# Volume, Density, Flow Rate

E82 – Basic Process Variables

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## Mass Density and Molar Density

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The mass density, or usually just density, is a measure of the mass per volume, with SI units of kg/m$^3$.
The reciprocal is the specific volume, with SI units of m$^3$/kg.

$$\rho = \frac{m}{V} = \frac{1}{\hat{V}} \qquad \hat{V} = \frac{V}{m} = \frac{1}{\rho}$$

The molar density is a measure of the number of moles per volume, with SI units of g-mol/m$^3$. It has the same units as concentration.
The reciprocal is the molar volume, with SI units of m$^3$/g-mol.
F,R,&B reuse the symbols for density and specific volume for these.

$$\rho = \frac{n}{V} = \frac{1}{\hat{V}} \qquad \hat{V} = \frac{V}{n} = \frac{1}{\rho}$$

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## Specific Gravity

The specific gravity is the ratio of the density to a reference density.

$$\text{SG} = \frac{\rho}{\rho_{\text{ref}}}$$

The most common reference density is liquid water at 4°C.

$$\rho_{\text{H}_2\text{O}(l)}(4^\circ\text{C}) = 1000\ \text{kg/m}^3$$
$$= 1.000\ \text{g/cm}^3$$
$$= 62.43\ \text{lb}_\text{m}\ /\ \text{ft}^3$$

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## Concentration

The *molar concentration* or simply *concentration* is the number of moles per unit volume.

$$C_\text{A} = \frac{n_\text{A}}{V}$$

For an ideal gas it can be calculated as:

$$C_\text{A} = \frac{n_\text{A}}{V} = \frac{p_A}{RT}$$

The *mass concentration* is the mass per unit volume (same units as density). It is most often used for quantities such as salinity.

$$C_\text{A} = \frac{m_\text{A}}{V}$$

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## Mass, Molar, and Volumetric Flow Rates

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The *mass flow rate* is simply the amount of mass flowing past a given location in a period of time. For open, steady-state systems, the sum of the mass flow rates in equals the sum of the mass flow rates out.

$$\sum \dot{m}_{i_{\text{in}}} = \sum \dot{m}_{i_{\text{out}}} \qquad \text{(open, steady state)}$$

The *molar flow rate* is number of moles flowing past a given location in a period of time. For open, steady-state systems *with no reactions*, the sum of the molar flow rates in equals the sum of the molar flow rates out. For reacting systems, it is in general, not true.

$$\sum \dot{n}_{i_{\text{in}}} = \sum \dot{n}_{i_{\text{out}}} \qquad \text{(open, steady state, no reaction)}$$

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## Mass, Molar, and Volumetric Flow Rates (cont.)

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The *volumetric flow rate* is the volume of fluid flowing past a given location in a period of time. In general, for open, steady-state systems, the sum of the volumetric flow rates in is *not* equal to the sum of the volumetric flow rates out.

$$\sum \dot{V}_{i_{\text{in}}} \neq \sum \dot{V}_{i_{\text{out}}} \qquad \text{(in general for open, steady state)}$$

The following relationship exists among the volumetric flow rate of a fluid, the average fluid velocity, and the cross-sectional area of the flow.

$$\dot{V} = uA$$

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**Mass, Molar, and Volumetric Flow Rates (cont.)**

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The relationship between the mass flow rate and the volumetric flow rate is:

$$\dot{m} = \dot{V}\rho$$

For an open, steady-state system with one inlet and one outlet.

$$\dot{V}_{\text{in}}\rho_{\text{in}} = \dot{V}_{\text{out}}\rho_{\text{out}}$$

Do not forget! Volume is *not* a conserved quantity. Just because the mass or molar flowrate is constant, it *does not* follow that the volumetric flow rate is constant.