Liquid and Solid Densities

E82 – Variations with Temperature and Composition

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Variations with Temperature and Pressure

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For most purposes solids and liquids are treated as incompressible, meaning the density is not a function of pressure. They are also regarded as having a low coefficient of thermal expansion, so variations of density with temperature are often ignored. However, it is not always safe to do so. Designing a liquid thermometer is impossible without a knowledge of how the density changes with temperature. From thermodynamics we have the volume expansivity

$$\beta \equiv \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P$$

and the isothermal compressibility

$$\kappa \equiv -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T$$

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Variations with Temperature and Pressure (cont.)

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Values for these come from experimental data, handbooks and tables, and equations of state. The website *The Engineering Toolbox* has some tables of values.

In Advanced Engineering Thermodynamics, E134, we will discuss these issues as well as partial molar volume, which is a method for calculating molar volumes for liquid mixtures.

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Density of Mixtures of Liquids and Solids

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For ideal mixtures (the attraction between like molecules is essentially the same as between unlike molecules) the density of a mixture can be calculated with volume additivity

$$\hat{V}_{\text{mix}} = \sum_{i=1}^{n} x_i \hat{V}_i$$

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

$$\frac{1}{\rho_{\text{mix}}} = \sum_{i=1}^{n} \frac{x_i}{\rho_i}$$

For a binary.

$$\frac{1}{\rho_{\text{mix}}} = \frac{x_1}{\rho_1} + \frac{1 - x_1}{\rho_2}$$

$$\rho_{\text{mix}} = \frac{\rho_1 \rho_2}{\left(1 - x_1\right)\rho_1 + x_1 \rho_2}$$

Mixtures of aliphatic hydrocarbons are often close to ideal.

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Density of Mixtures of Liquids and Solids (cont.)

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Lacking any better information, you can use a density average

$$\rho_{\text{mix}} = \sum_{i=1}^{n} x_i \rho_i$$

It would be really nice if the true values were bracketed by volume additivity and density average, but values can be way outside these two formulas. See ethanol and water on the next slide.

Experimental data, handbooks and tables, and equations of state are always your best bet if you can find them.

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Example of Ethanol and Water

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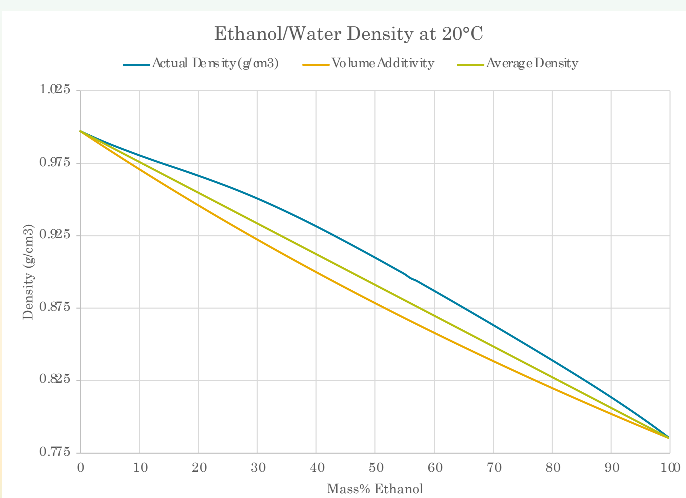

Volume Additivity

$$\rho_{\text{mix}} = \frac{\rho_1 \rho_2}{\left(1 - x_1\right)\rho_1 + x_1 \rho_2}$$

Density Average

$$\rho_{\text{mix}} = x_1 \rho_1 + \left(1 - x_1\right)\rho_2$$

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