Borgnakke's

Fundamentals of Thermodynamics

Global Edition

Solution Manual

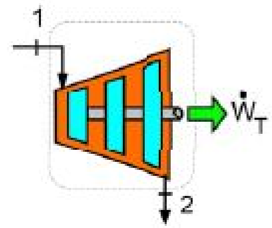
Chapter 1

Introduction and Preliminaries

In-Text Concept Questions

1.a Make a control volume around the turbine in the steam power plant in Fig. 1.2 and list the flows of mass and energy that are there.

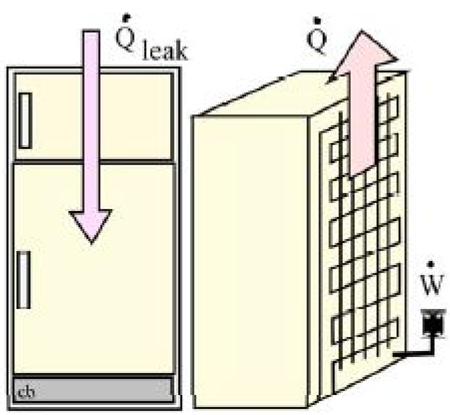
Solution:
We see hot high pressure steam flowing in at state 1 from the steam drum through a flow control (not shown). The steam leaves at a lower pressure to the condenser (heat exchanger) at state 2. A rotating shaft gives a rate of energy (power) to the electric generator set.



1.b Take a control volume around your kitchen refrigerator and indicate where the components shown in Figure 1.3 are located and show all flows of energy transfers.

Solution:

The valve and the cold line, the evaporator, is inside close to the inside wall and usually a small blower distributes cold air from the freezer box to the refrigerator room.



The black grille in the back or at the bottom is the condenser that gives heat to the room air.

The compressor sits at the bottom.

1.c Why do people float high in the water when swimming in the Dead Sea as compared with swimming in a fresh water lake?

As the dead sea is very salty its density is higher than fresh water density. The buoyancy effect gives a force up that equals the weight of the displaced water. Since salt water density is higher the displaced volume is smaller for the same force.

$$F = m_{H2O\ salt}\, g = m_{H2O\ fresh}\, g = (\rho V)_{H2O\ salt}\, g = (\rho V)_{H2O\ fresh}\, g$$

1.d Density of liquid water is $\rho = 1008 - T/2$ [kg/m^3] with T in °C. If the temperature increases, what happens to the density and specific volume?

Solution:

The density is seen to decrease as the temperature increases.

$$\Delta\rho = -\Delta T/2$$

Since the specific volume is the inverse of the density $v = 1/\rho$ it will increase.

1.e A car tire gauge indicates 195 kPa; what is the air pressure inside?

The pressure you read on the gauge is a gauge pressure, ΔP, so the absolute pressure is found as

$$P = P_o + \Delta P = 101 + 195 = 296 \text{ kPa}$$

Figure 1.21

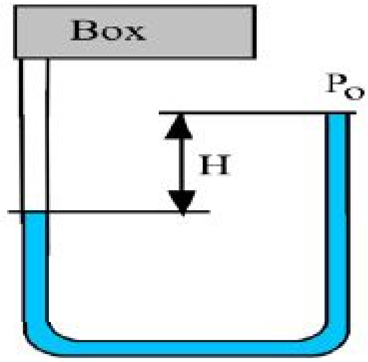
1.f Can I always neglect ΔP in the fluid above location A in figure 1.13? What does that depend on?

If the fluid density above A is low relative to the manometer fluid then you neglect the pressure variation above position A, say the fluid is a gas like air and the manometer fluid is like liquid water. However, if the fluid above A has a density of the same order of magnitude as the manometer fluid then the pressure variation with elevation is as large as in the manometer fluid and it must be accounted for.

1.g A U tube manometer has the left branch connected to a box with a pressure of 110 kPa and the right branch open. Which side has a higher column of fluid?

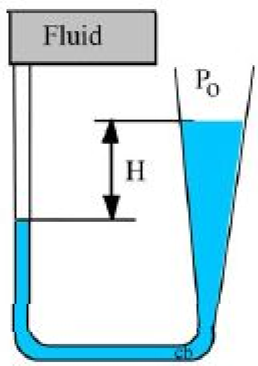
Solution:

Since the left branch fluid surface feels 110 kPa and the right branch surface is at 100 kPa you must go further down to match the 110 kPa. The right branch has a higher column of fluid.



1.h If the right side pipe section in Fig. 1.13 is V shaped like a funnel does that change the pressure at location B?

The shape does not affect the pressure only depth from surface at P_o matters.



1.i If the cylinder pressure in Ex. 1.3 does not give $F_{net} = 0$ what happens?

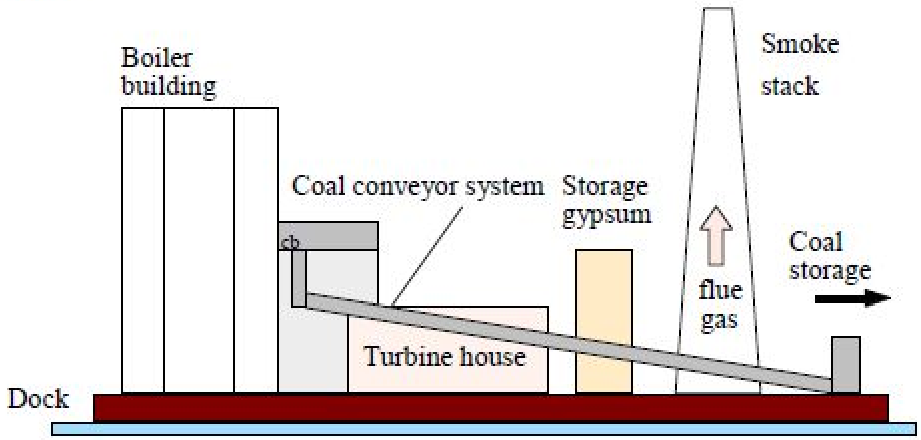
If: $F_{net} = ma \neq 0 \quad \Rightarrow \quad a \neq 0$

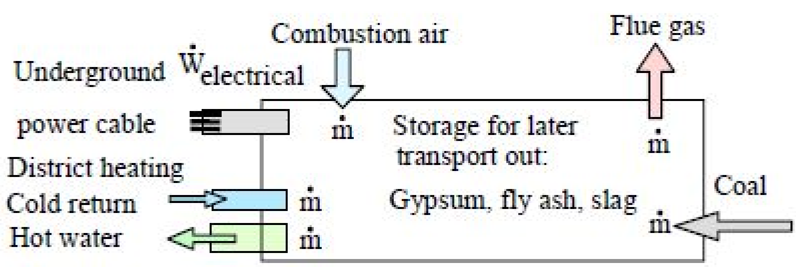
The piston will accelerate up if $P_{cyl} > 250$ kPa given F = 932.9 N or down up if $P_{cyl} < 250$ kPa given F = 932.9 N which changes the cylinder volume. Thus by controlling the pressure you can move the piston, which is the basis for the hydraulic cylinder used in a bulldozer, a backhoe or front loader.

Concept-Study Guide Problems

1.1 Make a control volume around the whole power plant in Fig. 1.1 and with the help of Fig. 1.2 list what flows of mass and energy are in or out and any storage of energy. Make sure you know what is inside and what is outside your chosen C.V.

Solution:

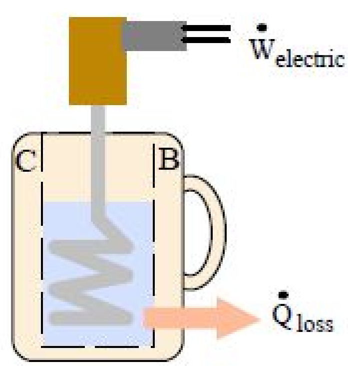




1.2 An electric dip heater is put into a cup of water and heats it from 20°C to 80°C. Show the energy flow(s) and storage and explain what changes.

Solution:

Electric power is converted in the heater element (an electric resistor) so it becomes hot and gives energy by heat transfer to the water. The water heats up and thus stores energy and as it is warmer than the cup material it heats the cup which also stores some energy. The cup being warmer than the air gives a smaller amount of energy (a rate) to the air as a heat loss.



1.3 Separate the list P, F, V, v, ρ, T, a, m, L, t, and **V** into intensive, extensive, and non-properties.

Solution:

Intensive properties are independent upon mass: P, v, ρ, T
Extensive properties scales with mass: V, m
Non-properties: F, a, L, t, **V**

Comment: You could claim that acceleration a and velocity **V** are physical properties for the dynamic motion of the mass, but not thermal properties.

1.4 The overall density of fibers, rock wool insulation, foams and cotton is fairly low. Why is that?

Solution:

All these materials consist of some solid substance and mainly air or other gas. The volume of fibers (clothes) and rockwool that is solid substance is low relative to the total volume that includes air. The overall density is

$$\rho = \frac{m}{V} = \frac{m_{solid} + m_{air}}{V_{solid} + V_{air}}$$

where most of the mass is the solid and most of the volume is air. If you talk about the density of the solid only, it is high.

1.5 A tray of liquid water is placed in a freezer where it cools from 20°C to -5°C. Show the energy flow(s) and storage and explain what changes.

Inside the freezer box, the walls are very cold as they are the outside of the evaporator, or the air is cooled and a small fan moves the air around to redistribute the cold air to all the items stored in the freezer box. The fluid in the evaporator absorbs the energy and the fluid flows over to the compressor on its way around the cycle, see Fig. 1.3. As the water is cooled it eventually reaches the freezing point and ice starts to form. After a significant amount of energy is removed from the water it is turned completely into ice (at 0°C) and then cooled a little more to -5°C. The water has a negative energy storage and the energy is moved by the refrigerant fluid out of the evaporator into the compressor and then finally out of the condenser into the outside room air.

1.6 How much mass is there approximately in 1 L of engine oil? Atmospheric air?

Solution:

A volume of 1 L equals 0.001 m^3, see Table A.1. From Table A.4 the density is 885 kg/m^3 so we get

$$m = \rho V = 885 \text{ kg/m}^3 \times 0.001 \text{ m}^3 = \mathbf{0.885 \text{ kg}}$$

For the air we see in Figure 2.7 that density is about 1 kg/m^3 so we get

$$m = \rho V = 1 \text{ kg/m}^3 \times 0.001 \text{ m}^3 = \mathbf{0.001 \text{ kg}}$$

A more accurate value from Table A.5 is $\rho = 1.17 \text{ kg/m}^3$ at 100 kPa, 25°C.

1.7 Water in nature exists in different phases such as solid, liquid and vapor (gas). Indicate the relative magnitude of density and specific volume for the three phases.

Solution:

Values are indicated in Figure 1.8 as density for common substances. More accurate values are found in Tables A.3, A.4 and A.5

Water as solid (ice) has density of around 900 kg/m^3

Water as liquid has density of around 1000 kg/m^3

Water as vapor has density of around 1 kg/m^3 (sensitive to P and T)

Ice cube

Liquid drops falling

Cloud*

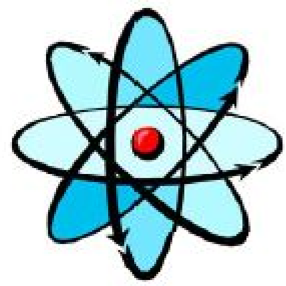
* Steam (water vapor) cannot be seen, what you see are tiny drops suspended in air from which we infer that there was some water vapor before it condensed.

1.8 Is density a unique measure of mass distribution in a volume? Does it vary? If so, on what kind of scale (distance)?

Solution:

Density is an average of mass per unit volume and we sense if it is not evenly distributed by holding a mass that is more heavy in one side than the other. Through the volume of the same substance (say air in a room) density varies only little from one location to another on scales of meter, cm or mm. If the volume you look at has different substances (air and the furniture in the room) then it can change abruptly as you look at a small volume of air next to a volume of hardwood.

Finally if we look at very small scales on the order of the size of atoms the density can vary infinitely, since the mass (electrons, neutrons and positrons) occupy very little volume relative to all the empty space between them.



1.9 An operating room has a positive gage pressure, whereas an engine test cell has a vacuum; why is that?

Solution:

For the operating room any air leak should be out so there will not be a chance that any microbes or other matter could come in from the outside and contaminate the patient.

For the engine test cell you do not want any leak of fuel, oil fumes or exhaust gasses to go out. They are exhausted by a fan to the outside where they will be highly diluted. If in a manufacturing situation you exhaust large amounts of fumes (like in a paint operation or chemical process) the fumes must be burned in an incinerator (thermal oxidicer) before exhausted to the outside.

1.10 A manometer with water shows a ΔP of $P_o/20$; what is the column height difference?

Solution:

$$\Delta P = P_o/20 = \rho H g$$

$$H = P_o/(20\ \rho\ g) = \frac{101.3 \times 1000\ \text{Pa}}{20 \times 997\ \text{kg/m}^3 \times 9.80665\ \text{m/s}^2}$$

$= \mathbf{0.502\ m}$

1.11 If something floats in water, what does it say about its density?

Solution:

The density must be less than the density of the water.

1.13 Convert the formula for water density in In-text Concept Question "d" to be for T in degrees Kelvin.

Solution:

$$\rho = 1008 - T_C/2 \quad [\text{kg/m}^3]$$

We need to express degrees Celsius in degrees Kelvin

$$T_C = T_K - 273.15$$

and substitute into formula

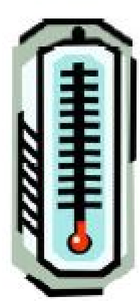
$$\rho = 1008 - T_C/2 = 1008 - (T_K - 273.15)/2 = 1144.6 - T_K/2$$

1.14 What is the lowest temperature in degrees Celsuis? In degrees Kelvin?

Solution:

The lowest temperature is absolute zero which is at zero degrees Kelvin at which point the temperature in Celsius is negative

$$T_K = 0\ \text{K} = -273.15\ ^{\text{o}}\text{C}$$



1.15 What is the main difference between the macroscopic kinetic energy in a motion like the blowing of wind versus the microscopic kinetic energy of individual molecules? Which one can you sense with your hand?

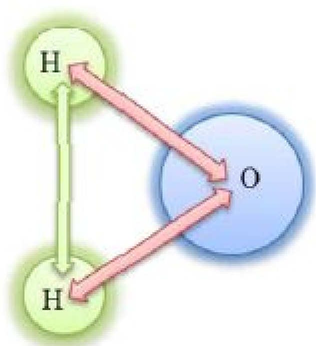
Answer:

The microscopic kinetic energy of individual molecules is too small for us to sense however when the combined action of billions (actually more like in the order of 10E18) are added, we get to the macroscopic magnitude we can sense. The wind velocity is the magnitude and direction of the averaged velocity over many molecules which we sense. The individual molecules are moving in a random motion (with zero average) on top of this mean (or average) motion. A characteristic velocity of this random motion is the speed of sound, around 340 m/s for atmospheric air and it changes with temperature.

1.16 How can you illustrate the binding energy between the three atoms in water as they sit in a tri-atomic water molecule. Hint: imagine what must happen to create three separate atoms.

Answer:

If you want to separate the atoms you must pull them apart. Since they are bound together with strong forces (like non-linear springs) you apply a force over a distance which is work (energy in transfer) to the system and you could end up with two hydrogen atoms and one oxygen atom far apart so they no longer have strong forces between them. If you do not do anything else the atoms will sooner or later recombine and release all the energy you put in and the energy will come out as radiation or given to other molecules by collision interactions.

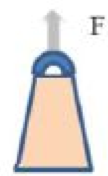


Properties, Units, and Force

1.17 One kilopond (1 kp) is the weight of 1 kg in the standard gravitational field. How many Newtons (N) is that?

$F = ma = mg$

$1 \text{ kp} = 1 \text{ kg} \times 9.807 \text{ m/s}^2 = \mathbf{9.807\ N}$



1.18 The Rover Explorer has a mass of 185 kg, how much does this weigh on the Moon ($g = g_{std}/6$) and on Mars where $g = 3.75 \text{ m/s}^2$

Solution:

Density is mass per unit volume

Moon: $F = mg = 185 \text{ kg} \times (9.81 / 6) \text{ m/s}^2 = \mathbf{302.5\ N}$

Mars: $F = mg = 185 \text{ kg} \times 3.75 \text{ m/s}^2 = \mathbf{693.8\ N}$

The 185 kg on earth will give a weight of 1815 N = 185 kp

1.19 A steel cylinder of mass 4 kg contains 4 L of liquid water at 25°C at 100 kPa. Find the total mass and volume of the system. List two extensive and three intensive properties of the water

Solution:

Density of steel in Table A.3: $\rho = 7820 \text{ kg/m}^3$

Volume of steel: $V = m/\rho = \dfrac{4 \text{ kg}}{7820 \text{ kg/m}^3} = 0.000\,512 \text{ m}^3$

Density of water in Table A.4: $\rho = 997 \text{ kg/m}^3$

Mass of water: $m = \rho V = 997 \text{ kg/m}^3 \times 0.004 \text{ m}^3 = 3.988 \text{ kg}$

Total mass: $m = m_{steel} + m_{water} = 4 + 3.988 = \mathbf{7.988\ kg}$

Total volume: $V = V_{steel} + V_{water} = 0.000\,512 + 0.004$

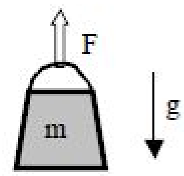
$= \mathbf{0.004\,512\ m^3 = 4.51\ L}$

Extensive properties: m, V

Intensive properties: ρ (or $v = 1/\rho$), T, P

1.20 The "standard" acceleration (at sea level and 45° latitude) due to gravity is $9.80665\ m/s^2$. What is the force needed to hold a mass of 2 kg at rest in this gravitational field? How much mass can a force of 1 N support?

Solution:



$$ma = 0 = \sum F = F - mg$$

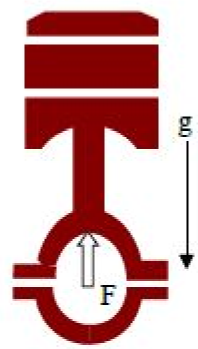
$$F = mg = 2\ kg \times 9.80665\ m/s^2 = \mathbf{19.613\ N}$$

$$F = mg \qquad \Rightarrow$$

$$m = \frac{F}{g} = \frac{1\ N}{9.80665\ m/s^2} = \mathbf{0.102\ kg}$$

1.21 An aluminum piston of 2.5 kg is in the standard gravitational field where a force of 25 N is applied vertically up. Find the acceleration of the piston.

Solution:



$$F_{up} = ma = F - mg$$

$$a = \frac{F - mg}{m} = \frac{F}{m} - g$$

$$= \frac{25\ N}{2.5\ kg} - 9.807\ m/s^2$$

$$= \mathbf{0.193\ ms^{-2}}$$

1.22 A car rolls down a hill with a slope so the gravitational "pull" in the direction of motion is one tenth of the standard gravitational force (see Problem 1.26). If the car has a mass of 2500 kg find the acceleration.

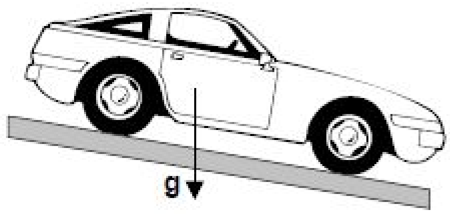
Solution:

$ma = \sum F = mg / 10$

$a = mg / 10m = g/10$

$= 9.80665 \ (m/s^2) / 10$

$= \mathbf{0.981 \ m/s^2}$



This acceleration does not depend on the mass of the car.

1.23 A 1500-kg car moving at 20 km/h is accelerated at a constant rate of 4 m/s^2 up to a speed of 75 km/h. What are the force and total time required?

Solution:

$$a = \frac{dV}{dt} = \frac{\Delta V}{\Delta t} \quad =>$$

$$\Delta t = \frac{\Delta V}{a} = \frac{(75 - 20) \ km/h \times 1000 \ m/km}{3600 \ s/h \times 4 \ m/s^2} = \mathbf{3.82 \ sec}$$

$$F = ma = 1500 \ kg \times 4 \ m/s^2 = \mathbf{6000 \ N}$$

1.24 A van is driven at 60 km/h and is brought to a full stop with constant deceleration in 5 seconds. If the total car and driver mass is 2075 kg find the necessary force.

Solution:

Acceleration is the time rate of change of velocity.

$$a = \frac{dV}{dt} = \frac{60 \times 1000}{3600 \times 5} = 3.333 \ m/s^2$$

$ma = \sum F$;

$F_{net} = ma = 2075 \ kg \times 3.333 \ m/s^2 = \mathbf{6916 \ N}$

1.25 A bottle of 12 kg steel has 1.75 kmole of liquid propane. It accelerates horizontal with 3 m/s^2, what is the needed force?

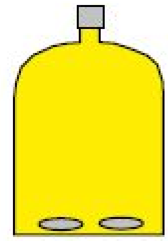
Solution:

The molecular weight for propane is M = 44.094 from Table A.2. The force must accelerate both the container mass and the propane mass.

$$m = m_{steel} + m_{propane} = 12 + (1.75 \times 44.094) = 90.645 \text{ kg}$$

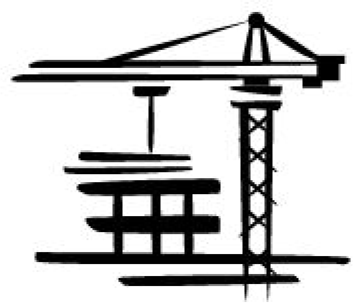
$$ma = \sum F \quad \Rightarrow$$

$$F = ma = 90.645 \text{ kg} \times 3 \text{ m/s}^2 = \mathbf{271.9 \text{ N}}$$



1.26 Some steel beams with a total mass of 700 kg are raised by a crane with an acceleration of 2 m/s^2 relative to the ground at a location where the local gravitational acceleration is 9.5 m/s^2. Find the required force.

Solution:



$$F = ma = F_{up} - mg$$

$$F_{up} = ma + mg = 700 \text{ kg } (2 + 9.5) \text{ m/s}^2$$

$$= \mathbf{80\ 500 \text{ N}}$$

1.27 The elevator in a hotel has a mass of 750 kg, and it carries six people with a total mass of 450 kg. One of the people weighs 80 kg standing still. How much weight does this person feel when the elevator starts moving?

Solution:

The equation of motion is

$$ma = \sum F = F - mg$$

so the force from the floor becomes

$$\begin{aligned} F &= ma + mg = m(a + g) \\ &= 80 \text{ kg} \times (1 + 9.81) \text{ m/s}^2 \\ &= 864.8 \text{ N} \\ &= x \text{ kg} \times 9.81 \text{ m/s}^2 \end{aligned}$$

Solve for x

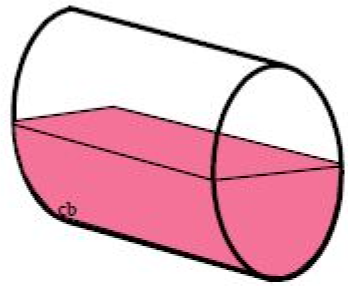
$$x = 864.8 \text{ N/ } 9.81 \text{ m/s}^2 = \mathbf{88.15\ kg}$$

The person then feels like having a mass of 88 kg instead of 80 kg. The weight is really force so to compare to standard mass we should use kp. So in this example the person is experiencing a force of 88 kp instead of the normal 80 kp.

Specific Volume

1.28 A 15-kg steel gas tank holds 300 L of liquid gasoline, having a density of 800 kg/m^3. If the system is decelerated with 2g what is the needed force?

Solution:



$$m = m_{tank} + m_{gasoline}$$
$$= 15 \text{ kg} + 0.3 \text{ m}^3 \times 800 \text{ kg/m}^3$$
$$= 255 \text{ kg}$$
$$F = ma = 255 \text{ kg} \times 2 \times 9.81 \text{ m/s}^2$$
$$= \mathbf{5003\ N}$$

1.29 A 5 m^3 container is filled with 900 kg of granite (density 2400 kg/m^3) and the rest of the volume is air with density 1.15 kg/m^3. Find the mass of air and the overall (average) specific volume.

Solution:

$$m_{air} = \rho V = \rho_{air} (V_{tot} - \frac{m_{granite}}{\rho})$$

$$= 1.15 \text{ kg/m}^3 [5 - \frac{900}{2400}] \text{ m}^3 = 1.15 \times 4.625 \text{ kg} = \mathbf{5.32\ kg}$$

$$v = \frac{V}{m} = \frac{5}{900 + 5.32} \frac{\text{m}^3}{\text{kg}} = \mathbf{0.005\ 52\ m^3/kg}$$

Comment: Because the air and the granite are not mixed or evenly distributed in the container the overall specific volume or density does not have much meaning.

1.30 A 1 m^3 container is filled with 400 kg of granite stone, 200 kg dry sand and 0.2 m^3 of liquid 25°C water. Use properties from tables A.3 and A.4. Find the average specific volume and density of the masses when you exclude air mass and volume.

Solution:

Specific volume and density are ratios of total mass and total volume.

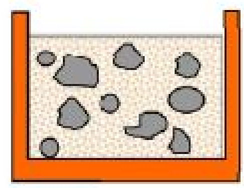
$$m_{liq} = V_{liq}/v_{liq} = V_{liq}\,\rho_{liq} = 0.2 \text{ m}^3 \times 997 \text{ kg/m}^3 = 199.4 \text{ kg}$$

$$m_{TOT} = m_{stone} + m_{sand} + m_{liq} = 400 + 200 + 199.4 = 799.4 \text{ kg}$$

$$V_{stone} = mv = m/\rho = 400 \text{ kg}/ 2750 \text{ kg/m}^3 = 0.1455 \text{ m}^3$$

$$V_{sand} = mv = m/\rho = 200 \text{ kg}/ 1500 \text{ kg/m}^3 = 0.1333 \text{ m}^3$$

$$V_{TOT} = V_{stone} + V_{sand} + V_{liq} = 0.1455 + 0.1333 + 0.2 = 0.4788 \text{ m}^3$$



$$v = V_{TOT} / m_{TOT} = 0.4788 \text{ m}^3 /799.4 \text{ kg} = \mathbf{0.000599 \text{ m}^3/\text{kg}}$$

$$\rho = 1/v = m_{TOT}/V_{TOT} = 799.4 \text{ kg} /0.4788 \text{ m}^3 = \mathbf{1670 \text{ kg/m}^3}$$

1.31 A tank has two rooms separated by a membrane. Room A has 1.5 kg air and volume 0.5 m^3, room B has 0.75 m^3 air with density 0.8 kg/m^3. The membrane is broken and the air comes to a uniform state. Find the final density of the air.

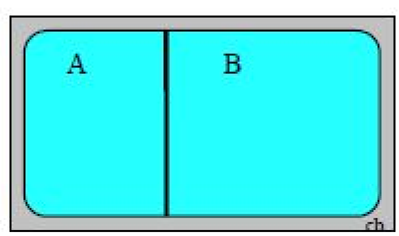
Solution:

Density is mass per unit volume

$$m = m_A + m_B = m_A + \rho_B V_B = 1.5 + 0.8 \times 0.75 = 2.1 \text{ kg}$$

$$V = V_A + V_B = 0.5 + 0.75 = 1.25 \text{ m}^3$$

$$\rho = \frac{m}{V} = \frac{2.1}{1.25} = \mathbf{1.68 \text{ kg/m}^3}$$



1.32 One kilogram of diatomic oxygen (O_2 molecular weight 32) is contained in a 500-L tank. Find the specific volume on both a mass and mole basis (v and $\bar{v}$).

Solution:

From the definition of the specific volume

$$v = \frac{V}{m} = \frac{0.5}{1} = \mathbf{0.5\ m^3/kg}$$

$$\bar{v} = \frac{V}{n} = \frac{V}{m/M} = M\,v = 32 \times 0.5 = \mathbf{16\ m^3/kmol}$$

1.33 A power plant that separates carbon-dioxide from the exhaust gases compresses it to a density of 110 kg/m^3 and stores it in an un-minable coal seam with a porous volume of 100 000 m^3. Find the mass they can store.

Solution:

$$m = \rho\,V = 110\ kg/m^3 \times 100\,000\ m^3 = 11 \times 10^6\ kg$$

Comment:

Just to put this in perspective a power plant that generates 2000 MW by burning coal would make about 20 million tons of carbon-dioxide a year. That is 2000 times the above mass so it is nearly impossible to store all the carbon-dioxide being produced.

Pressure

1.34 The piston cylinder in Fig. P1.34 has a diameter of 10 cm, inside pressure 735 kPa. What is the force holding the massless piston up as the piston lower side has P_0 besides the force?

Solution:

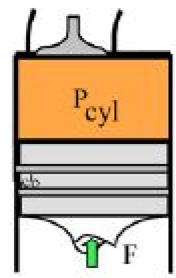
Force acting on the mass by the inside pressure

$$F\downarrow = P\ A$$

Force balance: $F\uparrow = F + P_0\ A = F\downarrow \quad => \quad F = (P - P_0)\ A$

$$A = \pi\ D^2\ (1\ /\ 4) = 0.007854\ m^2$$

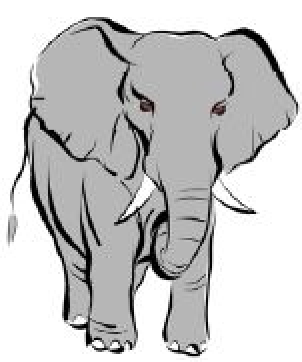
$$F = (735 - 101)\ kPa \times 0.007854\ m^2 = \mathbf{4.98\ kN}$$



1.35 A 5000-kg elephant has a cross sectional area of 0.02 m^2 on each foot. Assuming an even distribution, what is the pressure under its feet?

Force balance: $ma = 0 = PA - mg$

$$P = mg/A = 5000\ kg \times 9.81\ m/s^2\ /(4 \times 0.02\ m^2)$$
$$= 613\ 125\ Pa = \mathbf{613\ kPa}$$



1.36 The hydraulic lift in an auto-repair shop has a cylinder diameter of 0.2 m. To what pressure should the hydraulic fluid be pumped to lift 80 kg of piston/arms and 700 kg of a car?

Solution:

Force acting on the mass by the gravitational field

$$F\downarrow = ma = mg = 780 \times 9.80665 = 7649.2 \text{ N} = 7.649 \text{ kN}$$

Force balance: $F\uparrow = (P - P_0)A = F\downarrow \quad => \quad P = P_0 + F\downarrow / A$

$$A = \pi D^2 (1/4) = 0.031416 \text{ m}^2$$

$$P = 101 \text{ kPa} + \frac{7.649 \text{ kN}}{0.031416 \text{ m}^2} = \mathbf{344\ kPa}$$

1.37 A vertical hydraulic cylinder has a 125-mm diameter piston with hydraulic fluid inside the cylinder and an ambient pressure of 1 bar. Assuming standard gravity, find the piston mass that will create a pressure inside of 1500 kPa.

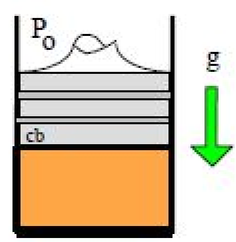
Solution:

Force balance:

$$F\uparrow = PA = F\downarrow = P_0 A + m_p g;$$

$$P_0 = 1 \text{ bar} = 100 \text{ kPa}$$

$$A = (\pi/4)\,D^2 = (\pi/4) \times 0.125^2 = 0.01227 \text{ m}^2$$



$$m_p = (P - P_0)\frac{A}{g} = (1500 - 100) \times 1000 \times \frac{0.01227}{9.80665} = \mathbf{1752\ kg}$$