Chapter 2 Introductory Concepts

Problem 2.1

Convert the following quantities to the ones designated :

a. 42 ft^2/hr to cm^2/s.
b. 25 psig to psia.
c. 100 Btu to hp-hr.

Solution

a. $$\frac{42.0\ \text{ft}^2}{\text{hr}}\left|\left(\frac{1.0\ \text{m}}{3.2808\ \text{ft}}\right)^2\right|\frac{10^4\ \text{cm}^2}{1.0\ \text{m}^2}\left|\frac{1\ \text{hr}}{3600\ \text{s}}\right| = \mathbf{10.8\ cm^2/s}$$

b. $$\frac{100\ \text{Btu}}{}\left|\frac{3.93\times10^{-4}\ \text{hp-hr}}{1\ \text{Btu}}\right. = \mathbf{3.93\times10^{-2}\ hp\text{-}hr}$$

c. $$\frac{80.0\ \text{lb}_f}{}\left|\frac{32.174\ (\text{lb}_m)(\text{ft})}{(\text{lb}_f)(\text{s})^2}\right|\frac{1\ \text{kg}}{2.20\ \text{lb}_m}\left|\frac{1\ \text{m}}{3.2808\ \text{ft}}\right|\frac{1\ \text{N}}{1\ (\text{kg})(\text{m})(\text{s})^{-2}} = \mathbf{356\ N}$$

Problem 2.2

Convert the ideal gas constant : R = $1.987\ \frac{\text{cal}}{(\text{gmol})(\text{K})}$ to $\frac{\text{Btu}}{(\text{lb mol})(^\circ\text{R})}$

Solution

$$\frac{1.987\ \text{cal}}{(\text{gmol})(\text{K})}\left|\frac{1\ \text{Btu}}{252\ \text{cal}}\right|\frac{454\ \text{gmol}}{1\ \text{lb mol}}\left|\frac{1\ \text{K}}{1.8\ ^\circ\text{R}}\right. = \mathbf{1.98\ \frac{Btu}{(lb\ mol)(^\circ R)}}$$

Problem 2.3

Mass flow through a sonic nozzle is a function of gas pressure and temperature. For a given pressure p and temperature T, mass flow rate through the nozzle is given by

$$m = 0.0549\ p\ /(T)^{0.5}$$ where m is in lb/min, p is in psia and T is in °R

a. Determine what the units for the constant 0.0549 are.
b. What will be the new value of the constant, now given as 0.0549, if the variables in the equation are to be substituted with SI units and m is calculated in SI units.

NOZZLES

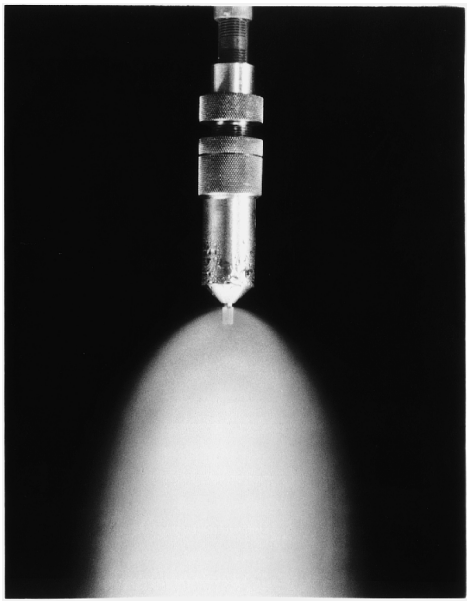


Fig. 1a. Ultrasonic nozzle (courtesy of Misonix Inc., Farmingdale, N.J.)

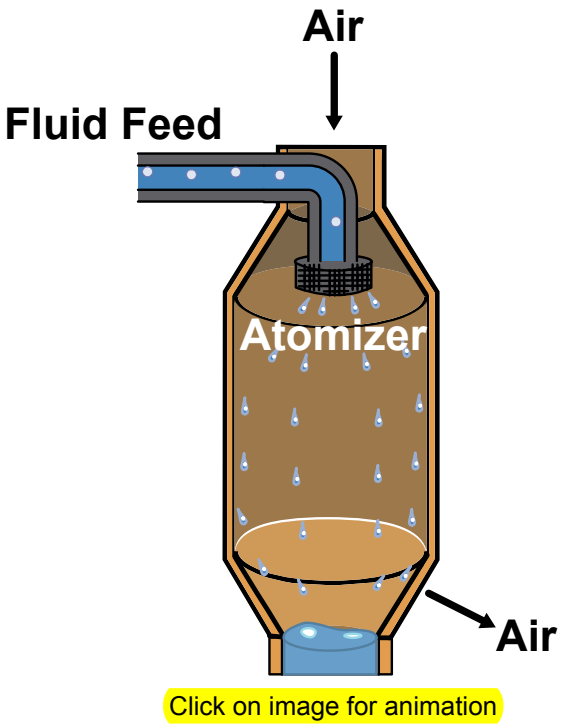


Fig. 1b. A conventional nozzle spraying a fluid of suspended particles in a flash dryer.

Spray nozzles are used for dust control, water aeration, dispersing a particular pattern of drops, coating, paintings, cleaning surfaces of tanks and vats, and numerous other applications. They develop a large interface between a gas and liquid, and can provide uniform round drops of liquid. Atomization occurs by a combination of gas and liquid pressure differences. The Figure below (courtesy of Misonix Inc.) compares the particle sizes from the ultrasonic nozzle with those from the conventional nozzle.

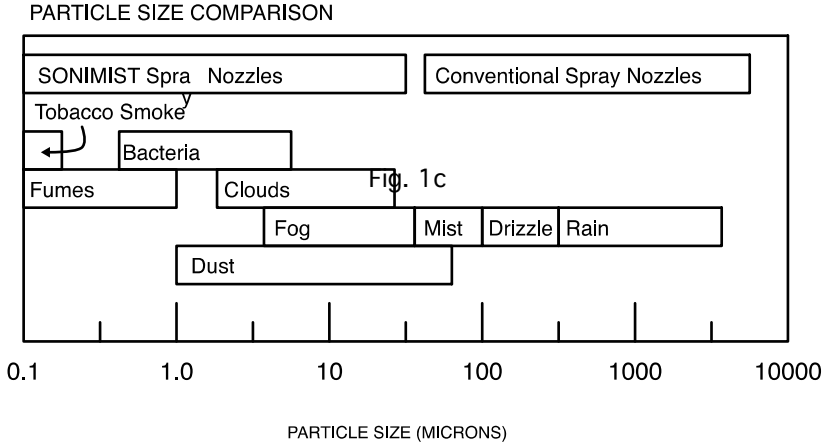


Fig. 1c

Solution

a. Calculation of the constant.

The first step is to substitute known units into the equation.

$$\frac{lb_m}{min} = 0.0549 \ \frac{lb_f}{(in^2)(°R)^{0.5}}$$

We want to find a set of units that convert units on the right hand side of the above expression to units on the left hand side of the expression. Such a set can be set up directly by multiplication.

$$\frac{lb_f}{(in^2)(°R)^{0.5}}\left|\frac{(lb_m)(in)^2(°R)^{0.5}}{(min)(lb_f)}\right. \quad \text{------>} \quad \frac{(lb_m)}{(min)}$$

Units for the constant 0.0549 are $\dfrac{(lb_m)(in)^2(°R)^{0.5}}{(min)(lb_f)}$

b. To determine the new value of the constant, we need to change the units of the constant to appropriate SI units using conversion factors.

$$\frac{0.0549\ (lb_m)(in^2)(°R)^{0.5}}{(lb_f)(min)}\left|\frac{(0.454\ kf)}{(1\ lb_m)}\right|\frac{(14.7\ lb_f/in^2)}{101.3\ \times\ 10^3 N/m^2}\left|\frac{(1\ min)}{(60\ s)}\right|\frac{(1K)^{0.5}}{(1.8\ °R)^{0.5}}\left|\frac{(p)}{(T)^{0.5}}\right.$$

$$\mathbf{m = 4.49 \times 10^{-8}\ (m)\ (s)\ (K)^{0.5}\ \frac{(p)}{(T)^{0.5}}}$$

Substituting pressure and temperature in SI units

$$m = 4.49 \times 10^{-8}\ (m)\ (s)\ (K)^{0.5}\ \frac{(p)(N/m^2)}{(T)^{0.5}(K)^{0.5}}\left|\frac{1\ kg/(m)(s)^2}{1\ N/m^2}\right.$$

$$\mathbf{m\ \frac{(kg)}{(s)} = 4.49 \times 10^{-8}\frac{(p)}{(T)^{0.5}}}$$ where p is in N/m^2 and T is in K

Problem 2.4

An empirical equation for calculating the inside heat transfer coefficient, h_i, for the turbulent flow of liquids in a pipe is given by:

$$h_i = \frac{0.023\ G^{0.8}\ K^{0.67}\ Cp^{0.33}}{D^{0.2}\ \mu^{0.47}}$$

where h_i = heat transfer coefficient, Btu/(hr)(ft)^2(°F)
G = mass velocity of the liquid, lb_m/(hr)(ft)^2
K = thermal conductivity of the liquid, Btu/(hr)(ft)(°F)
C_p = heat capacity of the liquid, Btu/(lb_m)(°F)
μ = Viscosity of the liquid, lb_m/(ft)(hr)
D = inside diameter of the pipe, (ft)

a. Verify if the equation is dimensionally consistent.
b. What will be the value of the constant, given as 0.023, if all the variables in the equation are inserted in SI units and h_i is in SI units.

Solution

a. First we introduce American engineering units into the equation:

$$h_i = \frac{0.023\left[(lb_m)/(ft)^2(hr)\right]^{0.80}}{(ft)^{0.2}} \frac{\left[Btu/(hr)(ft)(°F)\right]^{0.67}\left[Btu/(lb_m)(°F)\right]^{0.33}}{\left[lb_m/(ft)(hr)\right]^{0.47}}$$

Next we consolidate like units

$$h_i = \frac{0.023(Btu)^{0.67}\ (lb_m)^{0.8}}{[(lb_m)^{0.33}(lb_m)^{0.47}]} \left| \frac{(ft)^{0.47}}{[(ft)^{1.6}(ft)^{0.67}(ft)^{0.2}]} \right| \frac{(1)}{[(°F)^{0.67}(°F)^{0.33}]} \left| \frac{(hr)^{0.47}}{[(hr)^{0.8}(hr)^{0.67}]} \right.$$

$$h_i = 0.023 \quad \frac{Btu}{(hr)(ft)^2\ (°F)}$$

The equation is dimensionally consistent.

b. The constant 0.023 is dimensionless; a change in units of the equation parameters will not have any effect on the value of this constant.

Problem 2.5

Calcium carbonate is a naturally occuring white solid used in the manufacture of lime and cement. Calculate the number of lb mols of calcium carbonate in:

a. 50 g mol of $CaCO_3$.
b. 150 kg of $CaCO_3$.
c. 100 lb of $CaCO_3$.

Solution

a. $$\frac{50 \text{ g mol } CaCO_3}{} \left| \frac{100 \text{ g } CaCO_3}{1 \text{ g mol } CaCO_3} \right| \frac{1 \text{ lb } CaCO_3}{454 \text{ g } CaCO_3} \left| \frac{1 \text{ lb mol } CaCO_3}{100 \text{ lb } CaCO_3} \right. = \mathbf{0.11 \text{ lb mol}}$$

b. $$\frac{150 \text{ kg } CaCO_3}{} \left| \frac{2.205 \text{ lb } CaCO_3}{1 \text{ kg } CaCO_3} \right| \frac{1 \text{ lb mol } CaCO_3}{100 \text{ lb } CaCO_3} = \mathbf{3.30 \text{ lb mol}}$$

c. $$\frac{100 \text{ lb } CaCO_3}{} \left| \frac{1 \text{ lb mol } CaCO_3}{100 \text{ lb } CaCO_3} \right. = \mathbf{1.00 \text{ lb mol } CaCO_3}$$

Problem 2.6

Silver nitrate (lunar caustic) is a white crystalline salt, used in marking inks, medicine and chemical analysis. How many kilograms of silver nitrate ($AgNO_3$) are there in:

a. 13.0 lb mol $AgNO_3$.
b. 55.0 g mol $AgNO_3$

Solution

a. $$\frac{13.0 \text{ lb mol } AgNO_3}{} \left| \frac{170 \text{ lb } AgNO_3}{1 \text{ lb mol } AgNO_3} \right| \frac{1 \text{ kg}}{2.205 \text{ lb}} = 1002 \text{ kg } \mathbf{or\ 1000 \text{ kg}}$$

b. $$\frac{55.0 \text{ g mol } AgNO_3}{} \left| \frac{170 \text{ g } AgNO_3}{1 \text{ g mol } AgNO_3} \right| \frac{1 \text{ kg}}{1000 \text{ g}} = \mathbf{9.35 \text{ kg}}$$

Problem 2.7

Phosphoric acid is a colorless deliquescent acid used in the manufacture of fertilizers and as a flavoring agent in drinks. For a given 10 wt % phosphoric acid solution of specific gravity 1.10 determine:

a. the mol fraction composition of this mixture.

b. the volume (in gallons) of this solution which would contain 1 g mol H_3PO_4.

Solution

a. Basis: 100 g of 10 wt% solution

	g	MW	g mol	mol fr
H_3PO_4	10	97.97	0.102	0.020
H_2O	90	18.01	5.00	0.980

b. Specific gravity $= \dfrac{\rho_{soln}}{\rho_{ref}}$ The ref. liquid is water

The density of the solution is $\dfrac{1.10 \text{ g soln/cm}^3 \text{ soln}}{1.00 \text{ g } H_2O/\text{cm}^3} \left| \dfrac{1.00 \text{ g } H_2O/\text{cm}^3}{} \right. = 1.10 \dfrac{\text{g soln}}{\text{cm}^3}$

$$\frac{1 \text{ cm}^3 \text{ soln}}{1.10 \text{ g soln}} \left| \frac{1 \text{ g soln}}{0.1 \text{ g } H_3PO_4} \right| \frac{97.97 \text{ g } H_3PO_4}{1 \text{ g mol } H_3PO_4} \left| \frac{264.2 \text{ gal}}{10^6 \text{ cm}^3} \right. = \mathbf{0.24 \text{ gal/g mol}}$$

Problem 2.8

The density of a liquid is 1500 kg/m^3 at 20 ℃.

a. What is the specific gravity 20℃/4℃ of this material.

b. What volume (ft^3) does 140 lb_m of this material occupy at 20℃.

Solution

Assume the reference substance is water which has a density of 1000 kg/m^3 at 4℃.

a. Specific gravity $= \dfrac{\rho_{soln}}{\rho_{ref}} = \dfrac{(\text{kg/m}^3)_{soln}}{(\text{kg/m}^3)_{ref}} = \dfrac{1500 \text{ kg/m}^3}{1000 \text{ kg/m}^3} = \mathbf{1.50}$

b. $\dfrac{1 \text{ m}^3 \text{ liquid}}{1500 \text{ kg}} \left| \dfrac{1 \text{ kg}}{2.20 \text{ lb}} \right| \dfrac{35.31 \text{ ft}^3}{1 \text{ m}^3} \left| \dfrac{140 \text{ lb}_m}{} \right. = \mathbf{1.50 \text{ ft}^3}$

Problem 2.9

The 1993 Environmental Protection Agency (EPA) regulation contains standards for 84 chemicals and minerals in drinking water. According to the EPA one of the most prevalent of the listed contaminants is naturally occuring antimony. The maximum contaminant level for antimony and nickel has been set at 0.006 mg/L and 0.1 mg/L respectively.

A laboratory analysis of your household drinking water shows the antimony concentration to be 4 ppb (parts per billion) and that of nickel to be 60 ppb. Determine if the drinking water is safe with respect to the antimony and nickel levels.

Assume density of water to be 1.00 g/cm^3

Solution

The problem may be solved by either converting the EPA standards to ppb or vice versa. We will convert the EPA standards to ppb; ppb is a ratio, and therefore it is necessary for the numerator and denominator to have same mass or mole units. The mass and volume that the Sb contributes to the water solution is negligible.

Antimony

$$\frac{0.006 \text{ mg Sb}}{1\text{L soln}} \left| \frac{1 \text{ L soln}}{1000 \text{ cm}^3 \text{ soln}} \right| \frac{1 \text{ cm}^3 \text{ soln}}{1.00 \text{ g } H_2O} \left| \frac{1 \text{ g}}{1000 \text{ mg}} \right| = \frac{6 \text{ g Sb}}{10^9 \text{ g soln}} = \mathbf{6 \text{ ppb}}$$

Nickel

$$\frac{0.1 \text{ mg Ni}}{1 \text{ L soln}} \left| \frac{1 \text{ L soln}}{1000 \text{ cm}^3 \text{ soln}} \right| \frac{1 \text{ cm}^3 \text{ soln}}{1.0 \text{ g } H_2O} \left| \frac{1 \text{ g}}{1000 \text{ mg}} \right| = \frac{9 \text{ g Ni}}{10^9 \text{ g soln}} = \mathbf{100 \text{ ppb}}$$

House hold drinking water contains less than the EPA mandated tolerance levels of antimony and nickel. Drinking water is therefore safe.

Problem 2.10

Wine making involves a series of very complex reactions most of which are performed by microorganisms. The starting concentration of sugars determines the final alcohol content and sweetness of the wine. The specific gravity of the starting stock is therefore adjusted to achieve desired quality of wine.

A starting stock solution has a specific gravity of 1.075 and contains 12.7 wt% sugar. If all the sugar is assumed to be $C_{12}H_{22}O_{11}$, determine

a. kg sugar/kg H_2O

b. lb solution/ft^3 solution

c. g sugar/L solution

Solution

Basis: 100 kg starting stock solution

a. $\dfrac{12.7 \text{ kg sugar}}{100 \text{ kg soln}} \left| \dfrac{100 \text{ kg solution}}{87.3 \text{ kg } H_2O} \right. = \mathbf{.145} \ \mathbf{\dfrac{kg\ sugar}{kg\ H_2O}}$

b. $\dfrac{1.075 \text{ g soln/cm}^3}{1.0 \text{ g } H_2O/\text{cm}^3} \left| \dfrac{1.00 \text{ g } H_2O/\text{cm}^3}{} \right| \dfrac{1 \text{ lb}}{454 \text{ g}} \left| \dfrac{2.832 \times 10^4 \text{ cm}^3}{\text{ft}^3} \right. = \mathbf{67.1} \ \mathbf{\dfrac{lb\ soln}{ft^3\ soln}}$

c. $\dfrac{1.075 \text{ g soln/cm}^3}{1.0 \text{ g } H_2O/\text{cm}^3} \left| \dfrac{1.0 \text{ g } H_2O/\text{cm}^3}{} \right| \dfrac{12.7 \text{ g sugar}}{100 \text{ g soln}} \left| \dfrac{1000 \text{ cm}^3}{1 \text{ L}} \right. = \mathbf{136} \ \mathbf{\dfrac{g\ sugar}{L\ soln}}$

Problem 2.11

A liquified mixture of n-butane, n-pentane and n-hexane has the following composition in percent.

n - C_4H_{10}	50
n - C_5H_{12}	30
n - C_6H_{14}	20

Calculate the weight fraction, mol fraction and mol percent of each component and also the average molecular weight of the mixture.

Solution

Note that the hydrocarbon mixture is liquid so that the composition is therefore in weight percent. It is convenient to use a weight basis and set up a table to make the calculations.

Basis: 100 kg

	% = kgwt fr		MW	kg mol	mol fr
n - C_4H_{10}	50	**0.50**	58	0.86	**0.57**
n - C_5H_{12}	30	**0.30**	72	0.42	**0.28**
n - C_6H_{14}	20	**0.20**	86	0.23	**0.15**
	100	**1.00**		1.51	**1.00**

Average molecular weight $= \dfrac{\text{total mass}}{\text{total mol}} = \dfrac{100 \text{ kg}}{1.51 \text{ kg mol}} =$ **66**

Problem 2.12

Complete the table below with the proper equivalent temperatures.

°C	°F	K	°R
- 40.0	----------	----------	----------
----------	77.0	----------	----------
----------	----------	698	----------
----------	----------	----------	69.8

Solution

The conversion relations to use are:

$$°F = 1.8\,°C + 32$$
$$K = °C + 273$$
$$°R = °F + 460$$
$$°R = 1.8\,K$$

°C	°F	K	°R
- 40.0	**- 40.0**	**233**	**420**
25.0	77.0	**298**	**437**
425	**797**	698	**1257**
- 235	**-390**	**38.4**	69.8

Problem 2.13

The specific heat capacity of toluene is given by following equation

$$C_p = 20.869 + 5.293 \times 10^{-2} T$$

where C_p is in Btu/(LB mol) (° F) and T is in ° F

Express the equation in cal/(g mol) (K) with T in K.

Solution

First, conversion of the units for the overall equation is required.

$$C_p = \frac{[20.869 + 5.293 \times 10^{-2} (T_{°F})] \quad Btu}{1 \text{ (lb mol) (°F)}} \left| \frac{252 \text{ cal}}{1 \text{ Btu}} \right| \frac{1 \text{ lb mol}}{454 \text{ g mol}} \left| \frac{1.8 \text{ °F}}{1 \text{ K}} \right.$$

$$= [\,20.869 + 5.293 \times 10^{-2} (T_{°F})] \frac{\text{cal}}{\text{(g mol) (K)}}$$

Note that the coefficients of the equation remain unchanged in the new units for this particular conversion. The T of the equation is still in °F, and must be converted to kelvin.

MEASURING TANK PRESSURE

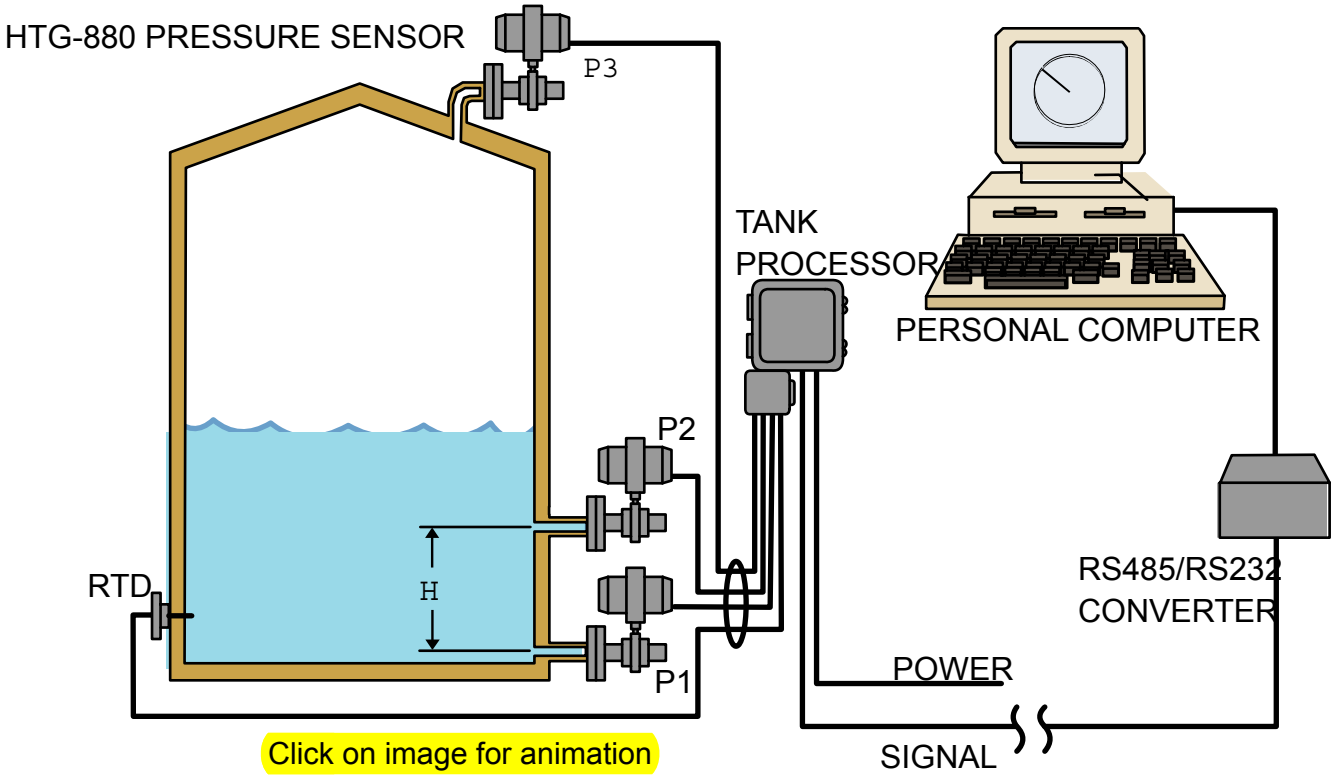


Fig. 2

The measurement of pressure at the bottom (at P1) of a large tank of fluid enables you to determine the level of fluid in the tank. A sensor at P2 measures the density of the fluid, and the sensor at P3 measures the pressure of the gas above the fluid. A digital signal is sent to the remote control room where the sensor readings and calculations for volume can be displayed on a PC. The volume of fluid in the tank is determined by multiplying the known area by the height of fluid calculated from the pressure and density measurements. Level can be determined to an accuracy of ± 1/8 inch, a value that leads to an accuracy of about 0.2% in the volume. In a tank containing 300,000 bbl of crude oil, the error roughly corresponds to about $12,000 in value.

$$T_{°F} = (T_K - 273)\,1.8 + 32$$

$$C_p = 20.69 + 5.293 \times 10^{-2}\,[(T_K - 273)\,1.8 + 32]$$

Simplifying $C_p = -3.447 + 9.527 \times 10^{-2}\,T_K$

Problem 2.14

A solvent storage tank, 15.0 m high contains liquid styrene (sp. gr. 0.909). A pressure gauge is fixed at the base of the tank to be used to determine the level of styrene.

a. Determine the gage pressure when the tank is full of styrene.
b. If the tank is to be used for storage of liquid hexane (sp. gr. 0.659), will the same pressure gage calibration be adequate ? What is the risk in using the same calibration to determine the level of hexane in the tank.
c. What will be the new pressure with hexane to indicate that the tank is full.

Solution

a. The liquid in full tank will exert a gage pressure at the bottom equal to 15.0 m of styrene. The tank has to operate with atmospheric pressure on it and in it, or it will break on expansion at high pressure or collapse at lower pressure.

$$p = h\,\rho\,g$$

$$= 15.0\text{ m}\ \frac{0.909\text{ g styrene/cm}^3}{1.0\text{ g H}_2\text{O/cm}^3}\left|\frac{1.0\text{ g H}_2\text{O/cm}^3}{}\right|\frac{10^3\text{ kg/m}^3}{1\text{ g/cm}^3}\left|\frac{9.80\text{ m/s}^2}{}\right|\frac{1\text{ Pa}}{1\text{ (kg)(m)}^{-1}\text{(s)}^{-2}}$$

$$= 134 \times 10^3\text{ Pa} = \mathbf{134\ kPa\ gage}$$

b. Hexane is a liquid of specific gravity lower than that of styrene; therefore a tank full of hexane would exert a proportionally lower pressure. If the same calibration is used the tank may overflow while the pressure gage was indicating only a partially full tank.

c. New $p = h\,\rho\,g$

$$= 15.0\text{ m}\ \frac{0.659\text{ g hexane/cm}^3}{1.0.0\text{ g H}_2\text{O/cm}^3}\left|\frac{1.0\text{ g H}_2\text{O/cm}^3}{}\right|\frac{10^3\text{ kg/m}^3}{}\left|\frac{9.8\text{ m/s}^2}{}\right|\frac{1\text{ Pa}}{1\text{(kg)(m)}^{-1}\text{(s)}^{-2}}$$

$$= 96900\text{ Pa} = \mathbf{96.9\ kPa}$$

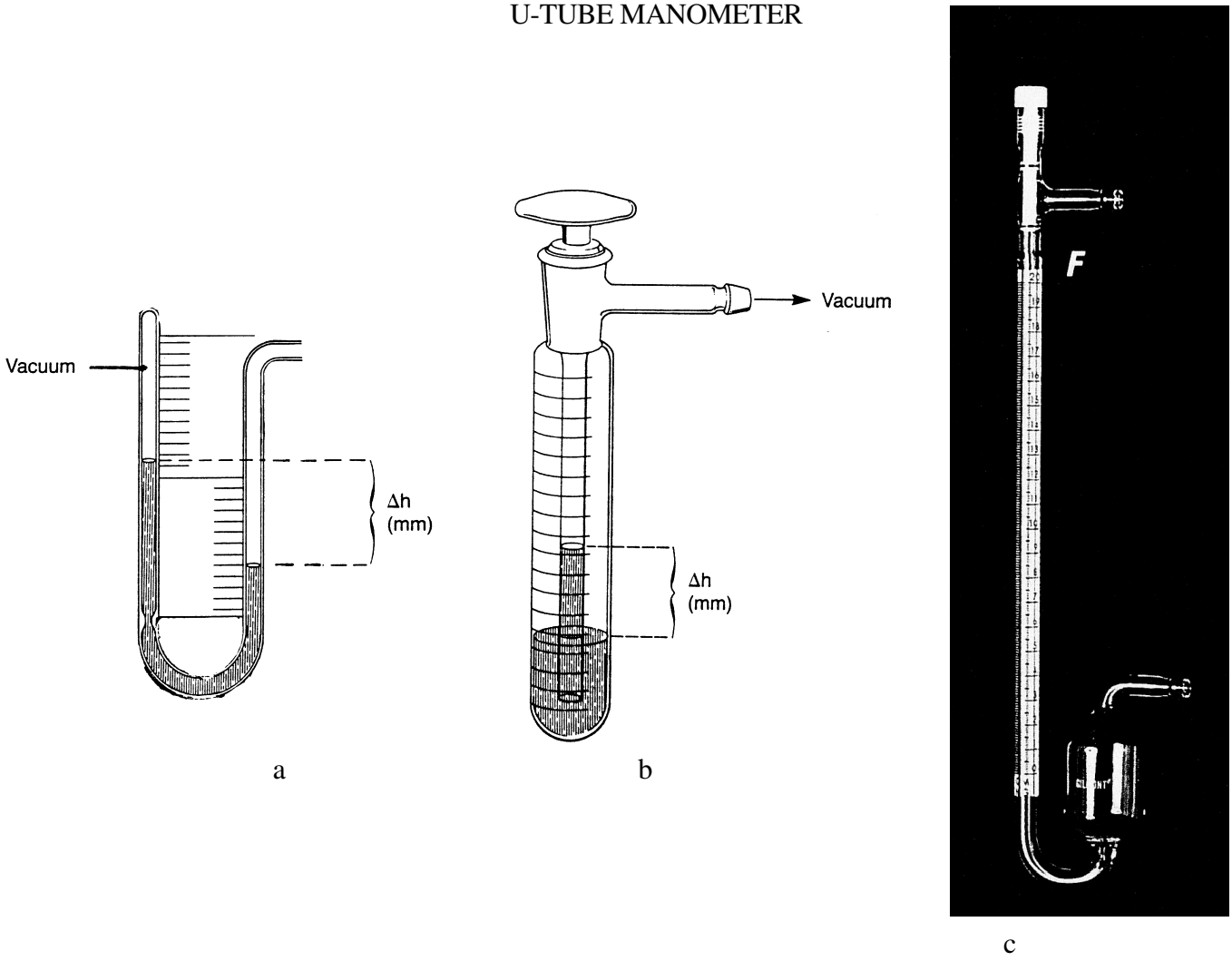


Fig. 3 Various forms of manometers

Typical liquid manometers consist of a U-shaped tube of glass or polycarbonate plastic partially filled with what is called a manometer fluid. The size and height of the manometer, and the manometer fluid, are selected so as to measure the desired pressure over the expected pressure range. Typical manometer fluids are mercury, water, the fluid in the system being measured, and heavy oils with very low vapor pressure. A manometer with the reference end open to the atmosphere makes gage measurements, i.e., measurements relative to the existing barometric pressure. A manometer with the reference end sealed so as to contain only the manometer fluid vapor measures roughly absolute pressure, but more precisely the reference pressure is the vapor pressure of the manometer fluid, hence the use of mercury which has an especially low vapor pressure at room temperature (2×10^{-3} mm Hg; 3×10^{-4} kPa). The sensitivity of a manometer can be increased by using special oils of specific gravity of 0.8 to 1.0 that also have very low vapor pressures. The accuracy of manometers depends on how closely you can read the meniscus in the glass tube.

Problem 2.15

A U-tube manometer is used to determine the pressure drop across an orifice meter. The liquid flowing in the pipe line is a sulfuric acid solution having a specific gravity (60°/60°) of 1.250. The manometer liquid is mercury, with a specific gravity (60°/60°) of 13.56. The manometer reading is 5.35 inches, and all parts of the system are at a temperature of 60°F. What is the pressure drop across the orifice meter in psi.

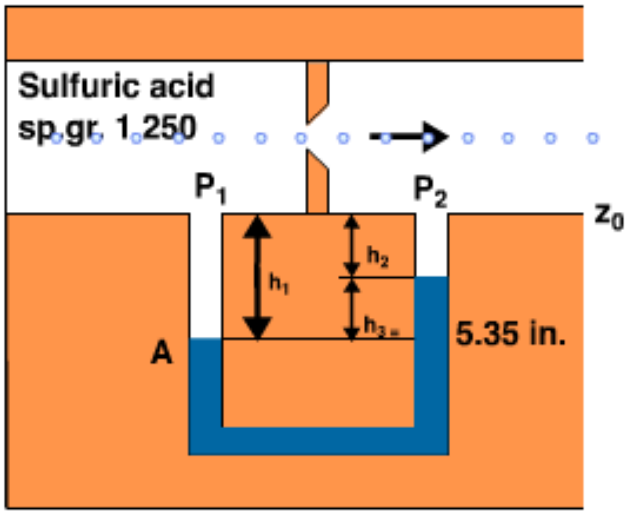
Solution

First we calculate density of acid and mercury.

$$\rho_{acid} = \left|1.250\right|\left|62.4\ \text{lb/ft}^3\right|\left|\frac{1\ \text{ft}^3}{1.728\times10^3\ \text{in}^3}\right| = 0.0451\ \text{lb/in}^3$$

$$\rho_{Hg} = \left|13.56\right|\left|62.4\ \text{lb/ft}^3\right|\left|\frac{1\ \text{ft}^3}{1.728\times10^3\ \text{in}^3}\right| = 0.490\ \text{lb/in}^3$$

Click on figure for Animation ▶



The procedure is to start with p_1 at z_o and add up the incremental pressure contributions. The pressures of the Hg in the left and right columns below A in the tube cancel each other, so we stop adding at level A.

	left column				*right column*		
At z_o	p_1	+ $\rho_a h_1 g$	=	p_2	+ $\rho_a h_2 g$	+	$\rho_{Hg} h_3 g$
	p_1	- p_2 + $\rho_a (h_1$	-	$h_2) g$	=		$\rho_{Hg} h_3 g$
	p_1	- p_2 + $\rho_a h_3 g$			=		$\rho_{Hg} h_3 g$
	p_1	- p_2			=		$(\rho_{Hg}$ - $\rho_a) h_3 g$

Substitute the densities in the final equation

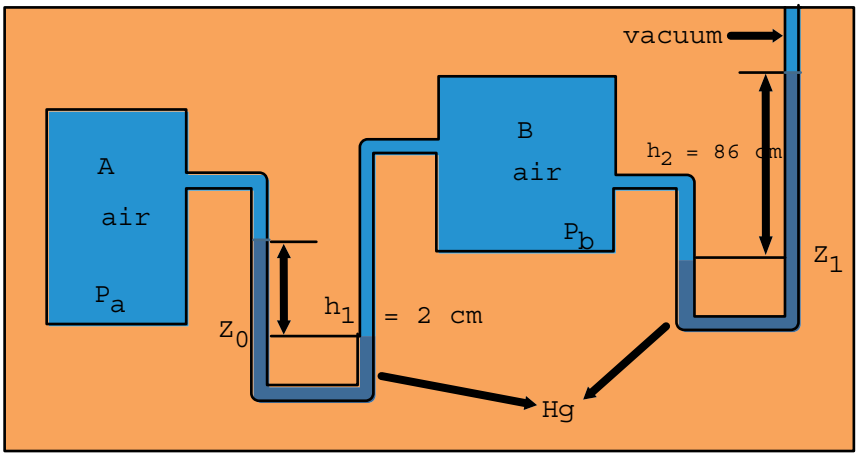
$$p_1 - p_2 = \left|\frac{(0.490 - 0.0451)\ \text{lb}_f}{\text{in}^2}\right|\left|(5.35)\ \text{in}\right|\left|\frac{32.2\ \text{ft/s}^2}{32.174\ (\text{ft})(\text{lb}_m)/(\text{s}^2)(\text{lb}_f)}\right| = \mathbf{2.38\ lb_f/in^2\ (psi)}$$

Problem 2.16

The pressure difference between two air tanks A and B is measured by a U - tube manometer, with mercury as the manometer liquid. The barometric pressure is 700 mm Hg.

a. What is the absolute pressure in the tank A ?
b. What is the gauge pressure in the tank A ?

Solution



Click on image for larger view

Tank A is connected to tank B through a U - tube and Tank B is connected to the vertical U - tube. The vertical tube can be used to measure the pressure in tank B and the U - tube can be used to relate the pressures of tanks A and B.

a. At Z_0 $\quad p_a + h_1 \rho_{Hg} g = p_b$ (neglecting the effect of air in the U - tube) (1)

at Z_1 $\quad p_b = h_2 \rho_{Hg} g$ (2)

Eliminate p_b from the equations

$$p_a + h_1 \rho_{Hg} g = h_2 \rho_{Hg} g$$

$$p_a = (h_2 - h_1) \rho_{Hg} g$$

$$= 840 \text{ mm Hg absolute}$$

The pressure measured by this manometer system is the absolute pressure because the reference (pressure above the mercury) in the vertical tube is a vacuum.

b. $p_a = 840 - 700 = 140$ mm Hg

PART 1 – ADDITIONAL PROBLEMS
(Answers will be found in Appendix A)

Chapter 2

2.1 Convert the following to the desired units:

(a) 60 mi/hr to m/s (b) 30 N/m^2 to lb$_f$/ft^2
(c) 16.3 J to Btu (d) 4.21 kW to J/s

2.2 Change the following to the desired units:

(a) 235 g to pounds. (b) 610 L to cubic feet.
(c) 30 g/L to pounds/cubic feet. (d) 14.7 lb/in^2 to kg/cm^2

2.3 Find the kinetic energy of a ton of water moving at 60 min/hr expressed as (ft)(lb$_f$).

2.4 An elevator which weights 10,000 lb is pulled up 10 ft between the first and second floors of a building 100 ft high. The greatest velocity the elevator attains is 3 ft/s. How much kinetic energy does the elevator have in (ft)(lb$_f$) at this velocity?

2.5 The Colburn equation for heat transfer is

$$\left(\frac{h}{CG}\right)\left(\frac{C\mu}{k}\right)^{2/3} = \frac{0.023}{(DG/\mu)^{0.2}}$$

where C = heat capacity, Btu/(lb of fluid)(°F); μ = viscosity, lb/(hr)(ft); k = thermal conductivity, Btu/(hr)(ft^2)(°F)/ft; D = pipe diameter, ft; and G = mass velocity, lb/(hr)(ft^2) of cross section. What are the units of the heat transfer coefficient h?

2.6 Countercurrent gas centrifuges have been used to separate ^{235}U from ^{238}U. The rate of diffusive transport is $K = 2\pi D\rho\bar{r}$. If K = rate of transport of light component to the center of the centrifuge, in g mol/(s)(cm of height); D = diffusion coefficient; ρ = molar density, g moles/cm^3; and $\bar{r}$ = log mean radius, $(r_2 - r_1)/\ln(r_2/r_1)$, with r in cm, what are the units of D?

2.7 The density of a certain liquid is given an equation of the following form:

$$\rho = (A + BT)e^{Cp}$$

where ρ = density in g/cm^3, t = temperature in °C, and P = pressure in atm.

(a) The equation is dimensionally consistent. What are the units of A, B, and C?
(b) In the units above, A = 1.096, B = 0.00086, and C = 0.000953. Find A, B, and C if ρ is expressed in lb/ft^3, T in °R, and p in lb$_f$/in^2.

2.8 (a) How many g moles are represented by 100 g of CO_2?
(b) Calculate the weight in pounds of 3.5 g moles of nitrogen.

2.9 Convert the following:
(a) 120 lb mol of NaCl to g. (b) 120 g mol of NaCl to lb.
(c) 120 lb of NaCl to g mol. (d) 120 g of NaCl to lb mol.

2.10 A solution of sulfuric acid at 60°F is found to have a sp gr of 1.22. From the tables in Perry's *Chemical Engineer's Handbook*, the solution is found to be 30 percent by weight H_2SO_4. What is the concentration of H_2SO_4 in the following units: (a) lb mol/gal, (b) lb/ft^3, (c) g/L, (d) lb H_2SO_4/lb H_2O, and (e) lb mol H_2O/lb mol total solution?

2.11 A mixture of liquid hydrocarbons contains 10.0 percent *n*-heptane, 40.0 percent *n*-octane, and 50.0 percent *i*-pentane by weight. The specific gravities $\left(\frac{60^\circ \text{F}}{60^\circ \text{F}}\right)$ of the pure components are

n-heptane = 0.685 *n*-octane = 0.705 *i*-pentane = 0.622

(a) What is the sp gr $\left(\frac{60^\circ \text{F}}{60^\circ \text{F}}\right)$ of 93 lb of this mixture?
(b) How many U.S. gallons will be occupied by 130 lb of this mixture?

2.12 Convert 17.2 ppm NH_3 in water to the equivalent number of ppm of NH_3 gas in water vapor.

2.13 Five thousand barrels of 28°API gas oil are blended with 20,000 bbl of 15° API fuel oil. What is the °API (API gravity) of the mixture? What is the density in lb/gal and lb/ft^3?

2.14 A mixture of gases is analyzed and found to have the following composition:

CO_2	12.0%
CO	6.0
CH_4	27.3
H_2	9.9
N_2	44.8

How much will 3 lb moles of this gas mixture weight?

2.15 You have 100 lb of gas of the following composition:

CH_4	30%
H_2	10%
N_2	60%

What is the average molecular weight of this gas?

2.16 What is the composition of the gas in Problem 3.1 on a nitrogen free basis (no N_2 in the analysis)?

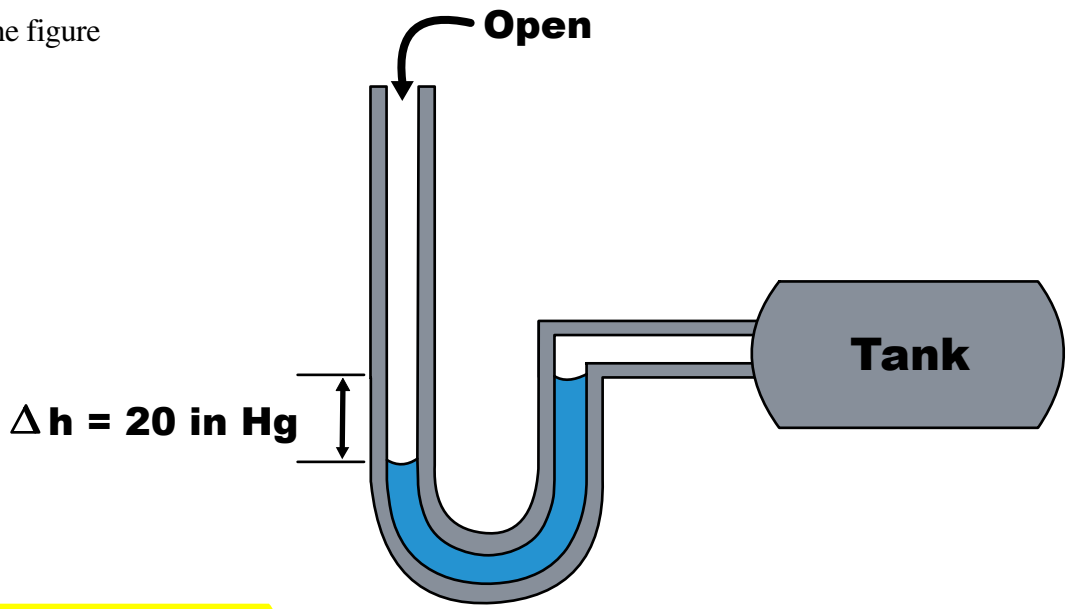
2.17 Two thermometers are to be checked against a standard thermometer. The standard reads – 22°F. What should the other two thermometers read if they are calibrated in °C and K, respectively?

2.18 Mercury boils at 630K. What is its boiling temperature expressed in °C? In °F? In °R?

2.19 What is the gauge pressure at a depth of 4.50 mi below the surface of the sea if the water temperature averages 60°F? Give your answer in lb (force) per sq. in. The sp gr of sea water at 60°F/60°F is 1.042 and is assumed to be independent of pressure.

2.20 The pressure gauge on the steam condenser for a turbine indicates 26.2 in. Hg of vacuum. The barometer reading is 30.4 in. Hg. What is the pressure in the condenser in psia?

2.21 Examine the figure



Click on image for larger view

The barometer reads 740 mm Hg. Calcula~~te~~ tank pressure in psia.

2.22 (a) An orifice is used to measure the flow rate of a gas through a pipe as shown in Fig. 2.22. The pressure drop across the orifice is measured with a mercury manometer, both legs of which are constructed of $\frac{1}{4}$ - in. inner diameter (ID) glass tubing. If the pressure drop across the orifice is equivalent to 4.65 in. Hg, calculate h_2 and h_3 (both in inches) if h_1 is equal to 13.50 in.

(b) The right glass leg of the manometer in Fig. P1.6D becomes corroded and is replaced with glass tubing which is $\frac{3}{8}$ - in. ID. The manometer is again filled with a sufficient volume of mercury. For the same pressure drop as in part (a), calculate h_2 and h_3 (both in inches).

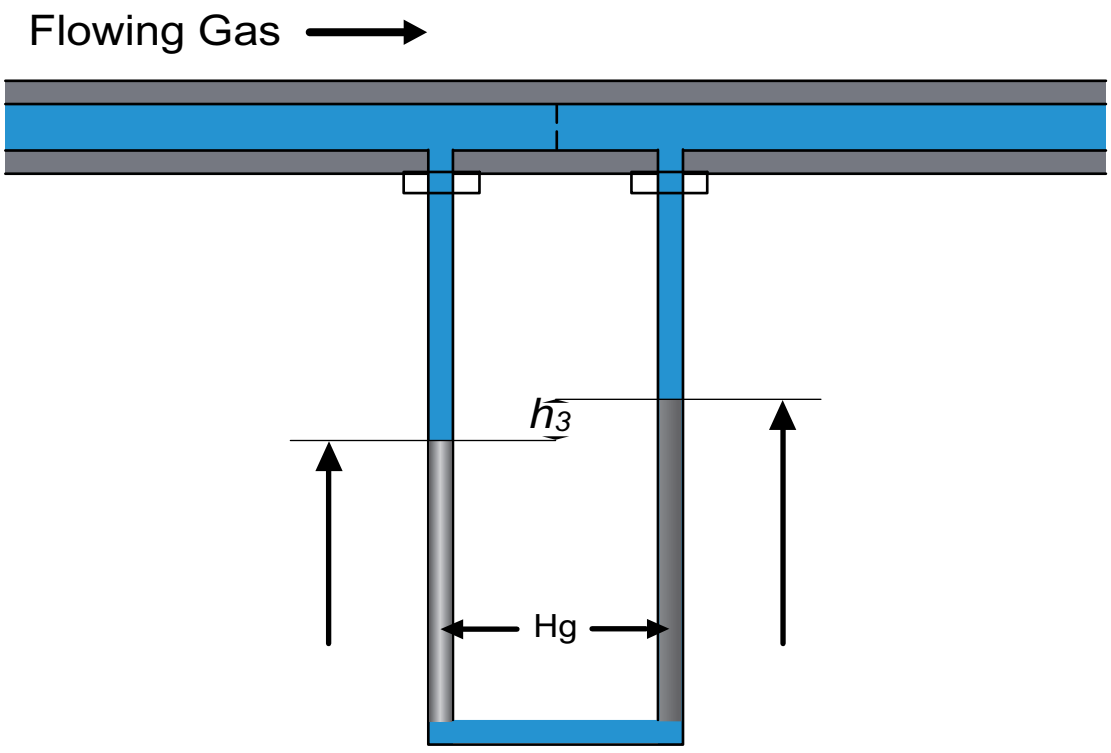


Figure 2.22

Click on image for animation