Chapter 4 – Answer Key, Introduction to Chemical Engineering: Tools for Today and Tomorrow

Reading Question 4.1:

Numerical value: 94,000
Basic dimensions: length is explicitly represented. The derived unit of force also includes the basic dimensions of mass, time, and length.
Base units: kg, m, s
Derived units: Newton (N) which is used to describe force

Reading Question 4.2:

a) Individuals working in multiple countries (e.g. sales or international companies) will need to be fluent in both sets of units.

b) Use of multiple systems of units has a negative impact on the trade of equipment and other items which may be unit specific.

c) Other responses are also possible.

Reading Question 4.3:

3.2 cm is equal to 0.032 meters.

Reading Question 4.4:

a. w_f is the "work of friction per mass of fluid" with dimensions of *energy/mass*

b. 1 *Btu* = 1055.0 *J*

c. $1\ lb_f \equiv 32.174\ lb_m ft/s^2$

d. Tungsten: symbol: W, atomic weight: 183.86

Reading Question 4.5:

Mass is a measure of the amount of matter. Therefore, the mass of the astronaut is the same on the distant planet as it is on earth. Weight is a type of force equal to the mass times the acceleration of gravity $W=mg$. Since the mass of the astronaut remains the same and the weight of the astronaut on the distant planet is 1/5 of his/her weight on earth, the acceleration of gravity on the distant planet must be 1/5 of that on earth.

Reading Question 4.6:

It appears that your colleague used the inverse of the correct conversion factor as follows:

$$36\,\text{min}\left(\frac{\text{min}}{60\,\text{sec}}\right) = 0.6\ \ \text{min}^2/\text{sec}$$

The correct answer is:

$$36\,\text{min}\left(\frac{60\,\text{sec}}{\text{min}}\right) = 2160\,\text{sec}$$

Reading Question 4.7:

As shown on p. 50 of the text, $\rho_{H2O} = 1000\,\text{kg/m}^3$ and $\rho_{air} = 1.2\,\text{kg/m}^3$. The ratio of the two is approximately 1000.

Reading Question 4.8:

The one with the lower molecular weight.

Reading Question 4.9:

The one with the low density.

Reading Question 4.10:

The one with the high molecular weight.

Reading Question 4.11:

a. Solution 2 has a lower density (mass/vol) and therefore the greater volume.

b. Since the volume is the same and solution 1 has a higher concentration of A (moles A/vol), there are more molecules of species A in 1 gallon of solution 1.

c. For the same volumetric flow rate:
   i) Solution 1 has the greater mass flow rate since it has the greater density
   ii) Solution 1 has the greater concentration of A (moles A/vol) and therefore the greater molar flow rate of A
   iii) Solution 1 has the greater molar flow rate of A and therefore must have the greater mass flow rate of A

Reading Question 4.12:

a. The mass of salt remains constant and the mass of water increases; therefore x_{salt} must decrease.

b. The addition of water causes the overall volume (V) to increase.

c. The amount of salt remains constant and the volume increases; therefore, c_{salt} must decrease.

d. No salt is added or taken away; therefore, the mass of salt (m_{salt}) remains constant.

Reading Question 4.13:

a. The density, ρ (mass/vol) is not a function of the flow rate and does not change.

b. The concentration of NaOH (moles NaOH/vol) does not change when the mass flow rate of the stream is increased since the concentration is not a function of the flow rate.

c. Since the composition of the stream remains the same and the mass flow rate of the stream is increased, the mass flow rate of the NaOH ($\dot{m}_{NaOH}$) must also increase.

d. Changing the mass flow rate does not change the relative amounts of NaOH and water. Therefore, the mole fraction of NaOH (y_{NaOH}) remains the same.

e. Since the mass flow rate increased, the molar flow rate must also increase since the two flow rates are related by a constant.

f. The density remains constant and the mass flow rate is increased. Since $\dot{m} = \rho\dot{V}$, the volumetric flow rate $\dot{V}$ must also increase.

g. The molecular weight is a physical constant relating the mass to the number of moles. It is not a function of the mass flow rate and therefore remains constant.

Homework Problem 4.1:

a. $\left(3.9\frac{cm}{s}\right)\left(3600\frac{s}{hr}\right)\left(\frac{1\,in}{2.54\,cm}\right)\left(\frac{1\,ft}{12\,in}\right)\left(\frac{1\,mi}{5280\,ft}\right)=0.087\frac{mi}{hr}$

b. $\left(177\frac{lb_m\,ft}{min^2}\right)\left(\frac{1 min}{60 s}\right)^2\left(\frac{1\,kg}{2.2\,lb_m}\right)\left(\frac{12\,in}{ft}\right)\left(\frac{2.54\,cm}{in}\right)=0.681\frac{kg\,cm}{s^2}$

c. $47\,ft^3\left(\frac{7.4805\,gal}{ft^3}\right)=352\,gal$

Homework Problem 4.2:

a. $$\left(1000\frac{kg}{m^3}\right)\left(\frac{1000g}{kg}\right)\left(\frac{1m}{100cm}\right)^3=1\frac{g}{cm^3}$$

b. $$\left(1000\frac{kg}{m^3}\right)\left(\frac{2.2046\ lb_m}{kg}\right)\left(\frac{.3048m}{ft}\right)^3=62.4\frac{lb_m}{ft^3}$$

c. $$\left(1000\frac{kg}{m^3}\right)\left(\frac{1000\ g}{kg}\right)\left(\frac{1\ gmol}{18\ g}\right)\left(\frac{1\ m^3}{1000\ L}\right)=55.6\frac{gmol}{L}$$

Homework Problem 4.3:

Given: $x_{N_2} = 0.7, x_{O_2} = 0.14, x_{CO} = 0.04, x_{CO_2} = 0.12$

From the atomic weights given at the front of the book:

$MW_{N_2} = 2(14.01) = 28.02$

$MW_{O_2} = 2(16.00) = 32.00$

$MW_{CO} = 12.01 + 16.00 = 28.01$

$MW_{CO_2} = 12.01 + 2(16.00) = 44.01$

Selecting a basis of 100 *g*,

$$n_{N_2} = \frac{x_{N_2} m_{total}}{MW_{N_2}} = \frac{(0.7)(100\,g)}{28.02\,g/gmol} = 2.50\ gmol$$

$$n_{O_2} = \frac{x_{O_2} m_{total}}{MW_{O_2}} = \frac{(0.14)(100\,g)}{32.00\,g/gmol} = .438\ gmol$$

$$n_{CO} = \frac{x_{CO} m_{total}}{MW_{CO}} = \frac{(0.04)(100\,g)}{28.01\,g/gmol} = .143\ gmol$$

$$n_{CO_2} = \frac{x_{CO_2} m_{total}}{MW_{CO_2}} = \frac{(0.12)(100\,g)}{44.01\,g/gmol} = .273\ gmol$$

Total = 3.354 *gmol*

mole fraction of N_2 = 2.50 *gmol* N_2/3.354 total gmol = 0.745 = 74.5%

mole fraction of O_2 = 0.438 *gmol* O_2/3.354 total gmol = 0.131 = 13.1%

mole fraction of CO = 0.143 *gmol* CO/3.354 total gmol = 0.043 = 4.3%

mole fraction of CO_2 = 0.273 *gmol* CO_2/3.354 total gmol = 0.081 = 8.1%

Homework Problem 4.4:

Given: $\dot{V}_{solution} = 100\ L/min$, $\rho_{solution} = 1.34\ g/cm^3$, $c_{H_2SO_4} = 6M = 6\ gmol/L$

a. $MW_{H_2SO_4} = 2(1.01) + 32.07 + 4(16.00) = 98.09$

b. $\dot{n}_{H_2SO_4} = c_{H_2SO_4}\dot{V}_{solution} = \left(6\dfrac{gmol}{L}\right)\left(100\dfrac{L}{\min}\right) = 600\ gmol/min$

c. $\dot{m}_{H_2SO_4} = MW_{H_2SO_4}c_{H_2SO_4}\dot{V}_{solution} = \left(98.09\dfrac{g}{gmol}\right)\left(6\dfrac{gmol}{L}\right)\left(100\dfrac{L}{\min}\right) = 58{,}900\ g/min$

d. $\dot{m}_{solution} = \rho_{solution}\dot{V}_{solution} = \left(1.34\dfrac{g}{cm^3}\right)\left(100\dfrac{L}{\min}\right)\left(1000\dfrac{cm^3}{L}\right) = 134{,}000\ g/min$

Homework Problem 4.5:

Given: $\dot{m}_{stream} = 10{,}000\ lb_m/hr, x_{benzene} = 0.40$

$MW_{benzene} = 6(12.01) + 6(1.01) = 78.12$

$MW_{toluene} = 7(12.01) + 8(1.01) = 92.15$

a. $\dot{m}_{benzene} = x_{benzene}\dot{m}_{stream} = (0.40)(10{,}000\ lb_m/hr) = 4{,}000\ lb_m/hr$

b. $x_{toluene} = 1 - x_{benzene} = 0.60$

$\dot{m}_{toluene} = x_{toluene}\dot{m}_{stream} = (0.60)(10{,}000\ lb_m/hr) = 6{,}000\ lb_m/hr$

c. $\dot{n}_{toluene} = \dfrac{\dot{m}_{toluene}}{MW_{toluene}} = \dfrac{6{,}000\ lb_m/hr}{92.15\ lb_m/lbmol} = 65.1\ lbmol/hr$

d. $\dot{n}_{benzene} = \dfrac{\dot{m}_{benzene}}{MW_{benzene}} = \dfrac{4{,}000\ lb_m/hr}{78.12\ lb_m/lbmol} = 51.2\ lbmol/hr$

$\dot{n}_{total} = \dot{n}_{benzene} + \dot{n}_{toluene} = 51.2 + 65.1 = 116.3\ lbmol/hr$

e. $y_{benzene} = \dfrac{\dot{n}_{benzene}}{\dot{n}_{total}} = \dfrac{51.2\ lbmol/hr}{116.3\ lbmol/hr} = 0.44$

Homework Problem 4.6:

Given: $y_{H_2SO_4} = 0.001, y_{O_2} = 0.202, y_{N_2} = 0.779, y_{H_2O} = 0.018$

$$MW_{H_2SO_4} = 2(1.01) + 32.07 + 4(16.00) = 98.09$$

$$MW_{O_2} = 2(16.00) = 32.00$$

$$MW_{N_2} = 2(14.01) = 28.02$$

$$MW_{H_2O} = 2(1.01) + 16.00 = 18.02$$

Selecting a basis of 100 *gmol*,

$$m_{H_2SO_4} = MW_{H_2SO_4} y_{H_2SO_4} n_{total} = (98.09\ g/gmol)(0.001)(100\ gmol) = 9.81\ g$$

$$m_{O_2} = MW_{O_2} y_{O_2} n_{total} = (32.00\ g/gmol)(0.202)(100\ gmol) = 646.4\ g$$

$$m_{N_2} = MW_{N_2} y_{N_2} n_{total} = (28.02\ g/gmol)(0.779)(100\ gmol) = 2182.8\ g$$

$$m_{H_2O} = MW_{H_2O} y_{H_2O} n_{total} = (18.02\ g/gmol)(0.018)(100\ gmol) = 32.4\ g$$

Total mass = 2871.4 g

mass fraction of H_2SO_4 =

$$x_{H_2SO_4} = \left(\frac{9.8\ g\ H_2SO_4}{2871.4\ g\ "air"}\right)\left(\frac{28.35\ g}{oz}\right)\left(\frac{16\ oz}{lb_m}\right)\left(\frac{2000\ lb_m}{ton}\right) = 3096\ g\ H_2SO_4/ton\ "air"$$

Homework Problem 4.7:

a. each of the terms being added (i.e. x/y, ab, and z) must have the same units.

$$\frac{x}{y} \; [=] \; \frac{g/s}{cm} \; [=] \; \frac{g}{cm\ s}$$

$$ab \; [=] \; (g/s)cm \; [=] \; \frac{g\ cm}{s}$$

$$z \; [=] \; \frac{g}{cm\ s}$$

Since the dimensions of the second term don't match those of the others, this expression is not dimensionally consistent

b. The group of terms in the exponent must be dimensionless

$$b\left[\frac{z}{x-a}+\frac{1}{y}\right] \; [=] \; cm\left[\frac{g/cm\,s}{g/s}+\frac{1}{cm}\right] \; [=] \; cm\left[\frac{1}{cm}+\frac{1}{cm}\right] \; [=] \; \text{dimensionless}$$

So, this expression satisfies dimensional consistency

Homework Problem 4.8:

$(P_{beneath} - P_{top})\ Area_{piston\ cross\ section} = mg$

Solving for m,

$$m = \frac{(P_b - P_t)A}{g}$$

substituting values and including appropriate conversion factors

$$m = \frac{\left(58.6\frac{lb_f}{in^2} - 14.7\frac{lb_f}{in^2}\right)0.074\,ft^2}{32.2\frac{ft}{s^2}}\left(\frac{144\ in^2}{ft^2}\right)\left(\frac{32.2\ lb_m ft}{s^2 lb_f}\right) = 468\ lb_m$$

Homework Problem 4.9:

Again, the terms being added $\left(\dfrac{P_s - P_e}{\rho},\ \dfrac{1}{2}\alpha(v_s^2 - v_e^2), \text{ and } g(z_s - z_e)\right)$ must have the same units (which can happen if they have the same dimensions)

American engineering system

Displaying a representative set of units, along with appropriate conversion factors:

$$\frac{P_s - P_e}{\rho} \;[=]\; \frac{lb_f \big/ in^2}{lb_m \big/ ft^3}\left(\frac{32.2\ lb_m ft}{s^2 lb_f}\right)\left(\frac{144\ in^2}{ft^2}\right) \;[=]\; \frac{ft^2}{s^2}$$

$$\frac{1}{2}\alpha(v_s^2 - v_e^2) \;[=]\; \left(\frac{ft}{s}\right)^2 \;[=]\; \frac{ft^2}{s^2}$$

$$g(z_s - z_e) \;[=]\; \frac{ft}{s^2}\cdot ft \;[=]\; \frac{ft^2}{s^2}$$

Metric system

Recognizing that the units of pressure are $N/m^2 = kg/m\ s^2$:

$$\frac{P_s - P_e}{\rho} \;[=]\; \frac{kg\ m \big/ s^2}{kg \big/ m^3} \;[=]\; \frac{m^2}{s^2}$$

$$\frac{1}{2}\alpha(v_s^2 - v_e^2) \;[=]\; \left(\frac{m}{s}\right)^2 \;[=]\; \frac{m^2}{s^2}$$

$$g(z_s - z_e) \;[=]\; \frac{m}{s^2}\cdot m \;[=]\; \frac{m^2}{s^2}$$