Solutions Manual for

Thermodynamics: An Engineering Approach

Seventh Edition

Yunus A. Cengel, Michael A. Boles

McGraw-Hill, 2011

Chapter 1

INTRODUCTION AND BASIC CONCEPTS

Thermodynamics

1-1C On a downhill road the potential energy of the bicyclist is being converted to kinetic energy, and thus the bicyclist picks up speed. There is no creation of energy, and thus no violation of the conservation of energy principle.

1-2C A car going uphill without the engine running would increase the energy of the car, and thus it would be a violation of the first law of thermodynamics. Therefore, this cannot happen. Using a level meter (a device with an air bubble between two marks of a horizontal water tube) it can shown that the road that looks uphill to the eye is actually downhill.

1-3C There is no truth to his claim. It violates the second law of thermodynamics.

Mass, Force, and Units

1-4C The "pound" mentioned here must be "**lbf**" since thrust is a force, and the lbf is the force unit in the English system. You should get into the habit of *never* writing the unit "lb", but always use either "lbm" or "lbf" as appropriate since the two units have different dimensions.

1-5C In this unit, the word *light* refers to the speed of light. The light-year unit is then the product of a velocity and time. Hence, this product forms a distance dimension and unit.

1-6C There is no acceleration, thus the net force is zero in both cases.

1-7E The weight of a man on earth is given. His weight on the moon is to be determined.

Analysis Applying Newton's second law to the weight force gives

$$W = mg \longrightarrow m = \frac{W}{g} = \frac{210\ \text{lbf}}{32.10\ \text{ft/s}^2}\left(\frac{32.174\ \text{lbm}\cdot\text{ft/s}^2}{1\ \text{lbf}}\right) = 210.5\ \text{lbm}$$

Mass is invariant and the man will have the same mass on the moon. Then, his weight on the moon will be

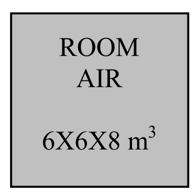
$$W = mg = (210.5\ \text{lbm})(5.47\ \text{ft/s}^2)\left(\frac{1\ \text{lbf}}{32.174\ \text{lbm}\cdot\text{ft/s}^2}\right) = \mathbf{35.8\ lbf}$$

1-8 The interior dimensions of a room are given. The mass and weight of the air in the room are to be determined.

Assumptions The density of air is constant throughout the room.

Properties The density of air is given to be $\rho = 1.16\ \text{kg/m}^3$.

Analysis The mass of the air in the room is



$$m = \rho \boldsymbol{V} = (1.16\ \text{kg/m}^3)(6\times6\times8\ \text{m}^3) = \mathbf{334.1\ kg}$$

Thus,

$$W = mg = (334.1\ \text{kg})(9.81\ \text{m/s}^2)\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right) = \mathbf{3277\ N}$$

1-9 The variation of gravitational acceleration above the sea level is given as a function of altitude. The height at which the weight of a body will decrease by 0.5% is to be determined.

Analysis The weight of a body at the elevation z can be expressed as

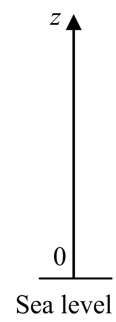
$$W = mg = m(9.807 - 3.32 \times 10^{-6} z)$$

In our case,

$$W = 0.995W_s = 0.995mg_s = 0.995(m)(9.81)$$

Substituting,

$$0.995(9.81) = (9.81 - 3.32 \times 10^{-6} z) \longrightarrow z = 14{,}774 \text{ m} \cong \mathbf{14{,}770\ m}$$



1-10 The mass of an object is given. Its weight is to be determined.

Analysis Applying Newton's second law, the weight is determined to be

$$W = mg = (200\,\text{kg})(9.6\,\text{m/s}^2) = \mathbf{1920\ N}$$

1-11E The constant-pressure specific heat of air given in a specified unit is to be expressed in various units.

Analysis Applying Newton's second law, the weight is determined in various units to be

$$c_p = (1.005\,\text{kJ/kg}\cdot°\text{C})\left(\frac{1\,\text{kJ/kg}\cdot\text{K}}{1\,\text{kJ/kg}\cdot°\text{C}}\right) = \mathbf{1.005\ kJ/kg\cdot K}$$

$$c_p = (1.005\,\text{kJ/kg}\cdot°\text{C})\left(\frac{1000\,\text{J}}{1\,\text{kJ}}\right)\left(\frac{1\,\text{kg}}{1000\,\text{g}}\right) = \mathbf{1.005\ J/g\cdot °C}$$

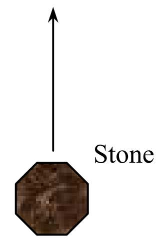
$$c_p = (1.005\,\text{kJ/kg}\cdot°\text{C})\left(\frac{1\,\text{kcal}}{4.1868\,\text{kJ}}\right) = \mathbf{0.240\ kcal/kg\cdot °C}$$

$$c_p = (1.005\,\text{kJ/kg}\cdot°\text{C})\left(\frac{1\,\text{Btu/lbm}\cdot°\text{F}}{4.1868\,\text{kJ/kg}\cdot°\text{C}}\right) = \mathbf{0.240\ Btu/lbm\cdot °F}$$

1-12 A rock is thrown upward with a specified force. The acceleration of the rock is to be determined.

Analysis The weight of the rock is

$$W = mg = (3\text{ kg})(9.79\text{ m/s}^2)\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right) = 29.37\text{ N}$$



Then the net force that acts on the rock is

$$F_{\text{net}} = F_{\text{up}} - F_{\text{down}} = 200 - 29.37 = 170.6\text{ N}$$

From the Newton's second law, the acceleration of the rock becomes

$$a = \frac{F}{m} = \frac{170.6\text{ N}}{3\text{ kg}}\left(\frac{1\text{ kg}\cdot\text{m/s}^2}{1\text{ N}}\right) = \mathbf{56.9\ m/s^2}$$

1-13 Problem 1-12 is reconsidered. The entire EES solution is to be printed out, including the numerical results with proper units.

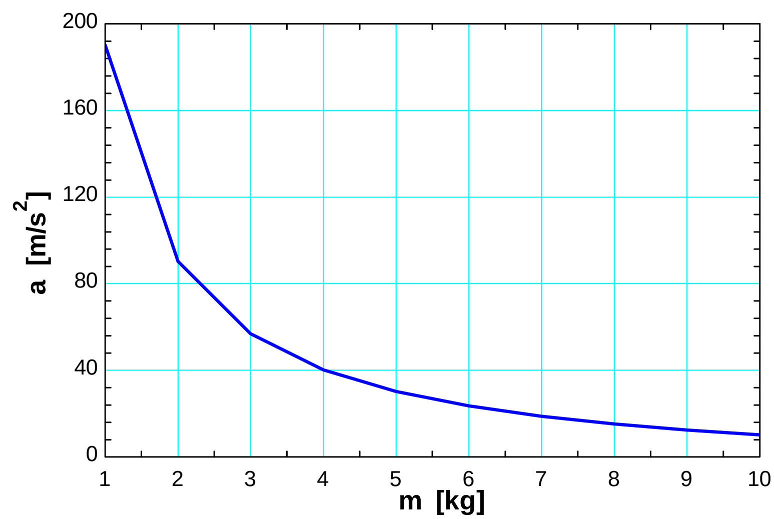
Analysis The problem is solved using EES, and the solution is given below.

```
"The weight of the rock is"
W=m*g
m=3 [kg]
g=9.79 [m/s2]
"The force balance on the rock yields the net force acting on the rock as"
F_up=200 [N]
F_net = F_up - F_down
F_down=W
"The acceleration of the rock is determined from Newton's second law."
F_net=m*a

"To Run the program, press F2 or select Solve from the Calculate menu."
```

SOLUTION
a=56.88 [m/s^2]
F_down=29.37 [N]
F_net=170.6 [N]
F_up=200 [N]
g=9.79 [m/s2]
m=3 [kg]
W=29.37 [N]

m [kg]	a [m/s^2]
1	190.2
2	90.21
3	56.88
4	40.21
5	30.21
6	23.54
7	18.78
8	15.21
9	12.43
10	10.21



1-14 During an analysis, a relation with inconsistent units is obtained. A correction is to be found, and the probable cause of the error is to be determined.

Analysis The two terms on the right-hand side of the equation

$$E = 25 \text{ kJ} + 7 \text{ kJ/kg}$$

do not have the same units, and therefore they cannot be added to obtain the total energy. Multiplying the last term by mass will eliminate the kilograms in the denominator, and the whole equation will become dimensionally homogeneous; that is, every term in the equation will have the same unit.

Discussion Obviously this error was caused by forgetting to multiply the last term by mass at an earlier stage.

1-15 A resistance heater is used to heat water to desired temperature. The amount of electric energy used in kWh and kJ are to be determined.

Analysis The resistance heater consumes electric energy at a rate of 4 kW or 4 kJ/s. Then the total amount of electric energy used in 2 hours becomes

$$\begin{aligned}\text{Total energy} &= (\text{Energy per unit time})(\text{Time interval})\\ &= (4 \text{ kW})(2 \text{ h})\\ &= \mathbf{8\ kWh}\end{aligned}$$

Noting that 1 kWh = (1 kJ/s)(3600 s) = 3600 kJ,

$$\begin{aligned}\text{Total energy} &= (8 \text{ kWh})(3600 \text{ kJ/kWh})\\ &= \mathbf{28{,}800\ kJ}\end{aligned}$$

Discussion Note kW is a unit for power whereas kWh is a unit for energy.

1-16 A gas tank is being filled with gasoline at a specified flow rate. Based on unit considerations alone, a relation is to be obtained for the filling time.

Assumptions Gasoline is an incompressible substance and the flow rate is constant.

Analysis The filling time depends on the volume of the tank and the discharge rate of gasoline. Also, we know that the unit of time is 'seconds'. Therefore, the independent quantities should be arranged such that we end up with the unit of seconds. Putting the given information into perspective, we have

$$t \text{ [s]} \quad \leftrightarrow \quad V \text{ [L], and } \dot{V} \text{ [L/s\}}$$

It is obvious that the only way to end up with the unit "s" for time is to divide the tank volume by the discharge rate. Therefore, the desired relation is

$$\boxed{t = \frac{V}{\dot{V}}}$$

Discussion Note that this approach may not work for cases that involve dimensionless (and thus unitless) quantities.

1-17 A pool is to be filled with water using a hose. Based on unit considerations, a relation is to be obtained for the volume of the pool.

Assumptions Water is an incompressible substance and the average flow velocity is constant.

Analysis The pool volume depends on the filling time, the cross-sectional area which depends on hose diameter, and flow velocity. Also, we know that the unit of volume is m^3. Therefore, the independent quantities should be arranged such that we end up with the unit of seconds. Putting the given information into perspective, we have

V [m^3] is a function of t [s], D [m], and V [m/s}

It is obvious that the only way to end up with the unit "m^3" for volume is to multiply the quantities t and V with the square of D. Therefore, the desired relation is

$$\boldsymbol{V = CD^2Vt}$$

where the constant of proportionality is obtained for a round hose, namely, $C = \pi/4$ so that $\boldsymbol{V = (\pi D^2/4)Vt}$.

Discussion Note that the values of dimensionless constants of proportionality cannot be determined with this approach.

1-18 It is to be shown that the power needed to accelerate a car is proportional to the mass and the square of the velocity of the car, and inversely proportional to the time interval.

Assumptions The car is initially at rest.

Analysis The power needed for acceleration depends on the mass, velocity change, and time interval. Also, the unit of power $\dot{W}$ is watt, W, which is equivalent to

$$\text{W} = \text{J/s} = \text{N·m/s} = (\text{kg·m/s}^2)\text{m/s} = \text{kg·m}^2/\text{s}^3$$

Therefore, the independent quantities should be arranged such that we end up with the unit $\text{kg·m}^2/\text{s}^3$ for power. Putting the given information into perspective, we have

$\dot{W}$ [$\text{kg·m}^2/\text{s}^3$] is a function of m [kg], V [m/s], and t [s]

It is obvious that the only way to end up with the unit "$\text{kg·m}^2/\text{s}^3$" for power is to multiply mass with the square of the velocity and divide by time. Therefore, the desired relation is

$\dot{W}$ is proportional to mV^2/t

or,

$$\boxed{\dot{W} = CmV^2/t}$$

where C is the dimensionless constant of proportionality (whose value is ½ in this case).

Discussion Note that this approach cannot determine the numerical value of the dimensionless numbers involved.

Systems, Properties, State, and Processes

1-19C This system is a region of space or open system in that mass such as air and food can cross its control boundary. The system can also interact with the surroundings by exchanging heat and work across its control boundary. By tracking these interactions, we can determine the energy conversion characteristics of this system.

1-20C The system is taken as the air contained in the piston-cylinder device. This system is a closed or fixed mass system since no mass enters or leaves it.

1-21C Any portion of the atmosphere which contains the ozone layer will work as an open system to study this problem. Once a portion of the atmosphere is selected, we must solve the practical problem of determining the interactions that occur at the control surfaces which surround the system's control volume.

1-22C Intensive properties do not depend on the size (extent) of the system but extensive properties do.

1-23C If we were to divide the system into smaller portions, the weight of each portion would also be smaller. Hence, the weight is an *extensive property*.

1-24C If we were to divide this system in half, both the volume and the number of moles contained in each half would be one-half that of the original system. The molar specific volume of the original system is

$$\bar{v} = \frac{V}{N}$$

and the molar specific volume of one of the smaller systems is

$$\bar{v} = \frac{V/2}{N/2} = \frac{V}{N}$$

which is the same as that of the original system. The molar specific volume is then an *intensive property*.

1-25C For a system to be in thermodynamic equilibrium, the temperature has to be the same throughout but the pressure does not. However, there should be no unbalanced pressure forces present. The increasing pressure with depth in a fluid, for example, should be balanced by increasing weight.

1-26C A process during which a system remains almost in equilibrium at all times is called a quasi-equilibrium process. Many engineering processes can be approximated as being quasi-equilibrium. The work output of a device is maximum and the work input to a device is minimum when quasi-equilibrium processes are used instead of nonquasi-equilibrium processes.

1-27C A process during which the temperature remains constant is called isothermal; a process during which the pressure remains constant is called isobaric; and a process during which the volume remains constant is called isochoric.

1-28C The state of a simple compressible system is completely specified by two independent, intensive properties.

1-29C The pressure and temperature of the water are normally used to describe the state. Chemical composition, surface tension coefficient, and other properties may be required in some cases.

As the water cools, its pressure remains fixed. This cooling process is then an isobaric process.

1- 30C When analyzing the acceleration of gases as they flow through a nozzle, the proper choice for the system is the volume within the nozzle, bounded by the entire inner surface of the nozzle and the inlet and outlet cross-sections. This is a control volume since mass crosses the boundary.

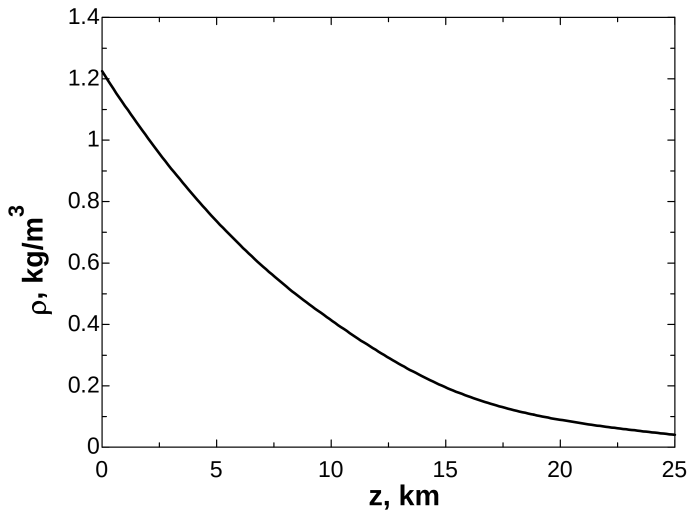
1-31C A process is said to be steady-flow if it involves no changes with time anywhere within the system or at the system boundaries.

1-32 The variation of density of atmospheric air with elevation is given in tabular form. A relation for the variation of density with elevation is to be obtained, the density at 7 km elevation is to be calculated, and the mass of the atmosphere using the correlation is to be estimated.

Assumptions **1** Atmospheric air behaves as an ideal gas. **2** The earth is perfectly sphere with a radius of 6377 km, and the thickness of the atmosphere is 25 km.

Properties The density data are given in tabular form as

r, km	z, km	ρ, kg/m^3
6377	0	1.225
6378	1	1.112
6379	2	1.007
6380	3	0.9093
6381	4	0.8194
6382	5	0.7364
6383	6	0.6601
6385	8	0.5258
6387	10	0.4135
6392	15	0.1948
6397	20	0.08891
6402	25	0.04008



Analysis Using EES, (1) Define a trivial function rho= a+z in equation window, (2) select new parametric table from Tables, and type the data in a two-column table, (3) select Plot and plot the data, and (4) select plot and click on "curve fit" to get curve fit window. Then specify 2nd order polynomial and enter/edit equation. The results are:

$\rho(z) = a + bz + cz^2 = 1.20252 - 0.101674z + 0.0022375z^2$ for the unit of kg/m^3,

(or, $\rho(z) = (1.20252 - 0.101674z + 0.0022375z^2)\times 10^9$ for the unit of kg/km^3)

where z is the vertical distance from the earth surface at sea level. At z = 7 km, the equation would give ρ = 0.60 kg/m^3.

(b) The mass of atmosphere can be evaluated by integration to be

$$m = \int_V \rho dV = \int_{z=0}^{h} (a + bz + cz^2)4\pi(r_0 + z)^2 dz = 4\pi\int_{z=0}^{h} (a + bz + cz^2)(r_0^2 + 2r_0 z + z^2)dz$$

$$= 4\pi\left[ar_0^2 h + r_0(2a + br_0)h^2/2 + (a + 2br_0 + cr_0^2)h^3/3 + (b + 2cr_0)h^4/4 + ch^5/5\right]$$

where r_0 = 6377 km is the radius of the earth, h = 25 km is the thickness of the atmosphere, and a = 1.20252, b = -0.101674, and c = 0.0022375 are the constants in the density function. Substituting and multiplying by the factor 10^9 for the density unity kg/km^3, the mass of the atmosphere is determined to be

m = $\mathbf{5.092\times10^{18}}$ **kg**

Discussion Performing the analysis with excel would yield exactly the same results.

EES Solution for final result:

```
a=1.2025166;          b=-0.10167
c=0.0022375;          r=6377;          h=25
m=4*pi*(a*r^2*h+r*(2*a+b*r)*h^2/2+(a+2*b*r+c*r^2)*h^3/3+(b+2*c*r)*h^4/4+c*h^5/5)*1E+9
```

Temperature

1-33C The zeroth law of thermodynamics states that two bodies are in thermal equilibrium if both have the same temperature reading, even if they are not in contact.

1-34C They are Celsius (°C) and kelvin (K) in the SI, and fahrenheit (°F) and rankine (R) in the English system.

1-35C Probably, but not necessarily. The operation of these two thermometers is based on the thermal expansion of a fluid. If the thermal expansion coefficients of both fluids vary linearly with temperature, then both fluids will expand at the same rate with temperature, and both thermometers will always give identical readings. Otherwise, the two readings may deviate.

1-36 A temperature is given in °C. It is to be expressed in K.

Analysis The Kelvin scale is related to Celsius scale by

$$T(\text{K}] = T(°\text{C}) + 273$$

Thus,

$$T(\text{K}] = 37°\text{C} + 273 = \mathbf{310\ K}$$

1-37E The temperature of air given in °C unit is to be converted to °F and R unit.

Analysis Using the conversion relations between the various temperature scales,

$$T(°\text{F}) = 1.8T(°\text{C}) + 32 = (1.8)(150) + 32 = \mathbf{302°F}$$
$$T(\text{R}) = T(°\text{F}) + 460 = 302 + 460 = \mathbf{762\ R}$$

1-38 A temperature change is given in °C. It is to be expressed in K.

Analysis This problem deals with temperature changes, which are identical in Kelvin and Celsius scales. Thus,

$$\Delta T(\text{K}] = \Delta T(°\text{C}) = \mathbf{45\ K}$$

1-39E The flash point temperature of engine oil given in °F unit is to be converted to K and R units.

Analysis Using the conversion relations between the various temperature scales,

$$T(\text{R}) = T(°\text{F}) + 460 = 363 + 460 = \mathbf{823\ R}$$

$$T(\text{K}) = \frac{T(\text{R})}{1.8} = \frac{823}{1.8} = \mathbf{457\ K}$$

1-40E The temperature of ambient air given in °C unit is to be converted to °F, K and R units.

Analysis Using the conversion relations between the various temperature scales,

$$T = -40°\text{C} = (-40)(1.8) + 32 = \mathbf{-40°C}$$

$$T = -40 + 273.15 = \mathbf{233.15\ K}$$

$$T = -40 + 459.67 = \mathbf{419.67\ R}$$

1-41E The change in water temperature given in °F unit is to be converted to °C, K and R units.

Analysis Using the conversion relations between the various temperature scales,

$$\Delta T = 10/1.8 = \mathbf{5.6°C}$$

$$\Delta T = 10/1.8 = \mathbf{5.6\ K}$$

$$\Delta T = 10°\text{F} = \mathbf{10\ R}$$

1-42E A temperature range given in °F unit is to be converted to °C unit and the temperature difference in °F is to be expressed in K, °C, and R.

Analysis The lower and upper limits of comfort range in °C are

$$T(°\text{C}) = \frac{T(°\text{F}) - 32}{1.8} = \frac{65 - 32}{1.8} = \mathbf{18.3°C}$$

$$T(°\text{C}) = \frac{T(°\text{F}) - 32}{1.8} = \frac{75 - 32}{1.8} = \mathbf{23.9°C}$$

A temperature change of 10°F in various units are

$$\Delta T(\text{R}) = \Delta T(°\text{F}) = \mathbf{10\ R}$$

$$\Delta T(°\text{C}) = \frac{\Delta T(°\text{F})}{1.8} = \frac{10}{1.8} = \mathbf{5.6°C}$$

$$\Delta T(\text{K}) = \Delta T(°\text{C}) = \mathbf{5.6\ K}$$

Pressure, Manometer, and Barometer

1-43C The pressure relative to the atmospheric pressure is called the *gage pressure*, and the pressure relative to an absolute vacuum is called *absolute pressure*.

1-44C The blood vessels are more restricted when the arm is parallel to the body than when the arm is perpendicular to the body. For a constant volume of blood to be discharged by the heart, the blood pressure must increase to overcome the increased resistance to flow.

1-45C No, the absolute pressure in a liquid of constant density does not double when the depth is doubled. It is the *gage pressure* that doubles when the depth is doubled.

1-46C If the lengths of the sides of the tiny cube suspended in water by a string are very small, the magnitudes of the pressures on all sides of the cube will be the same.

1-47C *Pascal's principle* states that *the pressure applied to a confined fluid increases the pressure throughout by the same amount*. This is a consequence of the pressure in a fluid remaining constant in the horizontal direction. An example of Pascal's principle is the operation of the hydraulic car jack.

1-48E The pressure given in psia unit is to be converted to kPa.

Analysis Using the psia to kPa units conversion factor,

$$P = (150\text{ psia})\left(\frac{6.895\text{ kPa}}{1\text{ psia}}\right) = \mathbf{1034\ kPa}$$

1-49 The pressure in a tank is given. The tank's pressure in various units are to be determined.

Analysis Using appropriate conversion factors, we obtain

(*a*) $$P = (1500\text{ kPa})\left(\frac{1\text{ kN/m}^2}{1\text{ kPa}}\right) = \mathbf{1500\ kN/m^2}$$

(*b*) $$P = (1500\text{ kPa})\left(\frac{1\text{ kN/m}^2}{1\text{ kPa}}\right)\left(\frac{1000\text{ kg}\cdot\text{m/s}^2}{1\text{ kN}}\right) = \mathbf{1{,}500{,}000\ kg/m\cdot s^2}$$

(*c*) $$P = (1500\text{ kPa})\left(\frac{1\text{ kN/m}^2}{1\text{ kPa}}\right)\left(\frac{1000\text{ kg}\cdot\text{m/s}^2}{1\text{ kN}}\right)\left(\frac{1000\text{ m}}{1\text{ km}}\right) = \mathbf{1{,}500{,}000{,}000\ kg/km\cdot s^2}$$

1-50E The pressure in a tank in SI unit is given. The tank's pressure in various English units are to be determined.

Analysis Using appropriate conversion factors, we obtain

(*a*) $$P = (1500\ \text{kPa})\left(\frac{20.886\ \text{lbf/ft}^2}{1\ \text{kPa}}\right) = \mathbf{31{,}330\ lbf/ft^2}$$

(*b*) $$P = (1500\ \text{kPa})\left(\frac{20.886\ \text{lbf/ft}^2}{1\ \text{kPa}}\right)\left(\frac{1\ \text{ft}^2}{144\ \text{in}^2}\right)\left(\frac{1\ \text{psia}}{1\ \text{lbf/in}^2}\right) = \mathbf{217.6\ psia}$$

1-51E The pressure given in mm Hg unit is to be converted to psia.

Analysis Using the mm Hg to kPa and kPa to psia units conversion factors,

$$P = (1500\ \text{mm Hg})\left(\frac{0.1333\ \text{kPa}}{1\ \text{mm Hg}}\right)\left(\frac{1\ \text{psia}}{6.895\ \text{kPa}}\right) = \mathbf{29.0\ psia}$$

1-52 The pressure given in mm Hg unit is to be converted to kPa.

Analysis Using the mm Hg to kPa units conversion factor,

$$P = (1250\ \text{mm Hg})\left(\frac{0.1333\ \text{kPa}}{1\ \text{mm Hg}}\right) = \mathbf{166.6\ kPa}$$