Lecture 5

Flow Rate

For continuous processes the flow rate of a process stream is the rate at which material is transported through a pipe. The mass flow rate(m) of a process stream is the mass(m) transported through a line per unit time(t).

$$\dot{m} = \frac{m}{t}$$

The volumetric flow rate (F) of a process stream is the volume (V) transported through a line per unit time.

$$F = \frac{V}{t}$$

The molar flow (n) rate of a process stream is the number of moles (n) of a substance transported through a line per unit time.

$$\dot{n} = \frac{n}{t}$$

Mole Fraction and Mass (Weight) Fraction

Mole fraction is simply the number of moles of a particular compound in a mixture or solution divided by the total number of moles in the mixture or solution.

- ❖ This definition holds for gases, liquids, and solids.
- ❖ Similarly, the mass fraction is nothing more than the mass of the compound divided by the total mass of all of the compounds in the mixture or solution.

Mathematically, these ideas can be expressed as**:**

$$\text{mole fraction of A} = \frac{\text{moles of A}}{\text{total moles}}$$

$$\text{mass fraction of A} = \frac{\text{mass of A}}{\text{total mass}}$$

Mole percent and mass percent are the respective fractions times 100.

Example 12

An industrial-strength drain cleaner contains 5 kg of water and 5 kg of NaOH. What are the masm fractions and mole fractions of each component in the drain cleaner container?

Solution

component	kg	Mass fraction	Mol. Wt.	kmol	Mole fraction
H_2O	5	5/10 = 0.5	18	0.278	0.278/0.403 = 0.69
NaOH	5	5/10 = 0.5	40	0.125	0.125/0.403 = 0.31
Total	10	1		0.403	1

Analyses of Multi Components Solutions and Mixtures

The composition of gases will always be presumed to be given in mole percent or fraction unless specifically stated otherwise.

The composition of liquids and solids will be given by mass percent or fraction unless otherwise specifically stated.

For Example Table below lists the detailed composition of dry air (composition of air 21% O_2 and 79% N_2).

Basis 100 mol of air

component	Moles	Mol. wt.	lb or kg	Mass %
O_2	21	32	672	23.17
N_2	79	28.2	2228	76.83
Total	100		2900	100
The average molecular weight is 2900 lb/100 lb mol = 29				

Concentration

Concentration generally refers to the quantity of some substance per unit volume.

a. Mass per unit volume : lb of solute/ft^3 of solution,
g of solute/L,
lb of solute/barrel,
kg of solute/m^3 .

b. Moles per unit volume : lb mol of solute/ft^{3}of solution,
g mol of solute/L,
g mol of solute/cm^3 .

c. Parts per million **(ppm)**; parts per billion **(ppb**), a method of expressing the concentration of extremely dilute solutions;

ppm is equivalent to a mass fraction for solids and liquids because the total amount of material is of a much higher order of magnitude than the amount of solute; **it is a mole fraction for gases**.

d. Parts per million by volume (ppmv) and parts per billion by volume (ppbv)

e. Other methods of expressing concentration with which you may be familiar are molarity (g mol/L), molality (mole solute/kg solvent), and normality (equivalents/L).

Example 13

The current OSHA 8-hour limit for HCN (MW = 27.03) in air is 10.0 ppm. A lethal dose of HCN in air is 300 mg/kg of air at room temperature. How many mg HCN/kg air is 10.0 ppm? What fraction of the lethal dose is 10.0 ppm?

Solution

Basis: 1 kmol of the air/HCN mixture

$$\text{The 10 ppm} = \frac{10\text{ mol HCN}}{10^6(\text{air+HCN})\text{mol}} = \frac{10\text{ mol HCN}}{10^6\text{ mol air}}$$

A. $\frac{10\text{ mol HCN}}{10^6\text{mol air}} \Big| \frac{27.03\text{ g HCN}}{1\text{ mol HCN}} \Big| \frac{1\text{ mol air}}{29\text{ g air}} \Big| \frac{1000\text{ mg HCN}}{1\text{ g HCN}} \Big| \frac{1000\text{ g air}}{1\text{ kg air}}$

= 9.32 mg HCN/kg air

B. $\frac{9.32}{300} = 0.031$

Example 14

A solution of KOH has a specific gravity of 1.0824 at 15°C. The concentration of the KOH is 0.813 lb/gal of solution. What are the mass fractions of KOH and H_2O in the solution?

Solution

Basis: 1 gal of solution

Mass of solution:

$$\frac{1.0824\,\frac{\text{lb solution}}{\text{ft}^3}}{1\,\frac{\text{lb H2O}}{\text{ft}^3}} \Big| 62.4\ \frac{\text{lb H2O}}{\text{ft}^3} \Big| \frac{1\text{ ft}^3}{7.481\text{ gal}} \Big| 1\text{ gal} = 9.03\ \text{lb solution}$$

$$\text{mass fraction KOH} = \frac{0.813}{9.03} = 0.09$$

$$\text{mass fraction H}_2\text{O} = 1 - 0.09 = 0.91$$

Example 15

To avoid the possibility of explosion in a vessel containing gas having the composition of 40% N_2, 45% O_2, and 15% CH_4, the recommendation is to dilute the gas mixture by adding an equal amount of pure N_2. What is the final mole fraction of each gas?

Solution

The basis is 100 moles of initial gas

Composition	Original mixture mol%	After addition N_2	Final mixture mole fraction
N_2	40	140	140/200 = 0.7
O_2	45	45	45/200 = 0.23
CH_4	15	15	15/200 = 0.07
Total	100	200	1

Problems

1. Convert the following:

a) 120 g mol of NaCl to g.

b) 120 g of NaCl to g mol.

c) 120 lb mol of NaCl to lb.

d) 120 lb of NaCl to lb mol.

2. Convert 39.8 kg of NaCl per 100 kg of water to kg mol of NaCl per kg mol of water.

3. How many lb mol of $NaNO_3$ are there in 100 lb?

4. The density of a material is 2 kg/m^3. What is its specific volume?

5. An empty 10 gal tank weighs 4.5 lb. What is the total weight of the tank plus the water when it is filled with 5 gal of water?

6. For ethanol, a handbook gives: sp. gr. 60°F = 0.79389. What is the density of ethanol at 60°F?

8. The specific gravity of steel is 7.9. What is the volume in cubic feet of a steel ingot weighing 4000 lb?

9. The specific gravity of a solution is 0.80 at 70°F. How many cubic feet will be occupied by 100 lb of the solution at 70°F?

10. A solution in water contains 1.704 kg of HNO_3/kg H_2O, and the solution has a specific gravity of 1.382 at 20°C. What is the mass of HNO_3 in kg per cubic meter of solution at 20°C?

11. Forty gal/min of a hydrocarbon fuel having a specific gravity of 0.91 flows into a tank truck with a load limit of 40,000 lb of fuel. How long will it take to fill the tank in the truck?

12. Pure chlorine enters a process. By measurement it is found that 2.4 kg of chlorine pass into the process every 3.1 minutes. Calculate the molar flow rate of the chlorine in kg mol/hr.

13. Commercial sulfuric acid is 98% H_2SO_4 and 2% H_2O. What is the mole ratio of H_2SO_4 to H_2O?

14. A compound contains 50% sulfur and 50% oxygen by mass. Is the empirical formula of the compound (1) SO, (2) SO2, (3) SO3, or (4) SO4?

15. How many kg of activated carbon (a substance used in removing trace impurities) must be mixed with 38 kg of sand so that the final mixture is 28% activated carbon?

16. A gas mixture contains 40 lb of O_2, 25 lb of SO_2, and 30 lb of SO_3. What is the composition of the mixture in mole fractions?

17. 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% and N_2 44.8%. How much will 3 lb mol of this gas weigh?

18. A liquefied mixture of n-butane, n-pentane, and n-hexane has the following composition: n-C_4H_{10} 50%, n-C_5H_{12} 30%, and n-C_6H_{14} 20%. For this mixture, calculate:

a) The weight fraction of each component.

b) The mole fraction of each component.

c) The mole percent of each component.

d) The average molecular weight of the mixture.

19. How many mg/L is equivalent to a 1.2% solution of a substance in water?