5.10 ENGINEERING APPLICATIONS

Energy Storage and Conversion

Energy can be stored in a number of different forms by various physical implementations, which have different characteristics with respect to storage efficiency, rate of energy transfer, and size (Figs. 5.13–5.16). These systems can also include a possible energy conversion that consists of a change of one form of energy to another form of energy. The storage is usually temporary, lasting for periods ranging from a fraction of a second to days or years, and can be for very small or large amounts of energy. Also, it is basically a shift of the energy transfer from a time when it is unwanted and thus inexpensive to a time when it is wanted and then often expensive. It is also very important to consider the maximum rate of energy transfer in the charging or discharging process, as size and possible losses are sensitive to that rate.

Notice from Fig. 5.13 that it is difficult to have high power and high energy storage in the same device. It is also difficult to store energy more compactly than in gasoline.

Mechanical Systems

$$\text{Kinetic energy storage (mainly rotating systems):} \quad \frac{1}{2}\,\text{m}V^2 \text{ or } \frac{1}{2}\,\text{I}\omega^2$$

A flywheel stores energy and momentum in its angular motion. It is used to dampen out fluctuations arising from single (or few) cylinder engines that otherwise would give an uneven rotational speed. The storage is for only a very short time.

A modern flywheel is used to dampen fluctuations in intermittent power supplies like a wind turbine. It can store more energy than the flywheel shown in Fig. 5.14. A bank of several flywheels can provide substantial power for 5–10 minutes.

A fraction of the kinetic energy in air can be captured and converted into electrical power by wind turbines, or the power can be used directly to drive a water pump or other equipment.

$$\text{Potential energy storage:} \quad \text{mg}Z \text{ or } \frac{1}{2}\,\text{k}\,x^2 \text{ (spring potential energy)}$$

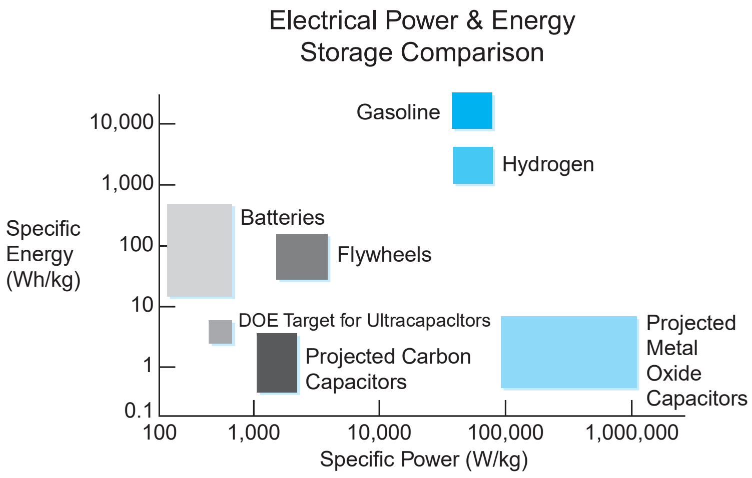

FIGURE 5.13 Specific energy versus specific power.

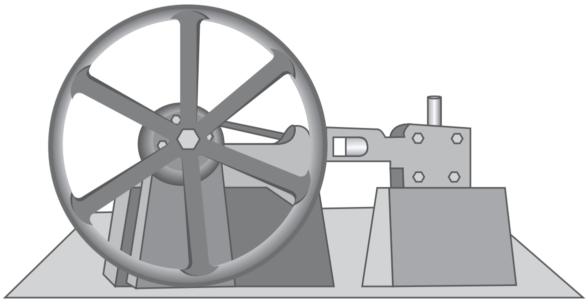

FIGURE 5.14 Simple flywheel.

When excess power is available, it can be used to pump water up to a reservoir at a higher elevation and later can be allowed to run out through a turbine, providing a variable time shift in the power going to the electrical grid.

Air can be compressed into large tanks or volumes (as in an abandoned salt mine) using power during a low-demand period. The air can be used later in power production when there is a peak demand.

One form of hybrid engine for a car involves coupling a hydraulic pump/motor to the drive shaft. When a braking action is required, the drive shaft pumps hydraulic fluid into a high-pressure tank that has nitrogen as a buffer. Then, when acceleration is needed, the high-pressure fluid runs backward through the hydraulic motor, adding power to the drive shaft in the process. This combination is highly beneficial for city driving, such as for a bus

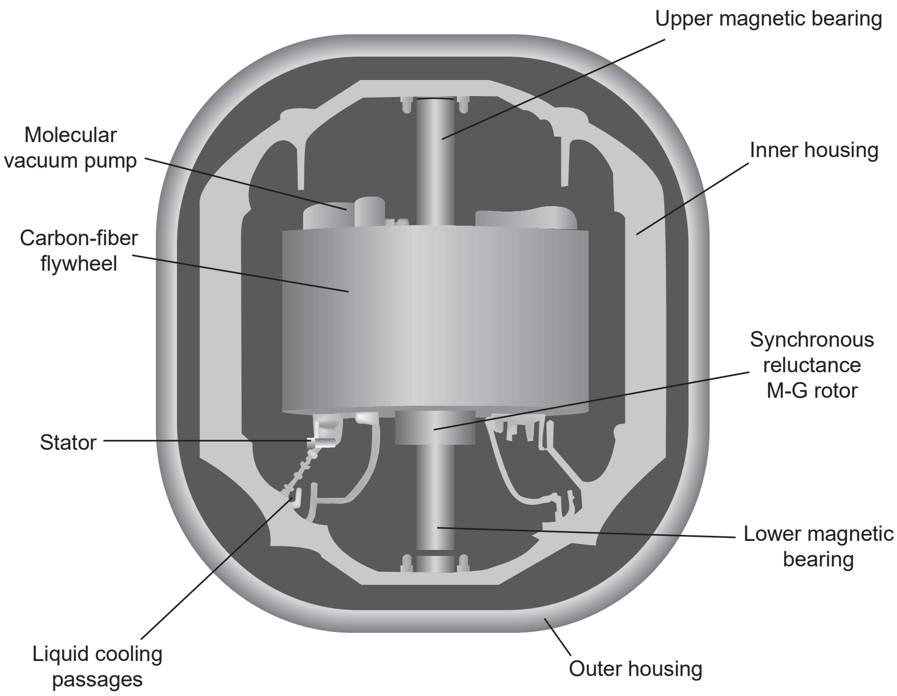

FIGURE 5.15 Modern flywheel.

FIGURE 5.16 Wind turbine.

that stops and starts many times, whereas there is virtually no gain for a truck driving long distances on the highway at nearly constant speed.

Thermal Systems

$$\text{Internal energy:} \quad mu$$

Water can be heated by solar influx, or by some other source to provide heat at a time when this source is not available. Similarly, water can be chilled at night to be used the next day for air-conditioning purposes. A cool-pack is placed in the freezer so that the next day it can be used in a lunch box to keep it cool. This is a gel with a high heat capacity or a substance that undergoes a phase change.

Electrical Systems

Some batteries can only be discharged once, but others can be reused and go through many cycles of charging-discharging. A chemical process frees electrons on one of two poles that are separated by an electrolyte. The type of pole and the electrolyte give the name to the battery, such as a zinc-carbon battery (typical AA battery) or a lead-acid battery (typical automobile battery). Newer types of batteries like a Ni-hydride or a lithium-ion battery are more expensive but have higher energy storage, and they can provide higher bursts of power (Fig. 5.17).

Chemical Systems

Various chemical reactions can be made to operate under conditions such that energy can be stored at one time and recovered at another time. Small heat packs can be broken to mix some chemicals that react and release energy in the form of heat; in other cases, they can be

FIGURE 5.17
Examples of different types of batteries.

glow-sticks that provide light. A fuel cell is also an energy conversion device that converts a flow of hydrogen and oxygen into a flow of water plus heat and electricity. High-temperature fuel cells can use natural gas or methanol as the fuel; in this case, carbon dioxide is also a product.

SUMMARY

Conservation of energy is expressed for a cycle, and changes of total energy are then written for a control mass. Kinetic and potential energy can be changed through the work of a force acting on the control mass, and they are part of the total energy.

The internal energy and the enthalpy are introduced as substance properties with the specific heats (heat capacity) as derivatives of these with temperature. Property variations for limited cases are presented for incompressible states of a substance such as liquids and solids and for a highly compressible state as an ideal gas. The specific heat for solids and liquids changes little with temperature, whereas the specific heat for a gas can change substantially with temperature.

The energy equation is also shown in a rate form to cover transient processes.

You should have learned a number of skills and acquired abilities from studying this chapter that will allow you to

- Recognize the components of total energy stored in a control mass.
- Write the energy equation for a single uniform control mass.
- Find the properties u and h for a given state in the tables in Appendix B.
- Locate a state in the tables with an entry such as (P, h).
- Find changes in u and h for liquid or solid states using Tables A.3 and A.4 or F.2 and F.3.
- Find changes in u and h for ideal-gas states using Table A.5 or F.4.
- Find changes in u and h for ideal-gas states using Tables A.7 and A.8 or F.5 and F.6.
- Recognize that forms for C_p in Table A.6 are approximations to what is shown in Fig. 5.11 and the more accurate tabulations in Tables A.7, A.8, F.5, and F.6.
- Formulate the conservation of mass and energy for a control mass that goes through a process involving work and heat transfers and different states.

- Formulate the conservation of mass and energy for a more complex control mass where there are different masses with different states.
- Use the energy equation in a rate form.
- Know the difference between the general laws as the conservation of mass (continuity equation), conservation of energy (first law), and the specific law that describes a device behavior or process.

KEY CONCEPTS AND FORMULAS

Total energy	$E = U + \mathrm{KE} + \mathrm{PE} = mu + \frac{1}{2}m\mathbf{V}^2 + mgZ$
Kinetic energy	$\mathrm{KE} = \frac{1}{2}m\mathbf{V}^2$
Potential energy	$\mathrm{PE} = mgZ$
Specific energy	$e = u + \frac{1}{2}\mathbf{V}^2 + gZ$
Enthalpy	$h \equiv u + Pv$
Two-phase mass average	$u = u_f + xu_{fg} = (1 - x)u_f + xu_g$ $h = h_f + xh_{fg} = (1 - x)h_f + xh_g$
Specific heat, heat capacity	$C_v = \left(\frac{\partial u}{\partial T}\right)_v;\ C_p = \left(\frac{\partial h}{\partial T}\right)_p$
Solids and liquids	Incompressible, so $v =$ constant $\cong v_f$ and v very small $C = C_v = C_p$ [Tables A.3 and A.4 (F.2 and F.3)] $u_2 - u_1 = C(T_2 - T_1)$ $h_2 - h_1 = u_2 - u_1 + v(P_2 - P_1)$ (Often the second term is small.) $h = h_f + v_f(P - P_{sat});\ u \cong u_f$ (saturated at same T)
Ideal gas	$h = u + Pv = u + RT$ (only functions of T) $C_v = \frac{du}{dT};\ C_p = \frac{dh}{dT} = C_v + R$ $u_2 - u_1 = \int C_v\, dT \cong C_v(T_2 - T_1)$ $h_2 - h_1 = \int C_p\, dT \cong C_p(T_2 - T_1)$ Left-hand side from Table A.7 or A.8, middle from Table A.6, and right-hand side from Table A.6 at a T_{avg} or from Table A.5 at 25°C Left-hand side from Table F.5 or F.6, right-hand side from Table F.4 at 77 F
Energy equation rate form	$\dot{E} = \dot{Q} - \dot{W}$ (rate = + in − out)
Energy equation integrated	$E_2 - E_1 = {}_1Q_2 - {}_1W_2$ (change = + in − out) $m(e_2 - e_1) = m(u_2 - u_1) + \frac{1}{2}m(\mathbf{V}_2^2 - \mathbf{V}_1^2) + mg(Z_2 - Z_1)$
Multiple masses, states	$E = m_A e_A + m_B e_B + m_C e_C + \cdots$

CONCEPT-STUDY GUIDE PROBLEMS

5.1 What is 1 cal in SI units and what is the name given to 1 Nm?

5.2 Why do we write ΔE or $E_2 - E_1$, whereas we write ${}_1Q_2$ and ${}_1W_2$?

5.3 If a process in a control mass increases energy $E_2 - E_1 > 0$, can you say anything about the sign for ${}_1Q_2$ and ${}_1W_2$?

5.4 When you wind up a spring in a toy or stretch a rubber band, what happens in terms of work, energy, and heat transfer? Later, when they are released, what happens then?

5.5 C.V. A is the mass inside a piston/cylinder, and C.V. B is that mass plus the piston, outside which is the standard atmosphere (Fig. P5.5). Write the energy equation and work term for the two C.V.s, assuming we have a nonzero Q between state 1 and state 2.

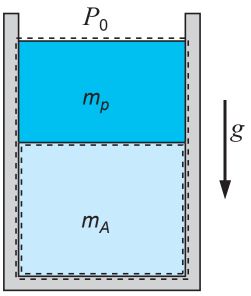

FIGURE P5.5

5.6 Saturated water vapor has a maximum for u and h at around 235°C. Is it similar for other substances?

5.7 Some liquid water is heated so that is becomes superheated vapor. Do I use u or h in the energy equation? Explain.

5.8 Some liquid water is heated so that it becomes superheated vapor. Can I use specific heat to find the heat transfer? Explain.

5.9 Look at the R-410a value for u_f at −50°C. Can the energy really be negative? Explain.

5.10 A rigid tank with pressurized air is used (a) to increase the volume of a linear spring-loaded piston/cylinder (cylindrical geometry) arrangement and (b) to blow up a spherical balloon. Assume that in both cases $P = A + BV$ with the same A and B. What is the expression for the work term in each situation?

5.11 An ideal gas in a piston/cylinder is heated with 2 kJ during an isothermal process. How much work is involved?

5.12 An ideal gas in a piston/cylinder is heated with 2 kJ during an isobaric process. Is the work positive, negative, or zero?

5.13 You heat a gas 10 K at $P = C$. Which one in Table A.5 requires most energy? Why?

5.14 A 500-W electric space heater with a small fan inside heats air by blowing it over a hot electrical wire. For each control volume: (a) wire only, (b) all the room air, and (c) total room plus the heater, specify the stoage, work, and heat transfer terms as +500 W, −500 W, or 0 (neglect any $\dot{Q}$ through the room walls or windos).

HOMEWORK PROBLEMS

Kinetic and Potential Energy

5.15 A piston motion moves a 25-kg hammerhead vertically down 1 m from rest to a velocity of 50 m/s in a stamping machine. What is the change in total energy of the hammerhead?

5.16 A steel ball weighing 5 kg rolls horizontally at a rate of 10 m/s. If it rolls up an incline, how high up will it be when it comes to rest, assuming standard gravitation?

5.17 A 1200-kg car accelerates from zero to 100 km/h over a distance of 400 m. The road at the end of the 400 m is at 10 m higher elevation. What is the total increase in the car's kinetic and potential energy?

5.18 A hydraulic hoist raises a 1750-kg car 1.8 m in an auto repair shop. The hydraulic pump has a constant pressure of 800 kPa on its piston. What is the increase in potential energy of the car and how much volume should the pump displace to deliver that amount of work?

5.19 The rolling resistance of a car depends on its weight as $F = 0.006\, m_{car}g$. How far will a 1200-kg car roll if the gear is put in neutral when it drives at 90 km/h on a level road without air resistance?

5.20 A 1200-kg car accelerates from 30 to 50 km/h in 5 s. How much work input does that require? If it continues to accelerate from 50 to 70 km/h in 5 s, is that the same?

5.21 Airplane takeoff from an aircraft carrier is assisted by a steam-driven piston/cylinder with an average pressure of 1250 kPa. A 17500-kg airplane should accelerate from zero to 30 m/s, with 30% of the energy coming from the steam piston. Find the needed piston displacement volume.

5.22 Solve Problem 5.21, but assume the steam pressure in the cylinder starts at 1000 kPa, dropping linearly with volume to reach 100 kPa at the end of the process.

5.23 A 25-kg piston is above a gas in a long vertical cylinder. Now the piston is released from rest and accelerates up in the cylinder, reaching the end 5 m higher at a velocity of 25 m/s. The gas pressure drops during the process, so the average is 600 kPa with an outside atmosphere at 100 kPa. Neglect the change in gas kinetic and potential energy and find the needed change in the gas volume.

5.24 A 2-kg piston accelerates to 20 m/s from rest. What constant gas pressure is required if the area is 10 cm^2, the travel is 10 cm, and the outside pressure is 100 kPa?

Properties (u, h) from General Tables

5.25 Find the phase and the missing properties of P, T, v, u, and x for water at
a. 500 kPa, 100°C
b. 5000 kPa, $u = 800$ kJ/kg
c. 5000 kPa, $v = 0.06$ m^3/kg
d. −6°C, $v = 1$ m^3/kg

5.26 Indicate the location of the four states in Problem 5.25 as points in both the P–v and T–v diagrams.

5.27 Find the phase and the missing properties of P, T, v, u, and x for
a. Water at 5000 kPa, $u = 3000$ kJ/kg
b. Ammonia at 50°C, $v = 0.08506$ m^3/kg
c. Ammonia at 28°C, 1200 kPa
d. R-134a at 20°C, $u = 350$ kJ/kg

5.28 Fing the missing properties of P, v, u, and x and the phase of ammonia, NH_3.
a. $T = 65$°C, $P = 600$ kPa
b. $T = 20$°C, $P = 100$ kPa
c. $T = 50$°C, $v = 0.1185$ m^3/kg

5.29 Find the missing properties of u, h, and x for
a. Water at 120°C, $v = 0.5$ m^3/kg
b. Water at 100°C, $P = 10$ MPa
c. Nitrogen at 100 K, $x = 0.75$
d. Nitrogen at 200 K, $P = 200$ kPa
e. Ammonia 100°C, $v = 0.1$ m^3/kg

5.30 Find the missing property of P, T, v, u, h, and x and indicate the states in a P–v and a T–v diagram for
a. R-410a at 500 kPa, $h = 300$ kJ/kg
b. R-410a at 10°C, $u = 200$ kJ/kg
c. R-134a at 40°C, $h = 400$ kJ/kg

5.31 Find the missing properties.

a. H_2O,	$T = 250$°C, $v = 0.02$ m^3/kg,	$P = ?$ $u = ?$
b. N_2,	$T = 120$ K, $P = 0.8$ MPa,	$x = ?$ $h = ?$
c. H_2O,	$T = -2$°C, $P = 100$ kPa,	$u = ?$ $v = ?$
d. R-134a,	$P = 200$ kPa, $v = 0.12$ m^3/kg,	$u = ?$ $T = ?$

5.32 Find the missing property of P, T, v, u, h, and x and indicate the states in a P–v and a T–v diagram for
a. Water at 5000 kPa, $u = 1000$ kJ/kg
b. R-134a at 20°C, $u = 300$ kJ/kg
c. Nitrogen at 250 K, 200 kPa

5.33 Find the missing properties for carbon dioxide at
a. 20°C, 2 MPa: $v = ?$ and $h = ?$
b. 10°C, $x = 0.5$: $T = ?$, $u = ?$
c. 1 MPa, $v = 0.05$ m^3/kg: $T = ?$, $h = ?$

5.34 Saturated liquid water at 20°C is compressed to a higher pressure with constant temperature. Find the changes in u and h from the initial state when the final pressure is
a. 500 kPa
b. 2000 kPa

Energy Equation: Simple Process

5.35 Saturated vapor R-410a at 0°C in a rigid tank is cooled to −20°C. Find the specific heat transfer.

5.36 A 100-L rigid tank contains nitrogen (N_2) at 900 K and 3 MPa. The tank is now cooled to 100 K. What are the work and heat transfer for the process?

5.37 Saturated vapor carbon dioxide at 2 MPa in a constant-pressure piston/cylinder is heated to 20°C. Find the specific heat transfer.

5.38 Two kilograms of water at 120°C with a quality of 25% has its temperature raised 20°C in a constant-volume process as in Fig. P5.38. What are the heat transfer and work in the process?

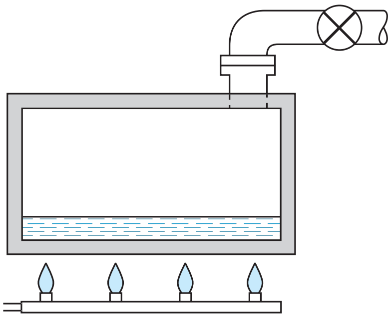

FIGURE P5.38

5.39 Ammonia at 0°C with a quality of 60% is contained in a rigid 200-L tank. The tank and ammonia are now heated to a final pressure of 1 MPa. Determine the heat transfer for the process.

5.40 A test cylinder with a constant volume of 0.1 L contains water at the critical point. It now cools to a room temperature of 20°C. Calculate the heat transfer from the water.

5.41 A rigid tank holds 0.75 kg ammonia at 70°C as saturated vapor. The tank is now cooled to 20°C by heat transfer to the ambient. Which two properties determine the final state? Determine the amount of work and heat transfer during the process.

5.42 A cylinder fitted with a frictionless piston contains 2 kg of superheated refrigerant R-134a vapor at 350 kPa, 100°C. The cylinder is now cooled so that the R-134a remains at constant pressure until it reaches a quality of 75%. Calculate the heat transfer in the process.

5.43 Water in a 150-L closed, rigid tank is at 100°C and 90% quality. The tank is then cooled to −10°C. Calculate the heat transfer for the process.

5.44 A piston/cylinder device contains 50 kg water at 200 kPa with a volume of 0.1 m^3. Stops in the cylinder are placed to restrict the enclosed volume to a maximum of 0.5 m^3. The water is now heated until the piston reaches the stops. Find the necessary heat transfer.

5.45 Find the heat transfer for the process in Problem 4.33.

5.46 A 10-L rigid tank contains R-410a at −10°C with a quality of 80%. A 10-A electric current (from a 6-V battery) is passed through a resistor inside the tank for 10 min, after which the R-410a temperature is 40°C. What was the heat transfer to or from the tank during this process?

5.47 A piston/cylinder contains 1 kg water at 20°C with volume 0.1 m^3. By mistake someone locks the piston, preventing it from moving while we heat the water to saturated vapor. Find the final temperature and the amount of heat transfer in the process.

5.48 A piston/cylinder contains 1.5 kg water at 600 kPa, 350°C. It is now cooled in a process wherein pressure is linearly related to volume to a state of 200 kPa, 150°C. Plot the P–v diagram for the process, and find both the work and the heat transfer in the process.

5.49 Two kilograms of water at 200 kPa with a quality of 25% has its temperature raised 20°C in a constant-pressure process. What are the heat transfer and work in the process?

5.50 A water-filled reactor with a volume of 1 m^3 is at 20 MPa and 360°C and is placed inside a containment room, as shown in Fig. P5.50. The room is well insulated and initially evacuated. Due to a failure, the reactor ruptures and the water fills the containment room. Find the minimum room volume so that the final pressure does not exceed 200 kPa.

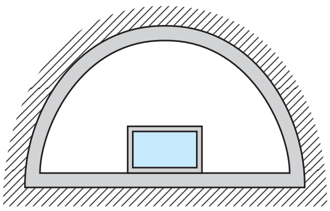

FIGURE P5.50

5.51 A 25-kg mass moves at 25 m/s. Now a brake system brings the mass to a complete stop with a constant deceleration over a period of 5 s. Assume the mass is at constant P and T. The brake energy is absorbed by 0.5 kg of water initially at 20°C and 100 kPa. Find the energy the brake removes from the mass and the temperature increase of the water, assuming its pressure is constant.

5.52 Find the heat transfer for the process in Problem 4.41.

5.53 A piston/cylinder arrangement has the piston loaded with outside atmospheric pressure and the piston mass to a pressure of 150 kPa, as shown in Fig. P5.53. It contains water at −2°C, which is then heated until the water becomes saturated vapor. Find the final temperature and specific work and heat transfer for the process.

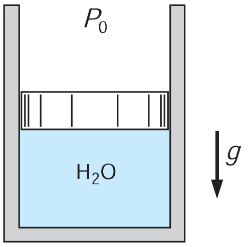

FIGURE P5.53

5.54 A constant-pressure piston/cylinder assembly contains 0.2 kg water as saturated vapor at 400 kPa. It is now cooled so that the water occupies half of the original volume. Find the heat transfer in the process.

5.55 A cylinder having a piston restrained by a linear spring (of spring constant 15 kN/m) contains 0.5 kg of saturated vapor water at 120°C, as shown in Fig. P5.55. Heat is transferred to the water, causing the piston to rise. If the piston's cross-sectional area is 0.05 m^2 and the pressure varies linearly with volume until a final pressure of 500 kPa is reached, find the final temperature in the cylinder and the heat transfer for the process.

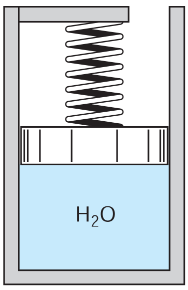

FIGURE P5.55

5.56 A piston/cylinder arrangement with a linear spring similar to Fig. P5.55 contains R-134a at 15°C, $x =$ 0.6 and a volume of 0.02 m^3. It is heated to 60°C, at which point the specific volume is 0.03002 m^3/kg. Find the final pressure, the work, and the heat transfer in the process.

5.57 A closed steel bottle contains carbon dioxide at −20°C, $x = 20\%$ and the volume is 0.05 m^3. It has a safety valve that opens at a pressure of 6 MPa. By accident, the bottle is heated until the safety valve opens. Find the temperature and heat transfer when the valve first opens.

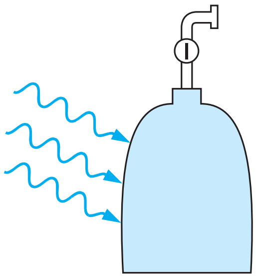

FIGURE P5.57

5.58 Superheated refrigerant R-134a at 20°C and 0.5 MPa is cooled in a piston/cylinder arrangement at constant temperature to a final two-phase state with quality of 50%. The refrigerant mass is 5 kg, and during this process 500 kJ of heat is removed. Find the initial and final volumes and the necessary work.

5.59 A 1-L capsule of water at 700 kPa and 150°C is placed in a larger insulated and otherwise evacuated vessel. The capsule breaks and its contents fill the entire volume. If the final pressure should not exceed 125 kPa, what should the vessel volume be?

5.60 A piston/cylinder contains carbon dioxide at −20°C and quality 75%. It is compressed in a process wherein pressure is linear in volume to a state of 3 MPa and 20°C. Find specific heat transfer.

5.61 A rigid tank is divided into two rooms, both containing water, by a membrane, as shown in Fig. P5.61. Room A is at 200 kPa, $v = 0.5$ m^3/kg, $V_A = 1$ m^3, and room B contains 3.5 kg at 0.5 MPa, 400°C. The membrane now ruptures and heat transfer takes place so that the water comes to a uniform state at 100°C. Find the heat transfer during the process.

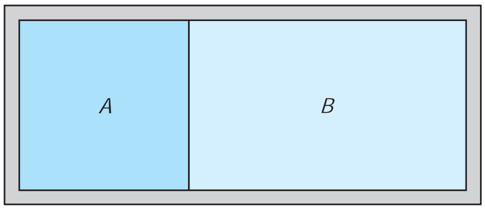

FIGURE P5.61

5.62 Two kilograms of nitrogen at 100 K, $x = 0.5$ is heated in a constant-pressure process to 300 K in a piston/cylinder arrangement. Find the initial and final volumes and the total heat transfer required.

5.63 Water in tank A is at 250 kPa with quality 10% and mass 0.5 kg. It is connected to a piston/cylinder holding constant pressure of 200 kPa initially with 0.5 kg water at 400°C. The valve is opened, and enough heat transfer takes place to have a final uniform temperature of 150°C. Find the final P and V, the process work, and the process heat transfer.

5.64 A 10-m-high open cylinder, with $A_{cyl} = 0.1\ m^2$, contains 20°C water above and 2 kg of 20°C water below a 198.5-kg thin insulated floating piston, as shown in Fig. P5.64. Assume standard g, P_0. Now heat is added to the water below the piston so that it expands, pushing the piston up, causing the water on top to spill over the edge. This process continues until the piston reaches the top of the cylinder. Find the final state of the water below the piston (T, P, v) and the heat added during the process.

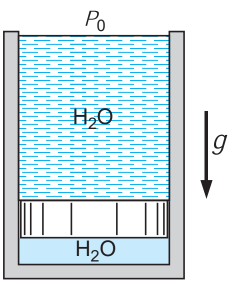

FIGURE P5.64

5.65 Assume the same setup as in Problem 5.50, but the room has a volume of 100 m^3. Show that the final state is two phase and find the final pressure by trial and error.

5.66 A piston/cylinder has a water volume separated in $V_A = 0.2\ m^3$ and $V_B = 0.3\ m^3$ by a stiff membrane. The initial state in A is 1000 kPa, $x = 0.75$ and in B it is 1600 kPa and 250°C. Now the membrane ruptures and the water comes to a uniform state at 200°C. What is the final pressure? Find the work and the heat transfer in the process.

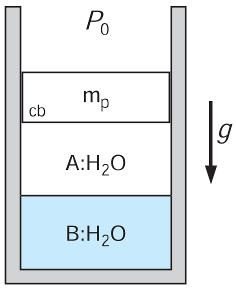

FIGURE P5.66

5.67 Two rigid tanks are filled with water. Tank A is 0.2 m^3 at 100 kPa, 150°C and tank B is 0.3 m^3 at saturated vapor of 300 kPa. The tanks are connected by a pipe with a closed valve. We open the valve and let all the water come to a single uniform state while we transfer enough heat to have a final pressure of 300 kPa. Give the two property values that determine the final state and find the heat transfer.

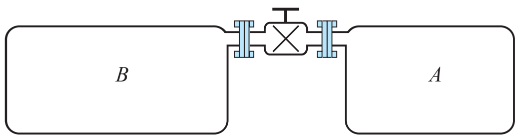

FIGURE P5.67

Energy Equation: Multistep Solution

5.68 A piston/cylinder shown in Fig. P5.68 contains 0.5 m^3 of R-410a at 2 MPa, 150°C. The piston mass and atmosphere give a pressure of 450 kPa that will float the piston. The whole setup cools in a freezer maintained at −20°C. Find the heat transfer and show the P–v diagram for the process when $T_2 =$ −20°C.

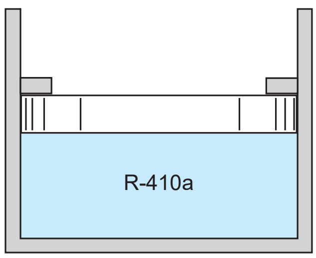

FIGURE P5.68

5.69 A setup like the one in Fig. P5.68 has the R-410a initially at 1000 kPa, 50°C of mass 0.1 kg. The balancing equilibrium pressure is 400 kPa, and it is now cooled so that the volume is reduced to half of the starting volume. Find the heat trasfer for the process.

5.70 A vertical cylinder fitted with a piston contains 5 kg of R-410a at 10°C, as shown in Fig. P5.70. Heat is transferred to the system, causing the piston to rise until it reaches a set of stops, at which point the volume has doubled. Additional heat is transferred until the temperature inside reaches 50°C, at which point the pressure inside the cylinder is 1.4 MPa.

a. What is the quality at the initial state?
b. Calculate the heat transfer for the overall process.

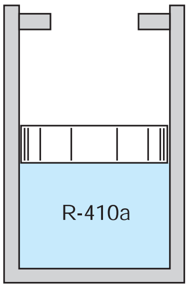

FIGURE P5.70

5.71 Find the heat transfer for the process in Problem 4.68.

5.72 Ten kilograms of water in a piston/cylinder arrangement exists as saturated liquid/vapor at 100 kPa, with a quality of 50%. The system is now heated so that the volume triples. The mass of the piston is such that a cylinder pressure of 200 kPa will float it, as in Fig. P5.72. Find the final temperature and the heat transfer in the process.

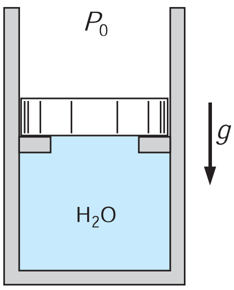

FIGURE P5.72

5.73 The cylinder volume below the constant loaded piston has two compartments, *A* and *B*, filled with water, as shown in Fig. P5.73. *A* has 0.5 kg at 200 kPa and 150°C and *B* has 400 kPa with a quality of 50% and a volume of 0.1 m^3. The valve is opened and heat is transferred so that the water comes to a uniform state with a total volume of 1.006 m^3. Find the total mass of water and the total initial volume. Find the work and the heat transfer in the process.

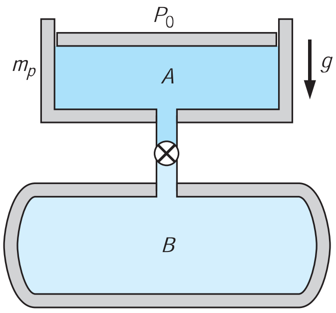

FIGURE P5.73

5.74 Calculate the heat transfer for the process described in Problem 4.65.

5.75 A rigid tank *A* of volume 0.6 m^3 contains 3 kg of water at 120°C, and rigid tank *B* is 0.4 m^3 with water at 600 kPa, 200°C. They are connected to a piston/cylinder initially empty with closed valves as shown in Fig. P5.75. The pressure in the cylinder should be 800 kPa to float the piston. Now the valves are slowly opened and heat is transferred so

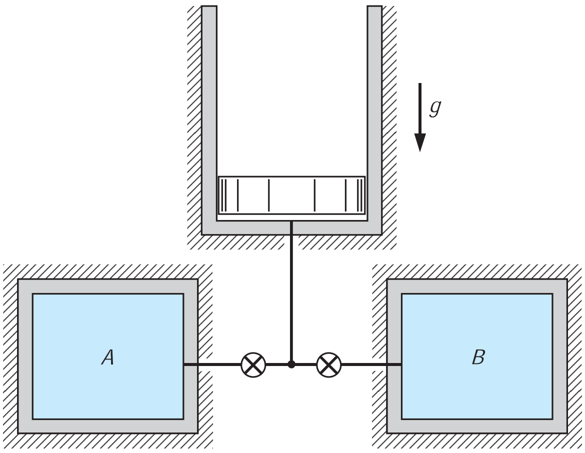

FIGURE P5.75

that the water reaches a uniform state at 250°C with the valves open. Find the final volume and pressure, and the work and heat transfer in the process.

5.76 Calculate the heat transfer for the process described in Problem 4.73.

5.77 A cylinder/piston arrangement contains 5 kg of water at 100°C with $x = 20\%$ and the piston, of $m_p = 75$ kg, resting on some stops, similar to Fig. P5.72. The outside pressure is 100 kPa, and the cylinder area is $A = 24.5\ \text{cm}^2$. Heat is now added until the water reaches a saturated vapor state. Find the initial volume, final pressure, work, and heat transfer terms and show the P–v diagram.

Energy Equation: Solids and Liquids

5.78 I have 2 kg of liquid water at 20°C, 100 kPa. I now add 20 kJ of energy at constant pressure. How hot does the water get if it is heated? How fast does it move if it is pushed by a constant horizontal force? How high does it go if it is raised straight up?

5.79 A copper block of volume 1 L is heat treated at 500°C and now cooled in a 200-L oil bath initially at 20°C, as shown in Fig. P5.79. Assuming no heat transfer with the surroundings, what is the final temperature?

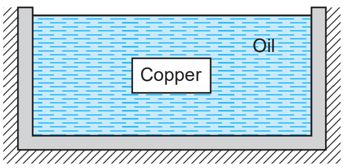

FIGURE P5.79

5.80 Because a hot water supply must also heat some pipe mass as it is turned on, the water does not come out hot right away. Assume 80°C liquid water at 100 kPa is cooled to 45°C as it heats 15 kg of copper pipe from 20 to 45°C. How much mass (kg) of water is needed?

5.81 In a sink, 5 L of water at 70°C is combined with 1 kg of aluminum pots, 1 kg of silverware (steel), and 1 kg of glass, all put in at 20°C. What is the final uniform temperature, neglecting any heat loss and work?

5.82 A house is being designed to use a thick concrete floor mass as thermal storage material for solar energy heating. The concrete is 30 cm thick, and the area exposed to the sun during the daytime is 4 × 6 m. It is expected that this mass will undergo an average temperature rise of about 3°C during the day. How much energy will be available for heating during the nighttime hours?

5.83 A closed rigid container is filled with 1.5 kg water at 100 kPa, 55°C; 1 kg of stainless steel, and 0.5 kg of polyvinyl chloride, both at 20°C; and 0.1 kg air at 400 K, 100 kPa. It is now left alone, with no external heat transfer, and no water vaporizes. Find the final temperature and air pressure.

5.84 A car with mass 1275 kg is driven at 60 km/h when the brakes are applied quickly to decrease its speed to 20 km/h. Assume that the brake pads have a 0.5-kg mass with a heat capacity of 1.1 kJ/kg K and that the brake disks/drums are 4.0 kg of steel. Further assume that both masses are heated uniformly. Find the temperature increase in the brake assembly.

5.85 A computer cpu chip consists of 50 g silicon, 20 g copper, and 50 g polyvinyl chloride (plastic). It now heats from 15°C to 70°C as the computer is turned on. How much energy did the heating require?

5.86 A 25-kg steel tank initially at −10°C is filled with 100 kg of milk (assumed to have the same properties as water) at 30°C. The milk and the steel come to a uniform temperature of +5°C in a storage room. How much heat transfer is needed for this process?

5.87 A 1-kg steel pot contains 1 kg liquid water, both at 15°C. The pot is now put on the stove, where it is heated to the boiling point of the water. Neglect any air being heated and find the total amount of energy needed.

5.88 A piston/cylinder (0.5 kg steel altogether) maintaining a constant pressure has 0.2 kg R-134a as saturated vapor at 150 kPa. It is heated to 40°C, and the steel is at the same temperature as the R-134a at any time. Find the work and heat transfer for the process.

5.89 An engine, shown in Fig. P5.89, consists of a 100-kg cast iron block with a 20-kg aluminum head, 20 kg of steel parts, 5 kg of engine oil, and 6 kg of glycerine (antifreeze). All initial temperatures are 5°C, and as the engine starts we want to know how hot it becomes if it absorbs a net of 7000 kJ before it reaches a steady uniform temperature.

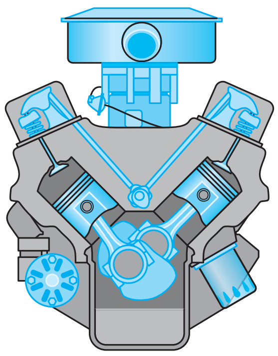

FIGURE P5.89

Properties (u, h, C_v, and C_p), Ideal Gas

5.90 Use the ideal-gas air Table A.7 to evaluate the heat capacity C_p at 300 K as a slope of the curve $h(T)$ by $\Delta h/\Delta T$. How much larger is it at 1000 K and at 1500 K?

5.91 We want to find the change in u for carbon dioxide between 600 K and 1200 K.
a. Find it from a constant C_{v0} from Table A.5.
b. Find it from a C_{v0} evaluated from the equation in Table A.6 at the average T.
c. Find it from the values of u listed in Table A.8.

5.92 We want to find the change in u for carbon dioxide between 50°C and 200°C at a pressure of 10 MPa. Find it using ideal gas and Table A.5, and repeat using the B section table.

5.93 Repeat Problem 5.91 for oxygen gas.

5.94 Estimate the constant specific heats for R-134a from Table B.5.2 at 100 kPa and 125°C. Compare this to the specific heats in Table A.5 and explain the difference.

5.95 Water at 400 kPa is raised from 150°C to 1200°C. Evaluate the change in specific internal energy using (a) the steam tables, (b) the ideal gas Table A.8, and the specific heat Table A.5.

5.96 Nitrogen at 300 K, 3 MPa is heated to 500 K. Find the change in enthalpy using (a) Table B.6, (b) Table A.8, and (c) Table A.5.

5.97 For a special application, we need to evaluate the change in enthalpy for carbon dioxide from 30°C to 1500°C at 100 kPa. Do this using the constant specific heat value from Table A.5 and repeat using Table A.8. Which table is more accurate?

5.98 Repeat the previous problem but use a constant specific heat at the average temperature from the equation in Table A.6 and also integrate the equation in Table A.6 to get the change in enthalpy.

5.99 Reconsider Problem 5.97, and determine if also using Table B.3 would be more accurate; explain.

5.100 Water at 20°C and 100 kPa is brought to 100 kPa and 1500°C. Find the change in the specific internal energy, using the water tables and ideal gas tables.

5.101 An ideal gas is heated from 500 to 1500 K. Find the change in enthalpy using constant specific heat from Table A.5 (room temperature value) and discuss the accuracy of the result if the gas is
a. Argon
b. Oxygen
c. Carbon dioxide

Energy Equation: Ideal Gas

5.102 Air is heated from 300 to 350 K at constant volume. Find ${}_1q_2$. What is ${}_1q_2$ if the temperature rises from 1300 to 1350 K?

5.103 A 250-L rigid tank contains methane at 500 K, 1500 kPa. It is now cooled down to 300 K. Find the mass of methane and the heat transfer using (a) the ideal-gas and (b) methane tables.

5.104 A rigid tank has 1 kg air at 300 K, 120 kPa and it is heated by a heater to 1500 K. Use Table A.7 to find the work and the heat transfer for the process.

5.105 A rigid container has 2 kg of carbon dioxide gas at 100 kPa and 1200 K that is heated to 1400 K. Solve for the heat transfer using (a) the heat capacity from Table A.5 and (b) properties from Table A.8.

5.106 Do the previous problem for nitrogen (N_2) gas.

5.107 A tank has a volume of 1 m^3 with oxygen at 15°C, 300 kPa. Another tank contains 4 kg oxygen at 60°C, 500 kPa. The two tanks are connected by a pipe and valve that is opened, allowing the whole system to come to a single equilibrium state with the ambient at 20°C. Find the final pressure and the heat transfer.

5.108 Find the heat transfer in Problem 4.43.

5.109 A 10-m-high cylinder, with a cross-sectional area of 0.1 m^2, has a massless piston at the bottom with water at 20°C on top of it, as shown in Fig. P5.109. Air at 300 K, with a volume of 0.3 m^3, under the piston is heated so that the piston moves up, spilling the water out over the side. Find the total heat transfer to the air when all the water has been pushed out.

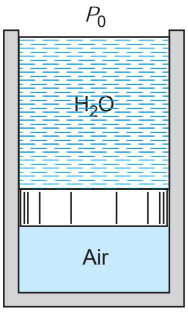

FIGURE P5.109

5.110 A piston/cylinder contains air at 600 kPa, 290 K and a volume of 0.01 m^3. A constant-pressure process gives 18 kJ of work out. Find the final temperature of the air and the heat transfer input.

5.111 An insulated cylinder is divided into two parts of 1 m^3 each by an initially locked piston, as shown in Fig. P5.111. Side A has air at 200 kPa, 300 K, and side B has air at 1.0 MPa, 1000 K. The piston is now unlocked so that it is free to move, and it conducts heat so that the air comes to a uniform temperature $T_A = T_B$. Find the mass in both A and B and the final T and P.

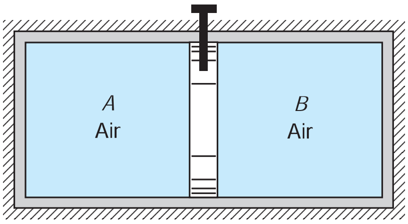

FIGURE P5.111

5.112 Find the specific heat transfer for the helium in Problem 4.62.

5.113 A rigid insulated tank is separated into two rooms by a stiff plate. Room A, of 0.5 m^3, contains air at 250 kPa and 300 K and room B, of 1 m^3, has air at 500 kPa and 1000 K. The plate is removed and the air comes to a uniform state without any heat transfer. Find the final pressure and temperature.

5.114 A cylinder with a piston restrained by a linear spring contains 2 kg of carbon dioxide at 500 kPa and 400°C. It is cooled to 40°C, at which point the pressure is 300 kPa. Calculate the heat transfer for the process.

5.115 A piston/cylinder has 0.5 kg of air at 2000 kPa, 1000 K as shown in Fig. P5.115. The cylinder has stops, so $V_{\text{min}} = 0.03$ m^3. The air now cools to 400 K by heat transfer to the ambient. Find the final volume and pressure of the air (does it hit the stops?) and the work and heat transfer in the process.

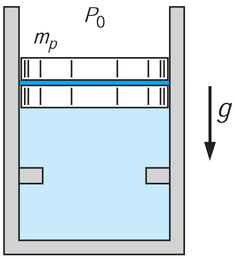

FIGURE P5.115

5.116 A piston/cyclinder contains 1.5 kg air at 300 K and 150 kPa. It is now heated in a two-step process: first, by a constant-volume process to 1000 K (state 2) followed by a constant-pressure process to 1500 K, state 3. Find the heat transfer for the process.

5.117 Air in a rigid tank is at 100 kPa, 300 K with a volume of 0.75 m^3. The tank is heated to 400 K, state 2. Now one side of the tank acts as a piston, letting the air expand slowly at constant temperature to state 3 with a volume of 1.5 m^3. Find the pressure at states 2 and 3. Find the total work and total heat transfer.

5.118 Water at 100 kPa and 400 K is heated electrically, adding 700 kJ/kg in a constant-pressure process. Find the final temperature using

a. The water Table B.1
b. The ideal-gas Table A.8
c. Constant specific heat from Table A.5

5.119 Air in a piston/cylinder assembly at 200 kPa and 600 K is expanded in a constant-pressure process to twice the initial volume, state 2, as shown in Fig. P5.119. The piston is then locked with a pin,

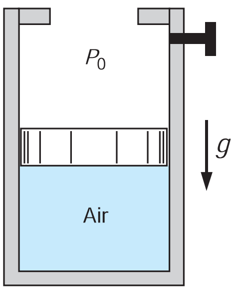

FIGURE P5.119

and heat is transferred to a final temperature of 600 K. Find P, T, and h for states 2 and 3, and find the work and heat transfer in both processes.

5.120 A spring-loaded piston/cylinder contains 1.5 kg of air at 27°C and 160 kPa. It is now heated to 900 K in a process wherein the pressure is linear in volume to a final volume of twice the initial volume. Plot the process in a P–v diagram and find the work and heat transfer.

Energy Equation: Polytropic Process

5.121 A helium gas in a piston/cylinder is compressed from 100 kPa, 300 K to 200 kPa in a polytropic process with $n = 1.5$. Find the specific work and specific heat transfer.

5.122 Oxygen at 300 kPa and 100°C is in a piston/cylinder arrangement with a volume of 0.1 m^3. It is now compressed in a polytropic process with exponent $n = 1.2$ to a final temperature of 200°C. Calculate the heat transfer for the process.

5.123 A piston/cylinder device contains 0.1 kg of air at 300 K and 100 kPa. The air is now slowly compressed in an isothermal (T = constant) process to a final pressure of 250 kPa. Show the process in a P–V diagram, and find both the work and heat transfer in the process.

5.124 A piston/cylinder contains 0.1 kg nitrogen at 100 kPa, 27°C and it is compressed in a polytropic process with $n = 1.25$ to a pressure of 250 kPa. Find the heat transfer.

5.125 Helium gas expands from 125 kPa, 350 K and 0.25 m^3 to 100 kPa in a polytropic process with $n = 1.667$. How much heat transfer is involved?

5.126 Find the specific heat transfer in Problem 4.52.

5.127 A piston/cylinder has nitrogen gas at 750 K and 1500 kPa, as shown in Fig. P5.127. Now it is expanded in a polytropic process with $n = 1.2$ to $P = 750$ kPa. Find the final temperature, the specific work, and the specific heat transfer in the process.

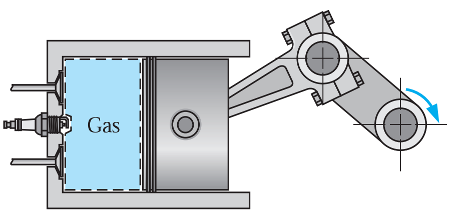

FIGURE P5.127

5.128 A gasoline engine has a piston/cylinder with 0.1 kg air at 4 MPa, 1527°C after combustion, and this is expanded in a polytropic process with $n = 1.5$ to a volume 10 times larger. Find the expansion work and heat transfer using the heat capacity value in Table A.5.

5.129 Solve the previous problem using Table A.7.

5.130 A piston/cylinder arrangement of initial volume 0.025 m^3 contains saturated water vapor at 180°C. The steam now expands in a polytropic process with exponent $n = 1$ to a final pressure of 200 kPa while it does work against the piston. Determine the heat transfer for this process.

5.131 A piston/cylinder assembly in a car contains 0.2 L of air at 90 kPa and 20°C, as shown in Fig. P5.131. The air is compressed in a quasi-equilibrium polytropic process with polytropic exponent $n = 1.25$ to a final volume six times smaller. Determine the final pressure and temperature, and the heat transfer for the process.

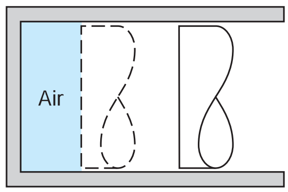

FIGURE P5.131

5.132 A piston/cylinder assembly has 1 kg of propane gas at 700 kPa and 40°C. The piston cross-sectional area is 0.5 m^2, and the total external force restraining the piston is directly proportional to the cylinder volume squared. Heat is transferred to the propane until its temperature reaches 700°C. Determine the final pressure inside the cylinder, the work done by the propane, and the heat transfer during the process.

5.133 A piston/cylinder contains pure oxygen at ambient conditions 20°C, 100 kPa. The piston is moved to a volume that is seven times smaller than the initial volume in a polytropic process with exponent $n = 1.25$. Use the constant heat capacity to find the final pressure and temperature, the specific work, and the specific heat transfer.

5.134 An air pistol contains compressed air in a small cylinder, as shown in Fig. P5.134. Assume that the volume is 1 cm^3, the pressure is 1 MPa, and the temperature is 27°C when armed. A bullet, with

$m = 15$ g, acts as a piston initially held by a pin (trigger); when released, the air expands in an isothermal process (T = constant). If the air pressure is 0.1 MPa in the cylinder as the bullet leaves the gun, find

a. the final volume and the mass of air
b. the work done by the air and work done on the atmosphere
c. the work done to the bullet and the bullet exit velocity

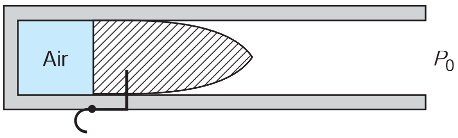

FIGURE P5.134

5.135 Calculate the heat transfer for the process in Problem 4.58.

Energy Equation in Rate Form

5.136 A crane uses 2 kW to raise a 100-kg box 20 m. How much time does it take?

5.137 A crane lifts a load of 450 kg vertically with a power input of 1 kW. How fast can the crane lift the load?

5.138 A 1.2-kg pot of water at 20°C is put on a stove supplying 250 W to the water. What is the rate of temperature increase (K/s)?

5.139 The rate of heat transfer to the surroundings from a person at rest is about 400 kJ/h. Suppose that the ventilation system fails in an auditorium containing 100 people. Assume the energy goes into the air of volume 1500 m^3 initially at 300 K and 101 kPa. Find the rate (degrees per minute) of the air temperature change.

5.140 A pot of water is boiling on a stove supplying 325 W to the water. What is the rate of mass (kg/s) vaporization, assuming a constant pressure process?

5.141 A 1.2-kg pot of water at 20°C is put on a stove supplying 250 W to the water. How long will it take to come to a boil (100°C)?

5.142 A 3-kg mass of nitrogen gas at 2000 K, $V = C$, cools with 500 W. What is dT/dt?

5.143 A computer in a closed room of volume 200 m^3 dissipates energy at a rate of 10 kW. The room has 50 kg of wood, 25 kg of steel, and air, with all material at 300 K and 100 kPa. Assuming all the mass heats up uniformly, how long will it take to increase the temperature 10°C?

5.144 A drag force on a car, with frontal area $A = 2$ m^2, driving at 80 km/h in air at 20°C, is $F_d = 0.225\, A\, \rho_{air} \mathbf{V}^2$. How much power is needed, and what is the traction force?

5.145 A piston/cylinder of cross-sectional area 0.01 m^2 maintains constant pressure. It contains 1 kg of water with a quality of 5% at 150°C. If we apply heat so that 1 g/s liquid turns into vapor, what is the rate of heat transfer needed?

5.146 A small elevator is being designed for a construction site. It is expected to carry four 75-kg workers to the top of a 100-m-tall building in less than 2 min. The elevator cage will have a counterweight to balance its mass. What is the smallest size (power) electric motor that can drive this unit?

5.147 The heaters in a spacecraft suddenly fail. Heat is lost by radiation at the rate of 100 kJ/h, and the electric instruments generate 75 kJ/h. Initially, the air is at 100 kPa and 25°C with a volume of 10 m^3. How long will it take to reach an air temperature of −20°C?

5.148 A steam-generating unit heats saturated liquid water at constant pressure of 800 kPa in a piston/cylinder device. If 1.5 kW of power is added by heat transfer, find the rate (kg/s) at which saturated vapor is made.

5.149 As fresh poured concrete hardens, the chemical transformation releases energy at a rate of 2 W/kg. Assume the center of a poured layer does not have any heat loss and that it has an average heat capacity of 0.9 kJ/kg K. Find the temperature rise during 1 h of the hardening (curing) process.

5.150 Water is in a piston/cylinder maintaining constant P at 700 kPa, quality 90% with a volume of 0.1 m^3. A heater is turned on, heating the water with 2.5 kW. How long does it take to vaporize all the liquid?

5.151 A 500-W heater is used to melt 2 kg of solid ice at −10°C to liquid at +5°C at a constant pressure of 150 kPa.

a. Find the change in the total volume of the water.
b. Find the energy the heater must provide to the water.

c. Find the time the process will take, assuming uniform T in the water.

Problem Analysis (no numbers required)

5.152 Consider Problem 5.57 with the steel bottle as C.V. Write the process equation that is valid until the valve opens, and plot the P–v diagram for the process.

5.153 Consider Problem 5.50. Take the whole room as a C.V. and write both conservation of mass and conservation of energy equations. Write equations for the process (two are needed) and use them in the conservation equations. Now specify the four properties that determine the initial state (two) and the final state (two); do you have them all? Count unknowns and match them with the equations to determine those.

5.154 Take Problem 5.61 and write the left-hand side (storage change) of the conservation equations for mass and energy. How should you write m_1 and Eq. 5.5?

5.155 Consider Problem 5.70. The final state was given, but you were not told that the piston hits the stops, only that $V_{\text{stop}} = 2\ V_1$. Sketch the possible P–v diagram for the process and determine which number(s) you need to uniquely place state 2 in the diagram. There is a kink in the process curve; what are the coordinates for that state? Write an expression for the work term.

5.156 Look at Problem 5.115 and plot the P–v diagram for the process. Only T_2 is given; how do you determine the second property of the final state? What do you need to check, and does it influence the work term?

Review Problems

5.157 Ten kilograms of water in a piston/cylinder setup with constant pressure is at 450°C and occupies a volume of 0.633 m^3. The system is now cooled to 20°C. Show the P–v diagram, and find the work and heat transfer for the process.

5.158 Ammonia (NH_3) is contained in a sealed rigid tank at 0°C, $x = 50\%$ and is then heated to 100°C. Find the final state P_2, u_2 and the specific work and heat transfer.

5.159 Find the heat transfer in Problem 4.122.

5.160 A piston/cylinder setup contains 1 kg of ammonia at 20°C with a volume of 0.1 m^3, as shown in Fig. P5.160. Initially the piston rests on some stops with the top surface open to the atmosphere, P_0, so that a pressure of 1400 kPa is required to lift it. To what temperature should the ammonia be heated to lift the piston? If it is heated to saturated vapor, find the final temperature, volume, and heat transfer, ${}_1Q_2$.

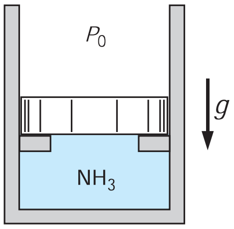

FIGURE P5.160

5.161 Consider the system shown in Fig. P5.161. Tank A has a volume of 100 L and contains saturated vapor R-134a at 30°C. When the valve is cracked open, R-134a flows slowly into cylinder B. The piston requires a pressure of 200 kPa in cylinder B to raise it. The process ends when the pressure in tank A has fallen to 200 kPa. During this process, heat is exchanged with the surroundings such that the R-134a always remains at 30°C. Calculate the heat transfer for the process.

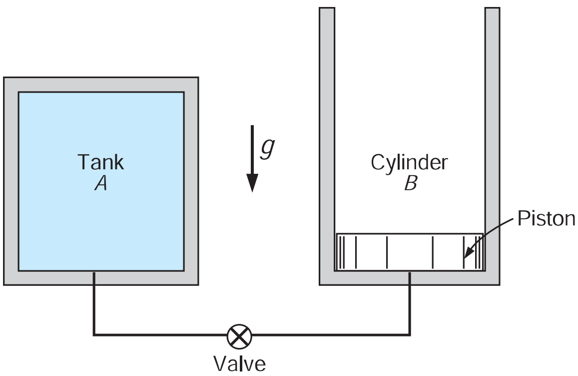

FIGURE P5.161

5.162 Water in a piston/cylinder, similar to Fig. P5.160, is at 100°C, $x = 0.5$ with mass 1 kg, and the piston rests on the stops. The equilibrium pressure that will float the piston is 300 kPa. The water is heated to 300°C by an electrical heater. At what temperature would all the liquid be gone? Find the final (P, v), the work, and the heat transfer in the process.

5.163 A rigid container has two rooms filled with water, each of 1 m^3, separated by a wall (see Fig. P5.61). Room A has $P = 200$ kPa with a quality of $x = 0.80$. Room B has $P = 2$ MPa and $T = 400°C$. The partition wall is removed, and because of heat transfer the water comes to a uniform state with a temperature of 200°C. Find the final pressure and the heat transfer in the process.

5.164 A piston held by a pin in an insulated cylinder, shown in Fig. P5.164, contains 2 kg of water at 100°C, with a quality of 98%. The piston has a mass of 102 kg, with cross-sectional area of 100 cm^2, and the ambient pressure is 100 kPa. The pin is released, which allows the piston to move. Determine the final state of the water, assuming the process to be adiabatic.

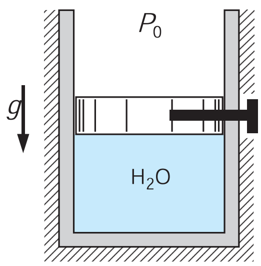

FIGURE P5.164

5.165 A piston/cylinder arrangement has a linear spring and the outside atmosphere acting on the piston shown in Fig. P5.165. It contains water at 3 MPa and 400°C with a volume of 0.1 m^3. If the piston is at the bottom, the spring exerts a force such that a pressure of 200 kPa inside is required to balance the forces. The system now cools until the pressure reaches 1 MPa. Find the heat transfer for the process.

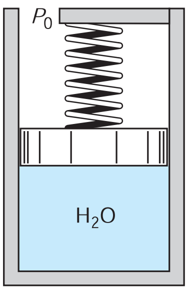

FIGURE P5.165

5.166 A piston/cylinder setup, shown in Fig. P5.166, contains R-410a at −20°C, $x = 20\%$. The volume is 0.2 m^3. It is known that $V_{stop} = 0.4$ m^3, and if the piston sits at the bottom, the spring force balances the other loads on the piston. The system is now heated to 20°C. Find the mass of the fluid and show the P–v diagram. Find the work and heat transfer.

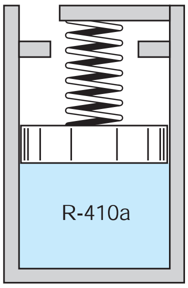

FIGURE P5.166

5.167 Consider the piston/cylinder arrangement shown in Fig. P5.167. A frictionless piston is free to move between two sets of stops. When the piston rests on the lower stops, the enclosed volume is 400 L. When the piston reaches the upper stops, the volume is 600 L. The cylinder initially contains water at 100 kPa, with 20% quality. It is heated until the water eventually exists as saturated vapor. The mass of the piston requires 300 kPa pressure to move it against the outside ambient pressure. Determine the final pressure in the cylinder, the heat transfer, and the work for the overall process.

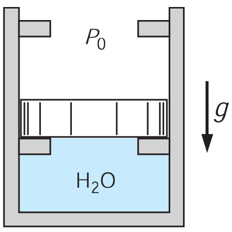

FIGURE P5.167

5.168 A spherical balloon contains 2 kg of R-410a at 0°C with a quality of 30%. This system is heated until the pressure in the balloon reaches 1 MPa. For this process, it can be assumed that the pressure in the balloon is directly proportional to the balloon diameter. How does pressure vary with volume, and what is the heat transfer for the process?

5.169 A 1-m^3 tank containing air at 25°C and 500 kPa is connected through a valve to another tank containing 4 kg of air at 60°C and 200 kPa. Now the valve is opened and the entire system reaches thermal equilibrium with the surroundings at 20°C. Assume constant specific heat at 25°C and determine the final pressure and the heat transfer.

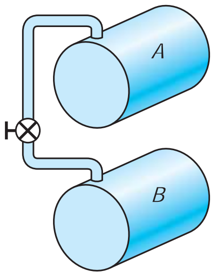

FIGURE P5.169

5.170 Ammonia (2 kg) in a piston/cylinder is at 100 kPa, −20°C and is now heated in a polytropic process with $n = 1.3$ to a pressure of 200 kPa. Do not use the ideal gas approximation and find T_2, the work, and the heat transfer in the process.

5.171 A piston/cylinder arrangement B is connected to a 1-m^3 tank A by a line and valve, shown in Fig. P5.171. Initially both contain water, with A at 100 kPa, saturated vapor and B at 400°C, 300 kPa, 1 m^3. The valve is now opened, and the water in both A and B comes to a uniform state.

a. Find the initial mass in A and B.
b. If the process results in $T_2 = 200$°C, find the heat transfer and the work.

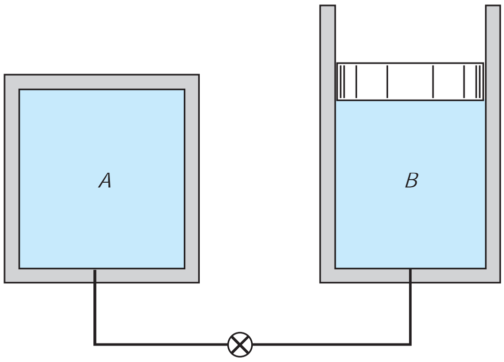

FIGURE P5.171

5.172 A small, flexible bag contains 0.1 kg of ammonia at −10°C and 300 kPa. The bag material is such that the pressure inside varies linearly with the volume. The bag is left in the sun with an incident radiation of 75 W, losing energy with an average 25 W to the ambient ground and air. After a while the bag is heated to 30°C, at which time the pressure is 1000 kPa. Find the work and heat transfer in the process and the elapsed time.

ENGLISH UNIT PROBLEMS

English Unit Concept Problems

5.173E What is 1 cal in English units? What is 1 Btu in ft lbf?

5.174E Work as $F\,\Delta x$ has units of lbf ft. What is that in Btu?

5.175E Look at the R-410a value for u_f at −60 F. Can the energy really be negative? Explain.

5.176E An ideal gas in a piston/cylinder is heated with 2 Btu in an isothermal process. How much work is involved?

5.177E You heat a gas 20 R at $P = C$. Which gas in Table F.4 requires most energy? Why?

English Unit Problems

5.178E A piston motion moves a 50-lbm hammerhead vertically down 3 ft from rest to a velocity of 150 ft/s in a stamping machine. What is the change in total energy of the hammerhead?

5.179E A hydraulic hoist raises a 3650-lbm car 6 ft in an auto repair shop. The hydraulic pump has a constant pressure of 100 lbf/in.^{2} on its piston. What is the increase in potential energy of the car, and how much volume should the pump displace to deliver that amount of work?

5.180E Airplane takeoff from an aircraft carrier is assisted by a steam-driven piston/cylinder with an average pressure of 200 psia. A 38 500-lbm airplane should be accelerated from zero to a speed of 100 ft/s, with 30% of the energy coming from the steam piston. Find the needed piston displacement volume.

5.181E A piston of 4 lbm is accelerated to 60 ft/s from rest. What constant gas pressure is required if the