CHAPTER 4
SOLUTIONS

4-1 Show that 1 g/m = 1000 kg/m

Given: Conversion factors inside back cover

Solution:

$$1\frac{\text{g}}{\text{mL}}\times 0.001\frac{\text{kg}}{\text{g}}\times 1000\frac{\text{mL}}{\text{L}}\times 1000\frac{\text{L}}{\text{m}^3}=1000\frac{\text{kg}}{\text{m}^3}$$

4-2 Show that 4.50% = 45.0 kg/m

Given: % by weight in water

Solution:

a. Assume density of water = 1000 kg/m

b. Calculate % by weight

0.045 x 1000 kg/m = 45.0 kg/m3

4-3 Concentration of NH_3 in mg/L

Given: Household ammonia at 3.00% by weight, ρ_{H2O} = 1000 kg/m^3

Solution:

a. Calculate the mass of NH_3

(0.0300)(1000 kg/m^3) = 30 kg/m^3

b. Convert kg/m^3 to mg/L

(30 kg/m^3)(10^6 mg/kg)(10^{-3} m^3/L) = 30,000 mg/L

4-4 Concentration of Cl_2 in mg/L

Given: Household bleach at 5.25% by weight, ρ_{H2O} = 1000 kg/m^3

Solution:

a. Calculate the mass of Cl_2

$$(0.0525)(1000\ \text{kg/m}^3)(10^6\ \text{mg/kg})(10^{-3}\ \text{m}^3/\text{L}) = 52{,}000\ \text{mg/L}$$

4-5 Show that 1 mg/L = 1 g/m^3

Given: Conversion factors inside back cover

Solution:

$$1\frac{\text{mg}}{\text{L}}\times 0.001\frac{\text{g}}{\text{mg}}\times 1000\frac{\text{L}}{\text{m}^3}=1\frac{\text{g}}{\text{m}^3}$$

4-6 Arsenic standard in mg/L

Given: Standard is 10 ppb

Solution:

a. Convert ppb to ppm

$$10\text{ppb}\left(\frac{10^{-3}\,\text{ppm}}{\text{ppb}}\right)=10\times 10^{-3}\ \text{ppm or } 0.010\ \text{ppm}$$

b. from Eqn. 4-5, 1ppm = 1 mg/L

therefore 10 ppb = 0.010 mg/L

4-7 Convert m^3/s to MGD

Given: Flows of 0.0438; 0.05; 0.438; 0.5; 4.38; 5; all in m^3/s

Solution: Use conversion factor from inside back cover

a. 0.0438 (3 significant figures)

$$(0.0438\ \text{m}^3/\text{s})(22.8245) = 0.99971 \text{ or } 1.00\ \text{MGD}$$

b. 0.05 (1 significant figure)

(0.05)(22.8245) = 1.14123 or 1. MGD

c. 0.438

(0.438)(22.8245) = 9.99713 or 10.0 MGD

d. 0.5
(0.5)(22.8245): = 11.41 or 10 MGD

e. 4.38

(4.38)(22.8245) = 99.9713 or 100. MGD

f. 5

(5)(22.8245) = 114.1225 or 100 MGD

4-8 Molarity and Normality

Given: Concentrations in mg/L

Solution: Molecular Weights are on inside of front cover. In each case:

$$\text{Molarity} = \frac{\text{mg/L} \cdot \text{of} \cdot \text{species}}{(1000\,\text{mg/g})(\text{molecular} \cdot \text{weight})}$$

Normality = (molarity)(n)

a. HCN

$$\text{Molarity} = \frac{200.0}{(1000)(36.4609)} = 0.005485\text{M}$$

Normality = (0.005485)(1) = 0.005485 N

b. H_2SO_4

$$\text{Molarity} = \frac{150.0}{(1000)(98.07)} = 0.001529\text{M}$$

Normality = (0.001529)(2) = 0.003059 N

c. $Ca(HCO_3)_2$

$$\text{Molarity} = \frac{100.0}{(1000)(162.1122)} = 0.0006168\text{M}$$

Normality = (0.0006169)(2) = 0.001234 N

d. H_3PO_4

$$\text{Molarity} = \frac{70.0}{(1000)(97.9951)} = 0.000714\text{M}$$

Normality = (0.000714)(3) = 0.00214 N

4-9 Molarity and Normality

Given: concentrations in μg/L

Solution:

a. HNO_3

Converting micrograms to milligrams

$$(80\,\mu\text{g/L})\left(\frac{1}{1000\,\mu\text{g/mg}}\right) = 0.08\,\text{mg/L}$$

$$\text{Molarity} = \frac{0.08}{(1000)(63.015)} = 1.3\times10^{-6}\,\text{M}$$

Normality = $(1.3 \text{ x } 10^{-6}$ M)(1) = $1.3 \text{ x } 10^{-6}$ N

b. $CaCO_3$

$$(135\,\mu\text{g/L})\left(\frac{1}{1000\,\mu\text{g/mg}}\right) = 0.135\,\text{mg/L}$$

$$\text{Molarity} = \frac{0.135}{(1000)(100.09)} = 1.3\times10^{-6}\,\text{M}$$

Normality = $(1.3 \text{ x } 10^{-6}$ M)(2) = $2.7 \text{ x } 10^{-6}$ N

c. $Cr(OH)_3$

$$(10\,\mu g/L)\left(\frac{1}{1000\,\mu g/mg}\right) = 0.01\,mg/L$$

$$\text{Molarity} = \frac{0.01}{(1000)(103.02)} = 1.0\times10^{-7}\,M$$

Normality = (1.0×10^{-7} M)(3) = 3×10^{-7} N

d. $Ca(OH)_2$

$$(1000\,\mu g/L)\left(\frac{1}{1000\,\mu g/mg}\right) = 1.0\,mg/L$$

$$\text{Molarity} = \frac{1.0}{(1000)(74.096)} = 1.35\times10^{-5}\,M$$

Normality = (1.35×10^{-5} M)(2) = 2.7×10^{-5} N

4-10 Calculate molarity and normality

Given: 0.05 mg/L As; 0.005 mg/L Cd; 0.002 mg/L Hg; 0.10 mg/L Ni

Solution:

$$\text{Molarity} = \frac{mg/L \cdot of \cdot species}{(1000\,mg/g)(molecular \cdot weight)}$$

Normality = (molarity)(n)

a. As^{3+}

$$\text{Molarity} = \frac{0.05}{(1000)(74.92)} = 6.67\times10^{-7}\,M$$

Normality = (6.67×10^{-7} M)(3) = 2.00×10^{-6} N

b. Cd^{2+}

$$\text{Molarity} = \frac{0.005}{(1000)(112.4)} = 4.45\times10^{-8}\,\text{M}$$

Normality = $(4.45 \times 10^{-8}$ M$)(2) = 8.90 \times 10^{-8}$ N

c. Hg^{2+}

$$\text{Molarity} = \frac{0.002}{(1000)(200.6)} = 9.97\times10^{-9}\,\text{M}$$

Normality = $(9.97 \times 10^{-9}$ M$)(2) = 1.99 \times 10^{-8}$ N

d. Ni^{2+}

$$\text{Molarity} = \frac{0.10}{(1000)(58.69)} = 1.70\times10^{-6}\,\text{M}$$

Normality = $(1.7 \times 10^{-6}$ M$)(2) = 3.41 \times 10^{-6}$ N

4-11 Converting to mg/L

Given: Molarity and normality

Solution:

a. Ca^{2+} (n = 2 since charge is +2)

$$(0.01000\text{N})\left(\frac{40.08}{2}\,\text{g/eq}\right)(1000\,\text{mg/g}) = 200.4\,\text{mg/L}$$

b. HCO_3^- (n = 1 since charge is 1)

(1.000 M)(61.016 g/mole)(1000 mg/g) = 61.020 mg/L

c. H_2SO_4 (n = 2)

$$(0.02000\text{N})\left(\frac{98.07}{2}\,\text{g/eq}\right)(1000\,\text{mg/g}) = 980.7\,\text{mg/L}$$

d. SO_4^{2-}

(0.02000 M)(96.054 g/mole)(1000 mg/g) = 1,921 mg/L

4-12 Converting to μg/L

Given: Molarity and normality

Solution:

a. H_2CO_3 (n = 2)

$(0.05\text{ N})(62.01\text{ g/eq})(1/2)(1{,}000{,}000\ \mu\text{g/g}) = 1.6 \times 10^6\ \mu\text{g/L}$

b. $CHCl_3$

$(0.0010\text{ M})(119.37\text{ g/mole})(1{,}000{,}000\ \mu\text{g/g}) = 1.2 \times 10^5\ \mu\text{g/L}$

c. $Ca(OH)_2$ (n = 2)

$(0.03\text{ N})(74.096\text{ g/eq})(1/2)(1{,}000{,}000\ \mu\text{g/g}) = 1.1 \times 10^6\ \mu\text{g/L}$

d. CO_3^{2-}

$(0.0080\text{ M})(60.011\text{ g/mole})(1{,}000{,}000\ \mu\text{g/g}) = 4.8 \times 10^5\ \mu\text{g/L}$

4-13 Convert to mg/L

Given: 0.250 M NaOH; 0.0704 M Na_2SO_4; 0.0340 M $K_2Cr_2O_7$; 0.1342 M KCl

Solution:

mg/L of species = (molarity)(10000 mg/g)(GMW)

a. NaOH

mg/L = (0.250)(1000)(40.00) = 10,000 mg/L

b. Na_2SO_4

mg/L = (0.0704)(1000)(142.05) = 10,000 mg/L

c. $K_2Cr_2O_7$

mg/L = (0.0340)(1000)(294.20) = 10,003 or 10,000 mg/L

d. KCl

mg/L = (0.1342)(1000)(74.55) = 10,005 or 10,000 mg/L

4-14 Solubility of Mg in mg/L

Given: Solution 0.001000 M in OH

Solution:

From Table 4-2 pK_{SP} = 11.25 for $Mg(OH)_2$

$K_{SP} = 10^{-11.25} = 5.62 \text{ x } 10^{-12}$

$K_{SP} = [Mg^{2+}][OH^-]^2$

$$\left[Mg^{2+}\right] = \frac{5.62\times10^{-12}}{(0.001)^2} = 5.62\times10^{-6} \text{ mole/L}$$

$Mg^{2+} = (5.62 \text{ x } 10^{-6} \text{ mole/L})(24.305 \text{ x } 10^3 \text{ mg/mole})$
$Mg^{2+} = 0.1367$ mg/L

4-15 pH to precipitate iron

Given: Groundwater has 1.800 mg/L Fe and desired concentration is 0.30 mg/L

Solution: From Table 4-2 pK_{SP} = 38.57 for $Fe(OH)_3$

$K_{SP} = 10^{-38.57} = 2.69 \text{ x } 10^{-39}$

$$[Fe] = \frac{0.30 \text{ mg/L}}{(55.85 \text{ g/mole})(1000 \text{ mg/g})} = 5.37\times10^{-6} \text{ mole/L}$$

$K_{SP} = [Fe][OH]^3$

$$\left[OH^-\right] = \left(\frac{2.69\times10^{-39}}{5.37\times10^{-6}}\right)^{1/3} = \left(5.01\times10^{-33}\right)^{1/3} = 7.94\times10^{-12} \text{ mole/L}$$

pOH = -log (7.94 x 10^{-12})

pOH = 11.10 and pH = 14.00 - 11.10 = 2.90

4-16 pH to precipitate Cu

Given: Starting concentration = 2.00 mg/L; ending concentration = 0.200 mg/L

Solution:

a. Notes:

(1) The starting concentration is not relevant to the solution of this problem
(2) From Appendix A

$$\mathrm{Cu(OH)_2} \leftrightarrow \mathrm{Cu^{2+}} + 2\mathrm{OH^-}$$

$K_{SP} = 2.0 \times 10^{-19}$

b. Molar concentration of Cu required

$$\left[\mathrm{Cu^{2+}}\right] = \frac{0.200\,\mathrm{mg/L}}{(63.55\,\mathrm{g/mole})(1000\,\mathrm{mg/g})} = 3.15\times10^{-6}\ \mathrm{mole/L}$$

c. Solve K_{SP} equation for $[OH^-]$

$K_{SP} = [Cu^{2+}]\,[OH^-]^2$

$$\left[\mathrm{OH^-}\right] = \left(\frac{2.0\times10^{-19}}{3.15\times10^{-6}}\right)^{1/2} = \left(6.36\times10^{-14}\right)^{1/2} = 2.52\times10^{-7}\ \mathrm{mole/L}$$

d. Calculate pOH

$pOH = -\log(2.52 \times 10^{-7}) = 6.60$

e. Calculate pH

$pH = 14.00 - 6.60 = 7.40$

4-17 Calcium remaining in solution

Given: Saturated solution of $CaCO_3$ and addition of 3.16×10^{-4} moles/L of Na_2CO_3

Solution: This solution requires the solution of a quadratic equation.

a. Begin with the equilibrium reaction (Eqn 4-9 or Table 4-2.)

$$\text{CaCO}_3 \leftrightarrow \text{Ca}^{2+} + \text{CO}_3^{\ 2-}$$

b. Write the equilibrium expression using K_{SP} from Table 4-2

$$K_{SP} = [\text{Ca}^{2+}][\text{CO}_3^{\ 2-}] = 10^{-8.305} = 4.95 \text{ x } 10^{-9}$$

c. Calculate the molar concentration of Ca^{2+} and $\text{CO}_3^{\ 2-}$ at equilibrium (before the addition of Na_2CO_3).

$$[\text{Ca}^{2+}] = [\text{CO}_3^{\ 2-}] = (4.95 \text{ x } 10^{-9})^{1/2} = 7.04 \text{ x } 10^{-5}$$

d. Set up quadratic equation where x = amount of Ca that will be removed from solution.

$$\left[\text{Ca}^{2+}\right] = \left(7.04\times10^{-5}\right) - \text{x}$$

$$\left[\text{CO}_3^{\ 2-}\right] = \left(7.04\times10^{-5}\right) + \left(3.16\times10^{-4}\right) - \text{x}$$

$$K_{SP} = \left(7.04\times10^{-5} - \text{x}\right)\left(3.86\times10^{-4} - \text{x}\right) = 4.95\times10^{-9}$$

$$\text{x}^2 - \left(4.57\times10^{-4}\right)(\text{x}) + \left(2.23\times10^{-8}\right) = 0$$

e. Solving the quadratic we get roots of

$$\text{x} = 4.01\times10^{-4} \text{ and } \text{x} = 5.56\times10^{-5}$$

Since 4.01×10^{-4} is greater than what we started with, we select the root $\text{x} = 5.56\times10^{-5}$

f. The amount of Ca^{2+} remaining is then

$$\left[\text{Ca}^{2+}\right] = \left(7.04\times10^{-5}\right) - \left(5.56\times10^{-5}\right) = 1.48\times10^{-5} \text{ mole/L}$$

NOTE: Because the carbonate buffer system is affected, the pH and solubility of CaCO_3 also change.

4-18 Fluoride solubility

Given: Solubility product of $\text{CaF}_2 = 3.45 \text{ x } 10^{-11}$, $\text{F}^- = 1.0$ mg/L and $\text{Ca}^{2+} = 200$ mg/L

Solution:

a. Convert Ca and F to moles/L

$$\left[\mathrm{Ca}^{2+}\right] = \frac{200\,\mathrm{mg/L}}{(40.08\,\mathrm{g/mole})(1000\,\mathrm{mg/g})} = 4.99\times10^{-3}\ \mathrm{mole/L}$$

$$\left[\mathrm{F}^{-}\right] = \frac{1.0\,\mathrm{mg/L}}{(19.00\,\mathrm{g/mole})(1000\,\mathrm{mg/g})} = 5.26\times10^{-6}\ \mathrm{mole/L}$$

b. Calculate solubility of F with 200 mg/L of Ca in solution.

$K_{SP} = [Ca^{2+}][F^{-}]^2$

$K_{SP} = [4.99 \times 10^{-3}][F^{-}]^2 = 3.45 \times 10^{-11}$

$$\left[\mathrm{F}^{-}\right] = \left(\frac{3.45\times10^{-11}}{4.99\times10^{-3}}\right)^{1/2} = 8.31\times10^{-5}\ \mathrm{mole/L}$$

c. Since 8.31 x 10^{-5} is greater than 5.26 x 10^{-5}, the 1.0 mg/L of F will be soluble.

4-19 Concentrations of Ca and SO_4

Given: $CaSO_4$ solution, addition of 5.00 x 10^{-3} M Na_2SO_4, $pK_{SP} = 4.31$

Solution:

a. From Appendix A

$$\mathrm{CaSO_4} \leftrightarrow \mathrm{Ca}^{2+} + \mathrm{SO_4}^{2-}$$

$K_{SP} = 10^{-4.31} = 4.898 \times 10^{-5}$

b. Calculate the molar concentrations of Ca^{2+} and SO_4^{2-} at equilibrium

$[Ca^{2+}] = [SO4^{2-}] = (4.898 \times 10^{-5})^{1/2} = 6.998 \times 10^{-3}$

c. Set up quadratic equation where

$$\left[\mathrm{Ca}^{2+}\right] = \left(6.998\times10^{-3}\right) - x$$

$$\left[\mathrm{SO_4}^{2-}\right] = \left(6.998\times10^{-3}\right) + \left(5.00\times10^{-3}\right) - x = \left(1.200\times10^{-2}\right) - x$$

$$K_{SP} = \left(6.998\times10^{-3} - x\right)\left(1.200\times10^{-2} - x\right) = 4.898\times10^{-5}$$

$$\left(8.398\times10^{-5}\right) - \left(1.899\times10^{-2}\right)x + x^{2} = 4.898\times10^{-5}$$

$$x^{2} - \left(1.899\times10^{-2}\right)x + \left(8.398\times10^{-5}\right) = 4.898\times10^{-5}$$

$$x^{2} - \left(1.899\times10^{-2}\right)x + \left(3.500\times10^{-5}\right) = 0$$

d. Solve the quadratic equation for roots

$$x = \frac{1.899\times10^{-2} \pm \left[\left(-1.899\times10^{-2}\right)^{2} - 4\left(3.500\times10^{-5}\right)\right]^{1/2}}{2}$$

$$x = \frac{1.899\times10^{-2} \pm \left[1.485\times10^{-2}\right]}{2}$$

$$x = 3.384\times10^{-2} \text{ and } x = 4.137\times10^{-3}$$

e. Because 3.384 x 10^{-2} > 6.998 x 10^{-3}, or more than we started with, select x = 4.137 x 10^{-3}

f. The amount of Ca^{2+} remaining is

$[Ca^{2+}]$ = 6.998 x 10^{-3} – 4.137 x 10^{-3} = 2.86 x 10^{-3} mole/L

g. The amount of sulfate remaining is

$[SO4^{2-}]$ = 6.998 x 10^{-3} + 5.00 x 10^{-3} – 4.137 x 10^{-3} = 7.861 x 10^{-3} mole/L

4-20 Amount of base to neutralize acid

Given: Acid concentrations in Example 4-6

Solution:

a. The reaction is

$$H_2SO_4 + 2NaOH \leftrightarrow Na_2SO_4 + 2H_2O$$

Therefore two moles of NaOH are required to neutralize each mole of H_2SO_4.

Assuming one liter:

$$\frac{100.00\text{mg}}{98.07\,\text{mg/mole}} = \frac{x}{2(39.996\,\text{mg/mole})}$$

x = (1.0197)(2)(39.997)

x = 81.5683 or 81.6 mg

4-21 Neutralize finished softened water

Given: pH is 10.74; normality of H_2SO_4 is 0.02000

Solution:

a. Assume only OH is present. Then

pOH = 14.00 - 10.74 = 3.26

$[OH^-] = 10^{-3.26} = 5.50 \times 10^{-4}$ mole/L

b. Since n = 1 for OH^- the normality = molarity. Then since

N x mL = N x mL

We can say

$(5.50 \times 10^{-4})(1000 \text{ mL}) = (0.02000)(\text{mL acid})$

c. Solving for (mL acid)
mL acid = 27.477 or 27.5 mL

4-22 Neutralize finished water with HCl

Given: Problem 4-21

Solution: Since the normality is exactly the same as in Problem 4-21 the form of the acid is irrelevant and the answer is the same as in Problem 4-21, i.e. 27.5 mL

4-23 Titration curve

Given: 50 mL solution of 0.0200 N NaOH; titrate with 0.0200 N HCl

Solution:

a. This is a strong base – strong acid titration. The reaction is

$$\mathrm{NaOH} + \mathrm{HCl} \leftrightarrow \mathrm{NaCl} + \mathrm{H_2O}$$

b. For this reaction n = 1 for both reactants and the molarity is equal to the normality.

c. The initial pH of the NaOH then is the pH of 0.0200 M OH^-

pOH = -log(0.0200) = 1.699

pH = 14.00 – 1.699 = 12.30

d. After reaction with 1.0 mL of 0.0200 N HCl the molar concentration of NaOH is

$$\frac{(50.0\mathrm{mL})(0.0200\mathrm{N}) - (1.00\mathrm{mL})(0.0200\mathrm{N})}{51.0\mathrm{mL}} = 0.0192\,\mathrm{mole/L}$$

e. The pH is then

pOH = -log(0.0192) = 1.716

pH = 14.00 – 1.716 = 12.28

f. See spreadsheet below for remaining tabular calculations and plot.

Titrant		
HCl	0.0200	N

Analyte		
NaOH	0.0200	N
	50.00	mL

Milliequivalents and moles of NaOH	
meq =	1.0000
moles =	0.0010

Note that in each case the number of moles per liter = the number of equivalents per liter

Initial pOH = 3.00
Initial pH = 11.00

Milliters of acid	Moles of HCl Added	Moles of NaOH Remaining	pOH	pH
5	0.0001	0.0009	3.045757	10.95424
10	0.0002	0.0008	3.09691	10.90309
15	0.0003	0.0007	3.154902	10.8451
20	0.0004	0.0006	3.221849	10.77815
25	0.0005	0.0005	3.30103	10.69897
30	0.0006	0.0004	3.39794	10.60206
35	0.0007	0.0003	3.522879	10.47712
40	0.0008	0.0002	3.69897	10.30103
45	0.0009	0.0001	4	10
46	0.00092	0.0001	4.09691	9.90309
47	0.00094	0.0001	4.221849	9.778151
48	0.00096	0.0000	4.39794	9.60206
49	0.00098	0.0000	4.69897	9.30103
49.2	0.000984	0.0000	4.79588	9.20412
49.4	0.000988	0.0000	4.920819	9.079181
49.6	0.000992	0.0000	5.09691	8.90309
49.8	0.000996	0.0000	5.39794	8.60206
50	0.001	0.0000	7	7

At the equivalence point the pOH = 7.00

From the equivalence point on, pH is calculated directly.

Milliters of acid	Moles of HCl Added	Moles of HCl Excess	pH	pOH
55	0.0011	0.0001	4	10
60	0.0012	0.0002	3.69897	10.30103
70	0.0014	0.0004	3.39794	10.60206
80	0.0016	0.0006	3.221849	10.77815
90	0.0018	0.0008	3.09691	10.90309
100	0.002	0.0010	3	11
110	0.0022	0.0012	2.920819	11.07918
115	0.0023	0.0013	2.886057	11.11394
120	0.0024	0.0014	2.853872	11.14613

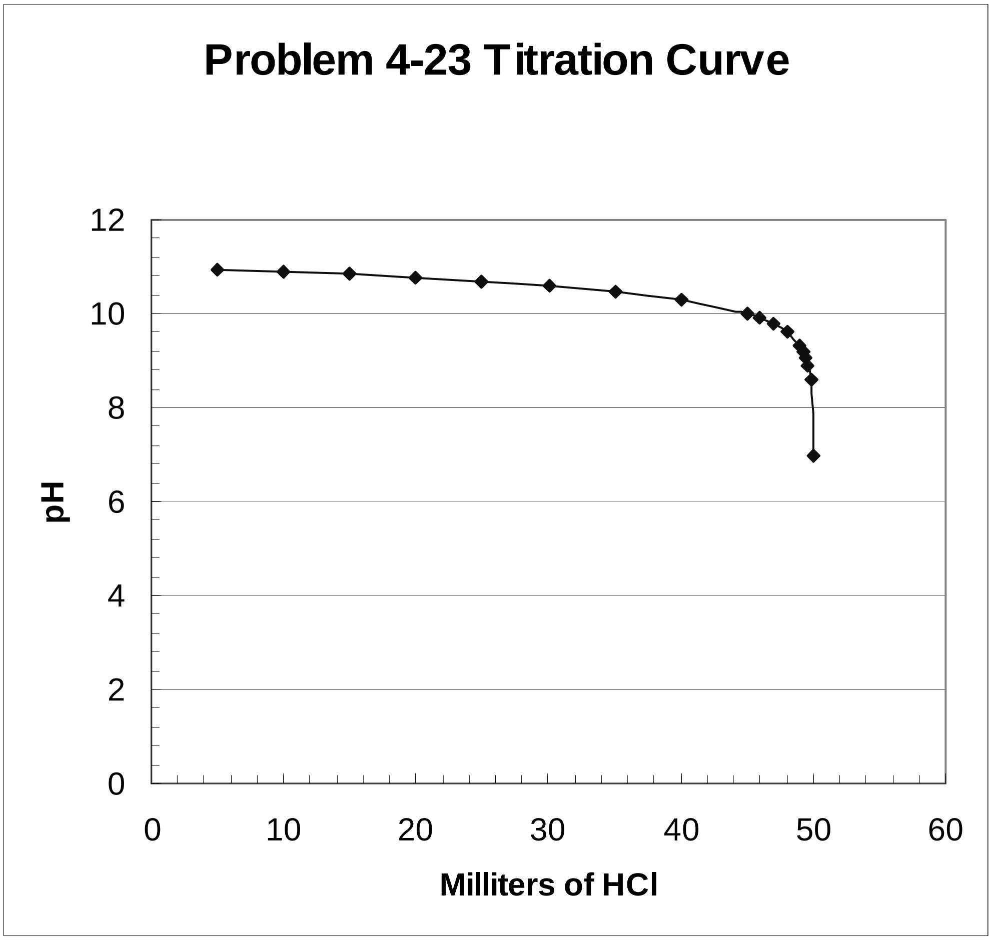


Figure S-4-23: Titration curve

4-24 pH of water containing carbonic acid

Given: 0.6580 mg/L H_2CO_3; assume $[H^+] = [HCO_3^-]$

Solution:

a. From Table 4-4, $pK_a = 6.35$ for H_2CO_3

b. Convert mg/L to moles/L

$$\frac{0.6580\text{mg}}{(62.026\,\text{g/mole})(1000\,\text{mg/g})} = 1.061\times10^{-5}\ \text{mole/L}$$

c. Write equilibrium expression

$$K_a = \frac{[H^+][HCO_3^-]}{[H_2CO_3]} = 10^{-6.35} = 4.467\times10^{-7}$$

d. Substitute carbonic acid concentration

$$K_a = \frac{[H^+][HCO_3^-]}{[1.061\times10^{-5}]} = 4.467\times10^{-7}$$

e. Assuming $[H^+] = [HCO_3^-]$

$[H^+]^2 = 4.739 \text{ x } 10^{-12}$

$[H^+] = 2.177 \text{ x } 10^{-6}$

$pH = -\log(2.177\text{x}10^{-6}) = 5.66$

4-25 HCO_3^- concentration at a pH of 4.50

Given: Problem 4-24

Solution:

a. From Table 4-4 $pK_a = 6.35$ for H_2CO_3

b. The molar concentration of H_2CO_3 is

$$[H_2CO_3] = \frac{0.6580\,\text{mg/L}}{(62.026\,\text{g/mole})(1000\,\text{mg/g})} = 1.061\times10^{-5}\text{ mole/L}$$

c. Calculate $[H^+]$

$[H^+] = 10^{-4.50} = 3.16 \text{ x } 10^{-5}$

d. Solve the equilibrium expression for $[HCO_3^-]$

$$[HCO_3^-] = \frac{K_a[H_2CO_3]}{[H^+]} = \frac{(10^{-6.35})(1.061\times10^{-5}\text{ mole/L})}{3.16\times10^{-5}\text{ mole/L}}$$

$= 1.498 \text{ x } 10^{-7}$ or $1.50 \text{ x } 10^{-7}$ mole/L

4-26 pH of water containing hypochlorous acid

Given: 0.5000 mg/L HOCl; assume equilibrium

Solution:

a. From Table 4-4, $pK_a = 7.54$ for HOCl.

b. Convert mg/L to mole/L

$$\frac{0.5000\text{mg}}{(52.45\,\text{g/mole})(1000\,\text{mg/g})} = 9.53\times10^{-6}\ \text{mole/L}$$

c. Write equilibrium expression

$$K_a = \frac{[H^+][OCl^-]}{[HOCl]} = 10^{-7.54} = 2.884\times10^{-8}$$

d. Substitute hypochlorous acid concentration

$$K_a = \frac{[H^+][OCl^-]}{[9.53\times10^{-6}]} = 2.884\times10^{-8}$$

e. Assuming $[H^+] = [OCl^-]$

$[H^+]^2 = 2.748 \times 10^{-13}$

$[H^+] = 5.24 \times 10^{-7}$

$pH = -\log(5.24 \times 10^{-7}) = 6.28$

4-27 OCl^- concentration

Given: Data in Problem 4-26 and pH = 7.00

Solution:

a. From Table 4-4, $pK_a = 7.54$ for HOCl.

b. Convert mg/L to mole/L

$$\frac{0.5000\text{mg}}{(36.46\,\text{g/mole})(1000\,\text{mg/g})} = 1.371\times10^{-5}\ \text{mole/L}$$

c. Write equilibrium expression

$$K_a = \frac{[H^+][OCl^-]}{[HOCl]} = 10^{-7.54} = 2.884\times10^{-8}$$

d. With $[H^+] = 10^{-7}$ and hypochlorous acid concentration

$$K_a = \frac{[10^{-7}][OCl^-]}{[1.371\times10^{-5}]} = 2.884\times10^{-8}$$

e. Solve for $[OCl^-]$

$[OCl^-] = 3.954 \text{ x } 10^{-6}$ mole/L

f. Convert to mg/L

(3.954 x 10 6 mole/L)(51.452 g/mole)(1000 mg/g) = 0.2034 mg/L

4-28 Converting from mg/L to mg/L as $CaCO_3$

Given: Concentrations in mg/L as ion.

Solution: E.W. of $CaCO_3$ = 50.04

a. Ca^{2+} (n = 2 because valence = 2)

$$\text{E.W.} = \frac{40.08}{2} = 20.04$$

$$\text{mg/L as } CaCO_3 = 83.00\,\text{mg/L}\left(\frac{50.04}{20.04}\right) = 207.3$$

b. Mg^{2+} (n = 2 because valence = 2)

$$\text{E.W.} = \frac{24.305}{2} = 12.1525$$

$$\text{mg/L as } CaCO_3 = 27.00\,\text{mg/L}\left(\frac{50.04}{12.1525}\right) = 111.2$$

c. CO_2 (n = 2 because H_2CO_3 has 2 hydrogens)

$$\text{E.W.} = \frac{44.01}{2} = 22.00$$

$$\text{mg/L as CaCO}_3 = 48.00\,\text{mg/L}\left(\frac{50.04}{22.00}\right) = 109.2$$

d. HCO_3^- (n = 1 because valence = 1)

$$\text{E.W.} = \frac{61.02}{1} = 61.02$$

$$\text{mg/L as CaCO}_3 = 220.00\,\text{mg/L}\left(\frac{50.04}{61.02}\right) = 180.4$$

e. CO_3^{2-} (n = 2 because valence = 2)

$$\text{E.W.} = \frac{60.01}{2} = 30.00$$

$$\text{mg/L as CaCO}_3 = 15.00\,\text{mg/L}\left(\frac{50.04}{30.00}\right) = 25.02$$

4-29 Converting from mg/L to mg/L as $CaCO_3$

Given: Concentrations in mg/L as ion

Solution: E.W. of $CaCO_3$ = 50.04

a. HCl (n = 1 because 1 replaceable H)

$$\text{E.W.} = \frac{36.461}{1} = 36.461$$

$$\text{mg/L as CaCO}_3 = 200.00\,\text{mg/L}\left(\frac{50.04}{36.461}\right) = 274.5$$

b. CaO (n = 2 since Ca must be replaced by 2 H^+)

$$\text{E.W.} = \frac{56.08}{2} = 28.04$$

$$\text{mg/L as CaCO}_3 = 280.00\,\text{mg/L}\left(\frac{50.04}{28.04}\right) = 499.7$$

c. Na_2CO_3 (n = 2 because Na must be replaced by 2 H^+)

$$\text{E.W.} = \frac{105.99}{2} = 53.00$$

$$\text{mg/L as CaCO}_3 = 123.45\,\text{mg/L}\left(\frac{50.04}{53.00}\right) = 116.6$$

d. $Ca(HCO_3)_2$ (n = 2 as in b.)

$$\text{E.W.} = \frac{162.12}{2} = 81.06$$

$$\text{mg/L as CaCO}_3 = 85.05\,\text{mg/L}\left(\frac{50.04}{81.06}\right) = 52.5$$

e. Na^+ (n = 1 because valence = 1)

$$\text{E.W.} = \frac{22.9898}{1} = 22.9898$$

$$\text{mg/L as CaCO}_3 = 19.90\,\text{mg/L}\left(\frac{50.04}{22.9898}\right) = 9.143$$

4-30 Converting from mg/L as $CaCO_3$ to mg/L

Given: Concentrations in mg/L as $CaCO_3$

Solution:

a. SO_4^{2-} (n = 2 because valence = 2)

$$\text{E.W.} = \frac{96.06}{2} = 48.03$$

$$\text{mg/L} = 100.00\text{ mg/L as CaCO}_3\left(\frac{48.03}{50.04}\right) = 95.98$$

b. HCO_3^- (n = 1 because valence = 1)

$$\text{E.W.} = \frac{61.016}{1} = 61.016$$

$$\text{mg/L} = 30.00 \text{ mg/L as } CaCO_3 \left(\frac{61.016}{50.04}\right) = 36.58$$

c. Ca^{2+} (n = 2 because valence = 2)

$$\text{E.W.} = \frac{40.08}{2} = 20.04$$

$$\text{mg/L} = 150.00 \text{ mg/L as } CaCO_3 \left(\frac{20.04}{50.04}\right) = 60.07$$

d. H_2CO_3 (n = 2 because 2 H)

$$\text{E.W.} = \frac{62.03}{2} = 31.02$$

$$\text{mg/L} = 10.00 \text{ mg/L as } CaCO_3 \left(\frac{31.02}{50.04}\right) = 6.198$$

e. Na^+ (n = 1 because valence = 1)

$$\text{E.W.} = \frac{22.9898}{1} = 22.9898$$

$$\text{mg/L} = 150.00 \text{ mg/L as } CaCO_3 \left(\frac{22.9898}{50.04}\right) = 68.91$$

4-31 Converting from mg/L as $CaCO_3$ to mg/L

Given: Concentrations in mg/L as $CaCO_3$

Solution:

a. CO_2 (n = 2 because H_2CO_3 has 2 H^+ replaceable)

$$\text{E.W.} = \frac{44.01}{2} = 22.00$$

$$\text{mg/L} = 10.00 \text{ mg/L as CaCO}_3 \left(\frac{22.00}{50.04}\right) = 4.397$$

b. $Ca(OH)_2$ (n = 2 because Ca requires 2 H^+ for replacement)

$$\text{E.W.} = \frac{74.09}{2} = 37.045$$

$$\text{mg/L} = 13.50 \text{ mg/L as CaCO}_3 \left(\frac{37.045}{50.04}\right) = 9.994$$

c. H_3PO_4 (n = 3 because of 3 H)

$$\text{E.W.} = \frac{97.9951}{3} = 32.6650$$

$$\text{mg/L} = 481.00 \text{ mg/L as CaCO}_3 \left(\frac{32.6650}{50.04}\right) = 314.0$$

d. H_2PO_4 (n = 2 because of 2 H)

$$\text{E.W.} = \frac{96.9872}{2} = 48.4936$$

$$\text{mg/L} = 81.00 \text{ mg/L as CaCO}_3 \left(\frac{48.4936}{50.04}\right) = 78.50$$

e. Cl^- (n = 1 because valence = 1)

$$\text{E.W.} = \frac{35.453}{1} = 35.453$$

$$\text{mg/L} = 40.00 \text{ mg/L as CaCO}_3 \left(\frac{35.453}{50.04}\right) = 28.34$$

4-32 Convert N to mg/L as $CaCO_3$

Given: 0.0100 N Ca^{2+}

Solution:

a. Convert N to molarity (Eqn. 4-8)

$$N = M * n$$

$$M = (0.0100\ N) / 2 = 0.0050\ M$$

b. Convert M to mg/L

mg/L of species = (molarity)(GMW)(1000 mg/g)

$= (0.0050)(40.08)(1000) = 200.40$ mg/L as Ca^{2+}

c. Calculate equivalent weights (n = 2 for each)

$$\text{E.W. } CaCO_3 = \frac{40.08 + 12.01 + 3(16.00)}{2} = \frac{100.09}{2} = 50.045$$

$$\text{E.W. Ca} = \frac{40.08}{2} = 20.04$$

d. Convert mg/L to mg/L as $CaCO_3$ using Eqn. 4-40

$$\text{mg/L as } CaCO_3 = 200.40\ \text{mg/L}\left(\frac{50.04}{20.04}\right) = 500.4 \text{ or 500 mg/L as } CaCO_3$$

4-33 Exact alkalinity

Given: $HCO_3^- = 0.6580$ mg/L; pH = 5.66; $CO_3^{2-} = 0.00$

Solution:

a. Convert HCO_3^- to mg/L as $CaCO_3$

$$0.6580\left(\frac{50.04}{61.016}\right) = 0.53963 \text{ mg/L as } CaCO_3$$

b. Convert pH to $[H^+]$

$[H^+] = 10^{-5.66} = 2.188 \text{ x } 10^{-6}$ moles/L

c. In mg/L

mg/L = $(2.1886 \text{ x } 10^{-6}$ mole/L$)(1.0079 \text{ x } 10^{3}$ mg/mole$) = 2.205 \text{ x } 10^{-3}$

d. In mg/L as $CaCO_3$

$$\left(2.205\times10^{-3}\right)\left(\frac{50.04}{1.0079}\right) = 0.10948$$

e. Convert pH to OH

pOH = 14.00 - 5.66 = 8.34

$[OH] = 10^{-8.34} = 4.571 \text{ x } 10^{-9}$ mole/L

f. In mg/L

mg/L = $(4.571 \text{ x } 10^{-9})(17.007 \text{ x } 10^{3}$ mg/mole$) = 7.774 \text{ x } 10^{-5}$

g. In mg/L as $CaCO_3$

$$\left(7.774\times10^{-5}\right)\left(\frac{50.04}{17.007}\right) = 2.287\times10^{-4}$$

h. Exact alkalinity (all in mg/L as $CaCO_3$)

$ALK = HCO_3^- + CO_3^{2-} + OH^- - H^+$

$ALK = 0.53963 + 0 + 2.287 \text{ x } 10^{-4} - 0.10948$

ALK = 0.4302 or 0.43 mg/L as $CaCO_3$

4-34 Calculate approximate alkalinity

Given: HCO_3^- = 120 mg/L; CO_3^{2-} = 15.00 mg/L

Solution:

a. Convert to mg/L as $CaCO_3$

HCO_3^- (120 mg/L)(50.04/61.02) = 98.41

CO_3^{2-} (15.00 mg/L)(50.04/30.00) = 25.02

b. Calculate approximate alkalinity

ALK = 98.41 + 25.02 = 123.43 or 123. mg/L as $CaCO_3$

4-35 Exact alkalinity

Given: Problem 4-34; HCO_3^- = 120 mg/L; pH = 9.43; CO_3^{2-} = 15.00 mg/L

Solution:

a. Convert HCO_3^- to mg/L as $CaCO_3$

$$120.0\left(\frac{50.04}{61.016}\right) = 98.41 \text{ mg/L as } CaCO_3$$

b. Convert CO_3^{2-} to mg/L as $CaCO_3$

$$15.0\left(\frac{50.04}{30.004}\right) = 25.02 \text{ mg/L as } CaCO_3$$

c. Convert pH to H

$[H^+] = 10^{-9.43} = 3.715 \times 10^{-10}$ mole/L

d. In mg/L

mg/L = $(3.715 \times 10^{-10}$ mole/L$)(1.0079 \times 10^3$ mg/mole$) = 3.745 \times 10^{-7}$

e. In mg/L as $CaCO_3$

$$\left(3.745\times10^{-7}\right)\left(\frac{50.04}{1.0079}\right) = 1.86\times10^{-5}$$

f. Convert pH to $[OH^-]$

pOH = 14.00 - 9.43 = 4.57

$[OH^-] = 10^{-4.57} = 2.692 \times 10^{-5}$ mole/L

g. In mg/L

mg/L = $(2.692 \times 10^{-5})(17.007 \times 10^{3}$ mg/mole$) = 0.4578$

h. In mg/L as $CaCO_3$

$$0.4578\left(\frac{50.04}{17.007}\right) = 1.347$$

i. Exact alkalinity (all in mg/L as $CaCO_3$)

$ALK = HCO_3^- + CO_3^{2-} + OH^- - H^+$

$ALK = 98.41 + 25.02 + 1.347 - (1.86 \times 10\ 5)$

$ALK = 124.78$ mg/L as $CaCO_3$

4-36 Approximate alkalinity

Given: 15.00 mg/L HCO_3^-, 120.0 mg/L CO_3^{2-}

Solution:

a. Convert to mg/L as $CaCO_3$

HCO_3^- $$(15.00\,\text{mg/L})\left(\frac{50.04}{61.02}\right) = 12.30$$

CO_3^{2-} $$(120.0\,\text{mg/L})\left(\frac{50.04}{30.00}\right) = 200.16$$

b. Approximate alkalinity

$ALK = 12.30 + 200.16 = 212.46$ or 212.5 mg/L as $CaCO_3$

4-37 Derivations

Given: Equations 4-28, 4-36, 4-38, 4-39

Solution:

a. Starting with

Eqn. 4-28 $K_w = [OH^-][H^+]$

Eqn. 4-36 Alk = $[HCO_3^-] + 2[CO_3^{2-}] + [OH^-] - [H^+]$

Eqn. 4-38 $H_2CO_3 = H^+ + HCO_3^-$ $pK_{a1} = 6.35$

Eqn. 4-39 $HCO_3^- = H^+ + CO_3^{2-}$ $pK_{a2} = 10.33$

b. From equilibrium reactions (Eqns. 4-38, 4-39)

$$K_1 = \frac{[H^+][HCO_3^-]}{[H_2CO_3]}$$

$$K_2 = \frac{[H^+][CO_3^{2-}]}{[HCO_3^-]}$$

c. From definition of alkalinity where A = Alkalinity

$[HCO_3^-] = A - 2[CO_3^{2-}] - [OH^-] + [H^+]$

d. Substituting from Eqn. 4-28

$$[HCO_3^-] = A - 2[CO_3^{2-}] - \frac{K_w}{[H^+]} + [H^+]$$

e. Substituting the K_2 equilibrium expression for CO_3^{2-}

$$[HCO_3^-] = A - 2\left(\frac{K_2[HCO_3^-]}{[H^+]}\right) - \frac{K_w}{[H^+]} + [H^+]$$

f. Collecting terms

$$[HCO_3^-] + 2\left(\frac{K_2[HCO_3^-]}{[H^+]}\right) = A - \frac{K_w}{[H^+]} + [H^+]$$

g. Factor out $[HCO_3^-]$

$$[HCO_3^-]\left\{1 + \left(\frac{2K_2}{[H^+]}\right)\right\} = A - \frac{K_w}{[H^+]} + [H^+]$$

h. Solve for HCO_3^-

$$\left[HCO_3^-\right]=\frac{A-\frac{K_w}{\left[H^+\right]}+\left[H^+\right]}{\left\{1+\left(\frac{2K_2}{\left[H^+\right]}\right)\right\}}$$

i. Since we need bicarbonate alkalinity in mg/L as $CaCO_3$, a factor of 5 x 10^4 is used to convert $[HCO_3^-]$ to mg/L as $CaCO_3$ ($5x10^4$ = 50 x 1000 = E.W. of $CaCO_3$ x mL/L)

$$HCO_3^- = \frac{A-\left(5\times10^4\right)\frac{K_w}{\left[H^+\right]}+\left(5\times10^4\right)\left[H^+\right]}{\left\{1+\left(\frac{2K_2}{\left[H^+\right]}\right)\right\}}$$

$$HCO_3^- = \frac{\left(5\times10^4\right)\left\{\frac{A}{5\times10^4}-\frac{K_w}{\left[H^+\right]}+\left[H^+\right]\right\}}{\left\{1+\left(\frac{2K_2}{\left[H^+\right]}\right)\right\}}$$

j. An equation for CO_3^{2-} can be derived by putting the HCO_3^- expression into the K_2 equilibrium expression:

$$\left[CO_3^{2-}\right]=\left(\frac{2K_2}{\left[H^+\right]}\right)\frac{A-\frac{K_w}{\left[H^+\right]}+\left[H^+\right]}{1+\left(\frac{2K_2}{\left[H^+\right]}\right)}$$

k. In terms of mg/L $CaCO_3$ alkalinity

$$CO_3^{2-} = \left(\frac{2K_2}{\left[H^+\right]}\right)\frac{\left(5\times10^4\right)\left\{\frac{A}{5\times10^4}-\frac{K_w}{\left[H^+\right]}+\left[H^+\right]\right\}}{1+\left(\frac{2K_2}{\left[H^+\right]}\right)}$$

$$CO_3^{2-} = \left(\frac{2K_2}{\left[H^+\right]}\right)\left[HCO_3^-\right]$$

4-38 Calculating bicarbonate and carbonate alkalinity

Given: Total alkalinity = 233.00 mg/L as $CaCO_3$; pH = 10.47; Eqns. from Prob. 4-37.

Solution:

$$HCO_3^- = \frac{5\times10^4\left(\frac{233.00}{5\times10^4}+10^{-10.47}-\frac{10^{-14}}{10^{-10.47}}\right)}{1+\left(\frac{2\left(4.68\times10^{-11}\right)}{10^{-10.47}}\right)}$$

$$HCO_3^- = \frac{5\times10^4\left(4.66\times10^{-3}+3.388\times10^{-11}-2.951\times10^{-4}\right)}{1+2.762}$$

$$HCO_3^- = \frac{2.182\times10^2}{3.762} = 58.01 \text{ mg/L as } CaCO_3$$

$$CO_3^{2-} = 58.01\left(\frac{2\left(4.68\times10^{-11}\right)}{10^{-10.47}}\right)$$

$$CO_3^{2-} = (58.01)(2.762) = 160.22 \text{ mg/L as } CaCO_3$$

The total (58.01 + 160.22 = 210.23) does not equal total alkalinity (233.0) because the OH^-alkalinity is significant at a pH of 10.47.

With pOH = 14.00 – 10.47 = 3.53

$[OH^-] = 10^{-3.53}$

and the OH^- alkalinity in mg/L as $CaCO_3$ is

(10-3.53)(17.01)(1000 mg/g)(50.04/17.01) = 14.77 mg/L as $CaCO_3$

Thus the total alkalinity = 58.01 + 160.22 + 14.77 = 233.0

4-39 Calculate bicarbonate and carbonate alkalinity

Given: Solution to Problem 4-37 and water specified in 4-43. Total alkalinity = 284.0 mg/L as $CaCO_3$, pH = 7.6

Solution:

a. Bicarbonate

$$HCO_3^- = \frac{5\times10^4\left(\frac{284.0}{50000}+10^{-7.6}-\frac{10^{-14}}{10^{-7.6}}\right)}{1+\left(\frac{2\left(4.68\times10^{-11}\right)}{10^{-7.6}}\right)}$$

$$HCO_3^- = \frac{5\times10^4\left(5.68\times10^{-3}+2.512\times10^{-8}-3.981\times10^{-7}\right)}{1+3.726\times10^{-3}}$$

HCO_3^- = 2.829 x 10^2 mg/L as $CaCO_3$

b. Carbonate

$$CO_3^{2-} = 2.892\times10^2\left(\frac{2\left(4.68\times10^{-11}\right)}{10^{-7.6}}\right)=1.08 \text{ mg/L as } CaCO_3$$

Check total alkalinity

Total ALK = 282.9 + 1.08 = 283.99 or 284.0 mg/L as $CaCO_3$

4-40 Bicarbonate alkalinity as ion

Given: CO_3^{2-} = 120.00 mg/L as ion; pH = 10.30

Solution:

a. Convert CO_3^{2-} to mg/L as $CaCO_3$

$$120.00\frac{50.04}{30.00}=200.16 \text{ or } 200.2 \text{ mg/L as } CaCO_3$$

b. From Problem 4-37

$$200.16=\frac{2\left(4.68\times10^{-11}\right)}{10^{-10.30}}\left(HCO_3^-\right)$$

c. Solve for HCO_3^-

$$HCO_3^- = \left(\frac{200.16}{1.868}\right) = 107.177 \text{ mg/L as } CaCO_3$$

d. Convert to ion

$$HCO_3^- = 107.177\left(\frac{61.016}{50.04}\right) = 130.686 \text{ or } 130.7 \text{ mg/L}$$

4-41 Determining pH from carbonate and bicarbonate

Given: HCO_3^- = 120.00 and CO_3^{2-} = 15.00 mg/L as ion

Solution:

a. Convert to mg/L as $CaCO_3$

HCO_3^- = 120.00 (50.04/61.016) = 100.053

CO_3^{2-} = 15.00 (50.04/30.00) = 25.020

b. Use solution to Problem 4-37 and solve for $[H^+]$

$$25.020 = \left(\frac{2(4.68\times10^{-11})}{[H^+]}\right)(100.053)$$

$$[H^+] = \frac{9.365\times10^{-9}}{25.020} = 3.743\times10^{-10}$$

pH = $-\log(3.743 \times 10^{-10})$ = 9.427 or 9.43

4-42 Calculating alkalinity by two methods

Given: Data in Problem 4-40 and equations from Problem 4-37

Solution:

a. Calculate CO_3^{2-} and HCO_3 concentrations in mg/L as $CaCO_3$ in the same fashion as in Problem 4-40.

CO_3^{2-} = 200.16 mg/L as $CaCO_3$

HCO_3^- = 107.177 mg/L as $CaCO_3$

b. Setup equation from Problem 4-37 and solve for "A"

$$107.177 = \frac{5\times10^{4}\left(\frac{A}{5\times10^{4}} + 10^{-10.30} - \frac{10^{-14}}{10^{-10.30}}\right)}{1+\left(\frac{2\left(4.68\times10^{-11}\right)}{10^{-10.30}}\right)}$$

A = 317.07 mg/L as $CaCO_3$

c. By the exact method we need $[H^+]$ and $[OH^-]$ in units of mg/L as $CaCO_3$

d. Convert pH to $[H^+]$

$[H^+] = 10^{-10.30} = 5.012 \text{ x } 10^{-11}$ mole/L

e. In mg/L

mg/L = $(5.012 \text{ x } 10^{-11}$ mole/L$)(1.0079 \text{ x } 10^{3}$ mg/mole)

$= 5.051 \text{ x } 10^{-8}$

f. In mg/L as $CaCO_3$

$$\left(5.051\times10^{-8}\right)\left(\frac{50.04}{1.0079}\right) = 2.508\times10^{-6}$$

g. Convert pH to $[OH^-]$

pOH = 14.00 - 10.30 = 3.70

$[OH^-] = 10^{-3.70} = 1.995 \text{ x } 10^{-4}$ mole/L

h. In mg/L

mg/L = $(1.995 \text{ x } 10^{-4})(17.007 \text{ x } 10^{3}$ mg/mole) = 3.393

i. In mg/L as $CaCO_3$

$$3.393\left(\frac{50.04}{17.007}\right) = 9.984 \text{ mg/L as } CaCO_3$$

j. Exact alkalinity (all in mg/L as $CaCO_3$)

$$ALK = HCO_3^- + CO_3^{2-} + OH^- - H^+$$

$$ALK = 107.177 + 200.16 + 9.984 - (2.508 \times 10^{-6})$$

$$ALK = 317.32 \text{ mg/L as } CaCO_3$$

4-43 Total carbonate and noncarbonate hardness

Given: Concentrations as ion, see table below

Solution:

a. Begin by converting to mg/L as $CaCO_3$

Compound	mg/L as ion	EW/EW	mg/L as $CaCO_3$
Ca^{2+}	67.2	2.50	168.0
Mg^{2+}	40.0	4.12	164.8
HCO_3^-	--	--	284.0

b. Calculate TH, CH and NCH

$$TH = 168.0 + 164.8 = 332.8 \text{ mg/L as } CaCO_3$$

$$CH = HCO_3^- = 284.0 \text{ mg/L as } CaCO_3$$

$$NCH = TH - CH = 332.8 - 284.0 = 48.8 \text{ mg/L as } CaCO_3$$

4-44 Compute exact TH, CH and NCH

Given: Data from Problem 4-43

Solution:

a. Begin by converting to mg/L as $CaCO_3$. Note valences may be found in appendix.

Compound	mg/L as ion	EW/EW	mg/L as $CaCO_3$
Ca^{2+}	67.20	2.50	168.00
Mg^{2+}	40.00	4.12	164.80
HCO_3^-	--	--	284.00
Fe^{3+}	0.20	2.69	0.54
Ba	0.50	0.73	0.36
B	0.10	13.89	1.39

b. Calculate TH, CH and NCH

TH = 168.0 + 164.8 + 0.54 + 0.36 + 1.39 = 335.1 mg/L as $CaCO_3$

CH = HCO_3^- = 284.0 mg/L as $CaCO_3$

NCH = TH - CH = 335.1 - 284.0 = 51.1 mg/L as $CaCO_3$

c. Calculate percent error.

Error in TH = $\frac{335.1-332.8}{335.1}\times 100 = 0.69\%$

Error in CH = 0.00%

Error in NCH = $\frac{51.1-48.8}{51.1}\times 100 = 4.5\%$

4-45 Total, Carbonate, Non Carbonate Hardness

Given: Concentrations as shown below

Solution:

a. Begin by converting to mg/L as $CaCO_3$

Compound	mg/L as ion	EW/EW	mg/L as $CaCO_3$
Ca^{2+}	78.0	2.50	195.0
Mg^{2+}	32.0	4.12	131.8
HCO_3^-	--	--	494.0

b. Calculate TH, CH and NCH

TH = 195.0 + 131.8 = 326.8 mg/L as $CaCO_3$

CH = 326.8 mg/L as $CaCO_3$ (all hardness is carbonate)

NCH = 0.0 mg/L as $CaCO_3$

4-46 Total, Carbonate, Non Carbonate Hardness

Given: Concentrations as shown below

Solution:

a. Begin by converting to mg/L as $CaCO_3$

Compound	mg/L as ion	EW/EW	mg/L as $CaCO_3$
Ca^{2+}	96.8	2.50	242.0
Mg^{2+}	30.4	4.12	125.3
HCO_3^-	318.0	0.82	260.9

b. Calculate TH, CH and NCH

TH = 242.0 + 125.3 = 367.3 mg/L as $CaCO_3$

CH = 260.9 mg/L as $CaCO_3$

NCH = TH - CH = 367.3 - 260.9 = 106.4 mg/L as $CaCO_3$

4-47 Total, Carbonate, and Non-carbonate hardness

Given: Kool Artesian Water analysis

Solution:

a. Using solution from Problem 4-32 to find bicarbonate concentration

$$HCO_3^- = \frac{5\times10^4\left(\dfrac{285.0}{50000}+10^{-7.6}-\dfrac{10^{-14}}{10^{-7.6}}\right)}{1+\left(\dfrac{2\left(4.68\times10^{-11}\right)}{10^{-7.6}}\right)}$$

$$HCO_3^- = \frac{5\times10^4\left(5.70\times10^{-3}+2.512\times10^{-8}-3.981\times10^{-7}\right)}{1+\left(3.762\times10^{-3}\right)}$$

HCO_3^- = 285.0 mg/L as $CaCO_3$

b. Convert Ca^{2+} and Mg^{2+} concentrations to mg/L as $CaCO_3$

$$Ca^{2+} = \left(37.0\,\text{mg/L}\right)\left(\frac{50.04}{20.04}\right) = 92.39 \text{ mg/L as } CaCO_3$$

$$Mg^{2+} = \left(18.1\text{mg/L}\right)\left(\frac{50.04}{12.16}\right) = 74.51 \text{ mg/L as } CaCO_3$$

c. TH, CH, and NCH

TH = 92.39 + 74.51 = 166.90 mg/L as $CaCO_3$

CH = 166.90 mg/L as $CaCO_3$

NCH = 0.0 mg/L as $CaCO_3$

4-48 Reaction order and rate constant

Given: Data table

Solution:

a. The data plot as a straight line on semi log paper. Thus, the reaction order is first order based on the linearized forms shown in Table 4-6.

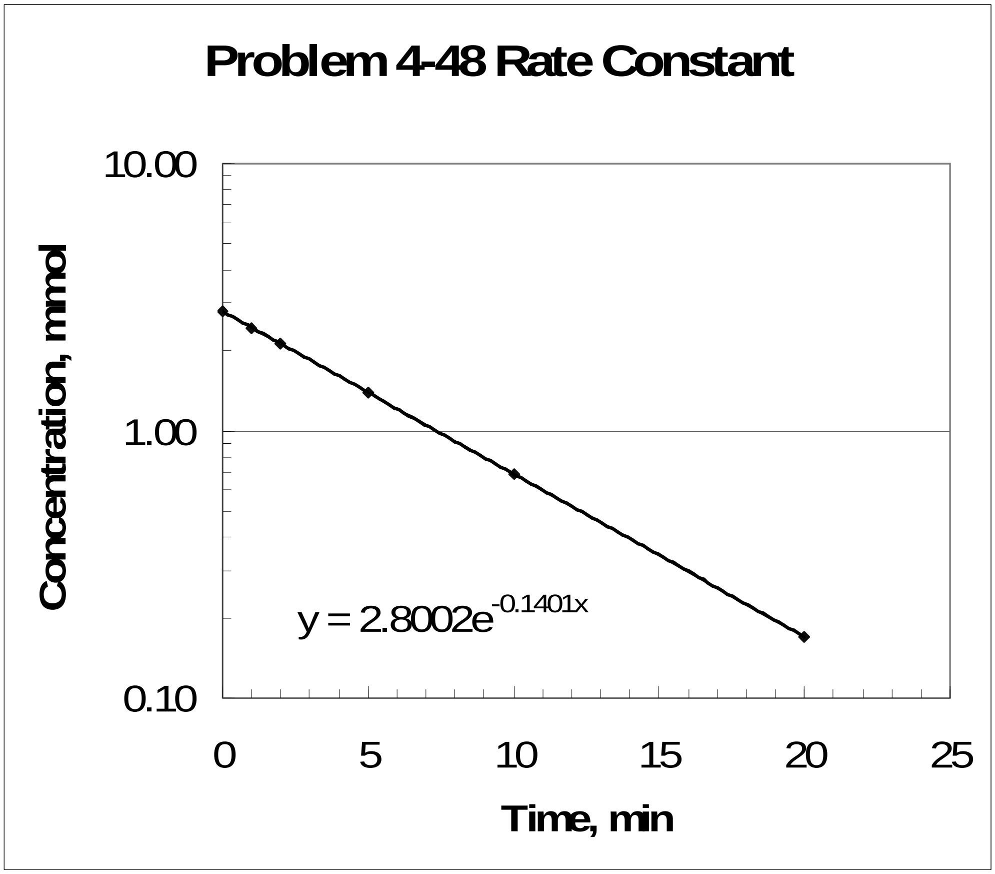


Figure S-4-48: Rate constant plot

b. The rate constant may be determined by selecting values of A_0, A, and the corresponding time increment.

$$\ln\left(\frac{A}{A_0}\right) = -Kt$$

At t = 5 min

$$\ln\left(\frac{1.39}{2.80}\right) = -K(5)$$

$$-0.7003 = -K(5)$$

$$K = 0.1401 \text{ min}^{-1}$$

4-49 Reaction order and rate constant

Given: Data table

Solution:

a. The data plot as a straight line on arithmetic paper if the concentration is plotted as $1/[A_0]$. Thus, the reaction order is second order based on the linearized forms shown in Table 4-6.

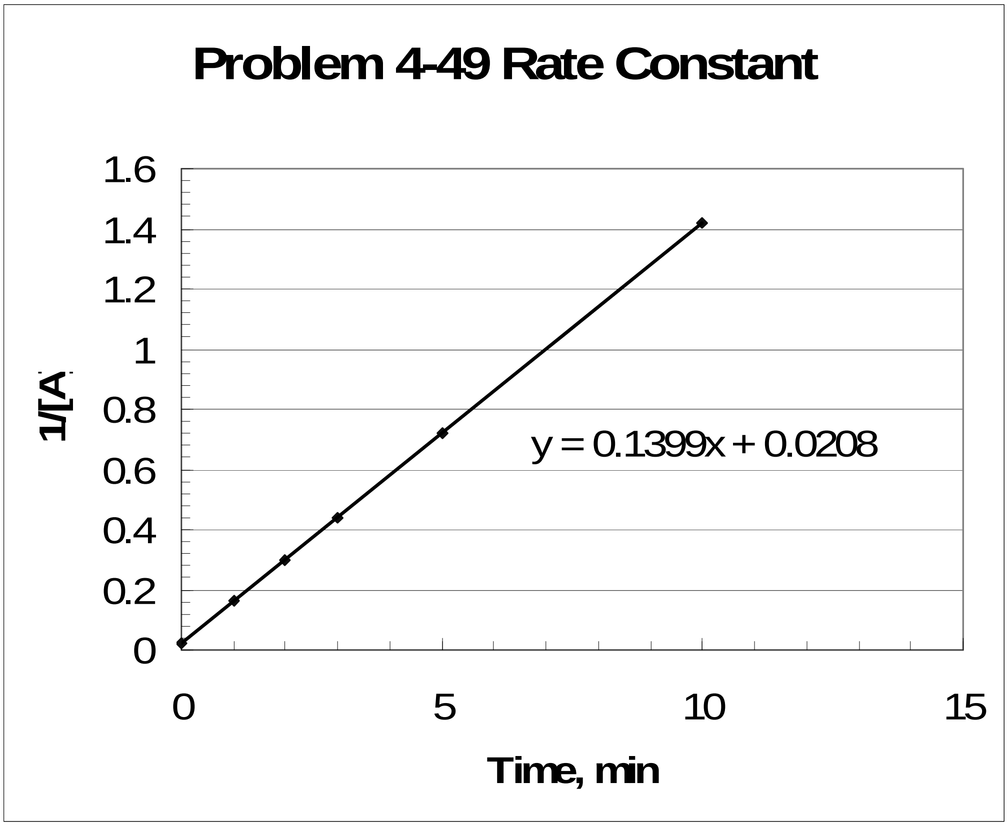


Figure S-4-49: Rate constant plot

b. The rate constant may be determined by selecting values of A_0, A, and the corresponding time increment.

$$\frac{1}{A} + \frac{1}{A_0} = Kt$$

At t = 5 min

$$\frac{1}{1.39} + \frac{1}{48.0} = K(5)$$

$$0.72 + 0.021 = K(5)$$

$$K = 0.1482 \text{ min}^{-1}$$

(Slightly different K will result for other time intervals.)

4-50 Alkalinity remaining after alum dose

Given: Total alkalinity = 130.0 mg/L as $CaCO_3$; pH = 7.4; alum dose = 60.00 mg/L

Solution:

a. Since pH is 7.4 all alkalinity may be assumed to be bicarbonate

b. Convert alum to $CaCO_3$ equivalent. From the equivalent weight equation and the discussion that follows the Eqn., n=6

$$\text{E.W.} = \frac{594.346}{6} = 99.058$$

$$60.00\left(\frac{50.04}{99.058}\right) = 30.31 \text{ mg/L as } CaCO_3$$

c. This is equal to the amount of alkalinity that will be destroyed. Thus, the alkalinity remaining is

HCO_3^- remaining = 130.0 - 30.31 = 99.69 or 100 mg/L as $CaCO_3$

4-51 Alkalinity remaining after ferric chloride dose

Given: Total alkalinity = 136.0 mg/L as $CaCO_3$; pH = 7.6; ferric chloride dose = 30.00 mg/L

Solution:

a. With pH = 7.6 assume all alkalinity is HCO_3^-

b. Convert ferric chloride to $CaCO_3$ equivalent. From Eqn 4-53, note that each mole of ferric chloride destroys 3 moles of alkalinity and n = 3.

$$\text{E.W.} = \frac{162.206}{3} = 54.069$$

$$30.00\left(\frac{50.04}{54.069}\right) = 27.76 \text{ mg/L as } CaCO_3$$

HCO_3^- remaining = 136.0 - 27.8 = 108.2 mg/L as $CaCO_3$

4-52 Alkalinity remaining after alum dose

Given: Total alkalinity = 29.5 mg/L as $CaCO_3$; pH = 7.2; alum dose = 40.00 mg/L

Solution:

a. Since pH is 7.2 all alkalinity may be assumed to be bicarbonate

b. Convert alum to $CaCO_3$ equivalent. From the equivalent weight equation and the discussion that follows the Eqn., n = 6

$$\text{E.W.} = \frac{594.346}{6} = 99.058$$

$$40.00\left(\frac{50.04}{99.058}\right) = 20.21 \text{ mg/L as } CaCO_3$$

c. This is equal to the amount of alkalinity that will be destroyed. Thus, the alkalinity remaining is

HCO_3^- remaining = 29.5 - 20.21 = 9.29 mg/L as $CaCO_3$

4-53 Bar chart of Problem 4-43

Given: Data in Problem 4-43

Solution:

a. E.W. $CaCO_3$

Ion	mg/L as ion	EW ion	mg/L as $CaCO_3$
Fe^{3+}	0.20	2.69	0.54
Mn	0.00	1.82	0.00
NH_3	0.50	2.78	1.39
Na	4.70	2.18	10.25
K	0.90	1.28	1.15
Ca	67.20	2.50	168.00
Mg	40.00	4.12	164.80
Ba	0.50	0.73	0.36
SiO_2	20.00	0.83	16.60
F	0.35	2.63	0.92
B	0.10	13.89	1.39
NO_3	0.00	0.81	0.00
Cl	4.50	1.41	6.35
SO_4	29.00	1.04	30.16
HCO_3	--	--	284.00

pH = 7.6

b. CO_2 calculation

With pH < 8.3 assume all alkalinity is HCO_3^-

$$K_{a1} = \frac{[H^+][HCO_3^-]}{[H_2CO_3]}$$

$pK_a = 6.35$ from Table 4-4

Assume 1 mole H_2CO_3 = 1 mole CO_2

$$CO_2 + H_2O \rightarrow H_2CO_3$$

Convert HCO_3^- mg/L as $CaCO_3$ to mole/L

$$[HCO_3^-] = (284\,mg/L)\left(\frac{1}{61\,g/mole}\right)\left(\frac{1}{1000\,mg/g}\right)\left(\frac{61 E.W. HCO_3^-}{50 E.W. CaCO_3}\right)$$

$[HCO_3^-] = 5.68 \times 10^{-3}$ mole/L

Convert pH to mole/L

$[H^+] = 10^{-7.6} = 2.51 \times 10^{-8}$ mole/L

Convert pK_{a1} to K_a

$K_{a1} = 10^{-6.35} = 4.47 \times 10^{-7}$

Solve for H_2CO_3

$$[H_2CO_3] = \frac{(2.51\times10^{-8})(5.68\times10^{-3})}{(4.47\times10^{-7})}$$

$[H_2CO_3] = 3.19 \times 10^{-4}$ mole/L

Since $CO_2 = H_2CO_3$

$[CO_2] = 3.19 \times 10^{-4}$ mole/L

Convert mole/L to mg/L as $CaCO_3$

$$(3.19\times10^{-4}\text{ mole/L})(44\text{ g/mole})(1000\text{ mg/g})\left(\frac{50.04}{22.00}\right)$$

$CO_2 = 31.9$ mg/L as $CaCO_3$

4-54 Bar chart of Problem 4-45

Given: Data in Problem 4-45

Solution:

a. E.W. $CaCO_3$

Ion	mg/L as ion	EW ion	mg/L as $CaCO_3$
Fe^{3+}	0.42	2.69	1.13
Mn	0.04	1.82	0.07
NH_3	11.00	2.78	30.58
Na	78.00	2.18	170.04
K	2.60	1.28	3.33
Ca	78.00	2.50	195.00
Mg	32.00	4.12	131.84
Ba	0.50	0.73	0.37
Cu	0.01	1.57	0.02
Zn	0.01	1.53	0.02
SiO_2	20.00	0.83	16.60
F	0.30	2.63	0.79
B	0.30	13.89	4.17
NO_3	0.00	0.81	0.00
Cl	9.00	1.41	12.69
SO_4	0.00	1.04	0.00
HCO_3	--	--	494.00

pH = 7.7

b. Calculate CO_2

$$K_a = \frac{[H^+][HCO_3^-]}{[H_2CO_3]}$$

$pK_a = 6.35$ from Table 4-4

Assume 1 mole H_2CO_3 = 1 mole CO_2

$$CO_2 + H_2O \rightarrow H_2CO_3$$

Convert HCO_3^- mg/L as $CaCO_3$ to mole/L

$$[HCO_3^-] = (494\,mg/L)\left(\frac{1}{61\,g/mole}\right)\left(\frac{1}{1000\,mg/g}\right)\left(\frac{61 E.W. HCO_3^-}{50 E.W. CaCO_3}\right)$$

$[HCO_3^-] = 9.88 \times 10^{-3}$ mole/L

Convert pH to mole/L

$[H^+] = 10^{-7.7} = 2.00 \times 10^{-8}$ mole/L

Convert pK_{a1} to K_a

$K_{a1} = 10^{-6.35} = 4.47 \times 10^{-7}$

Solve for $[H_2CO_3]$

$$[H_2CO_3] = \frac{(2.00\times10^{-8})(9.88\times10^{-3})}{(4.47\times10^{-7})}$$

$[H_2CO_3] = 4.42 \times 10^{-4}$ mole/L

Since $CO_2 = H_2CO_3$

$[CO_2] = 4.42 \times 10^{-4}$ mole/L

Convert mole/L to mg/L as $CaCO_3$

$$CO_2 = (4.42\times10^{-4}\text{ mole/L})(44\text{ g/mole})(1000\text{ mg/g})\left(\frac{50.04}{22.00}\right)$$

$CO_2 = 44.2$ mg/L as $CaCO_3$

4-55 Bar chart of Problem 4-46

Given: Data in Problem 4-46

Solution:

a. E.W. as $CaCO_3$ (continued on following page)

Ion	mg/L as ion	EW ion	mg/L as $CaCO_3$
F	1.10	2.63	2.89
Cl	4.00	1.41	5.64
NO_3	0.00	0.81	0.00
Na	14.00	2.18	30.52
K	1.60	1.28	2.05
Ca	96.80	2.50	242.00
Mg	30.40	4.12	125.25
SiO_2	13.40	0.83	11.12
HCO_3	318.00	0.82	260.76
SO_4	52.00	1.04	54.08
Fe	0.50	2.69	1.35
Mn	0.07	1.82	0.13
Zn	0.27	1.53	0.41
Ba	0.20	0.73	0.15

b. Because the pH is not given the CO2 concentration cannot be calculated.

4-56 Bar chart of Lake Michigan water

Given: Lake Michigan data

Solution:

a. Convert constituents to mg/L as $CaCO_3$

Constituent	mg/L as ion	EW ion	mg/L as $CaCO_3$
Ca	38.4	2.5	96
Mg	11.4	4.12	46.968
Fe	0.1	2.69	0.269
Na	5.8	2.18	12.644
Cl	14	1.41	19.74
SO_4	26	1.04	27.04
SiO_2	1.2	0.83	0.996
HCO_3^-	--	--	115

b. Calculate CO_2 (ignoring carbonate alkalinity)

$$K_{a1} = \frac{[H^+][HCO_3^-]}{[H_2CO_3]}$$

$pK_{a1} = 6.35$ From Table 4-4

Assume 1 mole H_2CO_3 = 1 mole CO_2

$$CO_2 + H_2O \rightarrow H_2CO_3$$

Convert HCO_3^- mg/L as $CaCO_3$ to mole/L

$$[HCO_3^-] = (115\,mg/L)\left(\frac{1}{61\,g/mole}\right)\left(\frac{1}{1000\,mg/g}\right)\left(\frac{61 E.W. HCO_3^-}{50 E.W. CaCO_3}\right)$$

$[HCO_3^-] = 2.30 \times 10^{-3}$ mole/L

Convert pH to mole/L

$[H^+] = 10^{-8.4} = 3.98 \times 10^{-9}$

Convert pK_{a1} to K_{a1}

$K_{a1} = 10^{-6.35} = 4.47 \times 10^{-7}$

Solve equilibrium expression for $[H_2CO_3]$

$$[H_2CO_3] = \frac{(3.98\times10^{-9})(2.30\times10^{-3})}{(4.47\times10^{-7})} = 2.05\times10^{-5}\ mole/L$$

Since $CO_2 = H_2CO_3$

$[CO_2] = 2.05 \times 10^{-5}$ mole/L

Convert mole/L to mg/L as $CaCO_3$

$$CO_2 = (2.05\times10^{-5}\ mole/L)(44\,g/mole)(1000\,mg/g)\left(\frac{50.04}{22.00}\right)$$

$CO_2 = 2.05$ mg/L as $CaCO_3$

4-57 Water softening; Mg < 40 mg/L as $CaCO_3$

Given: Ca = 120.0; Mg = 30.0; HCO_3^- = 70.0; CO_2 = 10.0; all mg/L as $CaCO_3$.

Solution:

a. Compute TH, CH and NCH

TH = 120.0 + 30.0 = 150.0 mg/L as $CaCO_3$

CH = 70.0 mg/L as $CaCO_3$

NCH_i = 150.0 - 70.0 = 80.0 mg/L as $CaCO_3$

b. Compute Lime Additions (all as mg/L as $CaCO_3$)

Lime = CO_2 = 10.0

Lime = HCO_3^- = 70.0

Since Mg^{2+} is < 40 add lime = 20.0

Total Lime = 10.0 + 70.0 + 20.0 = 100.0 mg/L as $CaCO_3$

c. Compute Soda (all as mg/L as $CaCO_3$)

NCH_f = 80.00 - 40.0 = 40.0

$NCH_R = NCH_i - NCH_f$ = 80.00 - 40.00 = 40.00

Add soda = 40.0 mg/L as $CaCO_3$

4-58 Water softening; Mg < 40 mg/L as $CaCO_3$

Given: CO_2 = 4.6, Ca = 257.9, Mg =22.2, HCO_3^- = 248.0, SO_4^{2+} = 32.1; all mg/L as $CaCO_3$

Solution:

a. Calculate TH, CH, and NCH_i

TH = 257.9 + 22.2 = 280.10 mg/L as $CaCO_3$

CH = 248.0 mg/L as $CaCO_3$

NCH_i = 280.10 – 248.0 = 32.10 mg/L as $CaCO_3$

b. Computer lime additions (all mg/L as $CaCO_3$)

Lime = CO_2 = 4.60

Lime = HCO_3^- = 248.0

Since Mg2+ < 40 add an excess of lime = 20.0

Total lime = 4.6 + 248.0 + 20.0 = 272.6 mg/L as $CaCO_3$

c. Compute Soda ash additions (all mg/L as $CaCO_3$)

NCH_f = 80.0 – 40.0 = 40.0

NCH_R = 32.10 – 40.0 = -7.90

Negative number, therefore no soda ash required.

4-59 Water softening; Mg < 40 mg/L as $CaCO_3$

Given: Ca = 210.0; Mg = 23.0; HCO_3^- = 165.0; CO_2 = 5.0; all mg/L as $CaCO_3$. Lime is 90% pure and soda ash is 97% pure.

Solution:

a. Compute TH, CH and NCH

TH = 210.0 + 23.0 = 233.0 mg/L as $CaCO_3$

CH = 165.0 mg/L as $CaCO_3$

NCHi = 233.0 - 165.0 = 68.0 mg/L as $CaCO_3$

b. Compute Lime Additions (all as mg/L as $CaCO_3$)

Lime = CO_2 = 5.0

Lime = HCO_3^- = 165.0

Since Mg^{2+} is < 40 add lime = 20.0

Total Lime = 5.0 + 165.0 + 20.00 = 190.0 mg/L as $CaCO_3$

c. Compute Soda (all as mg/L as $CaCO_3$)

NCH_f = 80.00 - 40.0 = 40.0

$NCH_R = NCH_i - NCH_f$ = 68.0 - 40.0 = 28.0

Soda = 28.0 mg/L as $CaCO_3$

d. Convert lime to CaO and correct for purity
(Note E.W. of CaO = 28 and E.W. of CaCO3 = 50)

$$(190.0 \text{ mg/L as } CaCO_3)\left(\frac{28}{50}\right)\left(\frac{1}{0.9}\right) = 118.22 \text{ or } 118 \text{ mg/L CaO}$$

e. Convert soda to Na_2CO_3 and correct for purity
(Note: E.W. of Na_2CO_3 = 53)

$$(28.0 \text{ mg/L as } CaCO_3)\left(\frac{53}{50}\right)\left(\frac{1}{0.97}\right) = 30.59 \text{ or } 31 \text{ mg/L } Na_2CO_3$$

4-60 Soften water

Given: Ca = 220.0; Mg = 75.0; HCO_3^- = 265.0; CO_2 = 17.0 all mg/L as $CaCO_3$

Solution:

a. Compute TH, CH and NCH

TH = 220.0 + 75.0 = 295.0 mg/L as $CaCO_3$

CH = 265.0 mg/L as $CaCO_3$

NCH = 295.0 - 265.0 = 30.0 mg/L as $CaCO_3$

b. Compute Lime Additions (all as $CaCO_3$)

Lime = CO_2 = 17.0

Lime = HCO_3^- = 265.0

Since Mg is > 40 add lime = 75.0 - 40.0 = 35.0
and Delta = 35.0

Is Delta > 40? No

Is Delta < 20? No

Add lime = Delta = 35.0

Total Lime = 17.0 + 265.0 + 35.0 + 35.0 = 352.0 mg/L as $CaCO_3$

c. Compute Soda

$NCH_f = 70.0 - 40 = 30$

$NCH_R = NCH_i - NCH_f = 30.0 - 30.0 = 0$

Add no soda ash

4-61 Water softening; (Mg – 40) is >20 and < 40

Given: $CO_2 = 39.8$, Ca = 167.7, Mg = 76.3, $HCO_3^- = 257.9$; all in mg/L as $CaCO_3$

Solution:

a. Calculate TH, CH, and NCH

TH = 167.7 + 76.3 = 244.0 mg/L as $CaCO_3$

Because $HCO_3^- > TH$, all the hardness is CH.

CH = 244.0

$NCH_i = 0.0$

b. Calculate lime additions (all mg/L as $CaCO_3$)

Lime = $CO_2 = 39.8$

Lime = $HCO_3^- = 257.9$

Lime = Mg – 40 = 76.3 – 40 = 36.3

Because (Mg – 40) is > 20 and < 40 add excess lime = Mg – 40 = 36.3

Total Lime = 39.8 +257.9 +36.3 + 36.3 = 370.3 mg/L as $CaCO_3$

4-62 Soften water

Given: Ca = 137.0; Mg = 56.0; $HCO_3^- = 128.0$; $CO_2 = 7.0$ all mg/L as $CaCO_3$. Lime is 93% pure and soda ash is 95% pure.

Solution:

a. Compute TH, CH and NCH

TH = 137.0 + 56.0 = 193.0 mg/L as $CaCO_3$

CH = 128.0 mg/L as $CaCO_3$

NCH = 193.0 - 128.0 = 65.0 mg/L as $CaCO_3$

b. Compute Lime Additions (all as $CaCO_3$)

Lime = CO_2 = 7.0

Lime = HCO_3^- = 128.0

Since Mg is > 40 add lime = 56.0 - 40.0 = 16.0
and Delta = 16.0

Is Delta > 40? No

Is Delta < 20? Yes

Add lime = 20.0

Total Lime = 7.0 + 128.0 + 16.0 + 20.0 = 171.0 mg/L as $CaCO_3$

c. Compute Soda

NCH_f = 80.0 - 40 = 40

$NCH_R = NCH_i - NCH_f$ = 65.0 - 40.0 = 15.0

Soda = 15.0 mg/L as $CaCO_3$

d. Convert lime to CaO and correct for purity
(Note E.W. of CaO = 28 and E.W. of $CaCO_3$ = 50)

$$(171.0 \text{ mg/L as } CaCO_3)\left(\frac{28}{50}\right)\left(\frac{1}{0.93}\right) = 102.97 \text{ or } 103 \text{ mg/L CaO}$$

e. Convert soda to Na2CO3 and correct for purity
(Note: E.W. of Na_2CO_3 = 53)

$$(15.0 \text{ mg/L as } CaCO_3)\left(\frac{53}{50}\right)\left(\frac{1}{0.95}\right) = 16.74 \text{ or } 17 \text{ mg/L } Na_2CO_3$$

4-63 Water softening; Mg > 40 mg/L as $CaCO_3$

Given: CO_2 = 44.2, Ca = 87.4, Mg = 96.3, HCO_3^- = 204.6; all mg/L as $CaCO_3$

Solution:

a. Calculate TH, CH, and NCH (all mg/L as $CaCO_3$)

TH = 87.4 + 96.3 = 183.7

Because HCO_3^- > TH, all the hardness is CH.

CH = 183.7

NCH_i = 0.0

b. Lime addition (all mg/L as $CaCO_3$)

Lime = CO2 = 44.2

Lime = HCO3- = 204.6

Lime = Mg – 40 = 96.3 – 40 = 56.3

Because (Mg – 40) is > 40, add excess lime = 40.0

Total Lime = 44.2 + 204.6 +56.3 + 40.0 = 345.1 mg/L as $CaCO_3$

c. Compute soda ash additions

Because there is no NCH, add no soda ash.

4-64 Soften water

Given: Water described in Prob. 4-43
Ca = 67.2 mg/L as ion
Mg = 40.0 mg/L as ion
Alkalinity = 284. mg/L as $CaCO_3$
pH = 7.6

Required: Soften water to 100.0 mg/L as $CaCO_3$

Solution:

a. Calculate CO_2 content

Since pH < 8.3 assume all alkalinity is HCO_3^-

$$K_a = \frac{[H^+][HCO_3^-]}{[H_2CO_3]}$$

$pK_a = 6.35$ from Table 4-4

Assume 1 mole H_2CO_3 = 1 mole CO_2

$$CO_2 + H_2O \rightarrow H_2CO_3$$

Convert HCO_3^- mg/L as $CaCO_3$ to mole/L

$$[HCO_3^-] = (284\,\text{mg/L})\left(\frac{1}{61\,\text{g/mole}}\right)\left(\frac{1}{1000\,\text{mg/g}}\right)\left(\frac{61\text{E.W.}HCO_3^-}{50\text{E.W.}CaCO_3}\right)$$

$[HCO_3^-] = 5.68 \times 10^{-3}$ mole/L

Convert pH to mole/L

$[H^+] = 10^{-7.6} = 2.51 \times 10^{-8}$ mole/L

Convert pK_{a1} to K_a

$K_{a1} = 10^{-6.35} = 4.47 \times 10^{-7}$

Solve for H_2CO_3

$$[H_2CO_3] = \frac{(2.51\times10^{-8})(5.68\times10^{-3})}{(4.47\times10^{-7})}$$

$[H_2CO_3] = 3.19 \times 10^{-4}$ mole/L

Since $CO_2 = H_2CO_3$
$[CO_2] = 3.19 \times 10^{-4}$ mole/L

Convert mole/L to mg/L as $CaCO_3$

$$(3.19\times10^{-4}\,\text{mole/L})(44\,\text{g/mole})(1000\,\text{mg/g})\left(\frac{50.04}{22.0}\right) = 44.2\,\text{mg/L as } CaCO_3$$

b. Calculate concentration of Ca and Mg as mg/L as $CaCO_3$

Ca = (67.2 mg/L) (2.50 EW $CaCO_3$/EW ion) = 168 mg/L as $CaCO_3$

Mg = (40.0 mg/L) (4.12 EW $CaCO_3$/EW ion) = 164.8 mg/L as $CaCO_3$

c. Calculate TH, CH and NCH

TH = 168.0 + 164.8 = 332.8 mg/L as $CaCO_3$

CH = lesser of TH or alkalinity = 284.mg/L as $CaCO_3$

NCH = 332.8 - 284.0 = 48.8 mg/L as $CaCO_3$

d. Soften the water (All additions are mg/L as $CaCO_3$)

Lime = CO_2 = 31.90

Lime = HCO_3^- = 284.

Lime = Mg - 40. = 164.8 - 40. = 124.8 and Delta = 124.8

Since Delta is > 40, excess lime = 40.

Total Lime = 31.90 + 284. + 124.8 + 40 = 480.7 or 481 mg/L as $CaCO_3$

NCH = 100.0 - 40.0 = 60.0 mg/L as $CaCO_3$

NCH = 48.8 - 60.0 = 11.20 mg/L as $CaCO_3$

No soda ash is required

4-65 Soften water

Given: Water described in Prob. 4-50

TH = 260 mg/L as $CaCO_3$
Ca = 235 mg/L as $CaCO_3$
Mg = 25 mg/L as $CaCO_3$
Alkalinity = 130mg/L as $CaCO_3$
pH = 7.4

Required: Soften water to 90 mg/L as $CaCO_3$

Solution:

a. Calculate CO_2 content

Since pH < 8.3 assume all alkalinity is HCO_3^-

$$K_a = \frac{[H^+][HCO_3^-]}{[H_2CO_3]}$$

$pK_a = 6.35$ from Table 4-4

Assume 1 mole H_2CO_3 = 1 mole CO_2

$$CO_2 + H_2O \rightarrow H_2CO_3$$

Convert HCO_3^- mg/L as $CaCO_3$ to mole/L

$$[HCO_3^-] = (130\,mg/L)\left(\frac{1}{61\,g/mole}\right)\left(\frac{1}{1000\,mg/g}\right)\left(\frac{61 E.W. HCO_3^-}{50 E.W. CaCO_3}\right)$$

$[HCO_3^-] = 2.60 \times 10^{-3}$ mole/L

Convert pH to mole/L

$[H^+] = 10^{-7.4} = 3.98 \times 10^{-8}$ mole/L

Convert pK_{a1} to K_a

$K_{a1} = 10^{-6.35} = 4.47 \times 10^{-7}$

Solve for H_2CO_3

$$[H_2CO_3] = \frac{(3.98\times10^{-8})(2.60\times10^{-3})}{(4.47\times10^{-7})}$$

$[H_2CO_3] = 2.31 \times 10^{-4}$ mole/L

Since $CO_2 = H_2CO_3$

$[CO_2] = 2.31 \times 10^{-4}$ mole/L

Convert mole/L to mg/L as $CaCO_3$

$$(2.31\times10^{-4}\ mole/L)(44\,g/mole)(1000\,mg/g)\left(\frac{50.04}{22.0}\right) = 23.1\ mg/L\ as\ CaCO_3$$

b. Calculate CH and NCH

CH = lesser of TH or alkalinity = 130. mg/L as $CaCO_3$

NCH = TH - CH = 260. - 130. = 130. mg/L as $CaCO_3$

c. Lime additions (All additions mg/L as $CaCO_3$)

Lime = CO_2 = 21.15

Lime = HCO_3^- = 130.00

Since Mg < 40, lime = Mg to be removed = 0.0

Excess lime = 20.0

Total lime = 21.15 + 130.0 + 20.

= 171.15 or 171. mg/L as $CaCO_3$

d. Soda

NCH_f = 90.0 - 40.0 = 50.0 mg/L as $CaCO_3$

NCH_R = 130.0 - 50.0 = 80.0 mg/L as $CaCO_3$

Add Soda = 80. mg/L as $CaCO_3$

4-66 Water softening for Village of Galena

Given: Water analysis, HCO_3^- = 276.6 mg/L as $CaCO_3$, pH = 7.2, Ca = 177.8 mg/L as ion, Mg = 16.2 mg/L as ion, Pb = 0.020 mg/L as ion

Solution:

a. Compute CO_2 in mg/L as $CaCO_3$

$$K_{a1} = \frac{[H^+][HCO_3^-]}{[H_2CO_3]}$$

pK_{a1} = 6.35 from Table 4-4

Assume 1 mole H_2CO_3 = 1 mole CO_2 from

$$CO_2 + H_2O \rightarrow H_2CO_3$$

Convert HCO_3^- in mg/L as $CaCO_3$ to mole/L

$$[HCO_3^-] = (276.6\,mg/L)\left(\frac{1}{61\,g/mole}\right)\left(\frac{1}{1000\,mg/g}\right)\left(\frac{61E.W.HCO_3^-}{50E.W.CaCO_3}\right)$$

$[HCO_3^-] = 5.53 \times 10^{-3}$ mole/L

Convert pH to mole/L

$[H^+] = 10^{-7.2} = 6.31 \times 10^{-8}$ mole/L

Convert pK_{a1} to K_{a1}

$K_{a1} = 10^{-6.35} = 4.47 \times 10^{-7}$ mole/L

Solve for $[H_2CO_3]$

$$[H_2CO_3] = \frac{(6.31\times10^{-8})(5.53\times10^{-3})}{(4.47\times10^{-7})}$$

$[H_2CO_3] = 7.81 \times 10^{-4}$ mole/L

b. Calculate soda ash (mg/L as $CaCO_3$)

$NCH_f = 80 – 40 = 40.0$

NCHR = 234.06 – 40 = 194.06 or 194.1

Add soda ash = 194.1 mg/L as $CaCO_3$

c. Lime as CaO (93% pure)

$$\left(\frac{1}{0.93}\right)(408.1)\left(\frac{28.04E.W.CaO}{50.04E.W.CaCO_3}\right) = 245.9 \text{ or 246 mg/L as CaO}$$

d. Soda ash as Na_2CO_3 (95% pure)

$$\left(\frac{1}{0.95}\right)(194.1)\left(\frac{52.99\text{E.W.Na}_2\text{CO}_3}{50.04\text{E.W.CaCO}_3}\right) = 216.3 \text{ or } 216 \text{ mg/L as Na}_2\text{CO}_3$$

e. Lead removal

The concentration of Pb is 0.020 mg/L. This is

$$(0.020)\left(\frac{50.04\text{E.W.CaCO}_3}{103.6\text{E.W.Pb}}\right) = 0.0097 \text{ mg/L as CaCO}_3$$

This amount will be removed by the excess lime if the solubility is low enough. From table of solubility products in Appendix A, the solubility of $PbCO_3$ is less than $CaCO_3$. It will be removed.

4-67 Soften water

Given: Ca = 200; Mg = 100; HCO_3^- = 150; CO_2 = 22; all mg/L as $CaCO_3$; lime = \$100/megagram (Mg); soda = \$200/megagram (Mg); flow = 0.5 m^3/s.

Solution:

a. Compute TH, CH and NCH

TH = 200.0 + 100.0 = 300.0 mg/L as $CaCO_3$

CH = 150.0 mg/L as $CaCO_3$

NCH_i = 300.0 - 150.0 = 150.0 mg/L as $CaCO_3$

b. Compute Lime Additions (all mg/L as $CaCO_3$)

Lime = CO_2 = 22.0

Lime = HCO_3^- = 150.0

Since Mg is > 40 add lime = 100.0 - 40.0 = 60.0

Delta = 60.0

Since Delta is > 40 add lime = 40.0

Total lime = 22.0 + 150.0 + 60.0 + 40.0 = 272.0 mg/L as $CaCO_3$

c. Compute Soda

NCHf = 80.0 - 40.0 = 40.0

NCHR = 150.0 - 40.0 = 110.0 mg/L as $CaCO_3$

Soda = 110.0 mg/L as CaCO3

d. Lime as CaO

$$(272.00)\left(\frac{28.04\text{E.W.CaO}}{50.04\text{E.W.CaCO}_3}\right)=152.41\,\text{mg/L}$$

e. Soda as Na_2CO_3

$$\text{E.W.}=\frac{105.99}{2}=52.99$$

$$(110.00)\left(\frac{52.99\text{E.W.Na}_2\text{CO}_3}{50.04\text{E.W.CaCO}_3}\right)=116.49\,\text{mg/L}$$

f. Annual cost

$$\left(0.50\,\text{m}^3/\text{s}\right)\left(86400\,\text{s/d}\right)\left(365\,\text{d/y}\right)=15{,}768{,}000=1.58\times10^7\,\text{m}^3$$

$(1000 \text{ L/m}^3)(1.58 \times 10^7 \text{ m}^3) = 1.58 \times 10^{10}$ L

CaO

$(152.41 \text{ mg/L})(1.58 \times 10^{10} \text{ L}) = 2.40 \times 10^{12}$ mg

$(2.40 \times 10^{12} \text{ mg})(10^{-9} \text{ Mg/mg}) = 2.40 \times 10^3$ Mg

$(2.40 \times 10^3$ Mg)(\$100.00/Mg) = \$240,326.45

Na_2CO_3

$(116.49 \text{ mg/L})(1.58\text{x}10^{10} \text{ L})(10^{-9} \text{ Mg/mg}) = 1.84 \times 10^3$ Mg

$(1.84 \times 10^3$ Mg)(\$200.00/Mg) = \$367,376.80

Total Cost

240,326.45 + 367,376.80 = 607,703.25 or \$608,000

4-68 Soften water

Given: Ca = 293; Mg = 55; HCO_3^- = 301; CO_2 = 3; all mg/L as $CaCO_3$; lime = \$61.70/megagram (Mg); soda = \$172.5/megagram (Mg); flow = 1.35 m^3/s. Lime is 87% pure and soda is 97% pure.

Solution:

a. Compute TH, CH and NCH

TH = 293.0 + 55.0 = 348.0 mg/L as $CaCO_3$

CH = 301.0 mg/L as $CaCO_3$

NCH_i = 348.0 - 301.0 = 47.0 mg/L as $CaCO_3$

b. Compute Lime Additions (all mg/L as $CaCO_3$)

Lime = CO_2 = 3.0

Lime = HCO_3^- = 301.0

Since Mg is > 40 add lime = 55.0   40.0 = 15.0

Delta = 15.0

Since Delta is < 40 add lime = 20.0

Total lime = 3.0 + 301.0 + 15.0 + 20.0 = 339.0 mg/L as $CaCO_3$

c. Compute Soda

NCH_f = 120.0 - 40.0 = 80.0

NCH_R = 80.0 - 47.0 = 33.0 mg/L as $CaCO_3$

Soda = 33.0 mg/L as $CaCO_3$

d. Lime as CaO (87% pure)

$$\left(\frac{1}{0.87}\right)(339.0)\left(\frac{28.04\text{E.W.CaO}}{50.04\text{E.W.CaCO}_3}\right) = 218.34\,\text{mg/L}$$

e. Soda as Na_2CO_3 (97% pure)

$$\text{E.W.} = \frac{105.99}{2} = 52.99$$

$$\left(\frac{1}{0.97}\right)(33.0)\left(\frac{52.99\text{E.W.Na}_2\text{CO}_3}{50.04\text{E.W.CaCO}_3}\right) = 36.02\,\text{mg/L}$$

f. Annual cost

$(1.35\ m^3/s)(86400\ s/d)(365\ d/y) = 42{,}573{,}600 = 4.26 \times 10^7\ m^3$

$(1000\ L/m^3)(4.26 \times 10^7\ m^3) = 4.26 \times 10^{10}\ L$

CaO

$(218.34\ mg/L)(4.26 \times 10^{10}\ L) = 9.30 \times 10^{12}\ mg$

$(9.30 \times 10^{12}\ mg)(10^{-9}\ Mg/mg) = 9.30 \times 10^3\ Mg$

$(9.30 \times 10^3\ Mg)(\$61.70/Mg) = \$573{,}810$

Na_2CO_3

$(36.02\ mg/L)(4.26 \times 10^{10}\ L)(10^{-9}\ Mg/mg) = 1.53 \times 10^3\ Mg$

$(1.53 \times 10^3\ Mg)(\$172.50/Mg) = \$264{,}698$

Total Cost

\$573,810 + \$264,698 = \$838,508

4-69 Soften water

Given: Hardin, IL water

Ca = 102.0 mg/L as ion
Mg = 45.2 mg/L as ion
Alkalinity = 344. mg/L as $CaCO_3$
pH = 7.2
Q = 0.150 m^3/s

Required: (1) Soften water to 95.0 mg/L as $CaCO_3$

(2) Determine annual chemical cost using prices from Prob. 4-67. CaO price is \$100.000/Mg; Na_2CO_3 price is \$200.00/Mg

Solution:

a. Calculate CO_2 content

Since pH < 8.3 assume all alkalinity is HCO_3^-

$$K_{a1} = \frac{[H^+][HCO_3^-]}{[H_2CO_3]}$$

$pK_{a1} = 6.35$ from Table 4-4

Assume 1 mole H_2CO_3 = 1 mole CO_2

$$CO_2 + H_2O \rightarrow H_2CO_3$$

Convert HCO_3^- mg/L as CaCO3 to mole/L

$$[HCO_3^-] = (344\,mg/L)\left(\frac{1}{61\,g/mole}\right)\left(\frac{1}{1000\,mg/g}\right)\left(\frac{61 E.W. HCO_3^-}{50 E.W. CaCO_3}\right)$$

$[HCO_3^-] = 6.88 \times 10^{-3}$ mole/L

Convert pH to mole/L

$[H^+] = 10^{-7.2} = 6.31 \times 10^{-8}$ mole/L

Convert pK_{a1} to K_{a1}

$K_{a1} = 10^{-6.35} = 4.47 \times 10^{-7}$

Solve for H_2CO_3

$$[H_2CO_3] = \frac{(6.31\times10^{-8})(6.88\times10^{-3})}{(4.47\times10^{-7})}$$

$[H_2CO_3] = 9.71 \times 10^{-4}$ mole/L

Since $CO_2 = H_2CO_3$

$[CO_2] = 9.71 \times 10^{-4}$ mole/L

Convert mole/L to mg/L as $CaCO_3$

$$\left(9.71\times10^{-4}\text{ mole/L}\right)\left(44\text{ g/mole}\right)\left(1000\text{ mg/g}\right)\left(\frac{50.04}{22.00}\right)=97.1\text{ mg/L as }CaCO_3$$

b. Convert Ca and Mg to $CaCO_3$

Ca = (102.0)(2.50) = 255.0 mg/L as $CaCO_3$

Mg = (45.2)(4.12) = 186.2 mg/L as $CaCO_3$

c. Calculate CH and NCH

TH = 255.0 + 186.2 = 441.2 mg/L as $CaCO_3$

CH = lesser of TH or alkalinity = 344. mg/L as $CaCO_3$

NCH = 441.2 - 344. = 97.2 mg/L as $CaCO_3$

d. Lime additions (all mg/L as $CaCO_3$)

Lime = CO_2 = 97.10

Lime = HCO_3^- = 344.

Lime = Mg - 40. = 186.2 - 40 = 146.2

Delta = 146.2

Since Delta > 40, excess lime = 40.

Total Lime = 97.10 + 344. + 146.2 + 40. = 627.3 or 627. mg/L as $CaCO_3$

e. Soda calculations

NCH = 95.0 - 40.0 = 55.0 mg/L as $CaCO_3$

NCH = 97.2 - 55.0 = 42.2 mg/L as $CaCO_3$

Soda ash = 42.2 mg/L as $CaCO_3$

f. Calculate cost

Convert lime and soda from mg/L as $CaCO_3$ to mg/L as compound.
E.W. CaO = 28.04; E.W. Na_2CO_3 = 52.994

CaO (87% pure)

$$(627.3)\left(\frac{28.04}{50.04}\right)\left(\frac{1}{0.87}\right) = 415.63 \text{ or } 416 \text{ mg/L}$$

Na_2CO_3 (97% pure)

$$(42.2)\left(\frac{52.994}{50.04}\right)\left(\frac{1}{0.97}\right) = 46.08 \text{ or } 46 \text{ mg/L}$$

Estimate annual use. (Note that 1 mg/L = 1 g/m^3)

Lime = (415.63 g/m^3)(0.150 m^3/s)(86,400 s/d)(365 d/y)

= 1.97×10^9 g/y or 1966 Mg/y

Soda = (46.08 g/m^3)(0.150 m^3/s)(86,400 s/d)(365 d/y)

= 2.18×10^8 g/y or 218 Mg/y

Estimate annual cost

Lime = ($100.00/Mg)(1966 Mg/y) = $196,610./y

Soda = ($200.00/Mg)(218 Mg/y) = $43,598./y

Total Cost = $196,610./y + $43,598./y = $240,208/y or $240,000

4-70 Soften water

Given: Ca = 137; Mg = 40; HCO_3^- = 197; CO_2 = 9; all mg/L as $CaCO_3$; lime = $61.70/megagram (Mg); soda = $172.5/megagram (Mg); flow = 0.05 m^3/s. Lime is 90% pure and soda is 97% pure.

Solution:

a. Compute TH, CH and NCH

TH = 137.0 + 40.0 = 177.0 mg/L as $CaCO_3$

CH = 177.0 mg/L as $CaCO_3$

NOTE: CH = alkalinity (HCO_3^-) or TH whichever is less. In this case TH < CH

$NCH_i = 177.0 - 177.0 = 0.0$ mg/L as $CaCO_3$

b. Compute Lime Additions (all mg/L as $CaCO_3$)

Lime = $CO_2 = 9.0$

Lime = $HCO_3^- = 197.0$

NOTE: must still add lime = HCO_3^- to raise pH to achieve precipitation

Since Mg is < 40 add lime = 20.0

Total lime = 9.0 + 197.0 + 20.0 = 226.0 mg/L as $CaCO_3$

c. Compute Soda

$NCH_f = 90.0 - 40.0 = 50.0$

$NCH_R = 0.0 - 50.0 = 50.0$ mg/L as $CaCO_3$

Therefore, ADD NO SODA

d. Lime as CaO (90% pure)

$$(226.0)\left(\frac{28.04}{50.04}\right)\left(\frac{1}{0.90}\right) = 140.71 \text{mg/L}$$

e. Soda as Na_2CO_3 = 0.0 mg/L

f. Annual cost

$(0.05\ m^3/s)(86{,}400\ s/d)(365\ d/y) = 1{,}576{,}800 = 1.58 \times 10^6\ m^3$

$(1000\ L/m^3)(1.58 \times 10^6\ m^3) = 1.58 \times 10^9\ L$

CaO

$(140.71\ mg/L)(1.58 \times 10^9\ L) = 2.22 \times 10^{11}\ mg$

$(2.22 \times 10^{11}\ mg)(10^{-9}\ Mg/mg) = 2.22 \times 10^2\ Mg$

$(2.22 \times 10^2 \text{ Mg})(\$61.70/\text{Mg}) = \$13{,}717.31$

Na_2CO_3 = \$0.00

Total Cost = \$13,717.31 or \$13,700

4-71 Design a split treatment system

Given: CO_2 = 42.7, Ca = 102.0, Mg = 45.2 all in mg/L as ion, HCO_3^- = 344.0 mg/L as $CaCO_3$

Solution:

a. Convert all relevant compounds to mg/L as $CaCO_3$

$$CO_2 = (42.7\,\text{mg/L})\left(2.28\frac{\text{E.W.CaCO}_3}{\text{E.W.ion}}\right) = 97.36 \text{ mg/L as CaCO}_3$$

$$\text{Ca} = (102.0\,\text{mg/L})\left(2.50\frac{\text{E.W.CaCO}_3}{\text{E.W.ion}}\right) = 255.0 \text{ mg/L as CaCO}_3$$

$$\text{Mg} = (45.2\,\text{mg/L})\left(4.12\frac{\text{E.W.CaCO}_3}{\text{E.W.ion}}\right) = 186.22 \text{ mg/L as CaCO}_3$$

b. Because Mg is greater than 40 mg/L as $CaCO_3$, design for a split treatment system where in the first stage, the water is softened to practical solubility limits.

c. Chemical additions

	Lime (meq/L)	Soda (meq/L)
CO_2	0.40	
HCO_3^-	2.72	
Mg	1.12	
Ca + Mg - HCO_3^-	--	0.56
Excess (Mg - 40 > 40)	0.40	
Totals	4.64	0.56

d. Calculate the split

$$X = \frac{40 - 10}{186.22 - 10} = 0.17$$

The fraction passing through the first stage is 1 - 0.17 = 0.83 or 83%.

e. Check to see if hardness is less than normally accepted level

$$(0.17)(255 + 186.22) + (0.83)(40) = 108.2 \text{ mg/L as } CaCO_3$$

This is below the limit of 120 mg/L as $CaCO_3$. No further softening is required.

4-72 Design a split treatment system

Given: $CO_2 = 0.40$, Ca = 2.16, Mg = 1.12, $HCO_3^- = 2.72$, all as meq/L

Solution:

a. Because Mg is greater than 40 mg/L as $CaCO_3$ (1.12 meq/L x 50 mg $CaCO_3$/meq), design for a split treatment system where in the first stage, the water is softened to practical solubility limits.

b. Chemical additions

	Lime (meq/L)	Soda (meq/L)
CO_2	0.40	
HCO_3^-	2.72	
Mg	1.12	
Ca + Mg - HCO_3^-	--	0.56
Excess (Mg - 40 > 40)	0.40	
Totals	4.64	0.56

d. Calculate the split

$$X = \frac{40 - 10}{\{(1.12\,\text{meq/L})(50\,\text{mg}\,CaCO_3/\text{meq})\} - 10} = 0.65$$

The fraction passing through the first stage is then 1 - 0.65 = .35 or 35%

e. Check to see if hardness is less than normally accepted level

$$(0.65)(2.72 + 1.12) + (0.35)(0.60 + 0.20) = 2.78 \text{ meq/L}$$

$(2.78 \text{ meq/L})(50 \text{ mg } CaCO_3/\text{meq}) = 139 \text{ mg/L as } CaCO_3$

This is above the design limit of 120 mg/L as $CaCO_3$. Therefore second stage softening is required.

f. Chemical additions (NOTE: no further reduction in Mg is required)

	Lime (meq/L)
CO_2	0.40
HCO_3^-	2.72
Total	3.12

g. The chemical additions in proportion to the flows

Lime = (0.35)(4.64) + (0.65)(3.12) = 3.65 meq/L

Soda = (0.35(0.56) + (0.65) (0.0) = 0.20 meq/L

h. In terms of CaO and Na_2CO_3

Lime as CaO = 3.65(28 mg/meq) = 102.2 or 102 mg/L

Soda as Na_2CO_3 = (0.20)(53 mg/meq) = 10.6 or 11 mg/L

4-73 Design a split treatment system for What Cheer

Given: Water analysis in mg/L as $CaCO_3$

Solution:

a. Calculate TH, CH, and NCH (all mg/L as $CaCO_3$)

TH = 167.7 +76.3 = 244.0

Because HCO_3^- is > TH, all the hardness is CH.

CH = 244.0

NCH = 0.0

b. Split calculation

$$X = \frac{40 - 10}{76.3 - 10} = 0.4525$$

c. First stage softening chemical additions

	Lime (mg/L as $CaCO_3$)
CO_2	39.80
HCO_3^-	257.90
Mg	76.30
Excess (Mg - 40 > 40)	36.30
Total	410.30

d. TH of mixed water

(0.4525)(244.0) + (1 – 0.4525)(40) = 132.3 mg/L as $CaCO_3$

Because 132.3 mg/L is > 120 mg/L desired, need second stage softening.

e. Second stage softening to remove Ca only

Lime = CO_2 = 39.8

Lime = HCO_3^- = 257.9

Excess Lime = 36.3

Total Lime = 39.8 + 257.9 + 36.3 = 334.0 mg/L as $CaCO_3$

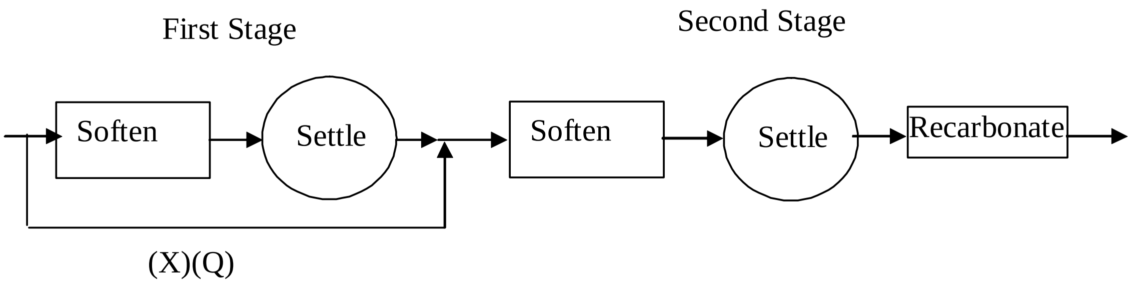
f. Final hardness

Ca = solubility limit = 30 mg/L as $CaCO_3$

Mg = design = 40 mg/L as $CaCO_3$

Total = 30 + 40 = 70 mg/L as $CaCO_3$

g. Split scheme



4-74 Volume of rapid mix tank

Given: Flow = 0.05 m^3/s; detention time = 10 s (NOTE: in the first printing of the third edition the detention time was given as 60 s.)

Solution:

$$V = Qt_0$$

$$V = (0.05\ m^3/s)(10\ s) = 0.5\ m^3$$

4-75 Volume of flocculators

Given: Flow = 0.150 m^3/s; detention time = 20 minutes; two parallel tanks

Solution:

$$V = Qt_0 = (0.150\ m^3/s)(20\ min)(60\ s) = 180\ m^3$$

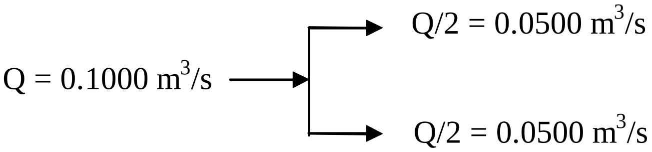
$$\text{Volume for each tank} = \frac{180}{2} = 90 m^3$$

4-76 Detention time

Given: 2 sedimentation tanks in parallel, combined Q = 0.1000 m^3/s, volume of each tank = 720 m^3

Solution:

a. Sketch of system



b. Convert flow rate to m^3/h

$Q = (0.0500\ m^3/s)(3600\ s/h) = 180\ m^3/h$

c. Detention time

$$\theta = \frac{\forall}{Q} = \frac{720 m^3}{180\, m^3/h} = 4.00 h$$

4-77 Power input for rapid mix

Given: Data from Problem 4-74; $G = 700\ s^{-1}$; temp = 20^oC

Solution:

a. Find viscosity from Appendix A and convert to proper units

$\mu = 1.002 \times 10^{-3}$ Pa-s

b. Solve Eqn 4-74 for P using volume of $0.5\ m^3$ from Prob. 4-74

$P = G^2(\mu)(V) = (700)^2(1.002 \times 10^{-3})(0.5)$

P = 245.49 or 250 W or 0.25 kW

4-78 Power input for flocculator

Given: Data from Problem 4-75; $G = 36\ s^{-1}$; temp = 17^oC

Solution:

a. Find viscosity from Appendix A and convert to proper units

$\mu = 1.081 \times 10^{-3}$ Pa-s

b. Solve Eqn 4-75 for P using volume of $90.0\ m^3$ from Prob. 4-75

$P = G^2(\mu)(V) = (36)^2(1.081 \times 10^{-3})(90.0)$

P = 126.09 or 126 W or 0.126 kW

4-79 Power input for rapid mix at lower water temp

Given: Data from Problem 4-77; $G = 700\ s^{-1}$; temp = $10^{o}C$

Solution:

a. Find viscosity from Appendix A and convert to proper units

$\mu = 1.307 \times 10^{-3}$ Pa-s

b. Solve Eqn 4-75 for P using volume of $0.5\ m^3$ from Prob. 4-77

$P = G^2(\mu)(V) = (700)^2(1.307 \times 10^{-3})(0.5)$

P = 320.21 or 320 W or 0.32 kW

4-80 Power input for flocculator at lower water temp

Given: Data from Problem 4-78; $G = 36\ s^{-1}$; temp = $10^{o}C$

Solution:

a. Find viscosity from Appendix A and convert to proper units

$\mu = 1.307 \times 10^{-3}$ Pa-s

b. Solve Eqn 4-75 for P using volume of $90.0\ m^3$ from Prob. 4-78

$P = G^2(\mu)(\cancel{V}) = (36)^2(1.307 \times 10^{-3})(90.0)$

P = 152.44 or 152 W or 0.15 kW

4-81 Rotational speed of impeller

Given: Example 4-20

Solution:

a. For 2nd compartment

P = 152 W from example

$N_P = 0.31$

D = 1.4 m

$$n = \left[\frac{152\text{W}}{(0.31)(1000\,\text{kg/m}^3)(1.4)^5}\right]^{1/3} = \left[\frac{152}{1667.25}\right]^{1/3} = (0.0912)^{1/3}$$

n = 0.45 rps or 27 rpm

b. For 3rd compartment

P = 54.7 W

$$n = \left[\frac{54.7\text{W}}{(0.31)(1000\,\text{kg/m}^3)(1.4)^5}\right]^{1/3} = \left[\frac{54.7}{1667.25}\right]^{1/3} = (0.0328)^{1/3}$$

n = 0.32 rps or 19 rpm

4-82 Rapid mix tank for Eau Gaullie

Given: Q = 0.1065 m^3/s, Temperature = 29°C, 1 tank, circular with depth = 2x diameter, detention time = 10 s, velocity gradient = 800 s^{-1}, Impeller = turbine, 6 flat blades, N_P = 5.7

Solution:

a. Calculate tank dimensions

$$\forall = \theta Q = (10\text{s})(0.1065\,\text{m}^3/\text{s}) = 1.065\text{m}^3$$

with H = 2T

$$\forall = \left(\frac{\pi T^2}{4}\right)(2T) = \frac{\pi T^3}{2}$$

$$1.065\text{m}^3 = \frac{\pi T^3}{2}$$

$$T = \left[\frac{(1.065)(2)}{\pi}\right]^{1/3} = (0.678)^{1/3} = 0.8785\text{m} \text{ or } 0.88 \text{ m diameter}$$

and H = 2(0.88) = 1.76 m depth

b. Calculate the power input

With a water temperature of 19oC, use Appendix A to find $\mu = 1.027 \times 10^{-3}$ Pa-s

$$P = (800)^2(1.027 \times 10^{-3})(1.065) = 700 \text{ W or } 0.7 \text{ kW}$$

c. Evaluate the available impeller diameters. Assume B = 1/3 of depth

T =	0.88	m
H =	1.76	m
B =	0.586661	m

Radial Turbine Impeller

Geometric Ratio	Allowable Range	Impeller Diameters, m		
		0.45	0.6	1.2
D/T	0.14 - 0.5	0.51	0.68	1.36
H/D	2.0 - 4.0	3.91	2.93	1.47
H/T	0.28 - 2.0	2.00	2.00	2.00
B/D	0.7 - 1.6	1.30	0.98	0.49

Best available diameter = 0.45 m

d. Calculate rotational speed

$$n = \left[\frac{700\text{W}}{(5.7)(1000\,\text{kg}/\text{m}^3)(0.45\text{m})^5}\right]^{1/3} = \left[\frac{700}{105.18}\right]^{1/3} = 6.66\text{rps} \ \text{ or } 400 \text{ rpm}$$

4-83 Rapid Mix Tank for Laramie

Given: $Q = 0.168 \text{ m}^3/\text{s}$, Temperature = 5°C, square tank with depth = width, detention time = 5 s, velocity gradient = 700 s^{-1}, impeller = turbine, 6 flat blades, $N_P = 5.7$

Solution:

a. Calculate tank dimensions

$$\forall = \theta Q = (5\text{s})(0.168\,\text{m}^3/\text{s}) = 0.84\text{m}^3$$

with H = T and square tank

$$T^3 = 0.84\text{m}^3$$

$$T = (0.84)^{1/3} = 0.94 \text{ m}$$

$$H = T = 0.94 \text{ m}$$

Equivalent T

$$T_e = \left[\frac{(4)(0.94)^2}{\pi}\right]^{1/2} = (1.125)^{1/2} = 1.06\text{m}$$

b. Calculate power input

With a water temperature of 5°C, use Appendix A to find $\mu = 1.519 \times 10^{-3}$ Pa-s

$P = (700)^2(1.519 \times 10^{-3})(0.84) = 625$ W or 0.625 kW

c. Evaluate the available impeller diameter. Assume B = 1/3 of depth.

T = 1.06 m
H = 0.94 m
B = 0.31333 m

Radial Turbine Impeller

Geometric Ratio	Allowable Range	Impeller Diameters, m		
		0.45	0.6	1.2
D/T	0.14 - 0.5	0.42	0.57	1.13
H/D	2.0 - 4.0	2.09	1.57	0.78
H/T	0.28 - 2.0	0.89	0.89	0.89
B/D	0.7 - 1.6	0.70	0.52	0.26

Best available diameter = 0.45 m

d. Calculate rotational speed

$$n = \left[\frac{625\text{W}}{(5.7)(1000\,\text{kg/m}^3)(0.45\text{m})^5}\right]^{1/3} = \left[\frac{625}{105.18}\right]^{1/3} = 1.81\text{rps} \ \text{ or } 110 \text{ rpm}$$

4-84 Rapid Mix Tank for Waffle

Given: Q = 0.050 m^3/s, Temperature = 8°C, circular tank with depth = 1.0 m, detention time = 5 s, velocity gradient = 750 s^{-1}, impeller = turbine, 6 flat blades, $N_P = 3.6$

Solution:

a. Calculate tank dimensions

$$\rlap{-}V = \theta Q = (5\text{s})(0.050\,\text{m}^3/\text{s}) = 0.25\text{m}^3$$

with H = 1.0 m

$$0.25\text{m}^3 = \left(\frac{\pi T^2}{4}\right)(1.0)$$

$$T = \left[\frac{(4)(0.25)}{\pi(1.0)}\right]^{1/2} = \left(\frac{1.0}{\pi}\right)^{1/2} = 0.5642 \text{ or } 0.56\text{ m}$$

b. Calculate power input

With water temperature of 8°C, use Appendix A to find μ.

5°C $\mu = 1.519 \times 10^{-3}$ Pa-s

10°C $\mu = 1.307 \times 10^{-3}$ Pa-s

$$\frac{8-5}{10-5} = \frac{x-1.519}{1.307-1.519}$$

$$\frac{3}{5} = \frac{x-1.519}{-0.212}$$

$x - 1.519 = -0.1272$

$x = 1.392$

Therefore, $\mu = 1.392 \times 10^{-3}$ Pa-s

$P = (750)^2(1.392 \times 10^{-3})(0.25) = 195.75$ or 196 W

c. Evaluate available impeller diameter. Assume B = 1/3 of depth

T = 0.56 m
H = 1 m
B = 0.33333 m

Radial Turbine Impeller

Geometric Ratio	Allowable Range	Impeller Diameters, m		
		0.25	0.5	1
D/T	0.14 - 0.5	0.45	0.89	1.79
H/D	2.0 - 4.0	4.00	2.00	1.00
H/T	0.28 - 2.0	1.79	1.79	1.79
B/D	0.7 - 1.6	1.33	0.67	0.33

Best available diameter = 0.25 m

d. Calculate rotational speed

$$n = \left[\frac{196W}{(3.6)(1000\,kg/m^3)(0.25m)^5}\right]^{1/3} = \left[\frac{196}{3.52}\right]^{1/3} = 3.82rps \text{ or } 230 \text{ rpm}$$

4-85 Flocculation Tank for Eau Gaullie

Given: Problem 4-82; 2 tanks; 3 compartments with G = 90 s^{-1}, 60 s^{-1}, and 30 s^{-1}; Gθ = 120,000; length = width = depth; axial flow impeller; impeller diameter available = 1.0 m, 1.5 m, and 2.0 m; $N_P = 0.31$

Solution:

a. Based on Gθ value and average G for the 3 compartments, calculate the detention time

$$G_{avg} = \frac{90+60+30}{3} = 60s^{-1}$$

$$\theta = \frac{G\theta}{G_{avg}} = \frac{120000}{60} = 2000s$$

b. Calculate the volume of each flocculation basin

$$V\!\!\!\!- = Q\theta = (0.1065\,m^3/s)(2000s) = 213m^3$$

Since the flow will be divided into 2 tanks

Volume for each tank = 213/2 = 106.5 m^3

c. Since each basin will be divided into 3 compartments, the volume of each compartment will be

Volume for each compartment = 106.5/3 = 35.5 m^3

d. Compartment dimensions with compartment length = depth = width (w)

$(w)^3 = 35.5\ m^3$

$w = (35.5)^{1/3} = 3.29$ or 3.3 m

So the compartment dimensions are 3.3 m by 3.3 m by 3.3 m

e. Power input with temperature = 19°C

1. For first compartment with $G = 90\ s^{-1}$

$$P = G^2(\mu)(\cancel{V}) = (90)^2(1.027 \times 10^{-3})(35.5) = 295 \text{ W or } 0.295 \text{ kW}$$

2. For second compartment with $G = 60\ s^{-1}$

$$P = G^2(\mu)(\cancel{V}) = (60)^2(1.027 \times 10^{-3})(35.5) = 131 \text{ W or } 0.131 \text{ kW}$$

f. Calculate equivalent tank diameter

Area = 3.3 x 3.3 x 3.3 = 10.89 m^3

$$T_e = \left[\frac{(4)(10.89)^2}{\pi}\right]^{1/2} = (13.86)^{1/2} = 3.72\text{m}$$

g. Evaluate available impeller diameter. Assume B = 1/3 of depth

T = 3.72 m
H = 3.3 m
B = 1.099989 m

Radial Turbine Impeller

Geometric Ratio	Allowable Range	Impeller Diameters, m		
		1	1.5	2
D/T	0.14 - 0.5	0.27	0.40	0.54
H/D	2.0 - 4.0	3.30	2.20	1.65
H/T	0.28 - 2.0	0.89	0.89	0.89
B/D	0.7 - 1.6	1.10	0.73	0.55

Based on trial calculation, 1.0 m diameter yields a tip speed of 3.1 m/s.
This is > allowable tip speed of 2.7 m/s.
Therefore, best available diameter = 1.5 m

h. Calculate rotational speed of impeller

1st compartment

$$n = \left[\frac{295\text{W}}{(0.31)(1000\,\text{kg/m}^3)(1.5\text{m})^5}\right]^{1/3} = \left[\frac{295}{2354}\right]^{1/3} = 0.50\text{rps} \text{ or } 30 \text{ rpm}$$

2nd compartment

$$n = \left[\frac{130\text{W}}{(0.31)(1000\,\text{kg/m}^3)(1.5\text{m})^5}\right]^{1/3} = \left[\frac{130}{2354}\right]^{1/3} = 0.38\text{rps} \text{ or } 23 \text{ rpm}$$

i. Check tip speed of 1st compartment impeller

Tip Speed = (0.50 rps)(π)(1.5) = 2.4 m/s

This is less than 2.7 m/s so okay.

4-86 Flocculation Tank for Laramie

Given: Problem 4-83; 2 tanks; 3 compartments with G = 90 s^{-1}, 60 s^{-1}, 30 s^{-1}; $G\theta$ = 120,000; length = width = depth; axial flow impeller; impeller diameters available = 1.0 m, 1.8m, 2.4m, N_P = 0.40

Solution:

a. Based on $G\theta$ value and average G for the 3 compartments, calculate the detention time.

$$G_{avg} = \frac{90+60+30}{3} = 60\text{s}^{-1}$$

$$\theta = \frac{G\theta}{G_{avg}} = \frac{120000}{60} = 2000\text{s}$$

b. Calculate the volume of each flocculation basin

~~V~~ $= Q\theta = (0.168\,\text{m}^3/\text{s})(2000\text{s}) = 336\text{m}^3$

Since the flow will be divided into 2 tanks

Volume for each tank = 336/2 = 168 m^3

c. Since each basin will be divided into 3 compartments, the volume of each compartment will be

Volume for each compartment = 168/3 = 56 m^3

d. Compartment dimensions with compartment length = depth = width (w)

$(w)^3 = 56\ \text{m}^3$

$w = (56)^{1/3} = 3.83$ or 3.8 m

So the compartment dimensions are 3.8 m by 3.8 m by 3.8 m

e. Power input with temperature = 5 ^{o}C

1. For first compartment with $G = 90\ \text{s}^{-1}$

P = $G^2(\mu)$(~~V~~) = $(90)^2(1.519 \times 10^{-3})(56)$ = 690 W or 0.69 kW

2. For second compartment with $G = 60\ \text{s}^{-1}$

P = $G^2(\mu)$(~~V~~) = $(60)^2(1.519 \times 10^{-3})(56)$ = 310 W or 0.31 kW

f. Calculate equivalent tank diameter

Area = 3.8 x 3.8 x 3.8 = 14.44 m^2

$$T_e = \left[\frac{(4)(14.44)^2}{\pi}\right]^{1/2} = (18.39)^{1/2} = 4.29\text{m}$$

g. Evaluate available impeller diameter. Assume B = 1/3 of depth

T =	4.29	m
H =	3.8	m
B =	1.266654	m

Radial Turbine Impeller

Geometric Ratio	Allowable Range	Impeller Diameters, m		
		1	1.8	2.4
D/T	0.14 - 0.5	0.23	0.42	0.56
H/D	2.0 - 4.0	3.80	2.11	1.58
H/T	0.28 - 2.0	0.89	0.89	0.89
B/D	0.7 - 1.6	1.27	0.70	0.53

Based on trial calculation, 1.0 m diameter yields a tip speed of 3.8 m/s.
This is > allowable tip speed of 2.7 m/s.
Therefore, best available diameter = 1.8 m

h. Calculate rotational speed of impeller

1^{st} compartment

$$n = \left[\frac{690\text{W}}{(0.40)(1000\,\text{kg/m}^3)(1.8\text{m})^5}\right]^{1/3} = \left[\frac{690}{7558}\right]^{1/3} = 0.45\text{rps or 27 rpm}$$

2^{nd} compartment

$$n = \left[\frac{310\text{W}}{(0.40)(1000\,\text{kg/m}^3)(1.8\text{m})^5}\right]^{1/3} = \left[\frac{310}{7558}\right]^{1/3} = 0.34\text{rps or 21 rpm}$$

i. Check tip speed of 1^{st} compartment impeller

Tip Speed = (0.45 rps)(π)(1.8) = 2.5 m/s

This is less than the allowable tip speed of 2.7 m/s so okay.

4-87 Flocculation tank for Waffle

Given: Problem 4-84; 1 tank; 3 compartments with G = 60 s^{-1}, 50 s^{-1}, 20 s^{-1}; detention time = 30 min; width = 3.5 m; axial flow impellers; available impeller diameter = 1.0 m, 1.5 m, 2.0 m; $N_P = 0.43$

Solution:

a. Calculate the volume of the flocculation tank

$$\forall = Q\theta = (0.050 \text{ m}^3/\text{s})(30 \text{ min})(60 \text{ s/min}) = 90 \text{ m}^3$$

b. With 3 compartments,

Volume for each compartment = 90/3 = 30 m^3

c. Compartment dimensions with depth = 3.5 m

$$\text{Area} = \frac{30\text{m}^3}{3.5\text{m}} = 8.57\text{m}^2$$

With length = width

$$L = w = (8.57)^{1/2} = 2.93 \text{ m}$$

d. Calculate equivalent tank diameter

$$T_e = \left[\frac{(4)(8.57)^2}{\pi}\right]^{1/2} = (10.91)^{1/2} = 3.3\text{m}$$

e. Evaluate available impeller diameters. Assume B = 1/3 of depth

T = 3.3 m
H = 3.8 m
B = 1.266654 m

Radial Turbine Impeller

Geometric Ratio	Allowable Range	Impeller Diameters, m		
		1	1.5	2
D/T	0.14 - 0.5	0.30	0.45	0.61
H/D	2.0 - 4.0	3.80	2.53	1.90
H/T	0.28 - 2.0	1.15	1.15	1.15
B/D	0.7 - 1.6	1.27	0.84	0.63

Both the 1 m and the 1.5 m impeller are acceptable.
I chose the 1.0 m impeller.

f. Calculate power input

From Problem 4-84, the temperature is 8°C and $\mu = 1.392 \times 10^{-3}$ Pa-s

1. For first compartment with $G = 60\ s^{-1}$

$$P = G^2(\mu)(\cancel{V}) = (60)^2(1.392 \times 10^{-3})(30) = 150 \text{ W or } 0.15 \text{ kW}$$

2. For second compartment with $G = 50\ s^{-1}$

$$P = G^2(\mu)(\cancel{V}) = (50)^2(1.392 \times 10^{-3})(30) = 104 \text{ W or } 0.10 \text{ kW}$$

g. Calculate rotational speed of impeller

1st compartment

$$n = \left[\frac{150\text{W}}{(0.43)(1000\,\text{kg/m}^3)(1.0\text{m})^5}\right]^{1/3} = \left[\frac{150}{430}\right]^{1/3} = 0.70\text{rps or 42 rpm}$$

2nd compartment

$$n = \left[\frac{104\text{W}}{(0.43)(1000\,\text{kg/m}^3)(1.0\text{m})^5}\right]^{1/3} = \left[\frac{104}{430}\right]^{1/3} = 0.62\text{rps or 37 rpm}$$

h. Calculate tip speed for 1st compartment

Tip speed = (0.70 rps)(π)(1.0 m) = 2.2 m/s

This is less than the maximum allowable tip speed of 2.7 m/s.

4-88 Percent removal of particles; horizontal clarifier

Given: $v_0 = 0.80$ cm/s; $v_p = 0.70$ cm/s

Solution:

$$\%\,\text{Removal} = \frac{0.70}{0.80} \times 100\% = 87.50 \text{ or } 88\%$$

4-89 Percent removal of particles; upflow clarifier

Given: $v_S = 2.80$ mm/s; $v_0 = 0.560$ cm/s

Solution:

$$v_S = \frac{2.80\,\text{mm/s}}{10\,\text{mm/cm}} = 0.280\,\text{cm/s}$$

Since $v_S << v_0$ no particles will be removed (retained)

% Retained = 0.0%

4-90 Percent removal; horizontal clarifier

Given: $v_S = 0.30$ cm/s, $v_0 = 0.25$ cm/s

Solution:

$$\%\,\text{Removal} = \frac{0.30\,\text{cm/s}}{0.25\,\text{cm/s}} \times 100\% = 120\%$$

The settling tank cannot remove more than 100%. Thus, the answer is 100%.

4-91 Repeat 4-88 with increased flow rate

Given: Data in Problem 4-88, increase in flow rate from 0.150 m^3/s to 0.200 m^3/s

Solution:

a. Since the surface area of the tank remains constant and overflow rate is directly proportional to flow rate, the new overflow rate is

$$\frac{v_0}{0.80} = \frac{0.200}{0.150}$$

$v_0 = 1.07$ cm/s

b. New % Removal

$$\%\,\text{Removal} = \frac{0.70}{1.07} \times 100\% = 65\%$$

4-92 Repeat Problem 4-89 with increased flow rate

Given: Data in Problem 4-89, doubling of flow rate

Solution:

Since no particles were removed at the lower flow rate, the increase in flow rate would only decrease the efficiency. The answer remains the same: 0.00% removal.

4-93 Percent removal; horizontal clarifier

Given: Problem 4-90, double flow rate

Solution:

a. Calculate new overflow rate

The surface area of the tank remains constant and the overflow rate is proportional to flow rate. The new overflow rate is

$$\frac{v_0}{0.25} = \frac{2Q}{Q}$$

$v_0 = (2)(0.25) = 0.50$ cm/s

b. % Removal

$$\%\,\text{Removal} = \frac{0.30\,\text{cm/s}}{0.50\,\text{cm/s}} \times 100\% = 60\%$$

4-94 Surface area of sedimentation tank

Given: $Q = 1.0\ \text{m}^3/\text{s}$, 10 sedimentation basins, $v_0 = 15\ \text{m}^3/\text{d-m}^2$

Solution:

a. Convert flow rate to same units

$$Q = (1.0\ \mathrm{m^3/s})(86400\ \mathrm{s/d}) = 86400\ \mathrm{m^3/d}$$

$$\frac{86400\,\mathrm{m^3/d}}{10\tan\mathrm{ks}} = 8640\,\mathrm{m^3/day \cdot \tan k}$$

$$A_s = \frac{8640\,\mathrm{m^3/d}}{15\,\mathrm{m^3/d \cdot m^2}} = 576.0\mathrm{m^2}$$

4-95 Surface area for two tanks for lime floc

Given: Two tanks to handle 0.05162 $\mathrm{m^3/s}$ of lime softening floc

Solution:

a. From Table 4-18 select 57 $\mathrm{m^3/d\text{-}m^2}$ as conservative overflow rate, i.e. one that will yield the larger and, hence, more conservative surface area.

b. Since two tanks (assume in parallel):

$$Q = \frac{0.05162\,\mathrm{m^3/s}}{2} = 0.02581\mathrm{m^3/s}$$

c. And surface area of each tank

$$A_s = \frac{(0.02581\,\mathrm{m^3/s})(86400\,\mathrm{s/d})}{57\,\mathrm{m^3/d \cdot m^2}} = 39.123 \text{ or } 39\ \mathrm{m^2}$$

4-96 Surface area for two tanks for iron/alum floc

Given: Two tanks to handle 0.05162 $\mathrm{m^3/s}$ of lime softening floc

Solution:

a. From Table 4-18 select 20 $\mathrm{m^3/d\text{-}m^2}$ as conservative overflow rate, i.e. one that will yield the larger and, hence, more conservative surface area.

b. Since two tanks (assume in parallel):

$$Q = \frac{0.05162\,\mathrm{m^3/s}}{2} = 0.02581\mathrm{m^3/s}$$

c. And surface area of each tank

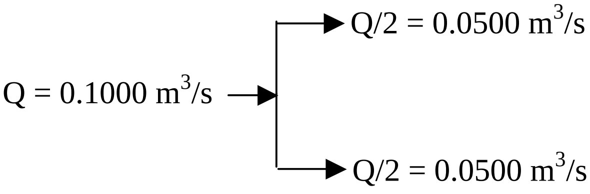
$$A_s = \frac{(0.02581\,\mathrm{m^3/s})(86400\,\mathrm{s/d})}{20\,\mathrm{m^3/d \cdot m^2}} = 111.49 \text{ or } 111\ \mathrm{m^2}$$

4-97 Detention time and surface area

Given: Two sedimentation tanks operate in parallel, total Q = 0.1000 $\mathrm{m^3/s}$, depth = 2.00 m, θ = 4.00 h

Solution:

a. Sketch of flow scheme



b. Convert Q to $\mathrm{m^3/h}$ for each tank

Q = (0.0500 $\mathrm{m^3/s}$)(3600 s/h) = 180 $\mathrm{m^3/h}$

c. Solve Eqn. 2-27 for $\cancel{V}$

$$\theta = \frac{\cancel{V}}{Q}$$

$$\cancel{V} = \theta Q = (4.00\mathrm{h})(180\,\mathrm{m^3/h}) = 720\mathrm{m^3}$$

d. Surface area

$$\cancel{V} = (H)(A_s)$$

$$A_s = \frac{\cancel{V}}{H} = \frac{720\mathrm{m^3}}{2.00\mathrm{m}} = 360\mathrm{m^2}$$

e. Overflow rate

$$v_0 = \frac{Q}{A_s} = \frac{180\,\mathrm{m}^3/\mathrm{h}}{360\mathrm{m}^2} = 0.50\,\mathrm{m}^3/\mathrm{h}\cdot\mathrm{m}^2 \text{ or } 12.0\ \mathrm{m}^3/\mathrm{d}\text{-}\mathrm{m}^2$$

4-98 Detention time and overflow rate

Given: Settling column test data; reduction in suspended solids concentration from 33.0 mg/L to 15.0 mg/L.

Solution:

a. Plot isoconcentration lines as in Figure 4-40

Time [min]	20% Depth [m]	30% Depth [m]	40% Depth [m]	50% Depth [m]	60% Depth [m]	70% Depth [m]	80% Depth [m]
0	0	0	0	0	0	0	0
10	2.5	1.7	1	0.5	0.3	0.3	0.1
20		3.5	2	1.1	0.75	0.7	0.22
30			3.1	1.7	1.2	1	0.45
40			4.5	2.3	1.7	1.35	0.7
50				3.1	2.3	1.7	0.95
60				3.8	2.75	2.1	1.2
70					3.4	2.45	1.58
80					4.05	2.8	1.9
90						3.2	2.28

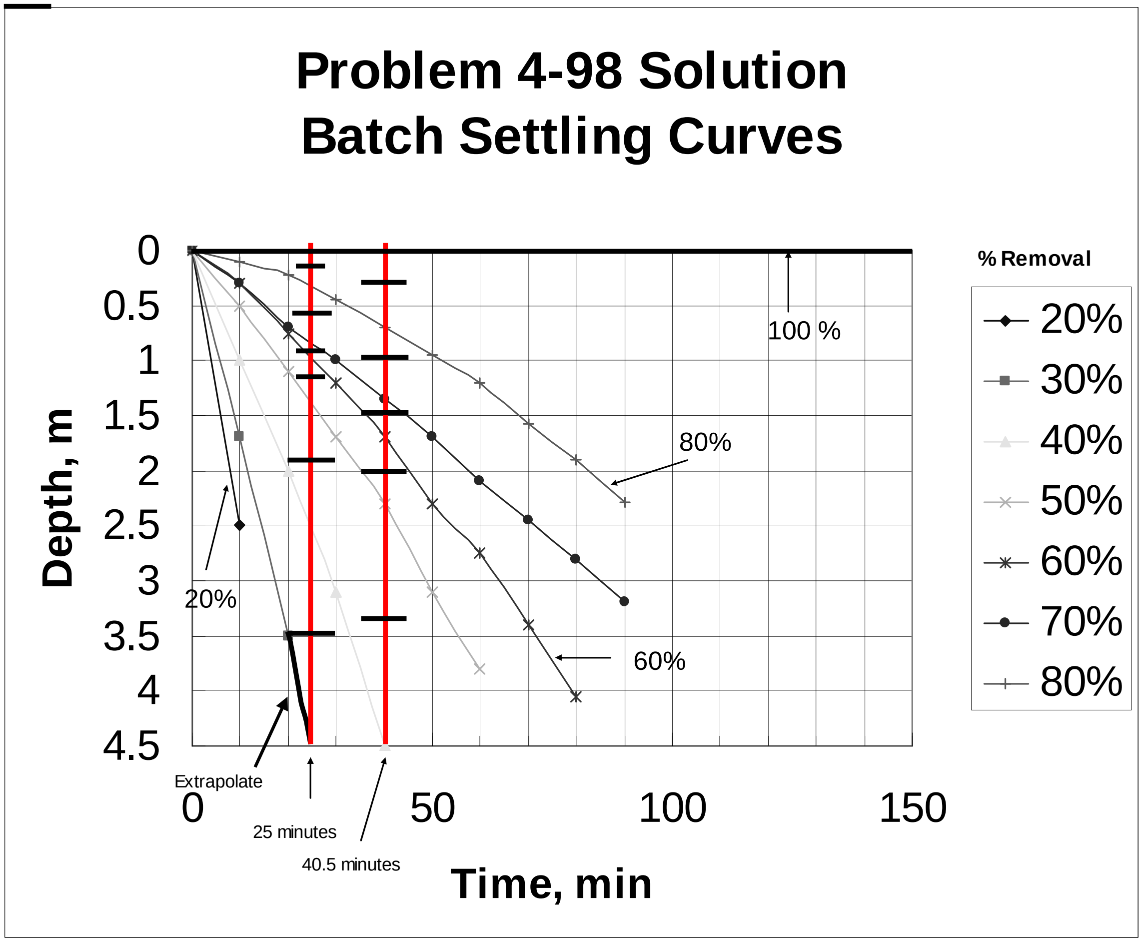


Figure S-4-98a: Batch Settling Curves

b. Required removal is

$$\%\,\text{Removal} = \frac{33.0\,\text{mg/L} - 15.0\,\text{mg/L}}{33.0\,\text{mg/L}} \times 100\% = 54.54\%$$

c. Calculate overflow rate, % removal and detention time for 40% removal line.

1. Overflow rate (Note: time is where 40% line intersects bottom of settling column, i.e. 4.5 m)

$$v_0 = \frac{4.5\text{m}}{40.5\,\text{min}}(1440\,\text{min/d}) = 160.0\,\text{m/d}$$

2. % removal (from vertical line at 40.5 min)

$$\%R_{T40} = 40 + \frac{3.4}{4.5}(50-40) + \frac{2.0}{4.5}(60-50) + \frac{1.5}{4.5}(70-60) + \frac{1.0}{4.5}(80-70) + \frac{0.35}{4.5}(100-80)$$

$\%R_{T40} = 40 + 7.56 + 4.56 + 3.33 + 2.22 + 1.56$

$\%R_{T40} = 59.11\%$

(Note: this exceeds the 54.54% required, so calculate next lower %R and interpolate)

3. Detention time = θ = 40.5 min

d. At 30% removal line

1. Overflow rate (Note: time is where 30% line intersects bottom of settling column, i.e. 4.5 m)

$$v_0 = \frac{4.5\text{m}}{25\,\text{min}}(1440\,\text{min/d}) = 259.2\,\text{m/d}$$

2. % removal (from vertical line at 25 min)

$$\%R_{T30} = 30 + \frac{3.5}{4.5}(40-30) + \frac{1.9}{4.5}(50-40) + \frac{1.2}{4.5}(60-50) + \frac{0.95}{4.5}(70-60) + \frac{0.6}{4.5}(80-70) + \frac{0.18}{4.5}(100-80)$$

$\%R_{T30} = 30 + 7.78 + 4.22 + 2.67 + 2.11 + 1.33 + 0.80$

$\%R_{T30} = 48.91\%$

3. Detention time = θ = 25 min

e. Plot % Removal versus detention time and % Removal versus overflow rate. Assume linear between points and use 54.54% removal to find:

θ = 33 min

v_0 = 204 m/d

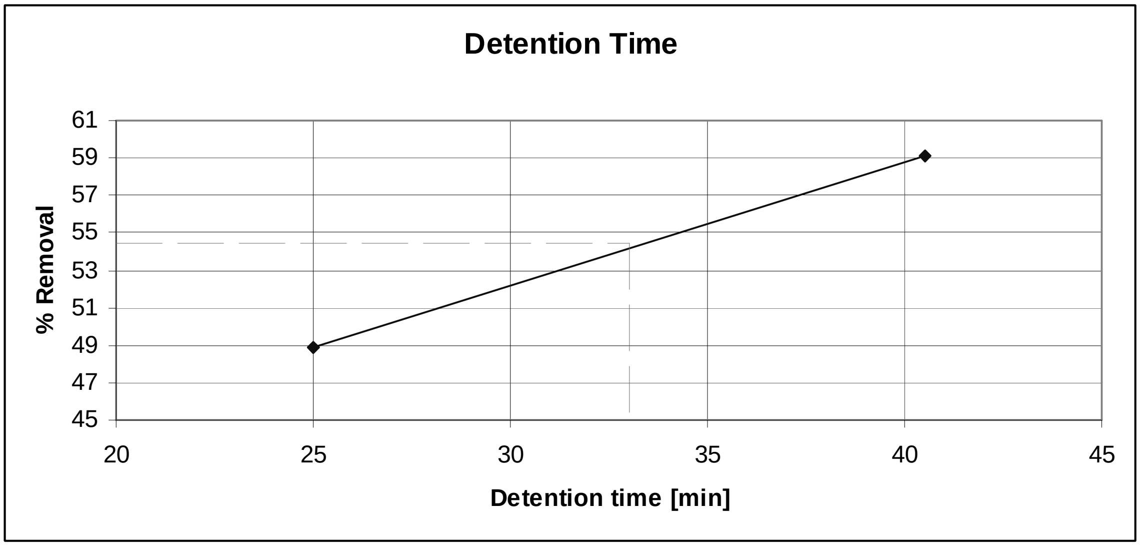


Figure S-4-98b: Detention time

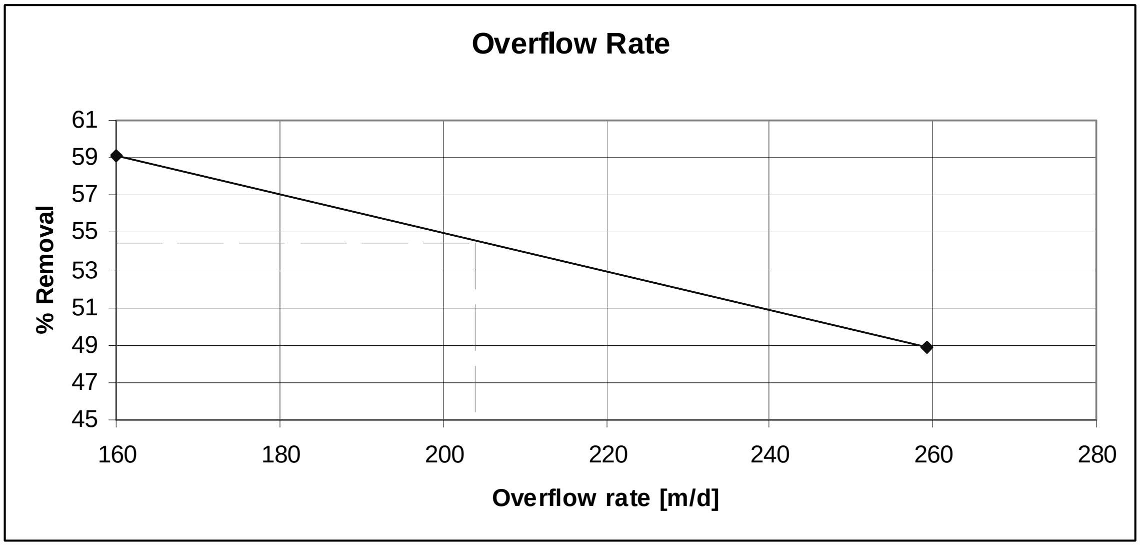


Figure S-4-98c: Overflow rate

f. Apply scale up factors

$\theta = (33 \text{ min})(1.75) = 57.75$ or 60 min

$v_0 = (204 \text{ m/d})(0.65) = 132.6$ or 130 m/d

4-99 Detention time and overflow rate

Given: Settling column test data; reduction in suspended solids concentration of 60%

Solution:

a. Convert suspended solids concentrations to percent removal by:

$$\%\,\text{Removal} = \left(1 - \frac{C_i}{C_0}\right) \times 100\%$$

where C_i = measured concentration at time and depth
C_0 = original concentration

Tabular results are as follows:

Depth [m]	Time [min]					
	10	20	35	50	70	85
0.5	30	50	65	69	75	80
1.0	25	35	47	59	65	70
1.5	23	29	40	50	61	65
2.0	20	27	37	45	55	60
2.5	15	25	35	43	50	56

b. Plot isoconcentration lines as in Figure 4-40

	20%	30%	40%	50%	60%	65%	70%
Time [min]	Depth [m]	Depth [m]	Depth [m]	Depth [m]	Depth [m]	Depth [m]	Depth [m]
0	0	0	0	0	0	0	0
10	2	0.5	0.35	0.23	0.18	0.12	0.05
20		1.4	0.75	0.5	0.35	0.25	0.15
30			1.22	0.75	0.55	0.42	0.23
40			1.8	1.1	0.75	0.57	0.34
50				1.5	1	0.72	0.46
60				1.95	1.25	0.85	0.6
70				2.5	1.55	1.03	0.75
80					1.85	1.33	0.9

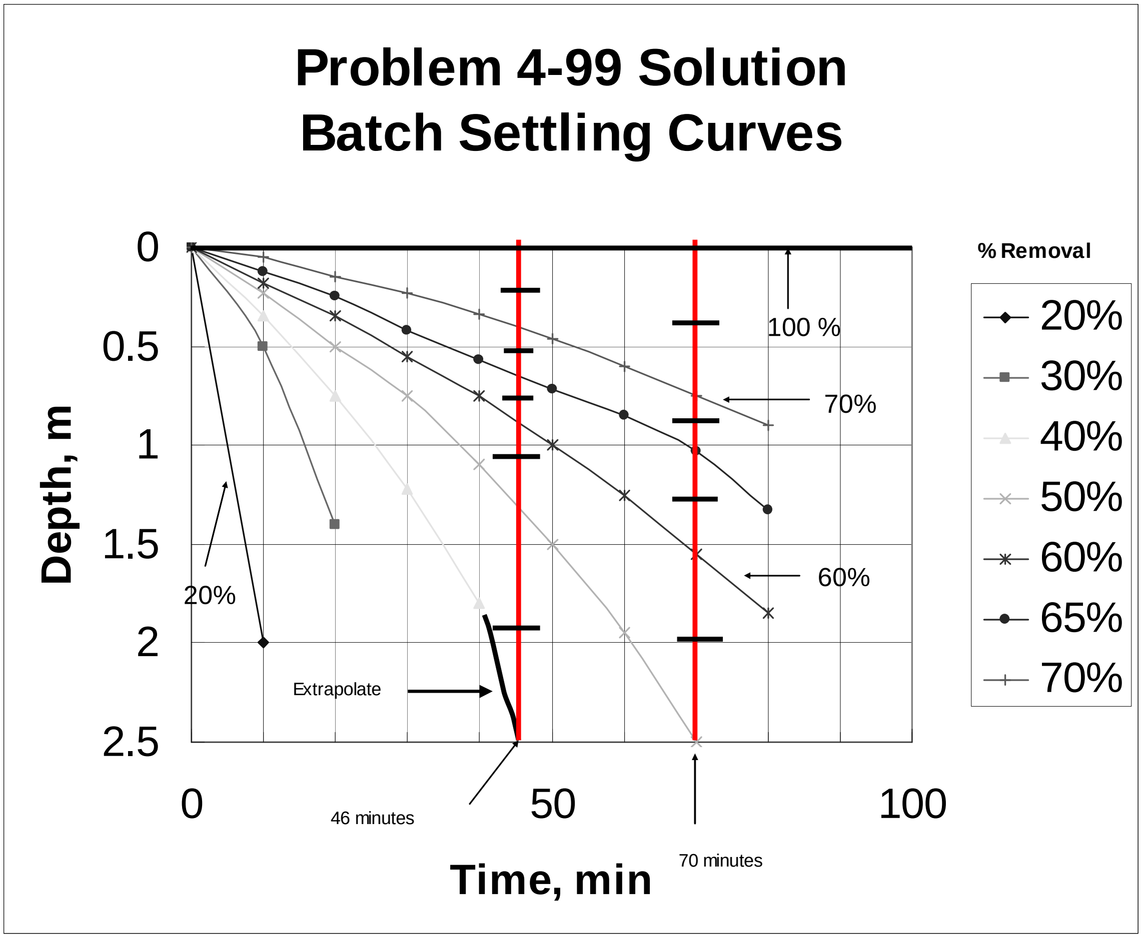


Figure S-4-99a: Batch Settling Curves

c. Calculate overflow rate, % removal and detention time for 50% removal line.

1. Overflow rate (Note: time is where 50% line intersects bottom of settling column, i.e. 2.5 m)

$$v_0 = \frac{2.5\,\text{m}}{70\,\text{min}}(1440\,\text{min/d}) = 51.43\,\text{m/d}$$

2. % removal (from vertical line at 70 min)

$$\%R_{T50} = 50 + \frac{2.0}{2.5}(60-50) + \frac{1.3}{2.5}(65-60) + \frac{0.9}{2.5}(70-65) + \frac{0.38}{2.5}(100-70)$$

$\%R_{T50}$ = 50 + 8.0 + 2.6 + 1.8 + 4.56

$\%R_{T50}$ = 66.96 %

(Note: this exceeds the 60% required, so calculate next lower %R and interpolate)

3. Detention time = θ = 70 min

d. At 40% removal line

1. Overflow rate (Note: time is where 40% line intersects bottom of settling column, i.e. 2.5 m)

$$v_0 = \frac{2.5\,\text{m}}{46\,\text{min}}(1440\,\text{min/d}) = 78.26\,\text{m/d}$$

2. % removal (from vertical line at 46 min)

$$\%R_{T40} = 40 + \frac{1.9}{2.5}(50-40) + \frac{1.1}{2.5}(60-50) + \frac{0.75}{2.5}(65-60) + \frac{0.55}{2.5}(70-65) + \frac{0.2}{2.5}(100-70)$$

$\%R_{T40}$ = 40 + 7.60 + 4.40 + 1.50 + 1.10 + 2.40

$\%R_{T40}$ = 57.0 %

3. Detention time = θ = 46 min

e. Plot % Removal versus detention time and % Removal versus overflow rate. Assume linear between points and use 60% removal to find:

θ = 53.5 min

v_0 = 70 m/d

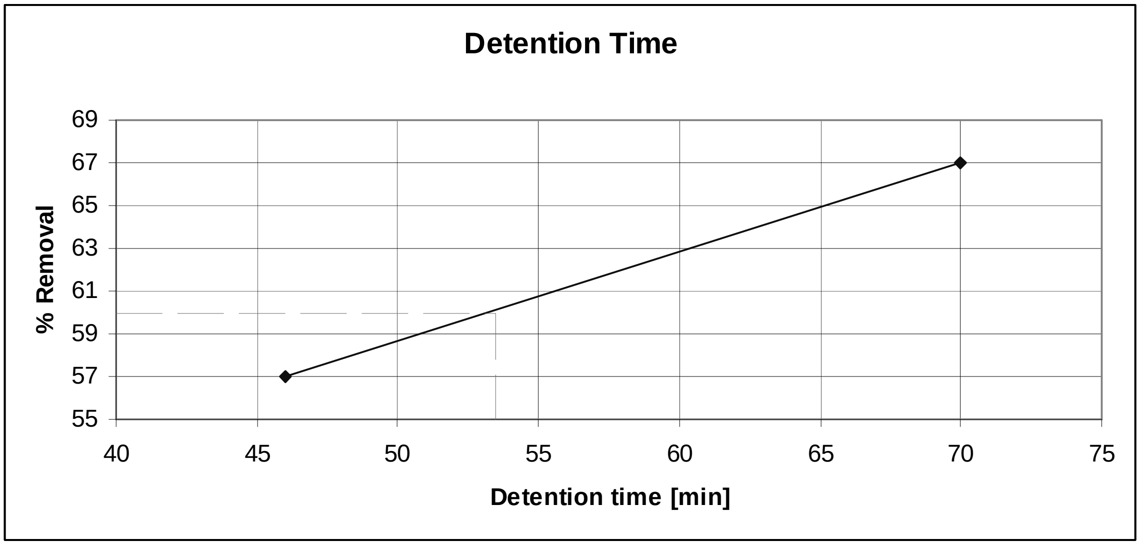


Figure S-4-99b: Detention time

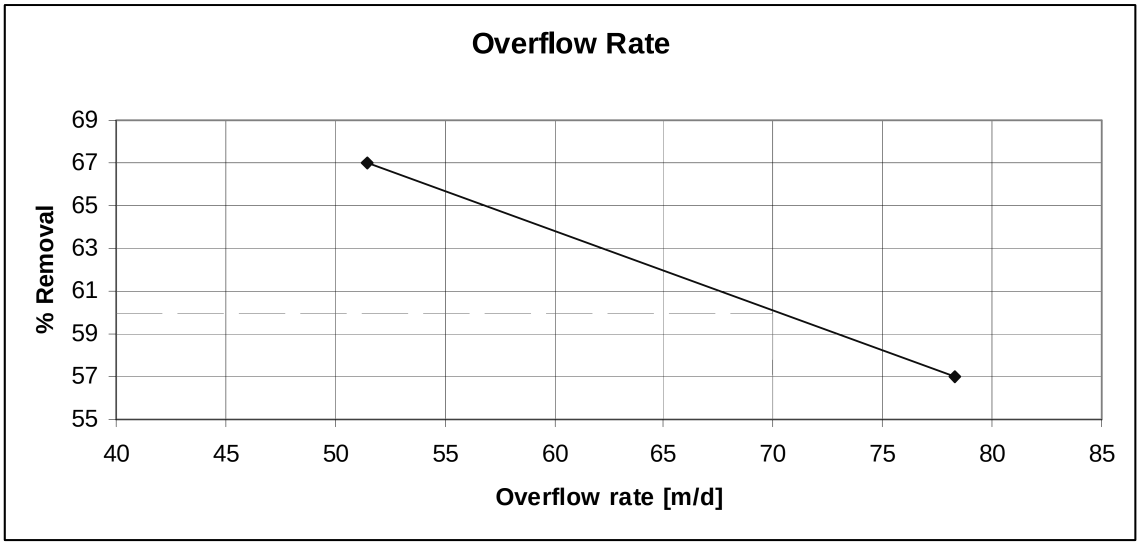


Figure S-4-99c: Overflow rate

f. Apply scale up factors

θ = (53.5 min)(1.75) = 93.63 or 94 min

v_0 = (70 m/d)(0.65) = 45.5 or 46 m/d

4-100 Detention time and overflow rate

Given: Settling column test data, 33 NTU initial turbidity, 88% removal required

Solution:

a. Convert NTU to percent removal by

$$\% \text{Removal} = \left(1 - \frac{C_i}{C_0}\right) \times 100\%$$

where C_i = measured NTU at time and depth
C_0 = original NTU

Tabular results are as follows (all in % removed)

Depth [m]	Time [min]			
	30	60	90	120
1.0	83	94		
2.0	66	82	92	
3.5	56	70	80	90

b. Plot isoconcentration lines

	55%	60%	65%	70%	75%	80%	90%
Time [min]	Depth [m]	Depth [m]	Depth [m]	Depth [m]	Depth [m]	Depth [m]	Depth [m]
0	0	0	0	0	0	0	0
10				0.5		0.3	0.1
20				1		0.6	0.25
30				1.5		0.9	0.4
40				2.05		1.2	0.6
50				2.65		1.5	0.75
60				3.5		1.85	1
70						2.25	1.25
80						2.7	1.5
90						3.5	1.8
100							2.3
110							2.8
120							3.5

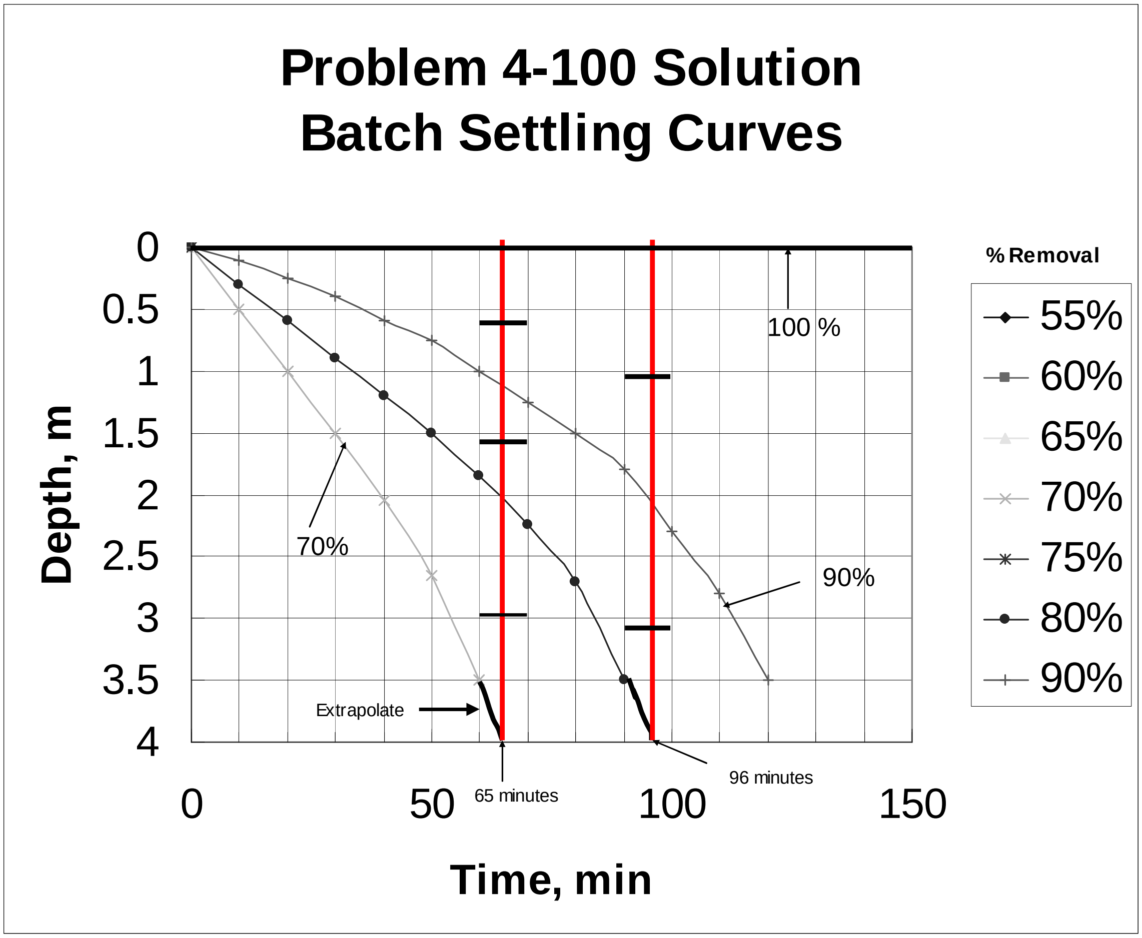


Figure S-4-100a: Batch Settling Curves

c. Calculate overflow rate, % removal, and detention time for 70% removal line

1. Overflow rate

$$v_0 = \frac{4.0\,\text{m}}{65\,\text{min}}\left(1440\,\text{min/d}\right) = 88.62\,\text{m/d}$$

2. % removal from vertical line at 65 min

$$\%R_{T70} = 70 + \frac{3.0}{4.0}(80-70) + \frac{1.6}{4.0}(90-80) + \frac{0.6}{4.0}(100-90)$$

$\%R_{T70} = 70 + 7.5 + 4.0 + 1.5$

$\%R_{T70} = 83.0\%$

(Note: this is less than 88% desired so calculate next higher %R and interpolate)

3. Detention time = θ = 65 min

d. Calculate overflow rate, % removal, and detention time for 80% removal line

1. Overflow rate

$$v_0 = \frac{4.0\text{m}}{96\,\text{min}}(1440\,\text{min/d}) = 60.00\,\text{m/d}$$

2. % removal from vertical line at 96 min

$$\%R_{T80} = 80 + \frac{3.1}{4.0}(90-10) + \frac{1.1}{4.0}(100-90)$$

$\%R_{T80} = 80 + 7.75 + 2.75$

$\%R_{T80} = 90.5\%$

3. Detention time = θ = 96 min

e. Plot % removal vs detention time and % removal vs overflow rate. Assume linear between points and use 88% removal to find

θ = 85 min

v_0 = 69 m/d

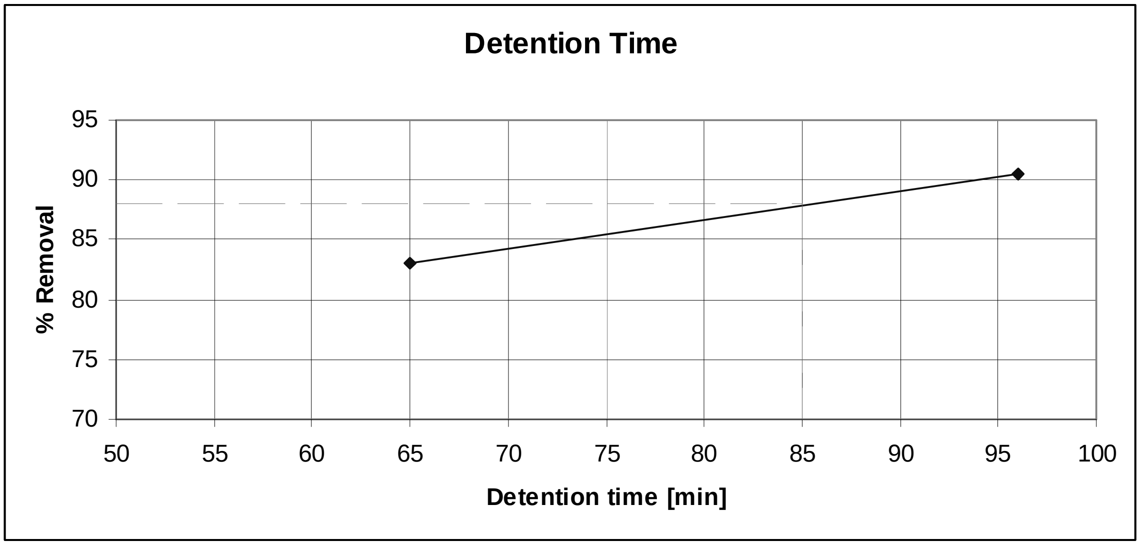


Figure S-4-100b: Detention time

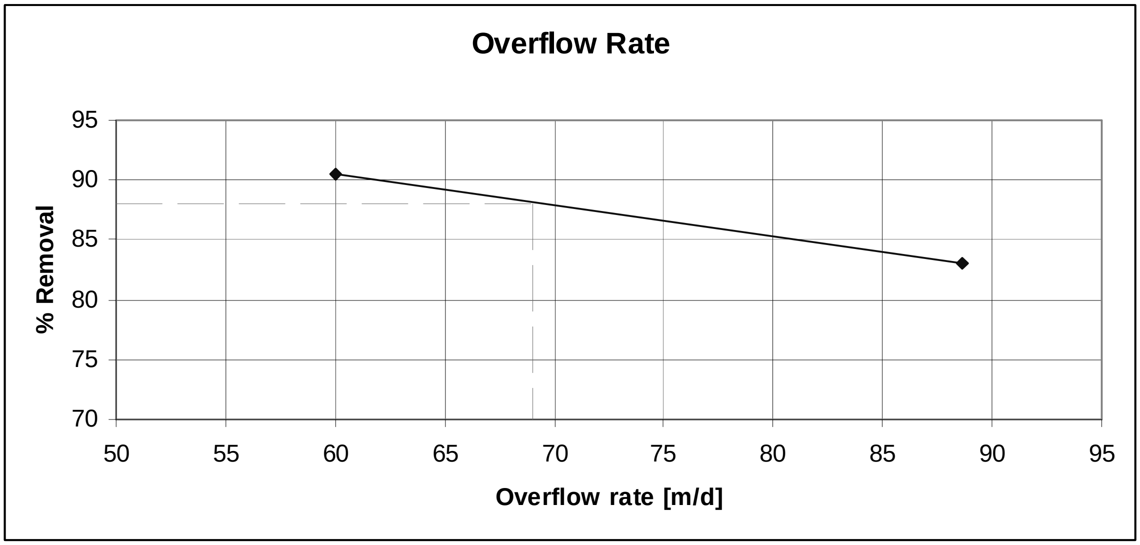


Figure S-4-100c: Overflow rate

f. Apply scale up factors

θ = (85 min)(1.75) = 148.8 or 150 min

v_0 = (69 m/d)(0.65) = 44.85 or 45 m/d

4-101 How many filters at standard loading?

Given: Q = 0.8 m^3/s; each filter 10 m x 20 m; loading rate = 110. $m^3/d\text{-}m^2$

Solution:

a. Determine Q in m^3/d

Q = (0.8 m^3/s)(86,400 s/d) = 69,120 m^3/d

b. Determine total area required

$$A_s = \frac{69120\,m^3/d}{110\,m^3/d\cdot m^{22}} = 628.36m^2$$

c. Number of filters (must round to next highest integer)

$$\text{No.} = \frac{628.36m^2}{(10m)(20m)} = 3.14 \text{ or 4 filters}$$

4-102 How many filters at high loading?

Given: Q = 0.8 m^3/s; each filter 10 m x 20 m; loading rate = 300. $m^3/d\text{-}m^2$

Solution:

a. Determine Q in m^3/d

Q = (0.8 m^3/s)(86,400 s/d) = 69,120 m^3/d

b. Determine total area required

$$A_s = \frac{69120\,m^3/d}{300\,m^3/d \cdot m^{22}} = 230.4 m^2$$

c. Number of filters (must round to next highest integer)

$$\text{No.} = \frac{230.4 m^2}{(10m)(20m)} = 1.152 \text{ or 2 filters}$$

4-103 Flow rate through filters

Given: Four filters (each 5.00 m x 10.00 m) loaded at 280 m/d.

Solution:

a. Note that 280 m/d = 280 $m^3/d\text{-}m^2$

b. Compute flow in m^3/d

Q = (280 $m^3/d\text{-}m^2$)(4)(5.00 m)(10.00 m)

Q = 56,000 m^3/d

c. Convert to m^3/s

$$Q = \frac{56000\,m^3/d}{86400\,s/d} = 0.648\,m^3/s$$

4-104 Plant expansion filter beds

Given: Example 4-25, mono-media filter loading of 600 $m^3/d\text{-}m^2$, filter box limit of $50m^2$

Solution:

a. Surface area required (Note: Q = 0.5 m^3/s from Example 4-25)

$$A_s = \frac{(0.5\,m^3/s)(86400\,s/d)}{600\,m^3/d \cdot m^2} = 72m^2$$

b. If the maximum surface area is 50 m^2, then the number required is

$$\frac{72m^2}{50m^2} = 1.44 \text{ filter boxes}$$

Therefore use 2 filter boxes.

c. Check with one filter box out of service

$$v_a = \frac{(0.5\,m^3/s)(86400\,s/d)}{(1\text{filters})(50\,m^2/\text{filter})} = 864\,m/d$$

This is greater than the design loading rate.

d. A number of alternatives are available. One example is to provide 4 filter boxes at 25 m^2 each. With one out of service

$$v_a = \frac{(0.5\,m^3/s)(86400\,s/d)}{(3\text{filters})(25\,m^2/\text{filter})} = 576\,m/d$$

This is less than the design loading rate.

4-105 Grain size analysis for Eau Gaullie

Given: U.S. sieve number and mass % retained

Solution:

a. Convert sieve number to size using Table 4-19 and compute cumulative mass %. Tabulation is shown below:

Cumul. Mass	Grain size [mm]	U.S. Sieve Number
0	0.149	100
0.1	0.21	70
3.8	0.297	50
24	0.42	40
68	0.59	30
93.9	0.84	20
99.6	1.19	16
99.99	1.68	12

b. Plot (following page)

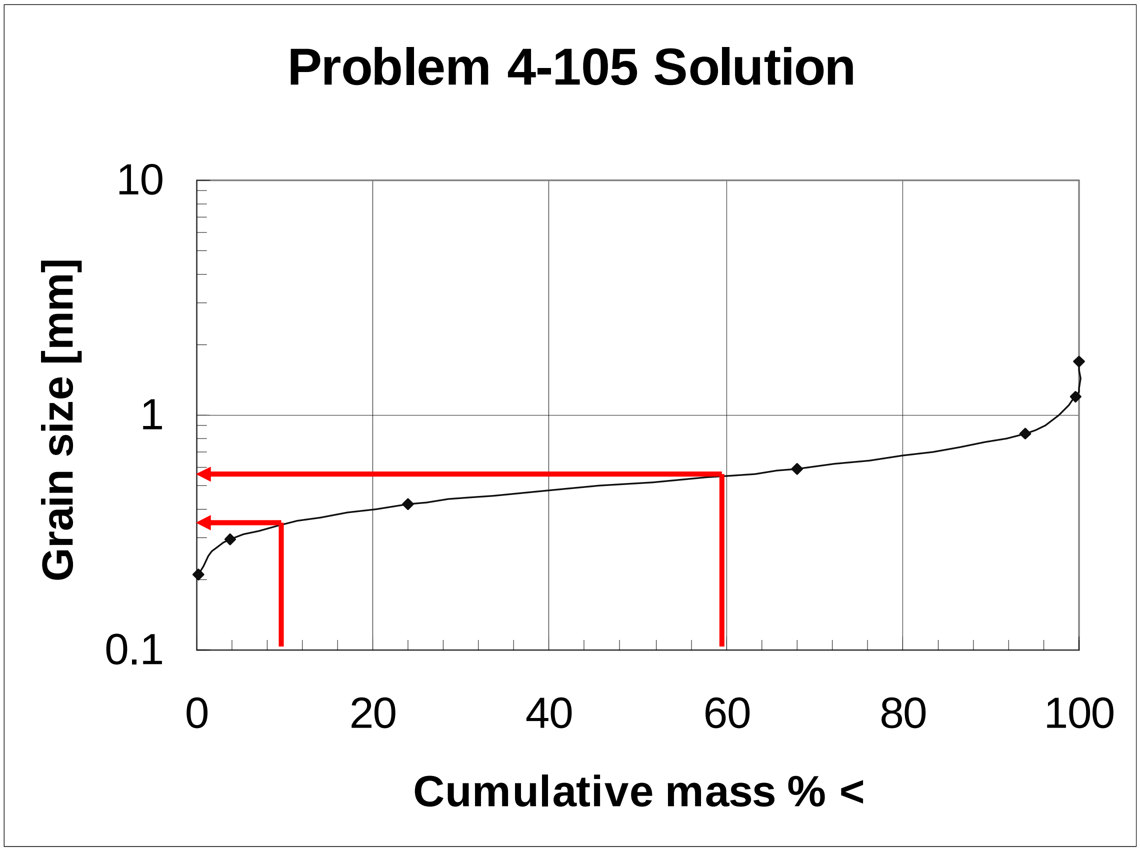


Figure S-4-105

c. From the graph find:

$E = P_{10} = 0.35$ mm

$$U = \frac{P_{60}}{P_{10}} = \frac{0.56\text{mm}}{0.35\text{mm}} = 1.60$$

d. The effective size just fits the lower end of the acceptable range of 0.35 to 0.55 mm. The uniformity coefficient falls within the acceptable range of 1.3 to 1.7. Therefore, the sand meets the specifications.

4-106 Grain size analysis for Laramie

Given: U.S. sieve number, mass retained and sample size of 500.00 g

Solution:

a. Convert sieve number to size using Table 4-19 and compute cumulative mass %. Tabulation is shown below:

Cumul. Mass	Grain size [mm]	U.S. Sieve Number
0.015	0.297	50
1.8	0.42	40
32	0.59	30
86.5	0.84	20
99.6	1.19	16

b. Plot

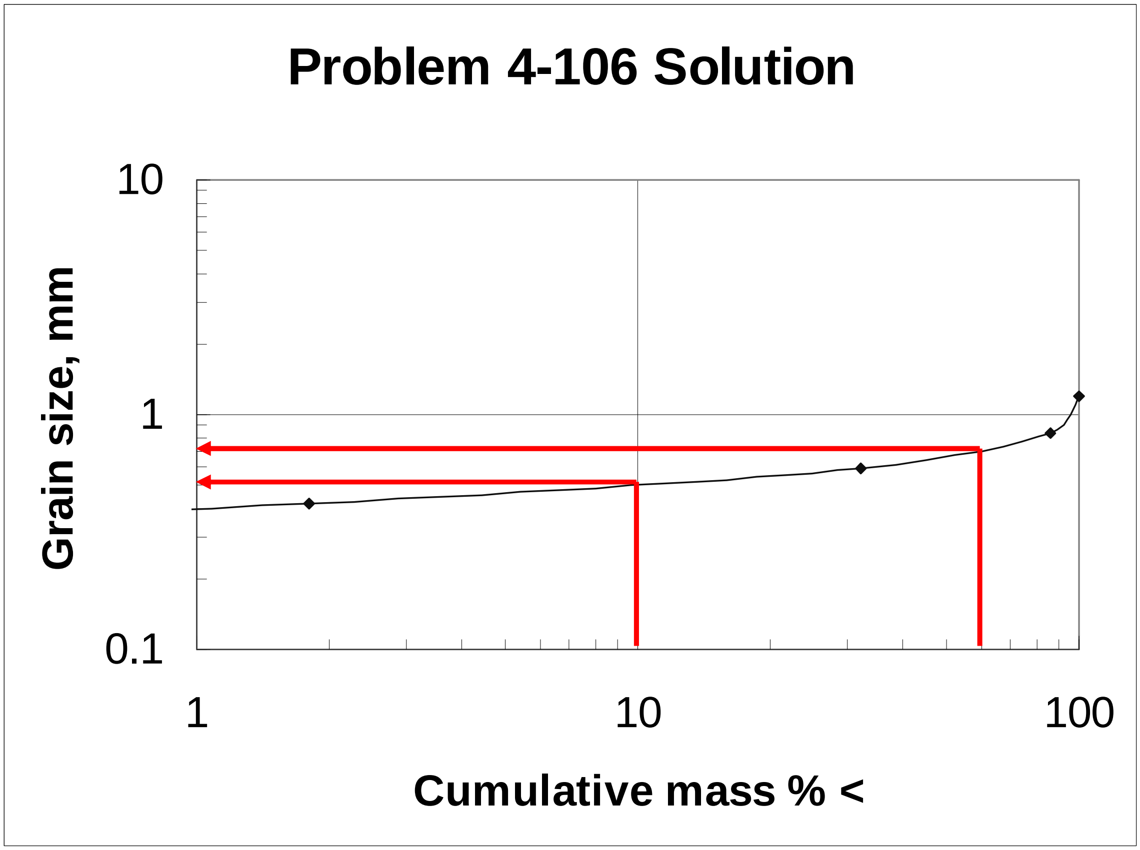


Figure S-4-106

c. From the graph find:

$$E = P_{10} = 0.495 \text{ mm}$$

$$U = \frac{P_{60}}{P_{10}} = \frac{0.68\text{mm}}{0.495\text{mm}} = 1.37$$

d. The effective size fits the acceptable range of 0.35 to 0.55 mm. The uniformity coefficient meets the acceptable range of 1.3 to 1.7. Therefore, the sand meets the specifications.

4-107 Rework Example 4-26

Given: Data in Example 4-26 with 70, 100 and 140 sieve fractions removed.

Solution:

a. Recompute cumulative % passing assuming that 4.0% of the sand (i.e. % passing the No. 70 sieve) is removed. For computational purposes assume 100 g was in original sample and 4.0 grams of lower sized fractions were removed. The tabulations are shown below. The computations for the 3rd, 4th and5th columns are explained below the table.

Cumul. Mass	Grain size [mm]	U.S. Sieve Number
6.21	0.297	50
18.74	0.42	40
37.27	0.59	30
58.74	0.84	20
74.11	1.19	16
92.11	1.68	12

b. Plot (following page)

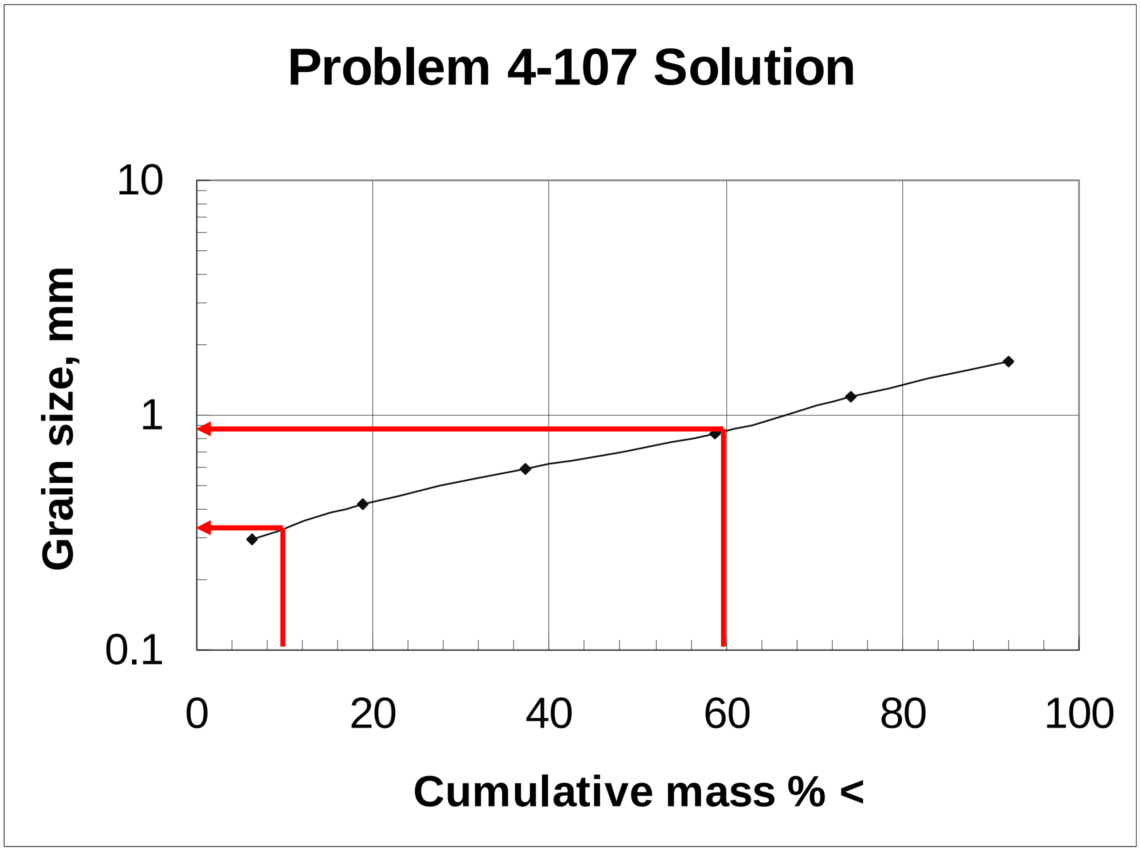


Figure S-4-107

c. From the graph find:

$$E = P_{10} = 0.34 \text{ mm}$$

$$U = \frac{P_{60}}{P_{10}} = \frac{0.84\text{mm}}{0.34\text{mm}} = 2.47$$

d. The effective size does not quite fit the acceptable range of 0.35 to 0.55 mm. The uniformity coefficient exceeds the acceptable range of 1.3 to 1.7. Therefore, the sand does not meet specifications but is improved from the example effective size of 0.30 mm and uniformity coefficient of 2.8.

4-108 Head loss for clean filter bed - Eau Gaullie

Given: Filter and sand data for Eau Gaullie

Solution:

a. The following tabulation for computing the solution was obtained from a spreadsheet program.

Sieve No.	% Retained	d [m x 10^{-4}]	Re	C_D	((C_D)(f)/d) x 10^4
8-12	0.01	20	2.7	11.056	0.00005528
12-16	0.39	14.2	1.917	15.029	0.004127683
16-20	5.7	10	1.35	20.703	0.1180071
20-30	25.9	7.14	0.964	28.299	1.026532353
30-40	44	5.05	0.682	39.184	3.414051485
40-50	20.2	3.57	0.482	54.469	3.08199944
50-70	3.7	2.52	0.34	70.56	1.036
70-100	0.1	1.78	0.24	99.894	0.056120225

SUM (C_D)(f)/d = 8.7369 x 10^4

b. Compute the approach velocity (v_a) in m/s

$$\frac{120\,\mathrm{m^3/d\cdot m^2}}{86400\,\mathrm{s/d}} = 0.0013889\,\mathrm{m/s}$$

c. The total head loss is then

$$h_L = \frac{1.067(0.0013889\,\mathrm{m/s})^2(0.60\mathrm{m})}{(1.00)(9.80)(0.42)^4}\left(8.7369\times10^4\right)$$

h_L = 0.3538 or 0.35 m

4-109 Height of expanded bed - Eau Gaullie

Given: Data from Problem 4-108 and backwash rate of 1,000 m/d

Solution:

a. The following tabulation for computing the solution was obtained from a spreadsheet program.

NOTE: The sieve ranges and fractions (f) are not shown due to space limitations. They are the same as in Problem 4-108. Also note that the backwash velocity (v_b) of 1,000 m/d is the same as 0.01157 m/s used to calculate e using Eqn. 4-107.

Estimated v_s [m/s]	Re	C_D	Calculated v_s [m/s]	ε_e	$f/(1 - \varepsilon_e)$
0.3	583	0.505	0.2785	0.4967	0.0002
0.2	276	0.608	0.214	0.5263	0.00823
0.15	145.8	0.753	0.1613	0.5601	0.12957
0.1	69.4	1.046	0.1157	0.6026	0.65174
0.07	34.4	1.55	0.0799	0.6537	1.2706
0.05	17.3	2.444	0.0535	0.714	0.70623
0.03	7.35	4.713	0.0323	0.7974	0.18267
0.02	3.46	8.89	0.0198	0.8884	0.00896

SUM $f/(1 - \varepsilon_e) = 2.9582$

b. Using Eqn. 4-106 the expanded bed depth is

$D_e = (1 - 0.42)(0.60)(2.9582) = 1.0294$ or 1.03 m

4-110 Head loss for clean filter bed Laramie

Given: Filter and sand data for Laramie

Solution:

a.

Sieve No.	% Retained	d [m x 10^{-4}]	Re	C_D	$((C_D)(f)/d) \times 10^4$
12-16	0.4	14.2	2.265	12.932	0.003642817
16-20	13.1	10	1.595	17.765	0.2327215
20-30	54.5	7.14	1.139	24.229	1.849412465
30-40	30.2	5.05	0.805	33.483	2.002349703
40-50	1.785	3.57	0.569	46.471	0.232355
50-70	0.015	2.52	0.402	59.719	0.003554702

SUM $(C_D)(f)/d = \quad 4.324 \times 10^4$

b. Compute the approach velocity (v_a) in m/s

$$\frac{230\,\mathrm{m^3/d \cdot m^2}}{86400\,\mathrm{s/d}} = 0.0026620\,\mathrm{m/s}$$

c. The total head loss is then

$$h_L = \frac{1.067(0.0026620\,\mathrm{m/s})^2(0.75\mathrm{m})}{(0.91)(9.80)(0.50)^4}\left(4.324 \times 10^4\right)$$

$h_L = 0.44$ m

4-111 Backwash rate and height of backwash troughs - Laramie

Given: Data from Problem 4-110

Solution:

a. The maximum backwash rate is determined by estimating the settling velocity of the smallest sand grain size that makes up the filter bed. From Figure 4-46, this is estimated to be 3.0 cm/s for the particle size 0.0252 cm. Using this velocity to estimate the Reynolds number yielded a calculated settling velocity of 2.9 cm/s. A backwash velocity of 2.9 cm/s cannot be used because it yields a negative expanded depth. A 2.8 cm/s backwash velocity was used to estimate the depth of the expanded bed and the height of the backwash troughs.

a. The following tabulation for computing the solution was obtained from a spreadsheet program.

NOTE: The sieve ranges and fractions (f) are not shown due to space limitations. They are the same as in Problem 4-110. Also note that the backwash velocity (v_b) of 0.028 m/s was used to calculate ̣e using Eqn. 4-107.

Estimated v_s [m/s]	Re	C_D	Calculated v_s [m/s]	ε_e	$f/(1 - \varepsilon_e)$
0.2	170.1	0.711	0.2167	0.6375	0.01103
0.15	89.9	0.924	0.1596	0.6819	0.41182
0.1	42.8	1.36	0.1111	0.7384	2.0834
0.07	21.2	2.125	0.0748	0.8057	1.5543
0.05	10.7	3.502	0.0489	0.8843	0.15427
0.03	4.52	7.049	0.029	0.9923	0.01957

SUM $f/(1 - \varepsilon_e)$ = 4.2343

b. Using Eqn. 4-106 the expanded bed depth is

$D_e = (1 - 0.50)(0.75)(4.2343) = 1.59$ m

c. The height of the backwash troughs should be

(1.59 m - 0.75 m) + 0.15 m = 0.99 or 1 m above top of sand surface

4-112 Rework Example 4-27

Given: Example 4-27 with 100 - 140 sieve fraction removed

Solution:

a. The problem is not explicitly clear that the % retained fractions should be recalculated. This is further confused by the fact that the example calculation ignores that fraction of the sand that is greater than the No. 8 sieve, so calculating the new fractional percentages is not straight forward. The solution yields a new head loss of 0.72 m.

b. The simple approach to solving this problem (and the one I would expect most students to take) is simply to insert 0.0% in the 100 -140 row and recompute. This yields a new head loss of 0.69 m.

4-113 Rework Example 4-28

Given: Example 4-28 with 100 - 140 sieve fraction removed.

Solution:

a. See discussion for Prob. 4-112. With new sieve percentages, the depth of the expanded bed is 0.79 m.

b. With the simple approach of removing the 100 -140 fraction, the depth of the expanded bed is 0.76 m.

4-114 Percent reduction

Given: 2.5 log inactivation

Solution:

a.

$$y = 100 - \frac{100}{10^{x}}$$

$$y = 100 - \frac{100}{10^{2.5}} = 100 - 0.32 = 99.68\%$$

4-115 Log inactivation

Given: 99.96 percent inactivation

Solution:

a. Solve for x

$$y = 100 - \frac{100}{10^x}$$

$$y - 100 = -\frac{100}{10^x}$$

$$10^x = \frac{-100}{y - 100}$$

$$\log\left(10^x\right) = \log\left(\frac{-100}{y - 100}\right)$$

$$x = \log\left(\frac{-100}{y - 100}\right)$$

b. Substitute value of y = 99.96%

$$x = \log\left(\frac{-100}{99.96 - 100}\right) = \log(2500) = 3.3979 \text{ or } 3.4$$

Therefore there is a 3.4 log inactivation of *Giardia lambia*

DISCUSSION QUESTIONS

4-1 pH of carbonated beverage

Given: carbonated beverage

Solution:

The pH will be below 7. This is an application of the carbonate buffer system. Since the beverage container is closed the addition of CO_2 forces the carbonate buffer system reaction to the right. Carbonic acid is formed. The dissociation results in an increase in hydrogen ion concentration and a lowering of the pH. See Equation 4-35 and Figure 4-5.

4-2 Explain turbidity

Given: mayor of community

Solution:

Turbidity is finely suspended particulate matter that refracts light. Materials that may cause turbidity include clay, silt, finely divided organic matter and algae.

4-3 Chemicals to make water palatable

Given: surface water

Solution:

Surface water may be unpalatable because of turbidity, color, taste, or odor. The chemicals used to treat the water to remove these contaminants are listed below:

turbidity and color - alum or ferric chloride
taste and odor - activated carbon (GAC or PAC)

4-4 Microorganisms and formation of hardness

Given: statement that microorganisms play a role in formation of hardness

Solution:

The answer is true.
The release of CO_2 by microorganisms causes the formation of carbonic acid which aids in the dissolution of calcium carbonate and magnesium carbonate. See Figure 4-14.

4-5 Chemicals required to soften water

Given: well water with no bicarbonate

Solution:

If there is no bicarbonate, then the water has only noncarbonate hardness and the chemicals required are lime and sodium carbonate (soda ash).

4-6 Partial removal in settling tank

Given: Horizontal flow clarifier, settling velocity of particles is 1/4 that of the overflow rate.

Solution:

See Figure 4-37.

4-7 Why chlorine residual?

Given: U.S. chlorine is preferred as disinfectant.

Solution:

The presence of a residual is important because it provides some protection in case of contamination of the water distribution system. It also provides a means to check for contamination because contaminants deplete the chlorine residual. The absence of a chlorine residual during routine examination is an indicator of contamination.

4-8 Sludge dewatering

Given: softening sludge to be disposed of in Lubbock, TX

Solution:

Cheap, available land favors lagoons and sand drying beds. The sand drying beds would provide more drying capacity in less space but at a higher capital cost. If the sludge is to be spread on the land for agricultural use, then the lagoons would probably be selected. If the sludge was to be buried, then sand drying beds would probably be selected.