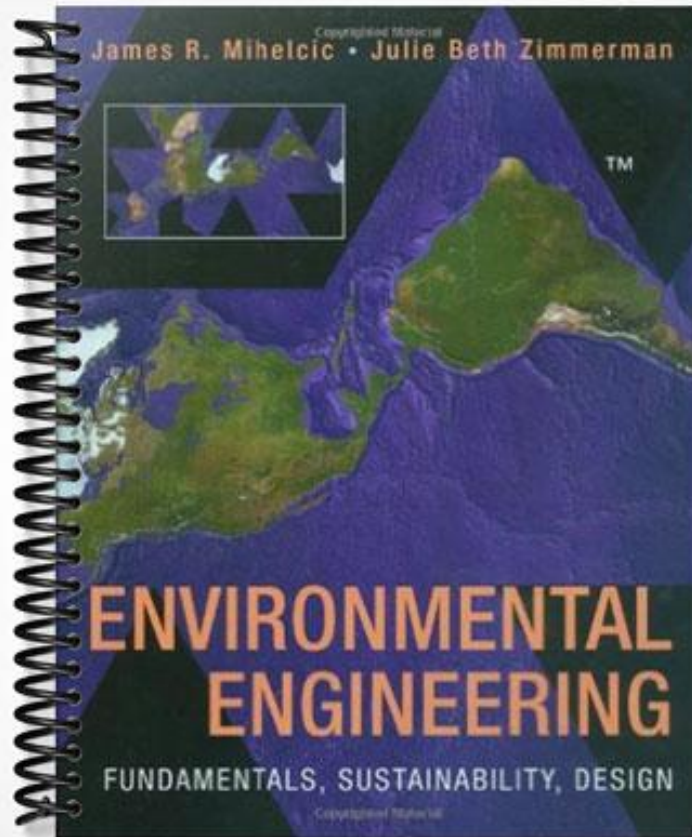


SOLUTIONS MANUAL



Chapter 2. Environmental Measurements

2-1. (a) During drinking water treatment, 17 lb. of chlorine (Cl) are added daily to disinfect 5 million gallons of water. What is the aqueous concentration of chlorine in mg/L? (b) The *chlorine demand* is the concentration of chlorine used during disinfection. The *chlorine residual* is the concentration of chlorine that remains after treatment so the water maintains its disinfecting power in the distribution system. If the residual concentration is 0.20 mg/L, what is the chlorine demand in mg/L?

Solution:

a) 17 lb. chlorine added to 5 million gallons of water. Chlorine dosage in mg/L:

$$\frac{17 \text{ lb} / \text{day}}{5 \times 10^6 \text{ gal} / \text{day}} \times \frac{454 \text{ g}}{1 \text{ lb}} \times \frac{1000 \text{ mg}}{1 \text{ g}} \times \frac{1 \text{ gal}}{3.78 \text{ L}} = \boxed{0.41 \text{ mg} / \text{L}}$$

b) Chlorine demand:

$$0.41 \text{ mg} / \text{L} - 0.20 \text{ mg} / \text{L} = \boxed{0.21 \text{ mg} / \text{L}}$$

2-2. A water sample contains 10 mg NO_3^-/L . What is the concentration in (a) ppm_m , (b) moles/L, (c) mg $\text{NO}_3^-/\text{N/L}$, and (d) ppb_m ?

Solution:

10 g NO_3^-/L in various units.

a) 1 L water = 1 kg water (in water, mg/L = ppm)

$$\frac{10 \text{ mg} / \text{L}}{1 \text{ kg} / \text{L}} = \boxed{10 \text{ ppm as } \text{NO}_3^-}$$

b) 62 grams $\text{NO}_3^- = 1 \text{ mole } \text{NO}_3^-$

$$\frac{10 \text{ mg}}{\text{L}} \times \frac{1 \text{ g}}{1,000 \text{ mg}} \times \frac{1 \text{ mole}}{62 \text{ g}} = \boxed{1.6 \times 10^{-4} \text{ moles } \text{NO}_3^- / \text{L}}$$

c) 62 grams $\text{NO}_3^- = 1 \text{ mole } \text{NO}_3^-$; 14 grams N = 1 mole N; 1 mole $\text{NO}_3^- = 1 \text{ mole N}$

$$\frac{10 \text{ mg } \text{NO}_3^-}{\text{L}} \times \frac{1 \text{ mole } \text{NO}_3^-}{62 \text{ g } \text{NO}_3^-} \times \frac{1 \text{ mole N}}{1 \text{ mole } \text{NO}_3^-} \times \frac{14 \text{ g N}}{1 \text{ mole N}} = \boxed{2.3 \text{ mg } \text{NO}_3^- \text{- N/L}}$$

d) 1 L water = 1 kg water; 1 kg = 10^6 mg; 1 billion = 10^3 million

$$\frac{10 \text{ mg} / \text{L}}{1 \text{ kg} / \text{L}} \times \frac{1000 \text{ million}}{1 \text{ billion}} = \boxed{10,000 \text{ ppb as } \text{NO}_3^-}$$

2-3. A liquid sample has a concentration of iron (Fe) of 5.6 mg/L. The density of the liquid is 2,000 g/L. What is the Fe concentration in ppm_m?

Solution:

$$2000 \text{ g} = 2 \text{ kg}$$

$$\frac{5.6 \text{ mg} / L}{2.0 \text{ kg} / L} = \boxed{2.8 \text{ ppm}}$$

2-4. Coliform bacteria (for example, *E. coli*) are excreted in large numbers in human and animal feces. Water that meets a standard of less than one coliform per 100 mL is considered safe for human consumption. Is a 1 L water sample that contains 9 coliforms safe for human consumption?

Solution:

Standard requires < 1 coliform/100 mL, or 10 coliform/1 L

$$\frac{9 \text{ coliforms}}{1 \text{ L}} \times \frac{1 \text{ L}}{10 \text{ coliforms (100 mL)}} = \boxed{0.9 \text{ coliforms / 100 mL}}$$

This value is < 1 coliform/100 mL; therefore, water is safe.

2-5. The treated effluent from a domestic wastewater-treatment plant contains ammonia (NH_3) at 9.0 mg N/L and nitrite (NO_2^-) at 0.5 mg N/L. Convert these concentrations to mg NH_3 /L and mg NO_2^- /L.

Solution:

$$17 \text{ g } \text{NH}_3 = 1 \text{ mole } \text{NH}_3$$

$$46 \text{ g } \text{NO}_2^- = 1 \text{ mole } \text{NO}_2^-$$

$$1 \text{ mole N} = 1 \text{ mole } \text{NH}_3 = 1 \text{ mole } \text{NO}_2^-$$

$$\frac{9.0 \text{ mg } \text{NH}_3 - \text{N}}{\text{L}} \times \frac{1 \text{ mole N}}{14 \text{ g N}} \times \frac{1 \text{ mole } \text{NH}_3}{1 \text{ mole N}} \times \frac{17 \text{ g } \text{NH}_3}{1 \text{ mole } \text{NH}_3} = \boxed{10.9 \text{ mg } \text{NH}_3 / \text{L}}$$

$$\frac{0.5 \text{ mg } \text{NO}_2 - \text{N}}{\text{L}} \times \frac{1 \text{ mole N}}{14 \text{ g N}} \times \frac{1 \text{ mole } \text{NO}_2}{1 \text{ mole N}} \times \frac{46 \text{ g } \text{NO}_2}{1 \text{ mole } \text{NO}_2} = \boxed{1.6 \text{ mg } \text{NO}_2 / \text{L}}$$

2-6. Nitrate concentrations exceeding 44.3 mg NO₃⁻/L are a concern in drinking water due to the infant disease, methemoglobinemia. Nitrate concentrations near three rural wells were reported as 0.01 mg NO₃⁻ N/L, 1.3 mg NO₃⁻ N/L, and 20.0 mg NO₃⁻ N/L. Do any of these three wells exceed the 44.3 ppm_m level?

Solution:

Convert the regulatory value to units of "as N". Then compare to the measured concentrations.

$$\frac{44.3 \text{ mg } NO_3^-}{L} \times \frac{1 \text{ mole } NO_3^-}{62.0 \text{ g } NO_3^-} \times \frac{1 \text{ mole } N}{1 \text{ mole } NO_3^-} \times \frac{14.0 \text{ g } N}{1 \text{ mole } N} = 10.0 \text{ mg } NO_3^- - N / L$$

The third well (20.0 mg NO₃⁻-N/L) exceeds the 10 ppm level.

2-7. Mirex (MW = 540) is a fully chlorinated organic pesticide that was manufactured to control fire ants. Due to its structure, mirex is very unreactive; thus, it persists in the environment. Lake Erie water samples have had mirex measured as high as 0.002 $\mu\text{g/L}$ and lake trout samples with 0.002 $\mu\text{g/g}$. (a) In the water samples, what is the aqueous concentration of mirex in units of (i) ppb_m , (ii) ppt_m , (iii) μM ? (b) In the fish samples, what is the concentration of mirex in fish in (i) ppm_m , (ii) ppb_m ?

Solution:

a) i)

$$\frac{0.002 \mu\text{g}}{\text{L}} \times \frac{1 \text{ mg}}{1000 \mu\text{g}} \times \frac{1 \text{ L}}{1 \text{ kg}} \times \frac{1000 \text{ million}}{1 \text{ billion}} = \boxed{0.002 \text{ ppb}}$$

ii)

$$\frac{0.002 \mu\text{g}}{\text{L}} \times \frac{1 \text{ mg}}{1000 \mu\text{g}} \times \frac{1 \text{ L}}{1 \text{ kg}} \times \frac{1,000,000 \text{ million}}{\text{trillion}} = \boxed{2 \text{ ppt}}$$

iii)

$$\frac{0.002 \mu\text{g}}{\text{L}} \times \frac{1 \text{ mole}}{540 \text{ g}} = \boxed{3.7 \times 10^{-6} \mu\text{M}}$$

b) i)

$$\frac{0.002 \mu\text{g}}{\text{g}} = \boxed{0.002 \text{ ppm}}$$

ii) In solids, $\text{ppb} = \mu\text{g/kg}$

$$\frac{0.002 \mu\text{g}}{\text{g}} \times \frac{1000 \text{ million}}{1 \text{ billion}} = \boxed{2 \text{ ppb}}$$

2-8. Chlorophenols impart unpleasant taste and odor to drinking water at concentrations as low as 5 mg/m^3 . They are formed when the chlorine disinfection process is applied to phenol-containing waters. What is the unpleasant taste and odor threshold in units of (a) mg/L , (b) $\mu\text{g/L}$, (c) ppm_m , (d) ppb_m ?

Solution:

a) in mg/L

$$\frac{5 \text{ mg}}{\text{m}^3} \times \frac{1 \text{ m}^3}{1000 \text{ L}} = \boxed{5 \times 10^{-3} \text{ mg / L}}$$

b) in $\mu\text{g / L}$

$$\frac{5 \text{ mg}}{\text{m}^3} \times \frac{1 \text{ m}^3}{1000 \text{ L}} \times \frac{1000 \mu\text{g}}{1 \text{ mg}} = \boxed{5 \mu\text{g / L}}$$

c) in water, $\text{mg/L} = \text{ppm}$

$$\frac{5 \text{ mg}}{\text{m}^3} \times \frac{1 \text{ m}^3}{1000 \text{ L}} \times \frac{1 \text{ L}}{1 \text{ kg}} = \boxed{5 \times 10^{-3} \text{ ppm}}$$

d) in water, $\mu\text{g/L} = \text{ppb}$

$$\frac{5 \text{ mg}}{\text{m}^3} \times \frac{1 \text{ m}^3}{1000 \text{ L}} \times \frac{1 \text{ L}}{1 \text{ kg}} \times \frac{1000 \text{ million}}{1 \text{ billion}} = \boxed{5 \text{ ppb}}$$

2-9. The concentration of monochloroacetic acid in rain water collected in Zurich was 7.8 nanomoles/L. Given that the formula for monochloroacetic acid is CH_2ClCOOH , calculate the concentration in $\mu\text{g/L}$.

Solution:

The molecular weight of monochloroacetic acid equals 94.5 g/mole.

$$\frac{7.8 \text{ nmoles}}{L} \times \frac{94.5 \text{ ng}}{1 \text{ nmole}} \times \frac{1 \mu\text{g}}{1000 \text{ ng}} = \boxed{0.74 \mu\text{g} / L}$$

2-10. Assume that concentrations of Pb, Cu, and Mn in rainwater collected in Minneapolis were found to be 9.5, 2.0, and 8.6 $\mu\text{g/L}$, respectively. Express these concentrations as nmole/L, given that the atomic weights are 207, 63.5, and 55, respectively.

Solution:

$$\frac{9.5 \mu\text{g Pb}}{\text{L}} \times \frac{1 \mu\text{mole}}{207 \mu\text{g Pb}} \times \frac{1000 \text{ nmole}}{1 \mu\text{mole}} = \boxed{45.9 \text{ nmole / L}}$$

$$\frac{2.0 \mu\text{g Cu}}{\text{L}} \times \frac{1 \mu\text{mole}}{63.5 \mu\text{g Cu}} \times \frac{1000 \text{ nmole}}{1 \mu\text{mole}} = \boxed{31.5 \text{ nmole / L}}$$

$$\frac{8.6 \mu\text{g Mn}}{\text{L}} \times \frac{1 \mu\text{mole}}{55 \mu\text{g Mn}} \times \frac{1000 \text{ nmole}}{1 \mu\text{mole}} = \boxed{156.4 \text{ nmole / L}}$$

2-11. The dissolved oxygen (DO) concentration is measured as 0.5 mg/L in the anoxic zone and 8 mg/L near the end (of a 108-ft-long aerated biological reactor). What are these two DO concentrations in units of (a) ppm_m, (b) moles/L?

Solution:

In water, mg/L = ppm

a)

$$\frac{0.5 \text{ mg } O_2}{L} \times \frac{1 L}{1 \text{ kg}} = \boxed{0.5 \text{ ppm}}$$

$$\frac{8 \text{ mg } O_2}{L} \times \frac{1 L}{1 \text{ kg}} = \boxed{8 \text{ ppm}}$$

b)

$$\frac{0.5 \text{ mg } O_2}{L} \times \frac{1 \text{ mole } O_2}{32 \text{ g } O_2} \times \frac{1 \text{ g}}{1000 \text{ mg}} = \boxed{1.6 \times 10^{-5} \text{ moles } O_2 / L}$$

$$\frac{8 \text{ mg } O_2}{L} \times \frac{1 \text{ mole } O_2}{32 \text{ g } O_2} \times \frac{1 \text{ g}}{1000 \text{ mg}} = \boxed{2.5 \times 10^{-4} \text{ moles } O_2 / L}$$

2-12. Assume that the average concentration of chlordane – a chlorinated pesticide now banned in the United States – in the atmosphere above the Arctic Circle in Norway was found to be 0.6 pg/m^3 . In this measurement, approximately 90 percent of this compound is present in the gas phase; the remainder is adsorbed to particles. For this problem, assume that all the compound occurs in the gas phase, the humidity is negligibly low, and the average barometric pressure is 1 atm. Calculate the partial pressure of chlordane. The molecular formula for chlordane is $\text{C}_{10}\text{Cl}_8\text{H}_6$. The average air temperature through the period of measurement was -5°C .

Solution:

First, find concentration in ppm_v . The molecular weight equals 409.8.

$$\frac{0.6 \text{ pg}}{\text{m}^3} \times \frac{\mu\text{g}}{10^6 \text{ pg}} = 0.6 \times 10^{-6} \mu\text{g} / \text{m}^3$$

$$\text{ppm}_v = nRT/PV = Q*(RT)/MW*P; \text{MW}=\text{mass}/n; \text{Q}=\text{mass}/V$$

$$\text{ppm}_v = \frac{\left(0.6 \times 10^{-6} \frac{\mu\text{g}}{\text{m}^3}\right) \left(0.08205 \frac{\text{L-atm}}{\text{mole-K}}\right) \times 268 \text{ K}}{\left(409.8 \frac{\text{g}}{\text{mole}}\right) \times \left(1000 \frac{\text{L}}{\text{m}^3}\right) \times 1 \text{ atm}}$$

$$\text{ppm}_v = 3.2 \times 10^{-11}$$

Now find partial pressure,

$$3.2 \times 10^{-11} = \frac{P_i}{1 \text{ atm}} \times 10^6$$

$$\text{Solve for } \boxed{P_i = 3.2 \times 10^{-17} \text{ atm}}$$

2-13. What is the concentration in (a) ppm_v, and (b) percent by volume, of carbon monoxide (CO) with a concentration of 103 μg/m³? Assume a temperature of 25°C and pressure of 1 atm.

Solution:

a) $R = 0.08205 \text{ L-atm/mole-}^\circ\text{K}$.

$$\frac{103 \mu\text{g CO}}{\text{m}^3} = \frac{\text{ppm} \times \left(28.0 \frac{\text{g}}{\text{mole}}\right) \times \left(1000 \frac{\text{L}}{\text{m}^3}\right) \times (1 \text{ atm})}{\left(0.08205 \frac{\text{L-atm}}{\text{mole-K}}\right) \times (298 \text{ K})} = \boxed{8.9 \times 10^{-2} \text{ ppm}}$$

b)

$$[\text{CO}] = \frac{8.9 \times 10^{-2} \text{ mg}}{10^6 \text{ mg}} \times 100 \% = \boxed{0.0000089 \%}$$

2-14. Ice resurfacing machines use internal combustion engines that give off exhaust containing CO and NO_x. Average CO concentrations measured in local ice rinks have been reported to be as high as 107 ppm_v and as low as 36 ppm_v. How do these concentrations compare to an outdoor-air-quality 1-h standard of 35 mg/m³? Assume the temperature equals 20°C.

Solution:

Convert the regulatory standard to ppm_v and compare to stated values.

$$35 \text{ mg/m}^3 \times 10^3 \text{ } \mu\text{g/mg} = 35,000 \text{ } \mu\text{g/m}^3$$

$$35,000 \text{ } \mu\text{g} / \text{m}^3 = \frac{\text{ppm}_v \times \left(28.0 \frac{\text{g}}{\text{mole}}\right) \times \left(1000 \frac{\text{L}}{\text{m}^3}\right) \times (1 \text{ atm})}{\left(0.08205 \frac{\text{L} \cdot \text{atm}}{\text{mole} \cdot \text{K}}\right) \times (293 \text{ K})}$$

ppm_v = 30; therefore, both are above the standard

2-15. Formaldehyde is commonly found in the indoor air of improperly designed and constructed buildings. If the concentration of formaldehyde in a home is 0.7 ppm_v and the inside volume is 800 m^3 , what mass (in grams) of formaldehyde vapor is inside the home? Assume $T = 298 \text{ K}$, $P = 1 \text{ atm}$. The molecular weight of formaldehyde is 30.

Solution:

$$\mu\text{g} / \text{m}^3 = \frac{0.7 \text{ ppm}_v \times \left(30 \frac{\text{g}}{\text{mole}}\right) \times \left(1,000 \frac{\text{L}}{\text{m}^3}\right) \times 1 \text{ atm}}{\left(0.08205 \frac{\text{L} \cdot \text{atm}}{\text{mole} \cdot \text{K}}\right) \times 298 \text{ K}}$$

Solve for concentration which equals $858.9 \mu\text{g}/\text{m}^3$

The mass of formaldehyde equals

$$\frac{858.9 \mu\text{g}}{\text{m}^3} \times 800 \text{ m}^3 \times \frac{\text{g}}{10^6 \mu\text{g}} = \boxed{0.7 \text{ g}}$$

2-16. The concentration of ozone (O_3) in Beijing on a summer day ($T = 30^\circ\text{C}$, $P = 1 \text{ atm}$) is 125 ppbv. What is the O_3 concentration in units of (a) $\mu\text{g}/\text{m}^3$, and (b) number of moles of O_3 per 106 moles of air?

Solution:

a) By definition, ppbv is related to the volume O_3 / volume total.

$$\frac{125 \text{ m}^3 O_3}{10^9 \text{ m}^3 \text{ air}} \times \frac{1 \text{ atm}}{8.205 \times 10^{-5} \frac{\text{m}^3 \cdot \text{atm}}{\text{mole} \cdot \text{K}} \times 303 \text{ K}} = 5 \times 10^{-6} \frac{\text{mole } O_3}{\text{m}^3 \text{ air}}$$

$$\frac{5 \times 10^{-6} \text{ mole } O_3}{\text{m}^3 \text{ air}} \times \frac{48 \text{ g } O_3}{1 \text{ mole } O_3} \times \frac{10^6 \mu\text{g}}{1 \text{ g}} = \boxed{241 \mu\text{g} / \text{m}^3}$$

b)

$$125 \text{ ppbv} = \frac{125 \text{ mole } O_3}{10^9 \text{ mole} - \text{air}} = \frac{0.125 \text{ mole } O_3}{10^6 \text{ mole} - \text{air}}$$

$$\frac{0.125 \text{ mole } O_3}{10^6 \text{ mole} - \text{air}} \times 106 \text{ mole} - \text{air} = \boxed{1.3 \times 10^{-5} \text{ mole of } O_3}$$

2-17. An empty balloon is filled with exactly 10 g of nitrogen (N_2) and 2 g of oxygen (O_2). The pressure in the room is 1 atm and the temperature is 25°C . (a) What is the oxygen concentration in the balloon in units of percent by volume? (b) What is the volume of the balloon after it's blown up, in L?

Solution:

a)

$$2 \text{ g } O_2 \times \frac{1 \text{ mole}}{32 \text{ g } O_2} = 6.3 \times 10^{-2} \text{ mole } O_2$$

$$10 \text{ g } N_2 \times \frac{1 \text{ mole}}{28 \text{ g } N_2} = 0.4 \text{ mole } N_2$$

$$\frac{\text{vol } O_2}{\text{vol} - \text{total}} = \frac{\text{moles } O_2}{\text{moles} - \text{total}} = \frac{6.3 \times 10^{-2}}{(6.3 \times 10^{-2} + 0.4)} = 0.136 \times 100 \% = \boxed{13.6 \%}$$

b) The balloon's volume can be found using the ideal gas law, $PV = nRT$ where n is from part a)

$$V = \frac{nRT}{P} = \frac{(6.3 \times 10^{-2} \text{ moles} + 0.4 \text{ moles}) \times \frac{0.08205 \text{ L} \cdot \text{atm}}{\text{mole} \cdot \text{K}} \times 298 \text{ K}}{1 \text{ atm}} = \boxed{11.3 \text{ L}}$$

2-18. A gas mixture contains 1.5×10^{-5} mole CO and has a total of 1 mole. What is the CO concentration in ppm_v?

Solution:

Remember, the determination of ppm_v can use volume, moles, or partial pressure. In this case we are provided information on the number of moles.

Therefore, ppm_v = $(1.5 \times 10^{-5} \text{ mole} / 1 \text{ mole}) \times 10^6 = \boxed{15 \text{ ppm}_v}$

2-19. “Clean” air might have a sulfur dioxide (SO₂) concentration of 0.01 ppm_v, while “polluted” air might have a concentration of 2 ppm_v. Convert these two concentrations to μg/m³. Assume a temperature of 298 K.

Solution:

$$\frac{\mu\text{g}}{\text{m}^3} = \text{ppm} \times MW \times \frac{1000 \times P}{RT} = \text{ppm} \times 64.1 \frac{\text{g}}{\text{mol}} \times \frac{1000 \text{L} / \text{m}^3}{0.08205 \frac{\text{L} \times \text{atm}}{\text{mol} \times \text{K}} \times 298 \text{K}}$$

$$1 \times 10^{-2} \times 64.1 \frac{\text{g}}{\text{mol}} \times \frac{1000 \text{L} / \text{m}^3}{0.08205 \frac{\text{L} \times \text{atm}}{\text{mol} \times \text{K}} \times 298 \text{K}} = \boxed{26 \frac{\mu\text{g}}{\text{m}^3}}$$

$$2 \times 64.1 \frac{\text{g}}{\text{mol}} \times \frac{1000 \text{L} / \text{m}^3}{0.08205 \frac{\text{L} \times \text{atm}}{\text{mol} \times \text{K}} \times 298 \text{K}} = \boxed{5,243 \frac{\mu\text{g}}{\text{m}^3}}$$

2-20. Carbon monoxide (CO) affects the oxygen carrying capacity of your lungs. Exposure to 50 ppm_v CO for 90 min has been found to impair one's ability to time/interval discriminate; thus, motorists in heavily polluted areas may be more prone to accidents. Are motorists at a greater risk to accidents if the CO concentration is 65 mg/m³? Assume a temperature of 298 K.

Solution:

$$65 \text{ mg/m}^3 = 65,000 \mu\text{g/m}^3$$

$$65,000 \frac{\mu\text{g}}{\text{m}^3} = \text{ppm} \times MW \times \frac{1000 \times P}{RT} = \text{ppm} \times \frac{28 \text{ g/mol} \times 1000 \text{ L/m}^3}{0.08205 \frac{\text{m}^3 \times \text{atm}}{\text{mole} \times \text{K}} \times 298 \text{ K}}$$

$$\boxed{\text{ppm} = 57 \text{ which is } > 50 \text{ so yes}}$$

2-21. The Department of Environmental Quality has determined that toxaphene concentrations in soil that exceed $60 \mu\text{g}/\text{kg}$ can pose a threat to underlying groundwater. a) If a 100-g sample of soil contains 10^{-5} g of toxaphene, what are the toxaphene soil and regulatory action level concentrations reported in units of ppb_m ?

Solution:

a) In soil, $\text{ppb} = \mu\text{g}/\text{kg}$

$$60 \frac{\mu\text{g}}{\text{kg}} = 60 \text{ ppb}$$

$$\frac{10^{-5} \text{ g toxaphene}}{100 \text{ g - soil}} \times \frac{1000 \text{ g}}{1 \text{ kg}} \times \frac{10^6 \mu\text{g}}{\text{g}} = 100 \frac{\mu\text{g}}{\text{kg}} = \boxed{100 \text{ ppb}}$$

b) 100 ppb > 60 ppb; therefore, the sample may pose a threat

2-22. Polycyclic aromatic hydrocarbons (PAHs) are a class of organic chemicals associated with the combustion of fossil fuels. Undeveloped areas may have total PAH soil concentrations of $5 \mu\text{g}/\text{kg}$, while urban areas may have soil concentrations that range from $600 \mu\text{g}/\text{kg}$ to $3,000 \mu\text{g}/\text{kg}$. What is the concentration of PAHs in undeveloped areas in units of ppm_m ?

Solution:

In soil $\text{mg}/\text{kg} = \text{ppm}$

$$5 \frac{\mu\text{g}}{\text{kg}} \times \frac{1 \text{ mg}}{1000 \mu\text{g}} = \boxed{5 \times 10^{-3} \text{ mg} / \text{kg}}$$

2-23. The concentration of toluene (C_7H_8) in subsurface soil samples collected after an underground storage tank was removed indicated the toluene concentration was 5 mg/kg. What is the toluene concentration in ppm_m?

Solution:

$$5 \frac{mg}{kg} = 5 ppm$$

2-24. While visiting Zagreb, Croatia, Mr. Arthur Van de Lay visits the Mimara Art Museum and then takes in the great architecture of the city. He stops at a café in the old town and orders a bottle of mineral water. The reported chemical concentration of this water is: $[Na^+] = 0.65 \text{ mg/L}$, $[K^+] = 0.4 \text{ mg/L}$, $[Mg^{2+}] = 19 \text{ mg/L}$, $[Ca^{2+}] = 35 \text{ mg/L}$, $[Cl^-] = 0.8 \text{ mg/L}$, $[SO_4^{2-}] = 14.3 \text{ mg/L}$, $[HCO_3^-] = 189 \text{ mg/L}$, $[NO_3^-] = 3.8 \text{ mg/L}$. The pH of the water is 7.3. (a) What is the hardness of the water in mg/L CaCO_3 ? (b) Is the chemical analysis correct?

Solution:

a) To determine the total hardness of a water sample, identify all the divalent cations, convert to units of mg/L as CaCO_3 , then sum up to find the total hardness.

$$Ca^{2+} = 35 \text{ mg/L} \times \frac{100 \text{ g} / 2 \text{ eqv}}{40.1 \text{ g} / 2 \text{ eqv}} = 87 \text{ mg/L as CaCO}_3$$

$$Mg^{2+} = 19 \text{ mg/L} \times \frac{100 \text{ g} / 2 \text{ eqv}}{24.3 \text{ g} / 2 \text{ eqv}} = 78 \text{ mg/L as CaCO}_3$$

Total hardness = $87 + 78 = 165 \text{ mg/L as CaCO}_3$

b) Convert the concentration of the major cations and anions to equivalents/L. Then sum up the cations and anions to see if they are within 5%.

$$Ca^{2+} = 35 \frac{\text{mg}}{\text{L}} \times \frac{\text{g}}{10^3 \text{ mg}} \times \frac{2 \text{ eqv}}{40.1 \text{ g}} = 1.7 \times 10^{-3}$$

$$Mg^{2+} = 19 \frac{\text{mg}}{\text{L}} \times \frac{\text{g}}{10^3 \text{ mg}} \times \frac{2 \text{ eqv}}{24.3 \text{ g}} = 1.6 \times 10^{-3}$$

$$K^+ = 0.4 \frac{\text{mg}}{\text{L}} \times \frac{\text{g}}{10^3 \text{ mg}} \times \frac{1 \text{ eqv}}{39.1 \text{ g}} = 1 \times 10^{-5}$$

$$Na^+ = 0.65 \frac{\text{mg}}{\text{L}} \times \frac{\text{g}}{10^3 \text{ mg}} \times \frac{1 \text{ eqv}}{23.0 \text{ g}} = 2.8 \times 10^{-4}$$

Sum of cations equals $3.6 \times 10^{-3} \text{ eqv/L}$

$$HCO_3^- = 189 \frac{\text{mg}}{\text{L}} \times \frac{\text{g}}{10^3 \text{ mg}} \times \frac{1 \text{ eqv}}{61.0 \text{ g}} = 3.1 \times 10^{-3}$$

$$Cl^- = 0.8 \frac{\text{mg}}{\text{L}} \times \frac{\text{g}}{10^3 \text{ mg}} \times \frac{1 \text{ eqv}}{35.5 \text{ g}} = 2 \times 10^{-5}$$

$$SO_4^{2-} = 14.3 \frac{\text{mg}}{\text{L}} \times \frac{\text{g}}{10^3 \text{ mg}} \times \frac{1 \text{ eqv}}{96.1 \text{ g}} = 1.49 \times 10^{-4}$$

Sum of anions equals $3.3 \times 10^{-3} \text{ eqv/L}$

Because the sum of all cations and anions (after we converted them to common units of eqv/L) are within 5% of each other, we can assume that the analysis is correct.

Solutions Manual prepared by: Ziad Katirji and Heather E. Wright Wendel

Environmental Engineering: Fundamentals, Sustainability, Design,

James R. Mihelcic and Julie Beth Zimmerman, John Wiley & Sons, New York, 2009.

2-25. In 2004, U.S. landfills emitted approximately 6,709 Gg of methane emissions and wastewater treatment plants emitted 1,758 Gg of methane. How many Tg of CO₂ equivalents did landfills and wastewater plants emit in 2004? What percent of the total 2004 methane emissions (and greenhouse gas emissions) do these two sources contribute (total methane emissions in 2004 were 556.7 Tg CO₂e and total greenhouse gas emissions in 2004 were 7,074.4 CO₂e).

Solution:

$$Tg\ CO_2e = 6709\ Gg\ CH_4 \times 21 \times \frac{Tg}{1000\ Gg} = 140.9\ Tg\ CO_2e\ \text{from landfills}$$

$$Tg\ CO_2e = 1758\ Gg\ CH_4 \times 21 \times \frac{Tg}{1000\ Gg} = 36.92\ Tg\ CO_2e\ \text{from WWTP}$$

$$Total\ CO_2\ e\ \text{from both} = 140.9 + 36.92 = 177.8\ Tg$$

$$\% \text{ of total } CH_4 \text{ emissions} = \frac{177.8\ Tg}{556.7\ Tg} \times 100\% = 31.9\%$$

$$\% \text{ of total greenhouse emissions} = \frac{177.8\ Tg}{7074.4\ Tg} \times 100\% = 2.5\%$$

2-26. Mobile combustion of N₂O in 2004 emitted 42.8 Tg CO₂e. How many Gg of N₂O was this?

Solution:

$$42.8 \text{ Tg} = CO_2e \text{ of } N_2O = Gg \text{ } N_2O \times 310 \times \frac{Tg}{1000 Gg}$$
$$\boxed{= 138 Gg \text{ } N_2O}$$

2-27. A laboratory provides the following solids analysis for a wastewater sample: TS = 200 mg/L; TDS = 30 mg/L; FSS = 30 mg/L. (a) What is the total suspended solids concentration of this sample? (b) Does this sample have appreciable organic matter? Why or why not?

Solution:

a)

$$TSS = TS - TDS = 200 \frac{mg}{L} - 30 \frac{mg}{L} = \boxed{170 \frac{mg}{L}}$$

b)

$$VSS = TSS - FSS = 170 \frac{mg}{L} - 30 \frac{mg}{L} = 140 \frac{mg}{L}$$

Because volatile solids consist primarily of organic matter, it can be concluded that approximately 70% (140/200) of the solids are organic.

2-28. A 100-mL water sample is collected from the activated sludge process of municipal wastewater treatment. The sample is placed in a drying dish (weight = 0.5000 g before the sample is added), and then placed in an oven at 104°C until all the moisture is evaporated. The weight of the dried dish is recorded as 0.5625 g. A similar 100-mL sample is filtered and the 100-mL liquid sample that passes through the filter is collected and placed in another drying dish (weight of dish before sample is added is also 0.5000 g). This sample is dried at 104°C and the dried dish's weight is recorded as 0.5325 g. Determine the concentration (in mg/L) of (a) total solids, (b) total dissolved solids, (c) total suspended solids, and (d) volatile suspended solids, (Assume that VSS = 0.7 x TSS.)

Solution:

a)

$$TS = \frac{0.5625 \text{ g} - 0.5000 \text{ g}}{100 \text{ mL}} \times \frac{1000 \text{ mL}}{L} \times \frac{1000 \text{ mg}}{g} = \boxed{625 \frac{\text{mg}}{L}}$$

b)

$$TDS = \frac{0.5325 \text{ g} - 0.5000 \text{ g}}{100 \text{ mL}} \times \frac{1000 \text{ mL}}{L} \times \frac{1000 \text{ mg}}{g} = \boxed{325 \frac{\text{mg}}{L}}$$

c)

$$TSS = TS - TDS = 625 \frac{\text{mg}}{L} - 325 \frac{\text{mg}}{L} = \boxed{300 \frac{\text{mg}}{L}}$$

d)

$$VSS = 0.7 \times TSS = 0.7 \times 300 \frac{\text{mg}}{L} = \boxed{210 \frac{\text{mg}}{L}}$$