1) Aroclor 1260 $\log K_{ow} = 6.91$ is a PCB

For PCBs $\log K_{oc} = 0.544 \log K_{ow} + 1.377$
$= 0.544\,(6.91) + 1.377$
$= 5.14$

$K_{oc} = 138{,}038$
$K_{ow} = 8{,}128{,}305$

$$f^*_{oc} = \frac{SSA}{200\,(K_{ow})^{0.84}} = \frac{35}{200\,(8{,}128{,}305)^{0.84}} = 2.75 \times 10^{-7}$$

$f_{oc} = 0.25\% = 0.0025$

$f_{oc} > f^*_{oc}$ so equation is valid.

$K_d = K_{oc} \times f_{oc}$
$= 138{,}038 \times 0.0025$
$= 345.1$

$$R = 1 + \frac{\rho_d K_d}{n} = 1 + \frac{1.55\ g/cm^3 \times 345.1\ mL/g}{0.45}$$

$= 1189.7$ → GW velocity 1189.7 times faster than rate of transport of Aroclor 1260

2) With advection dominant: plug flow, so full concentration

$$i = \frac{1.0 + 0.3}{1} = 1.3$$

$$V_s = \frac{Ki}{n_e} = \frac{1 \times 10^{-9}\ m/s \times 1.3}{0.45} = 2.89 \times 10^{-9}\ m/s$$

$$t = \frac{1.0\ m}{2.89 \times 10^{-9}\ m/s} = 3.46 \times 10^{8}\ s = 11.0\ \text{years}$$

3) With diffusion dominant:

$$\frac{C}{C_0} = erfc\left(\frac{x}{2\sqrt{\frac{D^* t}{R}}}\right) = \quad 0.25 = erfc(\beta)$$

$\beta = 0.8$ gives $erfc(\beta) = 0.258$ $\qquad 0.258 - 0.229 = 0.029$

$\beta = 0.85$ gives $erfc(\beta) = 0.229$ $\qquad \frac{0.008}{0.029} \times 0.05 = 0.014$

$$0.25 = erfc(0.814)$$

$$0.814 = \frac{1\ m}{2\sqrt{\frac{1.2 \times 10^{-10}\ m^2/s \times t}{1189.7}}}$$

$$D^* = 1.2 \times 10^{-10}\ \frac{m^2}{s} \times 3600\ \frac{s}{hr} \times 24\ \frac{hr}{d} \times 365\ \frac{d}{yr} = 0.00378\ \frac{m^2}{yr}$$

$$0.814 = \frac{1\ m}{2\sqrt{\frac{0.00378\ m^2/yr \times t}{1189.7}}}$$

$$t = \frac{1\ m}{4 \times \frac{0.00378}{1189.7} \times 0.814 \times 0.814} = \frac{1}{0.000008421}$$

$$= 118{,}750\ \text{years.}$$

4) With advection and diffusion both important

$$\frac{C}{C_0} = 0.25 = \frac{1}{2}\left\{ \text{erfc}\left(\frac{Rx - V_s t}{2\sqrt{D^* R t}}\right) + \exp\left(\frac{V_s x}{D^*}\right)\text{erfc}\left(\frac{Rx + V_s t}{2\sqrt{D^* R t}}\right)\right\}$$

$$\frac{V_s x}{D^*}$$

$$V_s = 2.89 \times 10^{-9}\ \frac{m}{s} \times 3600\ \frac{s}{hr} \times 24\ \frac{hr}{d} \times 365\ \frac{d}{yr} = 0.0911\ \frac{m}{yr}$$

$$\frac{V_s x}{D^*} = \frac{0.0911\ m/yr \times 1\ m}{0.00378\ m^2/yr} = 24.1$$

$$\exp(24.1) = 2.93 \times 10^{10}$$

$R = 1189.7$
$D^* = 0.00378$
$V_s = 0.0911$

consider $\text{erfc}\left(\frac{Rx + V_s t}{2\sqrt{D^* R t}}\right) = \text{erfc}(\beta)$

at $t = 10$ years
$$\beta = \frac{1189.7 \times 10 + 0.0911 \times 10}{2\sqrt{0.00378 \times 1189.7 \times 10}}$$

$$= \frac{11{,}897 + 0.911}{13.4} = 887.$$

β is too large and will always be too large so the second term will always be equal to zero, so ignore the second term.

$$\frac{C}{C_0} = 0.25 = \frac{1}{2}\text{erfc}\left(\frac{Rx - V_s t}{2\sqrt{D^* R t}}\right)$$

$0.5 = \text{erfc}(\beta)$; β between 0.45 and 0.5

4) cont'd. $\beta = 0.45$ $\quad erfc(\beta) = 0.524$ $\quad 0.524 - 0.480 = 0.044$

$\beta = 0.50$ $\quad erfc(\beta) = 0.480$ $\quad \frac{0.24}{0.44} \times 0.05 = 0.027$

$\beta = 0.477$ $\quad erfc(\beta) = 0.50$

$$\frac{Rx - V_s t}{2\sqrt{D^* R t}} = \frac{1189.7 \times 1 - 0.0911\,t}{2\sqrt{0.00378 \times 1189.7 \times t}} = 0.477$$

$$1189.7 - 0.0911t = 2.023\sqrt{t}$$

$$1189.7 - 2.023\sqrt{t} - 0.0911t = 0$$

$$1189.7 - 202.3 - 911 = 76.4$$ try $t = 10{,}000$ years

by trial and error $t = 10{,}756$ years.

5) Peclet number $= \frac{V_s d}{D_o}$

for a clay soil the grain size may be from 0.001 to 0.005 mm according to ASTM D 422 "Geoenvironmental Engineering", Sharma and Reddy, 2004, p. 46.

use $d = 0.0025$ mm $= 2.5 \times 10^{-6}$ m.

$V_s = 2.89 \times 10^{-9}$ m/s

$D_o = \frac{D^*}{\tau}$ where τ ranges from 0.01 to 0.5

let $\tau = 0.2$

$$D_o \simeq \frac{1.2 \times 10^{-10}\ m^2/s}{0.2} = 6 \times 10^{-10}\ m^2/s$$

$$\frac{V_s d}{D_o} = \frac{2.89 \times 10^{-9}\ m/s \times 2.5 \times 10^{-6}\ m}{6 \times 10^{-10}\ m^2/s} = 1.20 \times 10^{-5}$$

so diffusion dominates

5) Waste is represented by $C_{68}H_{111}O_{50}N$

$$C_{68}H_{111}O_{50}N + \left(\frac{4\times 68 - 111 - 2\times 50 + 3\times 1}{4}\right) H_2O \rightarrow$$

$$\left(\frac{4\times 68 + 111 - 2\times 50 - 3\times 1}{8}\right) CH_4 +$$

$$\left(\frac{4\times 68 - 111 + 2\times 50 + 3\times 1}{8}\right) CO_2 + NH_3$$

$$C_{68}H_{111}O_{50}N + 16H_2O \rightarrow 35CH_4 + 33CO_2 + NH_3$$

(68×12	816	16 × (2+16)	35(12+4)	33(12+32)	14+3
111 × 1	41				
50 × 16	800				
1 × 14	14				
	1741	288	560	1,452	17

1000 kg

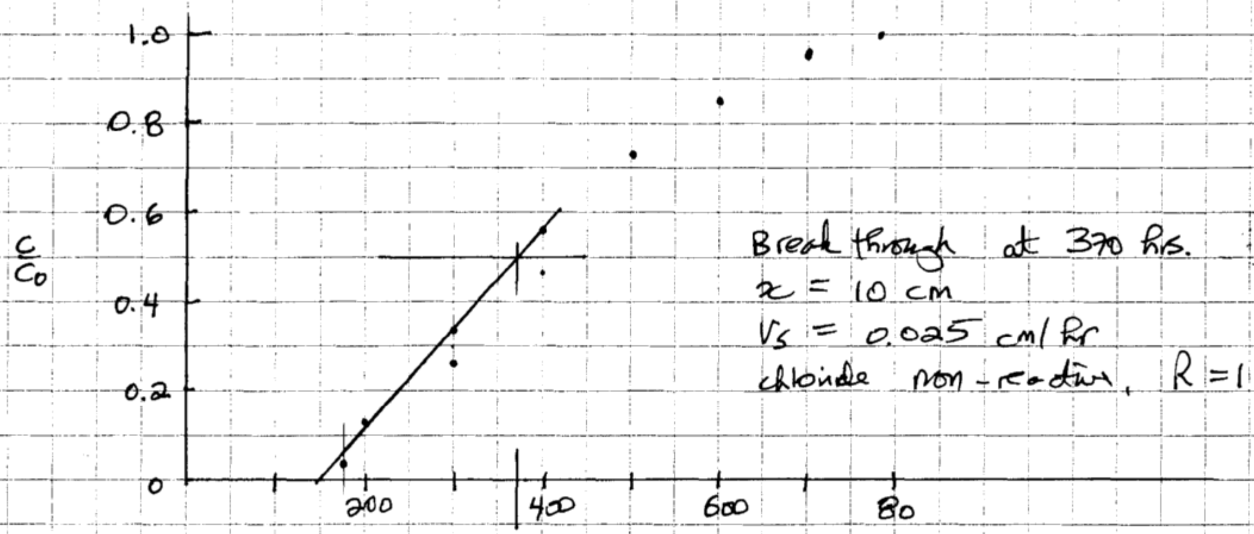
$0.7177 \frac{kg}{m^3}$.

$$\frac{1000 \text{ kg}}{1741} = \frac{x \text{ kg}}{560}$$

CH_4 = 321.65 kg.

$$\frac{321.65 \text{ kg}}{0.7177 \frac{kg}{m^3}} = 448 \text{ m}^3$$

= 448,000 L CH_4



$$\frac{c}{C_0} = 0.5 = 0.5\left\{ \operatorname{erfc}\left(\frac{Rx - V_s t}{2\sqrt{D^* R t}}\right) + \exp\left(\frac{V_s x}{D^*}\right)\operatorname{erfc}\left(\frac{Rx + V_s t}{2\sqrt{D^* R t}}\right)\right.$$

$$1 = \left\{ \operatorname{erfc}\left(\frac{10\,cm - 0.025\,cm/hr \times 370\,hr}{2\sqrt{D^*}\sqrt{370\,hr}}\right) + \exp\left(\frac{0.025\,cm/hr \times 10\,cm}{D^*}\right)\right. \ldots$$

$$1 = \left\{ \operatorname{erfc}\left(\frac{\overset{0.75}{10\,cm - 9.25\,cm}}{38.47\sqrt{D^*}}\right) + \exp\left(\frac{0.25\,cm^2/hr}{D^*}\right)\operatorname{erfc}\left(\frac{\overset{19.25}{10 + 9.25}}{38.47\sqrt{D^*}}\right)\right\}$$

Try $D^* = 2.75 \times 10^{-2}\ cm^2/hr.$

$\operatorname{erfc}(0.1176) + \exp(9.09)\operatorname{erfc}(3.02)$

$+ \quad 8866 \times 0.000022$

$0.86 \qquad 0.195 \qquad = 1.06$

0.15	1.76 = x	0.887
−0.10	5. 0.05	0.832
0.05	x = 0.019	0.055
	−0.887	
	0.868	

Try $D^* = 2.8 \times 10^{-2}\ cm^2/hr$

$\operatorname{erfc}(0.1165) + \exp(8.93)\operatorname{erfc}(2.99)$

$0. \qquad 7555 \times 0.000039$

$0.295 \qquad 1.20$

Try $D^* = 2.7 \times 10^{-2}\ cm^2/hr.$

$\operatorname{erfc}(0.119) + \exp(9.26)\operatorname{erfc}(3.04)$

$10{,}509 \times 0.000017$

$0.86 \qquad 0.18 \qquad =$

$= 1.04$

$$2.7 \times 10^{-2} \frac{cm^2}{hr} \times \frac{m^2}{10^4\, cm^2} \times \frac{hr}{3600\, sec} = 7.5 \times 10^{-10} \frac{m^2}{sec.}$$

This is reasonable because

$$D_0 \tau = D^*$$

if $D_0 = 20.3 \times 10^{-10} \frac{m^2}{s}$ and $\tau = 0.37$

then you get this value for D^* so this is

realistic since $\tau = 0.01$ to 0.5 usually.