SOLUTION

1. $$C_{H_2SO_4}\left(\frac{\text{kg } H_2SO_4}{\text{m}^3}\right) = \frac{0.50 \text{ mol } H_2SO_4}{\text{L}} \bigg| \frac{98 \text{ g}}{\text{mol}} \bigg| \frac{1 \text{ kg}}{10^3 \text{ g}} \bigg| \frac{10^3 \text{ L}}{1 \text{ m}^3} = \boxed{49 \frac{\text{kg } H_2SO_4}{\text{m}^3}}$$

2. $$\dot{m}_{H_2SO_4}\left(\frac{\text{kg } H_2SO_4}{\text{s}}\right) = \frac{1.25 \text{ m}^3}{\text{min}} \bigg| \frac{49 \text{ kg } H_2SO_4}{\text{m}^3} \bigg| \frac{1 \text{ min}}{60 \text{ s}} = \boxed{1.0 \frac{\text{kg } H_2SO_4}{\text{s}}}$$

3. The mass fraction of H_2SO_4 equals the ratio of the mass flow rate of H_2SO_4—which we know—to the total mass flow rate, which can be calculated from the total volumetric flow rate and the solution density.

$$\rho_{\text{solution}} = (1.03)\left(\frac{1000 \text{ kg}}{\text{m}^3}\right) = 1030 \frac{\text{kg}}{\text{m}^3}$$

$$\Downarrow$$

$$\dot{m}_{\text{solution}}\left(\frac{\text{kg}}{\text{s}}\right) = \frac{1.25 \text{ m}^3 \text{ solution}}{\text{min}} \bigg| \frac{1030 \text{ kg}}{\text{m}^3 \text{ solution}} \bigg| \frac{1 \text{ min}}{60 \text{ s}} = 21.46 \frac{\text{kg}}{\text{s}}$$

$$\Downarrow$$

$$x_{H_2SO_4} = \frac{\dot{m}_{H_2SO_4}}{\dot{m}_{\text{solution}}} = \frac{1.0 \text{ kg } H_2SO_4/\text{s}}{21.46 \text{ kg solution/s}} = \boxed{0.048 \frac{\text{kg } H_2SO_4}{\text{kg solution}}}$$

CREATIVITY EXERCISE

Itemize as many ways as you can think of to measure the concentration of a solute in a solution. (*Example:* If the solute absorbs light of a specific wavelength, pass a beam of light of this wavelength through the solution and measure the fractional light absorption.)

3.3d Parts per Million and Parts per Billion

The units **parts per million (ppm)** and **parts per billion (ppb)**[3] are used to express the concentrations of *trace species* (species present in minute amounts) in mixtures of gases or liquids. The definitions may refer to mass ratios (usual for liquids) or mole ratios (usual for gases) and signify how many parts (grams, moles) of the species are present per million or billion parts (grams, moles) of the mixture. If y_i is the fraction of component i, then by definition

$$\text{ppm}_i = y_i \times 10^6 \tag{3.3-9}$$

$$\text{ppb}_i = y_i \times 10^9 \tag{3.3-10}$$

For example, suppose air in the vicinity of a power plant is said to contain 15 ppm SO_2 (15 parts per million sulfur dioxide). Assuming that a molar basis has been used (customary for gases), this statement means that every million moles of air contains 15 moles of SO_2, or equivalently, that the mole fraction of SO_2 in the air is 15×10^{-6}. Units such as ppm and ppb have become increasingly common in recent years as public concern about potentially hazardous trace species in the environment has grown.

[3]We are using the standard American definition of a billion as 10^9 or 1000 million, as opposed to the English definition of 10^{12}.