objectives and instrumentation of each. Present your findings in a memorandum, including sketches of the respective instrumentation together with summaries of how the instrumentation is used in the laboratory.

3.5D A newspaper article reports that on a day when an airline cancelled eleven flights from Las Vegas because the local

temperature was approaching the 117°F operating limit for its jets, another airline canceled seven flights from Denver because the local temperature there was above the 104°F operating level for its propeller planes. Prepare a 30-min. presentation suitable for a middle school science class explaining the technical considerations behind these cancellations.

3.6D Due to their zero ozone depletion and low global warming potential *natural refrigerants* are actively under consideration for commercial refrigeration applications (see box in Sec. 3.4). Investigate the viability of natural refrigerants in systems to improve human comfort and safeguard food. Consider performance benefits, safety, and cost. On the basis of your study, recommend especially promising natural refrigerants and areas of application where each is particularly well suited. Report your findings in a PowerPoint presentation.

3.7D According to the New York City Transit Authority, the operation of subways raises tunnel and station temperatures as much as 14 to 20°F above ambient temperature. Principal contributors to the temperature rise include train motor operation, lighting, and energy from the passengers themselves. Passenger discomfort can increase significantly in hot-weather periods if air conditioning is not provided. Still, because on-board air-conditioning units discharge energy by heat transfer to their surroundings, such units contribute to the overall tunnel and station energy management problem. Investigate the application to subways of *alternative* cooling strategies that provide substantial cooling with a minimal power requirement, including but not limited to thermal storage and nighttime ventilation. Write a report with at least three references.

3.8D Some oil and gas companies use *hydraulic fracturing* to access oil and natural gas trapped in deep rock formations. Investigate the process of hydraulic fracturing, its benefits, and environmental impacts. On this basis, write a three-page *brief* for submission to a congressional committee considering

whether hydraulic fracturing should continue to be exempt from regulation under the *Safe Drinking Water Act*. The brief can provide either objective technical background to inform committee members or take a position in favor of, or against, continuing the exemption.

3.9D Water is one of our most important resources, yet one of the most poorly managed—it is too often wasted and polluted. Investigate ways we can improve water use as a society in industry, businesses, and households. Record your daily water use for at least three days and compare it to that of those living in the poorest parts of the globe: about one gallon per day. Write a report including at least three references.

3.10D Passive solar heating may become more effective in coming years through incorporating *phase-change materials* (PCMs) into building materials. Investigate incorporation of phase-change materials into products used by the building industry to enhance passive solar heating. For each product, determine the PCM type, melting point, and accompanying phase-change enthalpy. Discuss how the PCM affects performance of the building material and how this benefits space heating. Prepare a 25-minute PowerPoint presentation suitable for a high school chemistry class based on your findings. Include at least two instructional aides to enhance your presentation.