1.725 Problem Set #4 Solutions

(ch. 2 – 6, 11, 32, 47, 58)

6. pentane: C_5H_{12}, 72 g/mol
octane: C_8H_{18}, 114 g/mol

a) pentane is removed according to $C = C_0 e^{-k_r t}$

$$k_r = \frac{k}{\text{depth}} = \frac{1\ \text{cm/hr}}{400\ \text{cm}} = .0025\ \text{hr}^{-1}$$

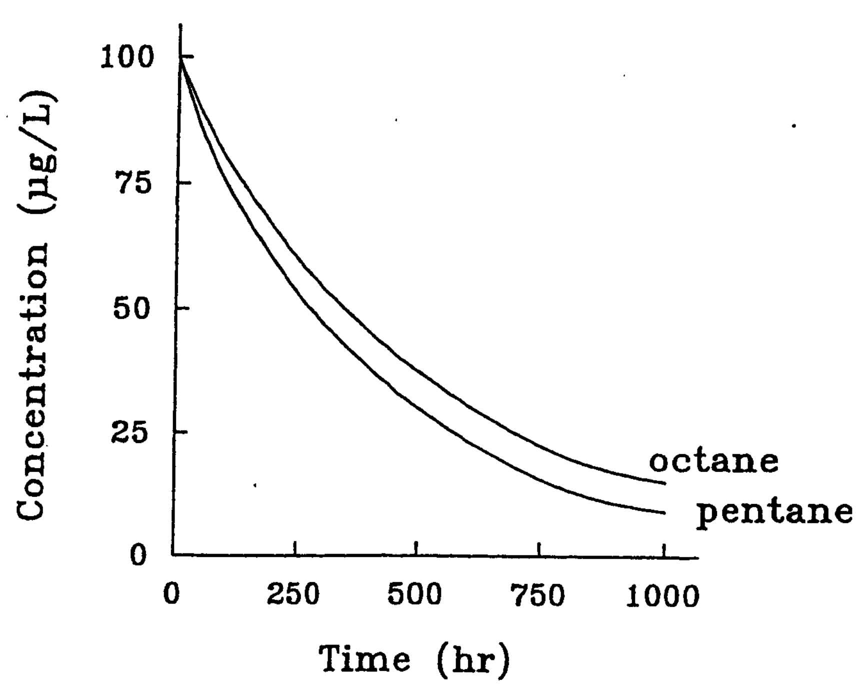
$$C = (100\ \mu g/L)\, e^{-(.0025\ \text{hr}^{-1})t}$$

b) first, find k for octane (using thin film model since it's a lake)

$$\frac{k_o}{k_p} = \frac{\sqrt{MW_p}}{\sqrt{MW_o}} = \frac{\sqrt{72}}{\sqrt{114}} = 0.795 \qquad k_o = 0.795\ \text{cm/hr}$$

$$k_r = \frac{0.795\ \text{cm/hr}}{400\ \text{cm}} = .0020\ \text{hr}^{-1}$$

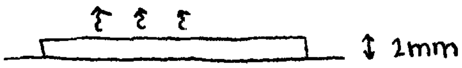
$$C = (100\ \mu g/L)\, e^{-(.0020\ \text{hr}^{-1})t}$$



c) Since pentane is volatilized more quickly (due to its lower molecular weight), over time the gasoline will contain a higher fraction of octane.

d) biodegradation, sorption onto particles that settle to sediment, removal through a stream

11.



at air-NAPL interface:

$$C_a = \frac{P}{RT}(MW) = \frac{(165\text{ mm Hg} \times 1\text{ atm}/760\text{ mm Hg})(97\text{ g/mol})}{(.08206\text{ L atm/mol K})(293\text{ K})} = 0.88\text{ g/L}$$

$$k_a\text{ (cm/hr)} \approx 1100\, u_{10}\text{ (m/s)}$$

$$= 3300\text{ cm/hr}$$

$$J = k_a C_a = \frac{3300\text{ cm}}{\text{hr}} \times \frac{0.88\text{ g}}{\text{L}} \times \frac{\text{L}}{1000\text{ cm}^3} = 2.9\frac{\text{g}}{\text{cm}^2\cdot\text{hr}}$$

taking an area of 1 cm^2 and finding the time for all the 1,2-dichloroethene to volatilize:

$$\text{volume} = 1\text{ cm}^2(0.2\text{ cm}) = 0.2\text{ cm}^3$$

$$0.2\text{ cm}^3 \times \frac{1.28\text{ g}}{\text{cm}^3} = 0.256\text{ g}$$

$$\text{time} = 0.256\text{ g} \times \frac{\text{hr}}{2.9\text{ g}} \times \frac{60\text{ min}}{\text{hr}} = 5.3\text{ min}$$

So 20 minutes after the spill, there is no more 1,2-dichloroethene on the road.

32. a) toluene 

92 g/mol

stream → surface renewal model

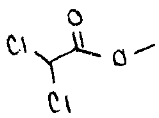
$$\frac{k_t}{k_p} = \sqrt{\frac{\sqrt{MW_p}}{\sqrt{MW_t}}} = \sqrt{\frac{\sqrt{44}}{\sqrt{92}}} = 0.832 \qquad k_t = 0.832\,(19\text{ cm/hr}) = 15.8\text{ cm/hr}$$

$$C_o = \frac{9.0\,mg/sec}{3\,L/sec} = 3\,mg/L$$

$$K_r = \frac{K}{d} = \frac{15.8\,cm/hr}{20\,cm} = 0.79\,hr^{-1}$$

$$C = C_o e^{-K_r \tau} = (3\,mg/L)\,e^{-0.79\,hr^{-1}(0.583\,hr)} = \boxed{1.9\,mg/L}$$

b) removed by hydrolysis rather than degassing, but same 1st-order approach:



$$K_n' = 1.5 \times 10^{-5}\,s^{-1}$$

$$K_b = 2.8 \times 10^{3}\,M^{-1}\,s^{-1}$$

$K_T' = K_n' + K_b[OH^-]$ neglecting acid-catalyzed hydrolysis

$$= 1.5 \times 10^{-5}\,s^{-1} + 2.8 \times 10^{3}\,M^{-1}s^{-1}\,(10^{-6.5}\,M) = 9.0 \times 10^{-4}\,s^{-1}$$

$$C = C_o e^{-K_T' t} = (3\,mg/L)\,e^{-(9.0\times10^{-4}s^{-1})(2100\,s)} = \boxed{0.45\,mg/L}$$

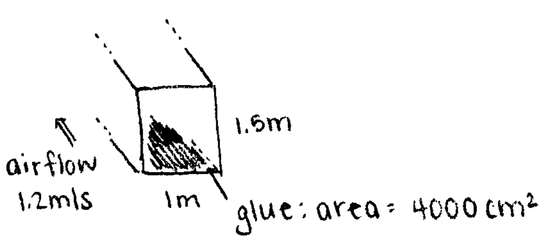
47.

$$A_d = A_o e^{-\lambda t} \Rightarrow t = -\frac{1}{\lambda}\ln\left(\frac{A_d}{A_o}\right)$$

$$\lambda(^{210}Pb) = .03\,y^{-1}$$

$$t = \frac{-1}{.03\,y^{-1}}\ln\left(\frac{0.9}{3.4}\right) = \boxed{44\text{ years}}$$

58.



a) $$C_a = \frac{P}{RT}(MW) = \frac{10^{-2}\,atm\,(92.14\,g/mol)}{(.08206\,L\,atm/mol\,K)(298\,K)} = .038\,g/L$$

$$K_a = 1100\,(1.2) = 1320\,cm/hr$$

$$J = K_a C_a = \frac{.038\,g}{L} \times \frac{L}{1000\,cm^3} \times \frac{1320\,cm}{hr} = \frac{.050\,g}{cm^2 \cdot hr}$$

over the whole surface: $$\frac{.050\,g}{cm^2 \cdot hr}(4000\,cm^2) \times \frac{hr}{3600\,s} = .055\,g/s$$

(amt. of toluene volatilized)

flow rate: $Q = vA$

$= (1.2\ m/s)(1.5\ m^2) = 1.8\ m^3/s$

For downstream, the toluene is distributed evenly throughout the air duct.

$$C_{tol} = \frac{.055\ g/s}{1.8\ m^3/s} \times \frac{mol}{92.14\ g} = \boxed{3.3 \times 10^{-4}\ mol/m^3}$$

b) $C_a = .038\ g/L$

$k_a = 1100(2) = 2200\ cm/hr$ } $\Rightarrow J = .083\ g/cm^2 \cdot hr$

volatilization rate = $.092\ g/s$

flow rate = $3\ m^3/s$ $\Rightarrow$ $\boxed{C_{tol} = 3.3 \times 10^{-4}\ mol/m^3}$

The concentration is the same because the airflow velocity affects both the volatilization and flow rates.

c)

I 2cm kitty litter

This is like the stagnant air layer in the thin film model; we are concerned with how much the toluene diffuses through the kitty litter, and how much kitty litter there is.

$$k = \frac{D}{\delta} = \frac{0.01\ cm^2/s}{2\ cm} = .005\ cm/s$$

now repeat previous calculations:

$C_a = .038\ g/L$

$$J = .038\frac{g}{L} \times \frac{L}{1000\ cm^3} \times \frac{.005\ cm}{s} = 1.9 \times 10^{-7}\ \frac{g}{cm^2 \cdot s}\ (4000\ cm^2) = 7.6 \times 10^{-4}\ g/s$$

$$C_{tol} = \frac{7.6 \times 10^{-4}\ g/s}{1.8\ m^3/s} \times \frac{mol}{92.14\ g} = 4.6 \times 10^{-6}\ mol/m^3, \text{ or } \boxed{\text{72 times smaller}}$$

note: flux can also be calculated using $J = -D\frac{dc}{dx}$, taking $c \approx 0$ at the top of the kitty litter.

(same numbers, slightly different thought process)