CHAPTER 10
SOLUTIONS

10-1 Lifetime CDI for occupational exposure to Cr(VI)

Given: Concentration = 0.05 mg/m^3, exposure = 8 h/d for age 18 to 65, 5 d/wk, 50 wk/y

Solution:

a. Exposure = (65-18) = 47 years

b. Inhalation rate = $\frac{20\text{m}^3}{24\text{h}}$ = 0.833 m^3/h

c. Using the inhalation form of the equation in Table 10-8

$$\text{CDI} = \frac{(0.05\,\text{mg/m}^3)(0.833\,\text{m}^3/\text{h})(8\,\text{h/d})(5\,\text{d/wk})(50\,\text{wk/y})(47\,\text{y})}{(70\text{kg})(70\text{y})(365\text{d})}$$

CDI = 2.2 x 10^{-3} mg/kg • d

10-2 CDI for sulfur dioxide

Given: NAAQS = 80 μg/m^3, lifetime (24 h/d, 365 d/y), average adult.

Solution:

a. Using the assumptions in Table 10-8

$$\text{CDI} = \frac{(80\,\mu\text{g/m}^3)(20\,\text{m}^3/\text{d})(365\,\text{d/y})(70\text{y})}{(78\text{kg})(70\text{y})(365\text{d})}$$

CDI = 20.51 μg/kg • d or 2.05 x 10^{-2} mg/kg • d

10-3 Comparison of adult and child CDI for nitrate

Given: Drinking water at 10 mg/L, one year averaging time, 1 year old child.

Solution:

a. Using Table 10-9 values for 1 year old child

$$\text{CDI} = \frac{(10\,\text{mg/L})(1\,\text{L/d})(365\,\text{d/y})(1\text{y})}{(16\text{kg})(1\text{y})(365\,\text{d/y})}$$

CDI = 0.625 mg/kg • d

b. Using Table 10-9 for an adult

$$\text{CDI} = \frac{(10\,\text{mg/L})(2\,\text{L/d})(365\,\text{d/y})(1\text{y})}{(65.4\text{kg})(1\text{y})(365\,\text{d/y})}$$

CDI = 0.31 mg/kg • d

10-4 Ingestion of soil with 2, 4-D

Given: Soil concentration of 2, 4-D = 10 mg/kg, child = 3 years old, adult, 1 year averaging time, 1 d/week, 20 weeks/y, FI = 0.10

Solution:

a. Using Table 10-9 values for 3 year old child

$$\text{CDI} = \frac{(10\,\text{mg/kg})(200\,\text{mg/d})(10^{-6}\,\text{kg/mg})(0.10)(1\,\text{d/wk})(20\,\text{wk/y})(1\text{y})}{(16\text{kg})(1\,\text{d/wk})(20\,\text{wk/y})(1\text{y})}$$

CDI = 1.25 x 10^{-5} mg/kg • d

b. For adult

$$\text{CDI} = \frac{(10\,\text{mg/kg})(100\,\text{mg/d})(10^{-6}\,\text{kg/mg})(0.10)(1\,\text{d/wk})(20\,\text{wk/y})(1\text{y})}{(70\text{kg})(1\,\text{d/wk})(20\,\text{wk/y})(1\text{y})}$$

CDI = 1.43 x 10^{-6} mg/kg • d

10-5 Estimating chronic daily intake

Given: Adult female consumes water, bathes 20 min/d and does not swim is exposed to toluene at drinking water limit.

Solution:

a. Routes of exposure are:

1. Ingestion of drinking water

2. Dermal contact with water during bath

3. Inhalation during bath

b. Drinking water standard is 1.0 mg/L

c. Ingestion (Eqn 10-10)

$$CDI = \frac{(1.0\,mg/L)(2.3\,L/d)(365\,d/y)(70y)}{(65.4kg)(70y)(365\,d/y)}$$

CDI = 3.52 x 10^{-2} mg/kg • d

d. Dermal contact (Eqn 10-12). NOTE: 80% submergence, PC = 9.0 x 10^{-6} m/h, and

$$ET = \frac{20\,min/d}{60\,min/h} = 0.3333\,h/d$$

$$AD = \frac{(1.0\,mg/L)(1.69m^2)(9.0\times10^{-6}\ m/h)(0.3333\,h/d)(365\,d/y)(70y)(10^3\ L/m^3)}{(65.4kg)(70y)(365\,d/y)}(0.80)$$

AD = (7.75 x 10^{-5})(0.80) = 6.20 x 10^{-5} mg/kg • d

e. Inhalation during bath (Eqn 10-15). NOTE: IR = 20 m^3/d = 0.8333 m^3/h

$$CDI = \frac{(1.0\,\mu g/m^3)(10^{-3}\ mg/\mu g)(0.8333\,m^3/h)(0.3333\,h/d)(365\,d/y)(70y)}{(65.4kg)(70y)(365\,d/y)}$$

CDI = 4.25 x 10^{-6} mg/kg • d

f. Total CDI

CDI = 3.52 x 10^{-2} + 6.20 x 10^{-5} + 4.25 x 10^{-6} = 3.53 x 10^{-2}

or 3.5 x 10^{-2} mg/kg • d

10-6 Estimating chronic daily intake

Given: Child exposed for 5 years to 1,1,1-trichloroethane at drinking water limit. She swims, bathes. Average age is 8 years over exposure period.

Solution:

a. Routes of exposure are:

1. Ingestion of drinking water
2. Ingestion while swimming
3. Dermal contact while swimming
4. Dermal contact with water during bath
5. Inhalation during bath

b. Drinking water standard is 0.2 mg/L.

c. Ingestion of drinking water (Eqn 10-10)

$$\mathrm{CDI} = \frac{(0.2\,\mathrm{mg/L})(1.0\,\mathrm{L/d})(365\,\mathrm{d/y})(5\mathrm{y})}{(26\mathrm{kg})(5\mathrm{y})(365\,\mathrm{d/y})}$$

CDI = 7.69 x 10^{-3} mg/kg • d

d. Ingestion while swimming (Eqn 10-11)

$$\mathrm{ET} = \frac{30\,\mathrm{min/wk}}{60\,\mathrm{min/h}} = 0.5\,\mathrm{h/wk}$$

$$\mathrm{CDI} = \frac{(0.2\,\mathrm{mg/L})(50\,\mathrm{mL/h})(10^{-3}\,\mathrm{L/mL})(0.5\,\mathrm{h/wk})(52\,\mathrm{wk/y})(5\mathrm{y})}{(26\mathrm{kg})(5\mathrm{y})(365\,\mathrm{d/y})}$$

CDI = 2.74 x 10^{-5} mg/kg • d

e. Dermal contact while swimming (Eqn 10-12). NOTE: Assume 100% of body is exposed during swimming (a bit high but no other data given) PC = 6.0 x 10^{-3} m/h, and

$$\mathrm{ET} = \frac{30\,\mathrm{min/wk}}{60\,\mathrm{min/h}} = 0.5\,\mathrm{h/wk}$$

$$\mathrm{AD} = \frac{(0.2\,\mathrm{mg/L})(0.925\mathrm{m}^2)(6.0\times10^{-3}\,\mathrm{m/h})(0.5\,\mathrm{h/wk})(52\,\mathrm{wk/y})(5\mathrm{y})(10^3\,\mathrm{L/m}^3)}{(26\mathrm{kg})(5\mathrm{y})(365\,\mathrm{d/y})}$$

AD = 3.04 x 10^{-3} mg/kg • d

f. Dermal contact while bathing (Eqn 10-12). NOTE: 50% submergence, PC = 6.0 x 10^{-3} m/h, and

$$ET = \frac{10\,\text{min/d}}{60\,\text{min/h}} = 0.1667\,\text{h/d}$$

$$AD = \frac{(0.2\,\text{mg/L})(0.925\text{m}^2)(6.0\times10^{-3}\ \text{m/h})(0.1667\,\text{h/d})(365\,\text{d/y})(5\text{y})(10^3\ \text{L/m}^3)}{(26\text{kg})(5\text{y})(365\,\text{d/y})}(0.50)$$

AD = (7.12 x 10^{-3})(0.50) = 3.56 x 10^{-3} mg/kg • d

g. Inhalation during bath (Eqn 10-15). NOTE: IR = 5 m^3/d = 0.2083 m^3/h

$$CDI = \frac{(1.0\,\mu\text{g/m}^3)(10^{-3}\ \text{mg}/\mu\text{g})(0.2083\,\text{m}^3/\text{h})(0.1667\,\text{h/d})(365\,\text{d/y})(5\text{y})}{(26\text{kg})(5\text{y})(365\,\text{d/y})}$$

CDI = 1.34 x 10^{-6} mg/kg • d

h. Total CDI

CDI = 7.69 x 10^{-3} + 2.74 x 10^{-5} + 3.04 x 10^{-3} + 3.56 x 10^{-3} + 1.34 x 10^{-6}

CDI = 1.43 x 10^{-2} mg/kg • d

10-7 Hexavalent chromium risk

Given: Data in Problem 10-1

Solution:

a. The slope factor for Cr(VI) from Table 10-5 is 42 kg • d/mg. From Problem 10-1 CDI = 2.2 x 10^{-3} mg/ kg • d. The risk is then:

Risk = (2.2 x 10^{-3} mg/ kg • d)(42 kg • d/mg) = 9.24 x 10^{-2}

b. This is greater than 0.01 so the risk must be calculated with Eqn. 10-18:

Risk = 1 – exp[9.24 x 10^{-2}] = 8.83 x 10^{-2} or 0.09

10-8 Concentration of hexavalent chromium = 10^{-5} risk

Given: Standard assumptions

Solution:

a. Using the slope factor from Table 10-5, calculate the CDI

risk = (SF)(CDI)

10^{-5} = (42 kg • d/mg)(CDI)

CDI = 2.38 x 10^{-7} mg/kg • d

b. Using assumptions from Table 10-9

$$2.38\times10^{-7}\ \mathrm{mg/kg\cdot d} = \frac{(\mathrm{CA})(20\,\mathrm{m^3/d})(365\,\mathrm{d/y})(70\mathrm{y})}{(78\mathrm{kg})(70\mathrm{y})(365\,\mathrm{d/y})}$$

CA = 9.28 x 10^{-7} mg/m^3

10-9 Characterize risk

Given: toluene, barium, and xylenes

Solution:

a. These are not carcinogens so calculate hazard index using Eqn 10-19 and 10-22 and Table 10-6

$$\mathrm{HI} = \frac{0.03}{0.2} + \frac{0.06}{0.05} + \frac{0.3}{2.0}$$

HI = 0.15 + 1.2 + 0.15 = 1.5

10-10 Characterize risk

Given: tetrachloroethylene, arsenic, dichloromethane

Solution:

a. These are all carcinogens so calculate risk using Eqn 10-17 and 10-20 and slope factors from Table 10-5

Risk = $(1.34 \times 10^{-4})(0.052) + (1.43 \times 10^{-3})(1.5) + (2.34 \times 10^{-4})(0.0075)$

Risk = 2.15×10^{-3}

10-11 Identifying RCRA hazardous waste

Given: Municipal wastewater containing 2.0 mg/L of selenium

Solution:

a. Municipal wastewater containing 2.0 mg/L of selenium is

not a RCRA hazardous waste

because municipal wastewaters are excluded (Figure 10-6)

10-12 Identifying RCRA hazardous waste

Given: An empty pesticide container that a homeowner wishes to discard

Solution:

a. An empty pesticide container that a homeowner wishes to discard

is **not** a RCRA hazardous waste

because household waste is excluded (Figure 10-6)

10-13 Fluorescent light bulb storage

Given: 250 kg/mo of light bulbs

Solution:

a. From http://www.gpoaccess.gov

Click on Code of Federal Regulations

Search under "Browse and/or search the CFR"

Under Titles column select 40

Select July 1 for current year

In 2006 select the range 266-299

Then select 273 Standards for universal waste

Then select 273.15 (accumulation time limits) for answer

The answer (in 2006) is 1 year

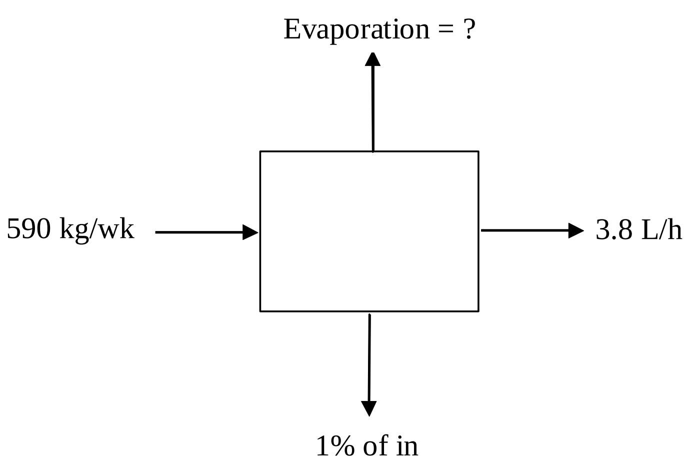
Alternatively, search by CFR code (40CFR273.15) at the browse step

10-14 TCE Evaporation Loss

Given: 590 kg/wk of TCE added, never dumped, drag out = 3.8 L/h, 8 h/d, 5 d/wk operation, sludge = 1.0% of incoming TCE, density = 1.460 kg/L

Solution:

a. Mass balance diagram



Figures S-10-14: Mass balance

b. Sludge mass

$M_{sludge} = (0.01)(590\ kg/wk) = 5.9\ kg/wk$

c. Drag out

$M_{drag\ out} = (3.8\ L/h)(8\ h/d)(5\ d/wk)(1.460\ kg/L) = 221.92\ kg/wk$

d. Mass balance

$M_{evaporation} = 590 - 221.92 - 5.9 = 362.18$ or 360 kg/wk

10-15 Mass flow condensate tank

Given: Flows and concentrations

Solution:

a. Mass flow into stripper (Sample location #1)

(5,858 mg/L)(40.5 L/min)(1,440 min/d)(10^{-6} kg/mg) = 341.63 kg/d

b. Mass flow in wastewater (Sample location #2)

(0.037 mg/L)(44.8 L/min)(1,440 min/d)(10^{-6} kg/mg) = 0.002386 kg/d

c. Mass flow from vent

GMW of methylene chloride (from Appendix A, Table A-8, note that methylene chloride = dichloromethane) = 84.93 g/mole

Volumetric flow rate of gas = (57 L/min)(0.4413) = 25.154 L/min

Assuming ideal gas law applies

$$n = \frac{PV}{RT} = \frac{(101.325\text{kPa})(25.154\,\text{L/min})}{(8.3143\,\text{J/K}\cdot\text{mole})(293\text{K})} = 1.046\,\text{moles}$$

Mass flow

(1.046 moles)(84.93 g/mole)(1,440 min/d)(10^{-3} kg/g) = 128.03 kg/d

d. Mass balance

Mass in = Mass out WW + Mass out vent + Mass to condensate

Mass to condensate = Mass in - Mass out WW - Mass out vent

Mass to condensate = 341.63 - 0.002386 - 128.03 = 213.59 kg/d

10-16 Efficiency of vent condenser

Given: Problem 10-15

Solution:

a. Efficiency

$$\text{Efficiency} = \frac{\text{IN} - \text{OUT}}{\text{IN}} \times 100\%$$

$$\text{Efficiency} = \frac{341.63 - 0.002386 - 128.03}{341.63} \times 100\%$$

Efficiency = 62.5%   Not very efficient!

10-17 Amount of lime to neutralize HCl and TDS formed

Given: Flow of 5 L/min containing 100 mg/L of HCl

Solution:

a. Write reaction

$$2HCl + Ca(OH)_2 \rightarrow 2H_2O + CaCl_2$$

b. Gram molecular weights

GMW_{HCl} = 36.5 g/mole

$GMW_{Ca(OH)2}$ = 74 g/mole

GMW_{CaCl2} = 111 g/mole

c. Molar flow of HCl

$$\frac{(100\,\text{mg/L})(5\,\text{L/min})}{(1000\,\text{mg/g})(36.5\,\text{g/mole})} = 0.0137\,\text{mole/min}$$

d. Molar flow of lime to neutralize

From the reaction in "a" one mole of lime will neutralize two moles of HCl or 1/2 mole of lime will neutralize one mole of HCl or 1/2(0.0137) = 0.006849 moles/min of lime

e. Mass flow of lime

$$\frac{(0.006849\,\text{mole/min})(74\,\text{g/mole})(1440\,\text{min/d})}{(1000\,\text{g/kg})} = 0.730\,\text{kg/d}$$

f. Total dissolved solids

TDS = moles of $CaCl_2$ formed

TDS = 1/2 moles of HCl destroyed = 0.006849 moles/min

In mg/L

$$\frac{(0.006849\ \text{moles/min})(111\ \text{g/mole})(1000\ \text{mg/g})}{(5\ \text{L/min})} = 152\ \text{mg/L}$$

10-18 Amount of sulfuric acid to neutralize NaOH and TDS formed

Given: Flow of 200 L/min containing 15 mg/L of NaOH

Solution:

a. Write reaction

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

b. Gram molecular weights

GMW_{NaOH} = 40 g/mole

GMW_{H2SO4} = 98 g/mole

GMW_{Na2SO4} = 142 g/mole

c. Molar flow of NaOH

$$\frac{(15\ \text{mg/L})(200\ \text{L/min})}{(1000\ \text{mg/g})(40\ \text{g/mole})} = 0.075\ \text{mole/min}$$

d. Molar flow of sulfuric acid to neutralize

From the reaction in "a" one mole of sulfuric acid will neutralize two moles of NaOH or 1/2 mole of sulfuric acid will neutralize one mole of NaOH or 1/2(0.075) = 0.0375 moles/min of sulfuric acid

e. Mass flow of sulfuric acid

$$\frac{(0.0375\,\text{mole/min})(98\,\text{g/mole})(1440\,\text{min/d})}{(1000\,\text{g/kg})} = 5.292\,\text{kg/d}$$

f. Total dissolved solids

TDS = moles of Na_2SO_4 formed

TDS = 1/2 moles of NaOH destroyed = 0.0375 moles/min

In mg/L

$$\frac{(0.0375\,\text{mole/min})(142\,\text{g/mole})(1000\,\text{mg/g})}{(200\,\text{L/min})} = 26.625\,\text{mg/L}$$

10-19 Estimated pH of bath mixture

Given: 1500 L of 5.00% H_2SO_4 by volume, 1500 L of 5.00% NaOH by weight, Specific gravity of H_2SO_4 = 1.841, H_2SO_4 purity = 96%, NaOH purity = 100%

Solution:

a. Calculate moles of H_2SO_4

(1500 L)(0.05) = 75.0 L pure

at 96% purity

(75.0 L)(0.96) = 72.0 L

at 1.841 kg/L the mass of H_2SO_4 is

(72.0 L)(1.841 kg/L) = 132.55 kg or 132,552 g

moles of H_2SO_4

$$\frac{132{,}552\text{g}}{98\,\text{g/mole}} = 1{,}352.57\text{moles}$$

b. Calculate moles of NaOH (5.00%)

(1500 L)(0.05)(1.0 kg/L) = 75.00 kg or 75,000 g of NaOH

moles of NaOH

$$\frac{75{,}000\text{g}}{40\,\text{g/mole}} = 1{,}875\text{moles}$$

c. Strong base – Strong acid reaction

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

So, 2705.14 moles of NaOH are required to neutralize 1352.57 moles of H_2SO_4

And 1352.57 moles of H_2SO_4 forms 1352.7 moles of Na_2SO_4

Thus there is an excess of H^+ equal to

2705.14 moles required – 1875 moles available

= 830.14 moles of H^+ in excess

d. The estimated pH is then

$$\frac{830.14\text{moles} \cdot H^+}{3000\text{L}} = 0.277\,\text{mole/L}$$

$$\text{pH} = \log\left(\frac{1}{0.277}\right) = 0.558 \text{ or } 0.56$$

e. TDS formation is result of Na_2SO_4

f. The estimated TDS

2 moles of NaOH form 1 mole of Na_2SO_4

$$\frac{1875}{2} = 937.5 \text{ moles of } Na_2SO_4 \text{ formed}$$

Excess acid of 830.14 moles H^+ forms

$$\frac{830.14}{2} = 415.07 \text{ moles } H_2SO_4$$

$$\text{TDS} = \frac{(937.5\text{moles} \cdot Na_2SO_4)(142\,\text{g/mole}) + (415.07\text{moles} \cdot H_2SO_4)(98\,\text{g/mole})}{3000\text{L}}$$

TDS = 57.93 g/L or 57,933 mg/L or 58,000 mg/L

10-20 Reaction to oxidize sodium cyanide

Given: NaCN to be oxidized with NaOCl

Solution:

a. Using two step reaction as in Eqns. 10-23 and 10-24

$$\mathrm{NaCN + NaOCl \rightarrow NaCNO + NaCl}$$

$$\mathrm{2NaCNO + 3NaOCl + H_2O \rightarrow 3NaCl + N_2 + 2HaHCO_3}$$

10-21 Reaction to oxidize cyanide with ozone

Given: Ozone to oxidize NaCN

Solution:

a. First step

$$\mathrm{NaCN + O_3 \rightarrow NaCNO + O_2}$$

b. Second step

$$\mathrm{2NaCNO + O_3 + H_2O \rightarrow 2NaHCO_3 + N_2}$$

10-22 Reaction to reduce hexavalent chromium

Given: Cr^{6+} to be reduced with $NaHSO_3$

Solution:

a. Using two step reaction and redox balance

$$\mathrm{NaHSO_3 + H_2O \rightarrow NaOH + H_2SO_3}$$

$$\mathrm{Cr_2O_7 + 3H_2SO_3 \rightarrow Cr_2(SO_4)_3 + 4H_2O}$$

10-23 Hydroxide concentration and pH to precipitate copper

Given: copper concentration to be reduced to 1.3 mg/L, $K_{sp} = 2.00 \times 10^{-19}$

Solution:

a. Reaction

$$Cu + 2OH \rightarrow Cu(OH)_2$$

b. Gram molecular weight

GMW of Cu = 63.54 g/mole

c. K_{sp} equation

$K_{sp} = [Cu][OH]^2 = 2.00 \times 10^{-19}$

d. Solving for [OH]

$$[OH] = \left(\frac{2 \times 10^{-19}}{(1.3\,mg/L)(10^{-3}\ g/mg)(63.54\,g/mole)} \right)^{1/2}$$

$[OH] = 1.56 \times 10^{-9}$ mole

e. Estimate of pH

pOH = -log [OH] = -log [1.56 x 10-9]

pOH = 8.81

pH = 14 - pOH = 14 – 8.81 = 5.19

10-24 pH and dose of lime to achieve standard

Given: Q = 100 L/min, 50.0 mg/L Zn in solution, standard = 2.6 mg/L

Solution:

a. Calculate final desired zinc concentration in moles/L

$$[Zn] = \frac{2.6\,mg/L}{65.4 \times 10^3\ mg/mole} = 3.98 \times 10^{-5}\ mole/L$$

b. From Table in Appendix A

K_{sp} for $Zn(OH)_2$ = 7.68 x 10^{-17}

c. From solubility product equation

7.68 x 10^{-17} = $[Zn][OH]^2$ = (3.98 x 10^{-5})$[OH]^2$

[OH] = (1.93 x 10^{-12})$^{1/2}$ = 1.39 x 10^{-6} mole/L

d. Calculate pH

pOH = -log(1.39 x 10^{-6}) = 5.86

pH = 14.00 – 5.86 = 8.14

e. Estimate dose of hydrated lime ($Ca(OH)_2$)

$$Zn + Ca(OH)_2 \rightarrow Zn(OH)_2 + Ca$$

GMW_{Zn} = 65.4

$GMW_{Ca(OH)2}$ = 74

Zinc to be removed

50.0 mg/L – 2.6 mg/L = 47.4 mg/L

Moles to me removed

$$\frac{47.4\,\text{mg/L}}{65.4\times10^3\ \text{mg/mole}} = 7.25\times10^{-4}\ \text{mole/L}$$

Dose of lime

Because 1 mole of lime reacts with 1 mole of Zn

(7.25 x 10^{-4} mole/L)(74 g/mole)(100 L/min) = 5.36 g/min

10-25 Volume reduction with filter press and dryer

Given: 1.0 m^3/d of metal plating sludge with solids concentration of 4%; filter press yields solids concentration of 30%; dryer yields solids concentration of 80%.

Solution:

a. Filter press volume

Using Eqn. 4-122 and solving for $\not{V}_2$

$$\frac{\not{V}_2}{1.0\,\text{m}^3/\text{d}} = \frac{0.04}{0.30}$$

$\not{V}_2 = 0.133\ \text{m}^3/\text{d}$

b. Dryer volume

$$\frac{\not{V}_2}{0.133\,\text{m}^3/\text{d}} = \frac{0.30}{0.80}$$

$\not{V}_2 = 0.05\ \text{m}^3/\text{d}$

10-26 Change in ferrocyanide concentration after filter press

Given: Problem 10-25, ferrocyanide concentration of 400 mg/kg at 4% solids

Solution:

a. The concentration of Fe-CN is the mass of Fe-CN divided by the mass per unit volume of solids. If the Fe-CN is part of the precipitate, then the reduction in solids volume will increase the Fe-CN concentration.

b. Set up mass balance

$(\text{Fe-CN}_{in})(Q_{in}) = (\text{Fe-CN}_{out})(Q_{out})$

c. Solve for Fe-CN_{out}

$$\text{Fe} - \text{CN}_{out} = \frac{(400\,\text{mg/kg})(1.0\,\text{m}^3/\text{d})}{0.133\,\text{m}^3/\text{d}} = 3000\,\text{mg/kg}$$

10-27 Design packed tower stripper for Oscoda, MI

Given: Design and operating parameters

Solution:

a. Calculate water flow (L) from gas/liquid ratio (G/L)

$$L = \frac{gas \cdot flow \cdot rate}{\frac{gas}{liguid}\,ratio} = \frac{60\,m^3/min}{18} = 3.33\,m^3/min$$

b. Find volume of tower $(Z_T)(A)$ using Eqn. 10-26

First computing the numerator

$$\ln\left[\frac{6000}{1.5} - \frac{(3.33)(8.206\times10^{-5})(298)}{(60)(6.74\times10^{-3})}\left(\frac{6000}{1.5} - 1\right)\right] = 8.069$$

Next computing the denominator

$$(0.720)\left(1 - \frac{(3.33)(8.206\times10^{-5})(298)}{(60)(6.74\times10^{-3})}\right) = 0.5749$$

$$(Z_T)(A) = 3.33\frac{8.069}{0.5749} = 46.787m^3$$

c. Assuming a maximum column height (Z_T) of 6 m

$$A = \frac{46.787m^3}{6m} = 7.798m^2$$

d. Calculating a diameter

$$d = \left(\frac{(4)(7.798)}{\pi}\right)^{1/2} = 3.15m$$

NOTE: other column height/diameter combinations are possible within the constraints that $Z_T < 6$ m and $d < 4$ m

10-28 Design packed tower stripper for Watapitae

Given: Design and operating parameters

Solution:

a. Find volume of tower (Z_T)(A) using Eqn. 10-26

First computing the numerator

$$\ln\left[\frac{440}{0.2}-\frac{(0.22)(8.206\times10^{-5})(293)}{(15)(100\times10^{-4})}\left(\frac{440}{0.2}-1\right)\right]=7.66$$

Next computing the denominator

$$(13.5\times10^{-3})\left(1-\frac{(0.22)(8.206\times10^{-5})(293)}{(15)(100\times10^{-4})}\right)=0.013024$$

$$(Z_T)(A)=0.22\frac{7.66}{0.013024}=129.4\text{m}^3$$

b. Assuming a maximum column height (Z_T) of 6 m

$$A=\frac{129.4\text{m}^3}{6\text{m}}=21.566\text{m}^2$$

c. Calculating a diameter

$$d=\left(\frac{(4)(21.566)}{\pi}\right)^{1/2}=5.24\text{m}$$

This exceeds the maximum column diameter of 4 m.

d. Assuming a maximum column diameter of 4 m

$$A=\frac{\pi(4.0)^2}{4}=12.566\text{m}^2$$

e. Recalculating column height

$$Z_T=\frac{129.4\text{m}^3}{12.566\text{m}^2}=10.29\text{m}$$

This is too tall for one column but two columns in series each with a height of 5.15 m would work. NOTE: other column height/diameter combinations are possible within the constraints that $Z_T < 6$ m and $d < 4$ m.

10-29 Packed tower stripping of ethylbenzene

Given: LaGrega form of stripping equation, $H_c = 6.44 \times 10^{-3}$ m^3-atm/mole, $T_g = 20$ ^oC, L = 7.13 L/s, $K_La = 1.6 \times 10^{-2}$ s^{-1}, column diameter ≤ 4.0 m, column height ≤ 6.0 m

Solution:

a. Converting liquid flow rate to mole/s

Mass rate = (1.0 kg/L)(7.13 L/s) = 7.13 kg/s

$$\text{Molar rate} = \frac{(7.13\,\text{kg/s})(10^3\ \text{g/kg})}{18\,\text{g/mole}} = 396.11\,\text{mole/s}$$

b. See following spreadsheet calculations

C_1	1000	μg/m³
C_2	35	μg/m³
H_c	6.44E-03	m³ - atm/mole
T_g	20	°C = 293.15 K
R	8.21E-05	atm-m³/mole-K
K_La	1.60E-02	s
M_w	55600	moles/m³
L	396.11	moles/s

Assume values for diameter and air flow rate

Diameter	1	m
Cross sectional area	0.7853975	m²
Air flow rate	8000	moles/s

Compute H'

H' = 2.68E-01

Compute R_{sf}

R_{sf} = 5.4067792

Compute height of transfer unit

HTU = 5.67E-01

Number of transferr units	
R_{sf} /Rsf -1 =	1.2269231
C_1/C_2 =	28.571429
Rsf -1 =	4.4067792
NTU =	3.86E+00
Z =	2.19E+00 m
Plus 20% =	2.63 m

Note: numerous solutions are available depending on the choice of G and diameter. Some are shown below.

For the following diameters with air flow rate = 8000 mole/s

	Z	
0.5 m	10.5 m	Too tall for specification
2.0 m	0.66 m	Columns are normally have Z>dia. This height is not very practical
3.0 m	0.24 m	Columns are normally have Z>dia. This height is not very practical
4.0 m	0.14 m	Columns are normally have Z>dia. This height is not very practical

For the follwing air flow rates with diameter = 1.0 m

	Z
2000 moles/s	5.25 m
4000 moles/s	3.12 m
10000 moles/s	2.55 m
20000 moles/s	2.41 m

10-30 Ion exchange column for nickel

Given: laboratory scale column data and corresponding breakthrough data

Solution:

Begin by calculating the coefficients using the laboratory scale data

a. Calculate the equivalent weight of C_0

$$\text{Equivalent weight} = \frac{58.7}{2} = 29.35\,\text{mg/meq}$$

$$C_0 = \frac{55\,\text{mg/L}}{29.35\,\text{mg/meq}} = 1.87\,\text{meq/L}$$

b. Calculate the quantity $(C_0/C) - 1$ as shown in following table

Volume [L]	C [mg/L]	C [meq/L]	C/C_o	Co/C	(Co/C)-1
0.16	4.23	0.144123	0.076909	13.00236	
0.32	5.14	0.175128	0.093455	10.70039	9.700389
0.48	10.03	0.341738	0.182364	5.483549	4.483549
0.64	16.65	0.567291	0.302727	3.303303	2.303303
0.8	23.62	0.80477	0.429455	2.328535	1.328535
0.96	29.54	1.006474	0.537091	1.861882	0.861882
1.12	35.46	1.208177	0.644727	1.551043	0.551043
1.28	39.04	1.330153	0.709818	1.408811	0.408811
1.44	44.04	1.500511	0.800727	1.248865	0.248865
1.6	49.54	1.687905	0.900727	1.110214	
1.76	53.32	1.816695	0.969455	1.031508	0.031508
1.92	54.14	1.844634	0.984364	1.015885	0.015885
2.08	53.22	1.813288	0.967636	1.033446	0.033446

c. Plot the data on semi-log paper as shown below.

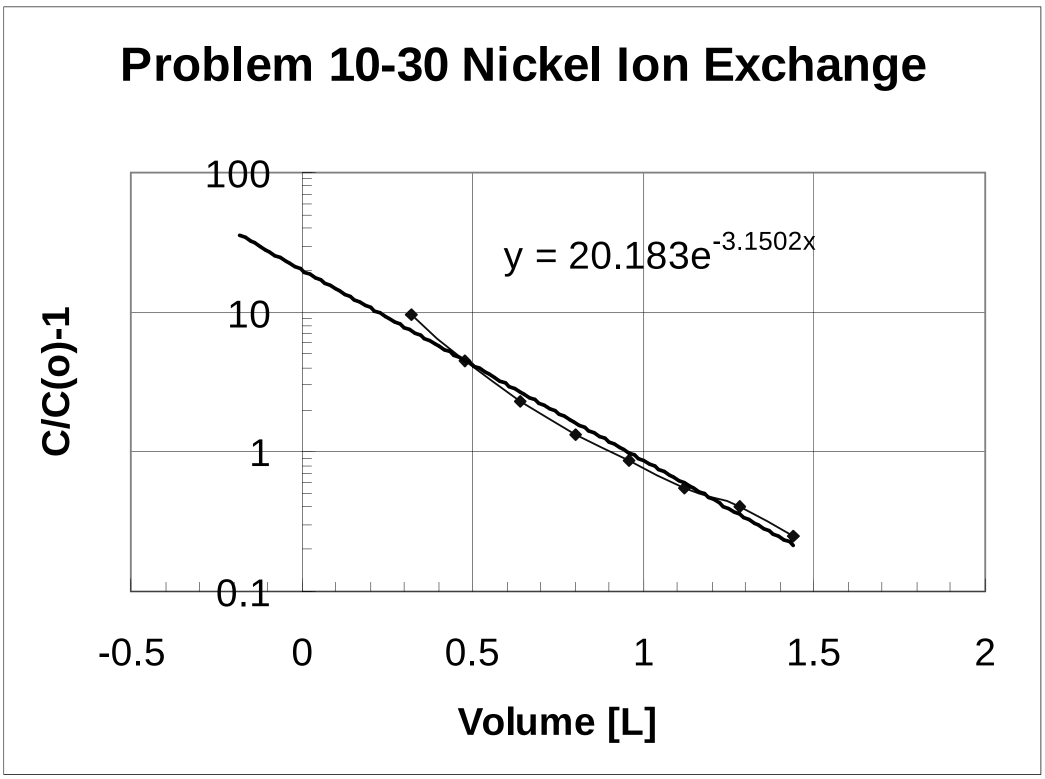


Figure S-10-30: Nickel ion exchange

d. From equation of trendline

$$b = \ln 20.18 = 3.00$$

e. From equation of trendline

slope = -3.1502 L^{-1}

f. Calculate k

$$k = (3.1502)\left(\frac{7.68\,L/d}{1.87\,meq/L}\right) = 12.94\,L/d\cdot meq$$

g. Calculate the dry weight of resin in the test column

M = (5.2 g)(1- 0.17) = 4.316 g

h. Calculate q_0

$$q_0 = \frac{(3.00)(7.68)}{(12.94)(4.316)} = 0.4125\,meq/mg$$

i. Now calculate the mass of resin for the full scale system

Using the influent and allowable effluent concentrations, calculate the left hand side of Equation 10-27

$$\ln\left(\frac{55}{2.6} - 1\right) = 3.00$$

The first term on the right hand side of Eqn 10-27 is

$$\frac{(12.94\,L/d\cdot meq)(0.4125\,meq/mg)(M)}{36{,}000} = 1.48\times10^{-4}(M)$$

where M is the unknown quantity of resin required

The operating cycle of 5 d and flow rate of 36,000 L/d gives

$\not{V}$ = (36,000)(5) = 180,000 L

The second term on the right hand side of Eqn 10-27 is

$$\frac{(12.94\,L/d\cdot meq)(1.87)(180{,}000)}{36{,}000} = 1.21\times10^{2}$$

Solving Eqn 10-27 for M

$$3.00 = 1.48 \times 10^{-4} (M) - 1.21 \times 10^{2}$$

$$M = 8.38 \times 10^{5} \text{ g or } 840 \text{ kg}$$

10-31 Ion exchange column for silver

Given: laboratory scale column data and corresponding breakthrough data

Solution:

Begin by calculating the coefficients using the laboratory scale data

a. Calculate the equivalent weight of C_0

$$\text{Equivalent weight} = \frac{108}{1} = 108 \, \text{mg/meq}$$

$$C_0 = \frac{10 \, \text{mg/L}}{108 \, \text{mg/meq}} = 0.0926 \, \text{meq/L}$$

b. Calculate the quantity $(C_0/C) - 1$ as shown in following table

Volume [L]	C [mg/L]	C [meq/L]	C/C_o	Co/C	(Co/C)-1
0.3	0.01	0.00	0.001	1000.00	999.00
0.4	0.02	0.00	0.002	500.00	499.00
0.5	0.04	0.00	0.004	250.00	249.00
0.6	0.08	0.00	0.008	125.00	124.00
0.7	0.16	0.00	0.016	62.50	61.50
0.8	0.31	0.00	0.031	32.26	31.26
0.9	0.61	0.01	0.061	16.39	15.39
1.0	1.15	0.01	0.115	8.70	7.70
1.1	2.00	0.02	0.200	5.00	4.00
1.2	3.33	0.03	0.333	3.00	2.00
1.3	5.00	0.05	0.500	2.00	1.00
1.4	6.67	0.06	0.667	1.50	0.50
1.5	8.00	0.07	0.800	1.25	0.25
1.6	8.89	0.08	0.889	1.12	0.12
1.7	9.41	0.09	0.941	1.06	0.06
1.8	9.69	0.09	0.969	1.03	0.03
1.9	9.84	0.09	0.984	1.02	0.02

c. Plot the data on semi-log paper as shown below

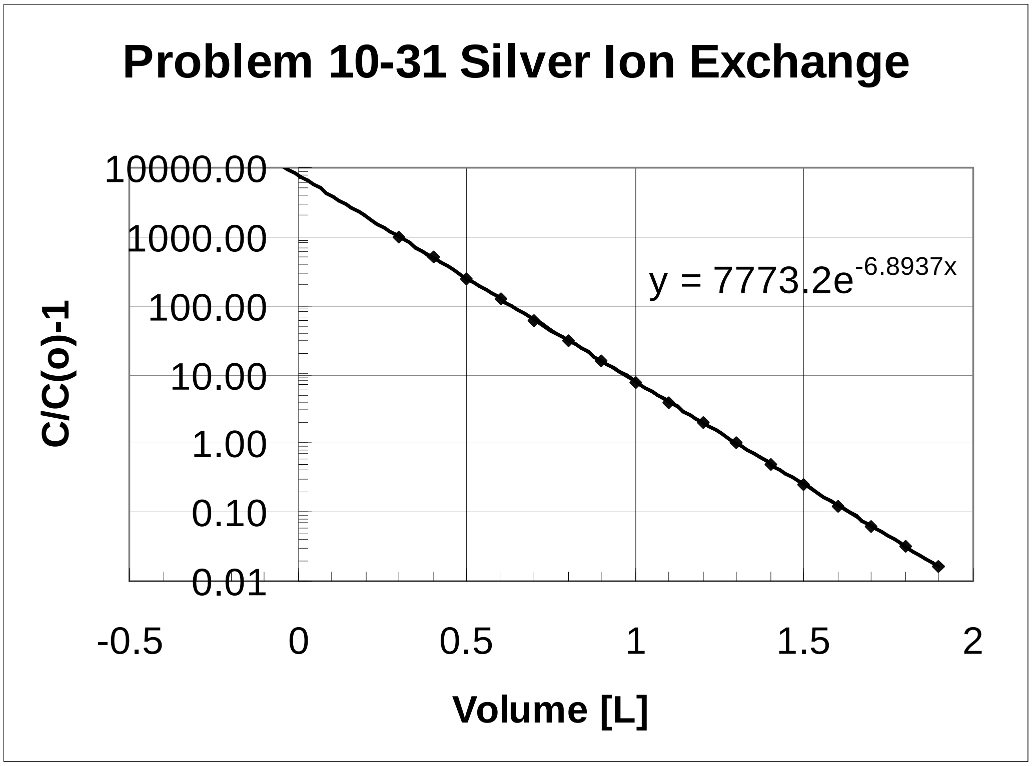


Figure S-10-31: Silver ion exchange

d. From equation of trendline

$$b = \ln 7773 = 8.96$$

e. From equation of trendline

$$\text{slope} = -6.89\ \text{L}^{-1}$$

f. Calculate k

$$k = \left(6.89\text{L}^{-1}\right)\left(\frac{4.523\,\text{L/d}}{0.0926\,\text{meq/L}}\right) = 336.54\,\text{L/d}\cdot\text{meq}$$

g. Calculate the dry weight of resin in the test column

$$M = (7.58\text{g})(1- 0.34) = 5.00\text{ g}$$

h. Calculate q_0

$$q_0 = \frac{(8.96)(4.523)}{(336.54)(5.00)} = 0.0241\,\text{meq/mg}$$

i. Now calculate the mass of resin for the full scale system

Using the influent and allowable effluent concentrations, calculate the left hand side of Equation 10-27

$$\ln\left(\frac{10}{0.24} - 1\right) = 3.7054$$

The first term on the right hand side of Eqn 10-27 is

$$\frac{(336.54\,\text{L/d}\cdot\text{meq})(0.0241\,\text{meq/mg})(\text{M})}{3600} = 2.25\times10^{-3}(\text{M})$$

where M is the unknown quantity of resin required

The operating cycle of 5 d and flow rate of 3,600 L/d gives

$\forall$ = (3,600)(5) = 18,000 L

The second term on the right hand side of Eqn 10-27 is

$$\frac{(336.54\,\text{L/d}\cdot\text{meq})(0.0926)(18{,}000)}{3600} = 1.56\times10^{2}$$

Solving Eqn 10-27 for M

$3.70 = 2.25 \times 10^{-3}$ (M) - 1.56×10^{2}

M = 7.10×10^{4} g or 71 kg

10-32 Ion exchange column for hardness

Given: Ca = 107 mg/L as ion, Mg = 18 mg/L as ion, data on size of pilot column

Solution:

Begin by calculating the coefficients using the pilot scale data

a. Calculate equivalent weight of C_0 where C_0 is the total hardness in meq/L

For Ca, the equivalent weight is 40.0/2 = 20 g/eq or 20 mg/meq

$$\frac{107\,\text{mg/L}}{20.0\,\text{mg/meq}} = 5.35\,\text{meq/L}$$

For Mg, the equivalent weight is 24.3/2 = 12.15 mg/meq

$$\frac{18\,\text{mg/L}}{12.15\,\text{mg/meq}} = 1.48\,\text{meq/L}$$

C_0 equals the total hardness

$C_0 = 5.35 + 1.48 = 6.83$ meq/L

b. Use a spreadsheet to estimate slope and intercept

Volume [m^3]	C [meq/L]	C/C_o	Co/C	(Co/C)-1
2.35	0.21	0.0307	32.5309	
2.90	0.48	0.0703	14.2323	13.2323
3.10	1.10	0.1610	6.2104	5.2104
3.26	1.64	0.2401	4.1655	3.1655
3.39	2.47	0.3616	2.7658	1.7658
3.49	3.22	0.4713	2.1216	1.1216
3.56	3.56	0.5211	1.9190	0.9190
3.71	4.52	0.6616	1.5114	0.5114
3.81	5.07	0.7422	1.3474	0.3474
4.03	5.96	0.8724	1.1462	0.1462
4.62	6.78	0.9925	1.0076	

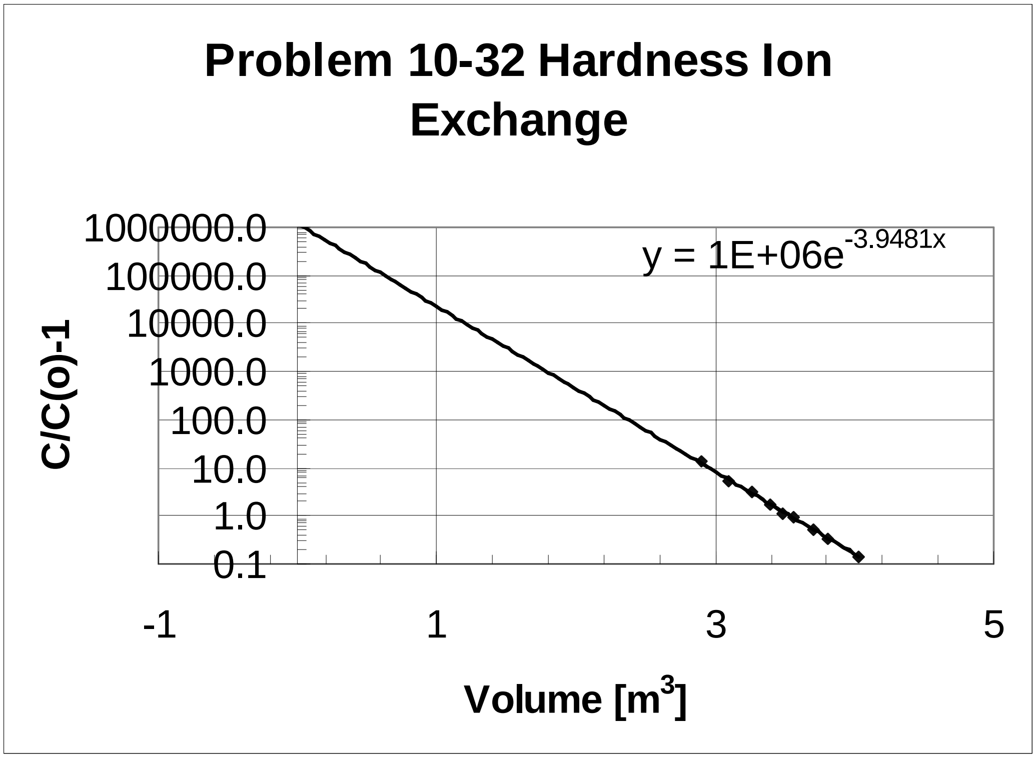


Figure S-10-32: Hardness ion exchange

c. From the equation of trendline

$b = \ln(1 \times 10^6) = 13.82$

d. From the equation of trendline

slope = $-3.95\ (m^3)^{-1}$

e. Calculate k (Note conversions to days and m^3)

$$k = \left(3.95\left(m^3\right)^{-1}\right)\left(\frac{(2.25\,L/h)(24\,h/d)\left(10^{-3}\,m^3/L\right)}{6.83\,meq/L}\right) = 3.12\times10^{-2}\ L/d\cdot meq$$

f. Calculate the dry weight of resin in the test column

$M = (5.0\ kg)(1 - 0.34) = 3.30\ kg$

g. Calculate q_0 (Note units in answer)

$$q_0 = \frac{(13.82)(2.25\,L/h)(24\,h/d)}{\left(3.12\times10^{-2}\ L/d\cdot meq\right)(3.30\,kg)} = 7.24\times10^3\ meq/kg$$

h. Now calculate mass of resin for full scale system

Using the influent and desired effluent concentrations, calculate the left hand side of equation 10-27. Begin by converting 10 mg/L as $CaCO_3$ to meq/L. The equivalent weight of $CaCO_3$ is 50 mg/meq.

$$\frac{10\,\text{mg/L as}\cdot\text{CaCO}_3}{50\,\text{mg/meq}} = 0.20\,\text{meq/L}$$

Then

$$\ln\left(\frac{6.83}{0.20}-1\right) = 3.50$$

The first term on the right hand side of equation 10-27 is

$$\frac{\left(3.12\times10^{-2}\ \text{L/d}\cdot\text{meq}\right)\left(7.24\times10^{3}\ \text{meq/kg}\right)(\text{M})}{\left(570\,\text{m}^3/\text{d}\right)\left(10^3\ \text{L/m}^3\right)} = 3.96\times10^{-4}\,\text{kg}^{-1}(\text{M})$$

Where M is the unknown quantity of resin. Note the units conversions.

The operating cycle is 60 days

$\text{V}\!\!\!-$ = (570 m^3/d)(60 d) = 34,200 m^3

The second term on the right hand side of equation 10-27 is

$$\frac{\left(3.12\times10^{-2}\ \text{L/d}\cdot\text{meq}\right)\left(6.83\,\text{meq/L}\right)\left(34{,}200\text{m}^3\right)}{570\,\text{m}^3/\text{d}} = 12.79$$

Solving Equation 10-27 for M

$3.50 = (3.96 \times 10^{-4}\ \text{kg}^{-1})(\text{M}) - 12.79$

M = 41,136 or 41,000 kg or 41 Mg

10-33 Blending waste to achieve 30% by mass chlorine

Given: Trichloroethylene = 18.9 m^3; 1,1,1 Trichloroethane = 5.3 m^3; Toluene = 21.3 m^3, o-Xylene = 4.8 m^3

Solution:

a. Using Appendix A obtain formulas, molecular weights and densities

Trichloroethylene

formula = $ClCH{=}CCl_2$, GMW = 131.29, density = 1.476 g/mL

1,1,1 Trichloroethane

formula = CH_3CCl_3, GMW = 133.41, density = 1.3390 g/mL

Toluene

formula = $C_6H_5CH_3$, GMW = 92.14, density = 0.8669 g/mL

o-Xylene

formula = $(CH_3)_2C_6H_4$, GMW = 106.17, density = 0.8802 g/mL

b. Fraction of compound that is chlorine

Trichloroethylene

formula = $ClCH{=}CCl_2$, GMW = 131.29

3 chlorines with GMW of 35.5 = 3(35.5) = 106.5

$$\text{chlorine fraction} = \frac{106.5}{131.29} = 0.811$$

1,1,1 Trichloroethane

formula = CH_3CCl_3, GMW = 133.41

3 chlorines with GMW of 35.5 = 3(35.5) = 106.5

$$\text{chlorine fraction} = \frac{106.5}{133.41} = 0.798$$

Toluene

contains no chlorine

o-Xylene

contains no chlorine

c. Compute mass of each compound

Trichloroethylene

density = 1.476 g/mL = 1,476 kg/m^3

mass = (1,476 kg/m^3)(18.9 m^3) = 27,896.4 kg

1,1,1 Trichloroethane

density = 1.3390 g/mL = 1,3390 kg/m^3

mass = (1,339 kg/m^3)(5.3 m^3) = 7,096.7 kg

Toluene

density = 0.8669 g/mL = 866.9 kg/m^3

mass = (866.9 kg/m^3)(21.3 m^3) = 18,464.97 kg

o-Xylene

density = 0.8802 g/mL = 880.2 kg/m^3

mass = (880.2 kg/m^3)(4.8 m^3) = 4,224.96 kg

Total mass

27,896.4 + 7,096.7 + 18,464.97 + 4,224.96 = 57,683.03 kg

d. Compute % chlorine

$$\%Cl = \frac{(0.811)(27{,}896.4) + (0.798)(7{,}096.7)}{57{,}683.03}(100)$$

%Cl = 49.03 or 49%

The operator cannot achieve 30% chlorine by mixing these waste quantities.

10-34 Blending waste to achieve 30% by mass chlorine

Given: Carbon tetrachloride = 1.2 m^3, Hexachlorobenzene = 15.3 m^3, Pentachlorophenol = 25.0 m^3, Methanol as required

Solution:

a. Using Appendix A obtain formulas, molecular weights and densities

Carbon tetrachloride

formula = CCl_4, GMW = 153.82, density = 1.594 g/mL

Hexachlorobenzene

formula = C_6Cl_6, GMW = 284.79, density = 1.5691 g/mL

Pentachlorophenol

formula = Cl_5C_6OH, GMW = 266.34, density = 1.978 g/mL

Methanol (NOTE: not in Appendix A)

formula = CH_3OH, GMW = 32.04, density = 0.7913 g/mL

b. Fraction of compound that is chlorine

Carbon tetrachloride

formula = CCl_4, GMW = 153.82

4 chlorines with GMW of 35.5 = 4(35.5) = 142.0

$$\text{Chlorine fraction} = \frac{142.0}{153.82} = 0.923$$

Hexachlorobenzene

formula = C_6Cl_6, GMW = 284.79

6 chlorines with GMW of 35.5 = 6(35.5) = 213.0

$$\text{Chlorine fraction} = \frac{213.0}{284.79} = 0.748$$

Pentachlorophenol

formula = Cl_5C_6OH, GMW = 266.34

5 chlorines with GMW of 35.5 = 5(35.5) = 177.5

$$\text{Chlorine fraction} = \frac{177.5}{266.34} = 0.667$$

c. Compute mass of each compound

Carbon tetrachloride

density = 1.594 g/mL = 1,594 kg/m^3

mass = (1,594 kg/m^3)(12.2 m^3) = 19,446.8 kg

Hexachlorobenzene

density = 1.5691 g/mL = 1,569.1 kg/m^3

mass = (1,569.1 kg/m^3)(153 m^3) = 240,072.3 kg

Pentachlorophenol

density = 1.978 g/mL = 1,978 kg/m^3

mass = (1,978 kg/m^3)(2.5 m^3) = 4,945.0 kg

Total mass

19,446.8 + 240,072.3 + 4,945.0 = 264,464.1 kg

d. Compute % chlorine

$$\%Cl = \frac{(0.923)(19{,}446.8) + (0.748)(240{,}072.3) + (0.667)(4{,}945)}{264{,}464.1} = 0.759$$

%Cl = 75.9 %

e. Compute amount of methanol that must be added

The chlorine fraction of the combination must be 30%, so the weighted fraction would be

$$\text{Chlorine fraction} = \frac{(0.759)(264{,}464.1) + (0.0)(M_{CH_3OH})}{264{,}464.1 + M_{CH_3OH}} = 0.30$$

where M_{CH3OH} = Mass of methanol with a chlorine content of 0.0%

Solving for M_{CH3OH}

(0.759)(264,464.1) + 0.0 = 0.3(264,464.1 + M_{CH3OH})

M_{CH3OH} = 404,630 kg

Calculate volume based on density of 7,913 kg/m^3

$$\not{V} = \frac{404{,}630\,\text{kg}}{7{,}913\,\text{kg}/\text{m}^3} = 51.135 \text{ or } 51 \text{ m}^3$$

10-35 Mass flow of methylene chloride in aqueous feed

Given: Methylene chloride concentration = 5,858 mg/L, flow rate of aqueous stream = 40.5 L/min

Solution:

(5,858 mg/L)(40.5 L/min) = 237,249 mg/min or 237.25 g/min

10-36 Mass flow of methylene chloride in flue gas

Given: Methylene chloride concentration = 211.86 μg/L, flow rate of flue gas = 597.55 m^3/min

Solution:

(211.86 μg/L)(597.55 m^3/min) = 126,596.9 μg/m^3 or 0.1266 g/min

10-37 DRE for Problems 10-35 and 10-36

Given: Problems 10-35 and 10-36

Solution:

a. Using Eqn. 10-31

$$DRE = \frac{237.25 - 0.1266}{237.25}(100) = 99.947\%$$

10-38 DRE for xylene

Given: mass flow into incinerator = 481 kg/h, mass flow in stack = 72.2 g/h

Solution:

a. Using Eqn. 10-31

$$DRE = \frac{481 - 0.0722}{481}(100) = 99.985\%$$

Incinerator does not comply with 99.99% DRE

10-39 Incinerator compliance for dichlorobenzene

Given: Incinerator operating conditions and stack gas concentrations after APC equipment

Solution:

a. Mass flow into incinerator

1,2 Dicholorobenzene data from Appendix A

formula = Cl_2-C_6H_4, GMW = 147.01, density = 1.3048 g/mL

mass flow = (13.0 g/L)(173.0 L/min) = 2,249 g/min

$$\text{molar flow} = \frac{2249\,\text{g/min}}{147.01\,\text{g/mole}} = 15.298\,\text{mole/min}$$

Hydrogen Chloride

Moles of HCl per mole of Cl_2-C_6H_4 = 2

mass flow = 2(15.298 moles/min)(36.5 g/mole) = 1,116.75 g/min

b. Mass flows out of incinerator

1,2 Dichlorobenzene

$(338.8\ \mu g/m^3)(10^{-6}\ g/\mu g)(6.70\ m^3/s)(60\ s/min) = 0.136\ g/min$

Hydrogen Chloride

without APC

$(1{,}116.75\ g/min)(10^{-3}\ kg/g)(60\ min/h) = 67.0\ kg/h$

with APC

$(77.2\ mg/m^3)(10^{-3}\ g/mg)(6.70\ m^3/s)(60\ s/min) = 31.03\ g/min$

or $(31.03\ g/min)(10^{-3}\ kg/g)(60\ min/h) = 1.86\ kg/h$

c. Compliance computations

DRE for 1,2 Dicholorobenzene

$$\text{DRE} = \frac{2249 - 0.136}{2249}(100) = 99.994\ \text{ Passes}$$

HCl

1.86 kg/h exceeds 1.8 kg/h, therefore check 1% limit

(0.01)(1,116.75 g/min) = 11.17 g/min

After the APC the emission is 31.03 g/min. This exceeds the 1% limit. Therefore the incinerator fails to comply with the HCl limits.

Particulates

The limit is 180 mg/dscm, therefore the incinerator emission of 181.6 mg/dscm fails to comply with the particulate limits.

10-40 Trial burn compliance for POHCs

Given: Temperature = 1,100 ^oC, Q_{stack} = 5.90 dscm/s, 10% oxygen, assume chlorine = HCl, inlet and outlet emissions

Solution:

a. Calculate DRE's

Benzene

$$\text{DRE} = \frac{913.98 - 0.2436}{913.98}(100) = 99.9733\% \quad \text{Fails}$$

Chlorobenzene

$$\text{DRE} = \frac{521.63 - 0.0494}{521.63}(100) = 99.9905\% \quad \text{Passes}$$

Xylenes

$$\text{DRE} = \frac{1378.91 - 0.5670}{1378.91}(100) = 99.9589\% \quad \text{Fails}$$

b. Calculate HCl

Emission rate of 4.85 kg/h exceeds emission limit of 1.8 kg/h. Now check % removal:

Inlet HCl

GMW of chlorobenzene = 112.5 g/mole

Moles of HCL per moles of chlorobenzene (C_6H_5Cl) = 1

Molar flow of C_6H_5Cl = $\frac{(521.63\,\text{kg/h})(10^3\ \text{g/kg})}{112.5\,\text{g/mole}} = 4636.71\,\text{mole/h}$

Mass flow of HCl = (1)(4636.71 mole/h)(36.5 g/mole) = 169,239.95 g/h

= 169.24 kg/h

Removal efficiency

$$= \frac{169.24\,\text{kg/h} - 4.85\,\text{kg/h}}{169.24\,\text{kg/h}}(100) = 97.13\%$$

97.13% is less than 99% required.

The HCl emissions fail on both requirements.

c. Particulate emissions

Convert the emissions rate to concentration

$$\frac{(10.61\,\text{kg/h})(10^6\ \text{mg/kg})}{(5.90\,\text{m}^3/\text{s})(3600\,\text{s/h})} = 499.53\,\text{mg/m}^3$$

Corrected to 10% oxygen

$$P_c = 499.53\left(\frac{14}{21-10}\right) = 635.76\,\text{mg/m}^3$$

This exceeds the allowable particulate emission of 180 mg/m^3

10-41 Incinerator compliance for trichloroethylene, 1,1,1 trichloroethane, and toluene

Given: Incinerator operating conditions and stack gas concentrations after APC equipment

Solution:

a. Mass flow into incinerator (@ 5% of volumetric flow)

Trichloroehtylene data from Appendix A

formula = $ClCH{=}CCl_2$, GMW = 131.29, density = 1.476 g/mL

mass flow = (0.05)(40.0 L/min)(1,476 g/L) = 2,952 g/min

$$\text{molar flow} = \frac{2952\,\text{g/min}}{131.29\,\text{g/mole}} = 22.485\,\text{mole/min}$$

Hydrogen chloride

Moles of HCl per mole of $ClCH{=}CCl_2$ = 3

mass flow = 3(22.485 moles/min)(36.5 g/mole) = 2,462 g/min HCl

1,1,1 Trichloroethane data from Appendix A

formula = CH_3CCl_3, GMW = 133.41, density = 1.3390 g/mL

mass flow = (0.05)(40.0 L/min)(1,339 g/L) = 2,678 g/min

$$\text{molar flow} = \frac{2678\,\text{g/min}}{133.41\,\text{g/mole}} = 20.07\,\text{mole/min}$$

Hydrogen chloride

Moles of HCl per mole of CH_3CCl_3 = 3

mass flow = 3(20.07 moles/min)(36.5 g/mole) = 2,198 g/min HCl

Toluene data from Appendix A

formula = $C_6H_5CH_3$, GMW = 92.14, density = 0.8669 g/mL

mass flow = (0.05)(40.0 L/min)(866.9 g/L) = 1,733.8 g/min

Hydrogen chloride

Moles of HCl per mole of $C_6H_5CH_3$ = 0.0

b. Mass flow out of incinerator

Trichloroethylene

$(170\ \mu g/m^3)(10^{-6}\ g/\mu g)(9.0\ m^3/s)(60\ s/min) = 0.0918\ g/min$

1,1,1 Trichloroethane

$(353\ \mu g/m^3)(10^{-6}\ g/\mu g)(9.0\ m^3/s)(60\ s/min) = 0.190\ g/min$

Toluene

$(28\ \mu g/m^3)(10^{-6}\ g/\mu g)(9.0\ m^3/s)(60\ s/min) = 0.0151\ g/min$

HCl

without APC

Total mass of HCl = 2,462 + 2,198 = 4,660 g/min

$(4{,}660\ g/min)(10^{-3}\ kg/g)(60\ min/h) = 279.6\ kg/h$

with APC

$(83.2\ mg/m^3)(10^{-3}\ g/mg)(9.0\ m^3/s)(60\ s/min) = 44.928\ g/min$

or (44.928 g/min)(10^{-3} kg/g)(60 min/h) = 2.696 or 2.7 kg/h

c. Compliance computations

DRE for Trichloroethylene

$$\text{DRE} = \frac{2952 - 0.0918}{2952}(100) = 99.9968\% \quad \text{Passes}$$

DRE for 1,1,1 Trichloroethane

$$\text{DRE} = \frac{2678 - 0.190}{2678}(100) = 99.9929\% \quad \text{Passes}$$

DRE for Toluene

$$\text{DRE} = \frac{1733.8 - 0.0151}{1733.8}(100) = 99.9991\% \quad \text{Passes}$$

HCl

2.7 kg/h exceeds 1.8 kg/h, therefore check 1% limit

(0.01)(4,660 g/min) = 46.6 g/min

After the APC the emission is 44.928 g/min. This is less than the 1% limit. Therefore the incinerator complies with the HCl limits.

Particulates

The limit is 180 mg/dscm, therefore the incinerator emission of 123.4 mg/dscm complies with the particulate limits.

The incinerator complies with all emission limits.

10-42 Incinerator compliance for hexachlorobenzene, pentachlorophenol, acetone

Given: Incinerator operating conditions and stack gas concentrations after APC equipment

Solution:

a. Mass flow into incinerator (@ 9.3% of volumetric flow)

Hexachlorobenzene data from Appendix A

formula = C_6Cl_6, GMW = 284.79, density = 1.5691 g/mL

mass flow = (0.093)(140.0 L/min)(1,569.1 g/L) = 20,430 g/min

$$\text{molar flow} = \frac{20{,}430\,\text{g/min}}{284.79\,\text{g/mole}} = 71.74\,\text{mole/min}$$

Hydrogen chloride

Moles of HCl per mole of C_6Cl_6 = 6

mass flow = 6(71.74 moles/min)(36.5 g/mole) = 15,710 g/min HCl

Pentachlorophenol data from Appendix A

formula = Cl_5C_6OH, GMW = 266.34, density = 1.978 g/mL

mass flow = (0.093)(140.0 L/min)(1,978 g/L) = 25,754 g/min

$$\text{molar flow} = \frac{25{,}754\,\text{g/min}}{266.34\,\text{g/mole}} = 96.69\,\text{mole/min}$$

Hydrogen chloride

Moles of HCl per mole of Cl_5C_6OH = 5

mass flow = 5(96.69 moles/min)(36.5 g/mole) = 17,647 g/min HCl

Acetone data from Appendix A

formula = CH_3COCH_3, GMW = 58.08, density = 0.79 g/mL

mass flow = (0.093)(140.0 L/min)(790 g/L) = 10,286 g/min

Hydrogen Chloride

Moles of HCl per mole of CH_3COCH_3 = 0.0

b. Mass flow out of incinerator

Hexachlorobenzene

$(170\ \mu g/m^3)(10^{-6}\ g/\mu g)(28.32\ m^3/s)(60\ s/min) = 0.2889\ g/min$

Pentachlorophenol

$(353\ \mu g/m^3)(10^{-6}\ g/\mu g)(28.32\ m^3/s)(60\ s/min) = 0.5998\ g/min$

Acetone

$(28\ \mu g/m^3)(10^{-6}\ g/\mu g)(28.32\ m^3/s)(60\ s/min) = 0.04758\ g/min$

HCl

without APC

Total mass of HCl = 17,647 + 10,286 = 27,933 g/min

$(27{,}933\ g/min)(10^{-3}\ kg/g)(60\ min/h) = 1{,}676\ kg/h$

with APC

$(83.2\ mg/m^3)(10^{-3}\ g/mg)(28.32\ m^3/s)(60\ s/min) = 141.37\ g/min$

or $(141.37\ g/min)(10^{-3}\ kg/g)(60\ min/h) = 8.48\ kg/h$

c. Compliance computations

DRE for Hexachlorobenzene

$$\text{DRE} = \frac{20{,}430 - 0.2889}{20{,}430}(100) = 99.9986\% \quad \text{Passes}$$

DRE for Pentachlorophenol

$$\text{DRE} = \frac{25{,}754 - 0.5998}{25{,}754}(100) = 99.9977\% \quad \text{Passes}$$

DRE for Acetone

$$\text{DRE} = \frac{10{,}286 - 0.04758}{10{,}286}(100) = 99.9995\% \quad \text{Passes}$$

HCl

8.48 kg/h exceeds 1.8 kg/h, therefore check 1% limit

(0.01)(27,933 g/min) = 279.33 g/min

After the APC the emission is 141.37 g/min. This is less than the 1% limit. Therefore the incinerator complies with the HCl limits.

Particulates

Correct 14% oxygen to 7% concentration using Eqn. 10-32

$$P_c = 123.4\left(\frac{14}{21-14}\right) = 246.8$$

The limit is 180 mg/dscm, therefore the incinerator emission of 246.8 mg/dscm fails to comply with the particulate limits.

The incinerator complies with all emission limits except particulates.

10-43 Rotary kiln

Given: Retention time required = 1.0 h, diameter = 3.00 m, length = 6.00 m, slope = 2.00%, peripheral speed = 1.5 m/min

Solution:

a. Calculate revolutions per minute

$$N = \frac{\text{PeripheralSpeed}}{\text{Circumference / rev}} = \frac{1.5\,\text{m/min}}{\pi(3.00\text{m})/\text{rev}} = 0.159\,\text{rev/min}$$

b. Slope

S = 2.00% = 0.02 m/m

c. Time

$$t = \frac{0.19(6.00\text{m}/3.00\text{m})}{(0.02\,\text{m/m})(0.159\,\text{rev/min})} = 119.4\,\text{min}$$

This is > 1 hour so permit conditions have been met.

10-44 Time to test 10^{-7} cm/s hydraulic conductivity

Given: Standard permeameter dimensions and measurements

Solution:

a. Compute area (A) of sample

$$A = \frac{\pi(5.0\text{cm})^2}{4} = 19.64\text{cm}^2$$

b. Solve permeameter equation for t

$$t = \frac{Q \cdot L}{k \cdot h \cdot A \cdot t}$$

$$t = \frac{(100.0\text{cm}^3)(10\text{cm})}{(10^{-7}\ \text{cm/s})(100\text{cm})(19.64\text{cm}^2)(86400\,\text{s/d})} = 58.95 \text{ or } 60 \text{ d}$$

10-45 Redesign of permeameter

Given: Figure P-10-44, 30 d for 100 mL minimum

Solution:

Note: there are many solutions that will work. I chose to double head to 2 m.

a. Solve equation for t

$$t = \frac{Q \cdot L}{k \cdot h \cdot A}$$

b. Area of sample

$$A = \frac{\pi(5.0\text{cm})^2}{4} = 19.64\text{cm}^2$$

c. Solve for t

$$t = \frac{(100.0\text{cm}^3)(10\text{cm})}{(10^{-7}\ \text{cm/s})(200\text{cm})(19.64\text{cm}^2)(86400\,\text{s/d})} = 29.5\text{d}$$

10-46 Soil hydraulic conductivity from falling head permeameter test

Given: Falling head permeameter dimensions and test results

Solution:

a. Calculate area of sample (A)

$$A = \frac{\pi(10.0\text{cm})^2}{4} = 78.54\text{cm}^2$$

b. Calculate area of stand pipe (a)

$$a = \frac{\pi(0.1\text{cm})^2}{4} = 0.007854\text{cm}^2$$

c. Calculate hydraulic conductivity (14 d = 1,209,600 s)

$$K = \frac{2.3(0.007854)(25)}{(78.54)(1,209,600)}\log\left(\frac{100}{25}\right) = 2.86\times10^{-9}\text{ cm/s}$$

The nominal permeability acceptable for a hazardous waste landfill is 10^{-7} cm/s. Thus, this is excellent.

10-47 Estimate of leachate volume

Given: 100 hectare landfill, permeability of 10^{-7} cm/s

Solution:

a. Convert cm/s to m/d

$k = (10^{-7}\text{ cm/s})(10^{-2}\text{ m/cm})(86,400\text{ s/d}) = 8.64 \text{ x } 10^{-5}\text{ m/d}$

b. Calculate flow

$Q = (8.64 \text{ x } 10^{-5}\text{ m/d})(100\text{ hectares})(104\text{ m}^2\text{/hectare}) = 86.4\text{ m}^3\text{/d}$

10-48 Time for leachate to migrate

Given: Three soils with differing permeability and depth

Solution:

SOIL A
a. Hydraulic gradient

$$i = \frac{H+T}{T} = \frac{0.3\text{m} + 3\text{m}}{3\text{m}} = 1.10$$

b. Darcy velocity

$$v = (1.8 \text{ x } 10^{-7} \text{ cm/s})(1.10) = 1.98 \text{ x } 10^{-7} \text{ cm/s}$$

c. Seepage velocity

$$v' = \frac{1.98 \times 10^{-7} \text{ cm/s}}{0.55} = 3.60 \times 10^{-7} \text{ cm/s}$$

d. Travel time

$$t = \frac{(3.0\text{m})(100\,\text{cm/m})}{(3.60 \times 10^{-7} \text{ cm/s})(86400\,\text{s/d})} = 9645\text{d}$$

SOIL B
a. Hydraulic gradient

$$i = \frac{H+T}{T} = \frac{0.3\text{m} + 3\text{m} + 10\text{m}}{10\text{m}} = 1.33$$

b. Darcy velocity

$$v = (2.2 \text{ x } 10^{-5} \text{ m/s})(1.33) = 2.93 \text{ x } 10^{-5} \text{ m/s}$$

c. Seepage velocity

$$v' = \frac{2.93 \times 10^{-5} \text{ m/s}}{0.25} = 1.17 \times 10^{-4} \text{ m/s}$$

d. Travel time

$$t = \frac{(10.0\text{m})}{(1.17 \times 10^{-4} \text{ m/s})(86400\,\text{s/d})} = 0.99\text{d}$$

SOIL C

a. Hydraulic gradient

$$i = \frac{H+T}{T} = \frac{0.3m + 3m + 10m + 12m}{12m} = 2.11$$

b. Darcy velocity

$$v = (5.3 \times 10^{-5} \text{ mm/s})(2.11) = 1.12 \times 10^{-4} \text{ mm/s}$$

c. Seepage velocity

$$v' = \frac{1.12 \times 10^{-4} \text{ mm/s}}{0.35} = 3.19 \times 10^{-4} \text{ mm/s}$$

d. Travel time

$$t = \frac{(12.0\text{m})(1000\text{ mm/m})}{(3.19 \times 10^{-4} \text{ mm/s})(86400\text{ s/d})} = 435\text{d}$$

TOTAL TIME

$$\text{Time} = \frac{9645\text{d} + 0.99\text{d} + 435\text{d}}{365\text{ d/y}} = 27.6 \text{ or } 28 \text{ y}$$

10-49 Cubic meters of water contaminated at PQL

Given: PQL for trichloroethylene = 5 μg/L, 0.12 m^3 barrel leaks to ground water

Solution:

a. Calculate mass of trichloroethylene in 0.12 m^3

From Appendix A, density = 1.476 g/mL = 1,476 kg/m^3

mass = (0.12 m^3)(1,476 kg/m^3) = 177.12 kg
In μg = (177.12 kg)(10^9 μg/kg) = 1.7712 x 10^{11} μg

b. Volume of water contaminated

$$\frac{1.7712 \times 10^{11} \mu g}{(5 \mu g/L)(10^3 \text{ L/m}^3)} = 35{,}424{,}000 \text{ or } 3.54 \times 10^7 \text{ m}^3$$

10-50 Travel time with retardation

Given: Hydraulic gradient = 8.6 x 10^{-4}, hydraulic conductivity = 200 m/d, porosity = 0.23, retardation factor = 2.3

Solution:

a. Find the Darcy velocity

v = k(i) = (200 m/d)(8.6 x 10^{-4}) = 0.172 m/d

b. Find average linear velocity

$$v' = \frac{v}{n} = \frac{0.172}{0.23} = 0.748\,\text{m/d}$$

c. Calculate the retardation factor

$$v'_R = \frac{v'}{R} = \frac{0.748\,\text{m/d}}{2.3} = 0.325\,\text{m/d}$$

d. Travel time

$$t = \frac{\text{distance}}{\text{speed}} = \frac{100\text{m}}{0.325\,\text{m/d}} = 307.55 \text{ or } 308\text{ d}$$

10-51 Pumping rate for purge well

Given: Depth of unconfined aquifer = 60.00 m, permeability = 6.4 x 10^{-3} m/s, plume depth at 130 m from center of leak is 0.1 m and plume does not extend beyond 150 m.

Solution:

a. Using Equation 3-30

Computing h1 and h2

h1 = H - s1 = 60.00 - 0.1 = 59.90 m

h2 = H - s2 = 60.00 - 0.0 = 60.00 m

$$Q = \frac{\pi\left(6.4\times10^{-3}\text{ m/s}\right)\left[\left(60.00\text{m}\right)^2 - \left(59.90\text{m}\right)^2\right]}{\ln\left(\frac{150}{130}\right)} = 1.68\,\text{m}^3/\text{s}$$

10-52 Single intercept well system

Given: 0.12 m^3 of CCl_4, K = 7 x 10^{-4} cm/s, n = 0.38, GWT = 3.0 m, i = 0.002, aquifer = 28 m, Q_w = 0.014 m^3/s

Solution:

a. Calculate the Darcy velocity

$$v = k(i) = (7 \times 10^{-4} \text{ m/s})(0.002) = 1.40 \times 10^{-6} \text{ m/s}$$

b. Width of capture zone at the well

$$\frac{Q}{D(v)} = \frac{0.014\,\text{m}^3/\text{s}}{(28.0\text{m})(1.40\times10^{-6}\text{ m/s})} = 357.14 \text{ or } 360 \text{ m}$$

10-53 Location of well

Given: Data in Problem 10-52, leading edge = 200 m width

Solution:

a. The well should be at a distance equal to x_{sp} (Eqn. 10-39)

$$x_{sp} = \frac{(0.014\,\text{m}^3/\text{s})}{2\pi(28.0\text{m})(1.40\times10^{-6}\text{ m/s})} = 56.8 \text{ or } 57 \text{ m}$$

DISCUSSION QUESTIONS

10-1 Dioxin toxicity

Given: LD50 for 2,3,7,8-TCDD

Solution:

The LD50 toxicity is based on oral intake for a particular species. This statement may be misleading if it is assumed to be the same for humans, the route of exposure is not orally, and because toxicity may manifest itself in forms other than death, i.e the slope of the dose-response curve may yield greater effects at lower doses but have a higher LD50.

10-2 Land ban

Given: Does "land ban" actually ban the disposal of hazardous waste?

Solution:

The "land ban" only prohibits land disposal of hazardous waste if there are no concentration levels or methods of treatment of waste established by EPA. A better term is "Land Disposal Restrictions (LDR).

10-3 Joint and several liability

Given: one drum identified, may be responsible for all others

Solution:

This is correct because CERCLA and courts have established strict, joint, and several liability.

10-4 Is recycling best first step?

Given: Instituting a program to minimize waste

Solution:

The best first step is to prevent the generation of pollution in the first place. Waste exchange and then recycling are logic follow-on steps.

10-5 Recycle, reuse or recover?

Given: plating sludge treated to recover nickel

Solution:

Treatment of the sludge to recover nickel is considered to be reclaiming. Since reclaiming is a form of recycling - it is also recycling.

10-6 Measuring POHCs

Given: True/false statement

Solution:

The statement is true. Only designated POHCs need to be measured.