SOLUTION

Remediation of soil and groundwater

Rizlan Bernier-Latmani

Problem set #8: physicochemical processes and barriers

Problem 1:

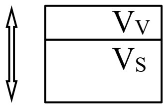
A sandy soil

$\varepsilon = 0.3$

vitrification

1 m^2

$V_T = 3\ m^3$ (for 1 m^2 surface)

V_T 

V_V → volume of void

V_S → volume of solid

$$porosity = \varepsilon = \frac{V_{void}}{V_T} = 0.3$$

prior to vitrification $V_V = \varepsilon * V_T = 0.9\ m^3$ (for 1 m^2 surface)

$V_S = V_T - V_V = 2.1\ m^3$

after vitrification: no porosity = pore space has collapsed due to melting of soil

$V_S = V_T = 2.1\ m^3$ (for 1 m^2 surface)

$\Delta V = 0.9\ m^3$

⟹ 0.9 m of subsidence for 1 m^2 surface

Problem 2:

$Q = 1.14 * 10^6$ L/d

$C_{ss} = 220$ mg/L

r_{ss}= remove 90 % ss

stabilization → 8 % lime by weight

80 $/ton

Daily solid production:

$$r_{solid} = Q * C_{ss} * r_{ss} = 1.14 * 10^6 \frac{L}{d} * 220 \frac{mg}{L} * 0.9 = 225\ kg$$

Annual solid production:

$$r'_{solid} = r_{solid} * 365 = 225 * 365 = 82\ t$$

Annual lime needs for stabilization:

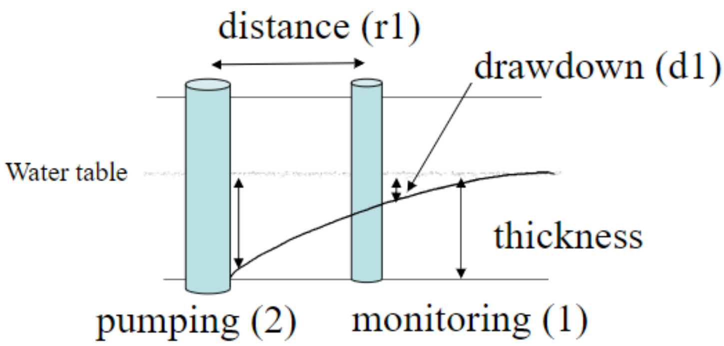
$$r_{lime} = r'_{solid} * 0.08 = 6.6\ t$$

Annual cost:

$$cost = r'_{solid} * 80 \frac{\$}{\mathrm{t}} = 6{,}592\ \$$$

Problem 3:

Q = pumping rate (m^3/s) ?
k = hydraulic conductivity = 4.2 * 10^{-4} m/s
B = aquifer thickness = 12 m
d_1= 0.2 m (drawdown at monitoring well)
d_2= 6 m (drawdown at pumping well)
r_2= 0.1m (radius of pumping well)
r_1= 18m (distance between pumping and monitoring wells)



What is the height of the water table at each well?

- ⇨ h_2= 12 - d_2 = 6 m
- ⇨ h_1= 12 – d_1 = 11.8 m

$$Q = \frac{1.366K(h_2^2 - h_1^2)}{\log\left(\frac{r_2}{r_1}\right)}$$

$$Q = \frac{1.366 * 4.2 * 10^{-4} * (6^2 - 11.8^2)}{\log\left(\frac{0.2}{18}\right)} = 0.03\ m^3/s$$

Problem 4:

C_0 = initial concentration
C_f = final concentration
W_w= weight of waste
W_{FA}= weight of fly ash

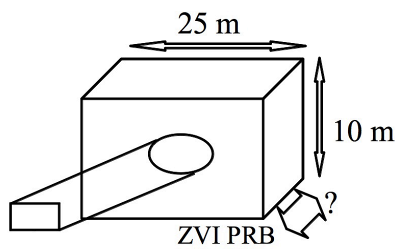
$$C_0 * W_w = C_f * (W_w + W_{FA})$$

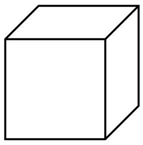
$$\frac{C_0}{C_f} = \frac{W_W + W_{FA}}{W_W} = \frac{1+1.2}{1} = 2.2$$

$$\Longrightarrow \frac{C_f}{C_0} = 0.45$$ reduction of 55 %

If we consider a reduction of 55% across all contaminants, the volatile solids should go from representing 72% of the mass to representing 32.4% (= 72%*(1-0.55)).
But the measurement reports 14% volatile solids. Hence, some of the volatile solids are lost (to volatilization and/or biodegradation) during the process.

Problem 5:





$C_0 = 20$ mg/L
$C_f = 0.1$ mg/L

K = 0.5 m/d

$t_{1/2} = 3\,h = 0.125\,d \quad \Longrightarrow \quad$ first order kinetics $\quad t_{1/2} = \frac{ln2}{k} \quad \Longrightarrow \quad k = 5.5\,d^{-1}$

$\varepsilon_{prb} = 0.6$
i = 1.2
SF = 3.5
$\rho_{ZVI} = 2.3$ g/cm^3
$\rho_{sand} = 1.6$ g/cm^3

<u>Width of the PRB:</u>

$$b = v \cdot t_{res} \cdot SF$$

$$v = \frac{K.i}{\varepsilon_{prb}}$$

$$t_{res} = \left[\frac{-ln\left(\frac{C_f}{C_0}\right)}{k}\right]$$

$$\Longrightarrow \; b = \frac{K.i}{\varepsilon_{prb}} \cdot \left[-\frac{ln\left(\frac{C_f}{C_0}\right)}{k}\right] \cdot SF$$

$$b = \frac{0.5\frac{m}{d} * 1.2}{0.6} \cdot \left[-\frac{ln\left(\frac{0.1}{20}\right)}{5.5d^{-1}}\right] \cdot 3.5 = 3.4\,m$$

<u>Amount of ZVI needed</u>

Total volume of PRB: V = 3.4 m·10 m · 25 m ≈ 850 m^3

If 100 % ZVI is used : $\quad M_{ZVI} = V \cdot \rho_{ZVI} = 850m^3 \cdot 2.3\frac{g}{cm^3} \cdot \frac{10^6 cm^3}{m^3} \cdot \frac{1kg}{10^3 g}$

$\quad M_{ZVI} = 1'955 \cdot 10^3 kg = 1'955\ metric\ tons$

If only 40 % ZVI used $\quad \Longrightarrow \quad$ 782 tons needed

Problem 6

PCE leaks Q = 4 mL/day
$K_D = 1.3 \cdot 10^{-5}\ L_{GW}/kg_{GW} = 1.3 \cdot 10^{-5}\ m^3{}_{GW}/g_{GW} = 1.3 \cdot 10^{-2}\ m^3{}_{GW}/kg_{GW}$
$\rho_{PCE} = 1.6$ kg/L

Target concentration: $C_{f,aq}$ = 5 ppb (m^3 PCE per m^3 groundwater GW)

1) How long does it take to reach the regulatory limit of 5 ppb?

Final concentration:

$$C_{f,aq} = 5\ ppb = 5 * 10^{-6}\frac{m^3_{PCE}}{m^3_{GW}} = 5 * 10^{-6}\ \frac{m^3_{PCE}}{m^3_{GW}} * 1.6\frac{kg_{PCE}}{L_{PCE}} * \frac{1{,}000L}{m^3} = 8 * 10^{-6}\frac{kg_{PCE}}{m^3_{GW}} = 8\frac{mg_{PCE}}{m^3_{GW}}$$

Partitioning of PCE in the aquifer (no gas phase):

$$m_{PCE} = Q * \rho_{PCE} * t = C_{aq}V_T(\epsilon + K_D(\rho_{wb} - \epsilon\rho_{water}))$$

Time to reach 50 ppb:

$$t_{5ppb} = \frac{C_{f,aq}V_T\left(\epsilon + K_D(\rho_{wb} - \epsilon\rho_{water})\right)}{Q * \rho_{PCE}}$$

$$= \frac{8 * 10^{-6}\ \frac{kg_{PCE}}{m^3_{GW}} * 3{,}927\ m^3_{GW} * \left(0.4 + 1.3 * 10^{-2}\ \frac{m^3_{GW}}{kg_{GW}} * 1{,}100\frac{kg_{GW}}{m^3_{GW}}\right)}{4 * 10^{-3}\ \frac{L_{PCE}}{d} * 1.6\frac{kg_{PCE}}{L_{PCE}}} = 72\ days$$

2) What is the aqueous concentration after 9 months?

$$C_{aq} = \frac{Q * \rho_{PCE} * t}{V_T\left(\epsilon + K_D(\rho_{wb} - \epsilon\rho_{water})\right)} = \frac{4 * 10^{-3}\frac{L_{PCE}}{d} * 1.6\frac{kg_{PCE}}{L_{PCE}} * 9 * 30\ d}{3{,}927\ m^3_{GW} * \left(0.4 + 1.3 * 10^{-2}\frac{m^3_{GW}}{kg_{GW}} * 1{,}100\frac{kg_{GW}}{m^3_{GW}}\right)} = 3 * 10^{-5}\frac{kg_{PCE}}{m^3_{GW}} = 30\frac{mg_{PCE}}{m^3_{GW}}$$

3) PRB thickness required

$$b = v \cdot t_{res} \cdot \mathrm{SF}$$

$$t_{res} = -\frac{ln\left(\frac{8}{30}\right)}{5.5\ d^{-1}} = 0.24\ d$$

$$b = 2\frac{m}{d} \cdot t_{res} \cdot 3.5 = 1.7\ m$$