Processes and Process Variables - CHAPTER 3

As a Chem E, during your career, you may be asked to design or operate a chemical process.

In order to do this effectively, you need to be very familiar with several definitions, concepts, and variables that characterize both individual process units and large processes comprised of numerous process units.

Mass and Volume

One of these quantities may be determined from the other in you know the density of the material.

$$\Rightarrow \text{Density} = \frac{\text{Mass}}{\text{Volume}} = \rho$$

$$\text{Mass} = \rho(\text{Volume}) \quad \& \quad \text{Volume} = \frac{\text{Mass}}{\rho}$$

Densities of pure solids & liquids are essentially independent of pressure and vary only slightly with temperature.

Specific Gravity

This quantity is the ratio of a substance's density to the density of a reference substance at a specific condition.

$$S.G. = \rho / \rho_{ref}$$

The most common reference density for solids and liquids is water @ 4°C.

$$\rho_{H_2O}(4°C) = 1.000 \ g/cm^3$$
$$= 1000. \ kg/m^3$$
$$= 62.43 \ lb_m/ft^3$$

So, if you are given a substance's specific gravity, to determine its density in any units, you need only multiply it by the reference density in those units.

<u>Example</u>: S.G. = 2.00

$$\rho = 2.00 \ gm/cm^3$$
$$= 2000 \ kg/m^3$$
$$= 125 \ lb_m/ft^3$$

NOTE: Specific gravity may also be reported in the following form:

$$S.G. = 0.6 \frac{20°}{4°}$$

This means the specific gravity of the substance at 20°C with reference to water at 4°C is 0.6.

Flow Rate

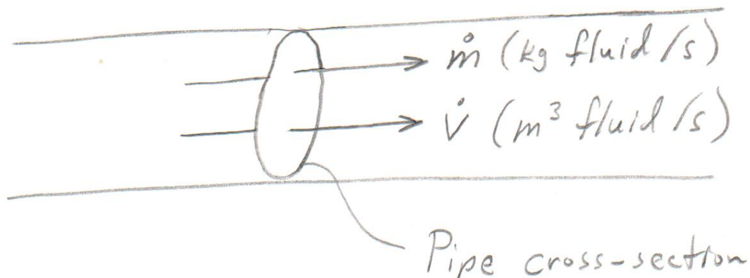
The rate at which material is transported in a pipe through a process is called the material's flow rate.

Flow rate can be expressed as:

Mass Flow rate (mass / time)

or

Volumetric Flow Rate (volume / time)



⇒ If the mass flow rate is reported as $\dot{m}$ (kg fluid / s), then every second, m kg fluid pass thru the above cross-section.

⇒ If the volumetric flow rate is reported as $\dot{V}$ (m^3 fluid / s), then every second, V m^3 of fluid pass thru the above cross-section.

In both cases, the mass and volume of the fluid that passes through each second are related by the fluid's density.

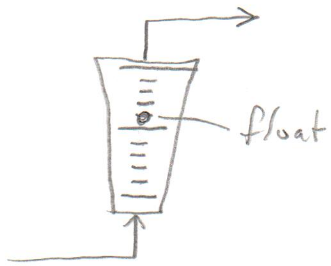
$$\rho = m/V = \dot{m}/\dot{V}$$ ← Flowrates are related by fluid density.

Flow Rate Measurement

Volumetric flow rates are cheaper to measure while mass flowrates are required for many process calculations.

Two methods of measuring volumetric flow rate are with a rotameter or orifice meter.

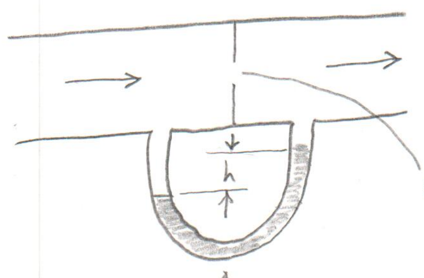
Rotameter



More flow raises the float higher in the vertical tapered tube.

Orifice Meter

The orifice causes the pressure to decrease from the upstream-side to the downstream-side.



Orifice Meter (A restriction in the pipe)

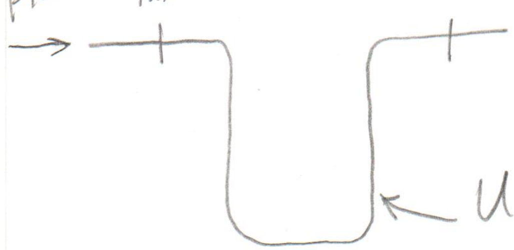
I'll discuss how these operate later.

Differential Manometer (Measures the pressure decrease or pressure drop across the orifice.)

The greater the flowrate, the larger the pressure drop.

MicroMotion Mass Flow Meters

⟹ Measures true mass flow by the Coriolis Principle



U-tube is vibrated like a tuning fork

Displacement rate of tube is related to the fluid velocity.

Look in the Chem E Equipment Encyclopedia for details of other types of mass flow meters.

Density of a Mixture

For this class, we will assume no volume change upon mixing.

∴ For a binary (Components A & B):

$$\rho_{mix} = \frac{m_A + m_B}{V_A + V_B}$$

⇒ In reality, there is volume change upon mixing & this will addressed in detail in Thermo II (or at the end of Thermo I).

Chemical Composition

Most materials in chemical processes are mixtures of various species. Mixture properties are strong functions of their composition.

Chemical composition can be reported in a number of ways.

Let's start by defining a few terms:

Atomic Weight – Mass of an atom on a scale that assigns ^{12}C a mass of exactly 12.

Molecular Weight – Sum of the atomic weights of atoms that constitute a molecule.

$$M.W.\ O_2 \cong (16)(2) = 32$$

↑ Atomic wt of Oxygen

gmole (or mol in SI units) – Amount of a species whose mass, in grams, is numerically equal to its molecular weight. (e.g. there are 32 gm O_2/gmole O_2)

NOTE: Other types of moles (i.e. lbmoles, kgmoles, etc.) are similarly defined.

⇒ The molecular weight of a substance can be used as a conversion factor relating the amount of substance mass to it's number of moles.

Q1: How many kmoles of ammonia are in 34 kgs of NH_3?

A1:

$$\frac{34 \text{ kgs } NH_3 \,|\, \text{kmole } NH_3}{|\, 17 \text{ kgs } NH_3} = 2.0 \text{ kmoles } NH_3$$

Q2: How many lb_m are in 4 lbmoles NH_3?

A2:

$$\frac{4 \text{ lbmoles } NH_3 \;\Big|\; 17 \text{ lb}_m\ NH_3}{\;\Big|\; \text{lbmole } NH_3} = 68 \text{ lb}_m\ NH_3$$

Important Points

1. The same conversion factors used to convert mass may be used to convert the equivalent molar units.

$$\frac{1 \text{ lbmole } NH_3 \;\Big|\; (17)\ \text{lb}_m\ NH_3 \;\Big|\; 454 \text{ g } NH_3 \;\Big|\; \text{gmole } NH_3}{\;\Big|\; \text{lbmole } NH_3 \;\Big|\; \text{lb}_m\ NH_3 \;\Big|\; (17)\text{ g } NH_3} = 454 \text{ gmole } NH_3$$

These MW's cancel (their units don't)

2. ONLY 1 gmole of any species contains 6.02×10^{23} molecules of that species.

Mass & Mole Fractions and Average MW

A mixture composition is typically either reported in mass or mole fractions of the species contained in the mixture.

For species A in a mixture:

Mass fraction of A, $x_A = \dfrac{\text{mass of A}}{\text{total mass}}$ $\left(\text{i.e. } \dfrac{\text{g A}}{\text{total g}} \text{ or } \dfrac{\text{kg A}}{\text{total kg}} \text{ etc.}\right)$

Mole fraction of A, $y_A = \dfrac{\text{moles of A}}{\text{total moles}}$ $\left(\text{i.e. } \dfrac{\text{gmole A}}{\text{total gmole}} \text{ or } \dfrac{\text{lbmole A}}{\text{total lbmole}}, \text{ etc.}\right)$

% by mass of A $= 100 x_A$ mole % of A $= 100 y_A$