

Lecture Notes 5

Soil vapor extraction

P_r = pressure at radial distance r = 0.91 atm

P_w = pressure at extraction well = 0.9 atm

P_{RI} = pressure at radius of influence = 1 atm

r = radial distance from extraction well = 5m

R_i = radius of influence where pressure = atm. pressure = ?

R_w = well radius of extraction well = 10 cm = 0.1m

$$P_r^2 - P_w^2 = (P_{RI}^2 - P_w^2) \frac{\ln\left(\frac{r}{R_w}\right)}{\ln\left(\frac{R_i}{R_w}\right)}$$

$$0.96^2 \text{ atm}^2 - 0.9^2 \text{ atm}^2 = (1 - 0.9^2 \text{ atm}^2) \frac{\ln\left(\frac{5 \text{ m}}{0.1 \text{ m}}\right)}{\ln\left(\frac{R_i}{0.1 \text{ m}}\right)}$$

$$(0.112) = (0.19) * 3.912 / \ln(R_i/0.1)$$

$$\ln(R_i/0.1) = 6.66$$

$$R_i = \exp(6.66) * 0.1$$

$R_i = 78 \text{ m}$

Calculate the pumping rate

$$1 \text{ atm} = 1.013 * 10^5 \text{ N/m}^2$$

Q_w = volumetric flow rate entering extraction well (m^3/sec) = ?

P_w = pressure at extraction well (N/m^2) = 0.9 atm * $1.013 * 10^5 \text{ (g/(cm} \cdot \text{sec}^2)) / \text{atm}$ = $0.912 * 10^6 \text{ g/(cm} \cdot \text{sec}^2)$

P_{RI} = pressure at radius of influence (=atm. pressure) (N/m^2) = $1.013 * 10^6 \text{ g/(cm} \cdot \text{sec}^2)$

H = length of screen in extraction well (m) = 1 m

R_i = radius of influence where pressure = atm. Pressure = 14 m

R_w = well radius of extraction well = 0.1 m

k = permeability of formation (m^2) = 10^{-12} m^2

μ = air viscosity = $1.8 * 10^{-4} \text{ g/cm} \cdot \text{sec}$

Q_{atm} = volumetric flow rate to atmosphere (m^3/sec) = ?

$$Q_w = H \left(\frac{\pi k}{\mu} \right) \left(\frac{P_w}{\ln\left(\frac{R_w}{R_i}\right)} \right) \left(1 - \left(\frac{P_{RI}}{P_w} \right)^2 \right)$$

$$Q_{atm} = \left(\frac{P_w}{P_{atm}} \right) Q_w$$

$$Q_w = 1 \text{ m} \left(\frac{3.14 * 2.2 * 10^{-6} \text{ m}^2}{0.18 \text{ g/(m.s)}} \right) \left(\frac{9.12 * 10^7 \text{ g/(m.s}^2)}{\ln\left(\frac{0.1 \text{ m}}{78 \text{ m}}\right)} \right) \left(1 - \left(\frac{1.013 * 10^8 \text{ g/(m.s}^2)}{0.912 * 10^7 \text{ g/(m.s}^2)} \right)^2 \right)$$

$$\underline{Q_w = 123.3 \text{ m}^3/\text{s}}$$

Time needed to remediate

$$\frac{dm_{i,tot}}{dt} = -C_{i,g}(t) * Q_w$$

Eq. (1)

$C_{i,g}(t)$ should be calculated as a function of mass of i.

Partitioning of i will be dependent on the mass of i left in the system $m_{i,tot}(t)$

$$m_{i,tot} = m_{i,s} + m_{i,aq} + m_{i,g} = C_{i,s}M_S + C_{i,aq}V_L + C_{i,g}V_G$$

$$m_{i,tot} = K_D M_S C_{i,aq} + C_{i,aq}V_L + K'_H C_{i,aq}V_G = C_{i,aq} * (K_D M_S + V_L + K'_H V_G)$$

$$C_{i,aq} = \frac{m_{i,tot}}{(K_D M_S + V_L + K'_H V_G)}$$

$$C_{i,g}(t) = K'_H C_{i,aq}(t) = \frac{K'_H * m_{i,tot}(t)}{K_D M_S + V_L + K'_H V_G} = \frac{K'_H * m_{i,tot}(t)}{K_D \rho_b V_T + \theta V_T + K'_H (\varepsilon - \theta) V_T}$$

$$C_{i,g}(t) = \frac{K'_H * m_{i,tot}(t)}{V_T (K_D \rho_b + \theta + K'_H (\varepsilon - \theta))}$$

Eq. (2)

Combining Eq. (1) and Eq. (2)

$$\frac{dm_{i,tot}}{dt} = -C_{i,g}(t) * Q_w = \frac{-K'_H * m_{i,tot}(t) * Q_w}{V_T (K_D \rho_b + \theta + K'_H (\varepsilon - \theta))}$$

$$\frac{dm_{i,tot}}{m_{i,tot}(t)} = \frac{-K'_H * Q_w}{V_T (K_D \rho_b + \theta + K'_H (\varepsilon - \theta))} dt$$

$$\text{Set } A = \frac{K'_H * Q_w}{V_T (K_D \rho_b + \theta + K'_H (\varepsilon - \theta))} \text{ All constant values}$$

$$\frac{dm_{i,tot}}{m_{i,tot}(t)} = -A dt$$

$$\int_{t_0}^t \frac{dm_{i,tot}}{m_{i,tot}} = \int_{t_0}^t -A dt$$

$$\ln \left(\frac{m_{i,tot}(t)}{m_{i,tot}(t_0)} \right) = - \frac{K'_H * Q_w}{V_T (K_D \rho_b + \theta + K'_H (\varepsilon - \theta))} dt$$

$$t = - \frac{\ln \left(\frac{m_{i,tot}(t)}{m_{i,tot}(t_0)} \right)}{K'_H * Q_w} * V_T (K_D \rho_b + \theta + K'_H (\varepsilon - \theta))$$

$$99\% \text{ removal} \Rightarrow \frac{m_{i,tot}(t)}{m_{i,tot}(t_0)} = 0.01$$

$$\ln(0.01) = -A dt$$

$$t = \frac{-\ln(0.01)}{K'_H * Q_w} * V_T (K_D \rho_b + \theta + K'_H (\varepsilon - \theta))$$

Bioventing problem

$$k_B = \frac{k_{O_2} * R_{C/O} * D_{O_2}}{\rho_{wb}} \Rightarrow k_{O_2} = \frac{k_B * \rho_{wb}}{R_{C/O} * D_{O_2}}$$

Using consistent units, kg for mass of soil and g for mass of C and O₂, m³ for volume and day for time

$$\begin{aligned} k_{O_2} \left(\frac{m^3 O_2}{m^3 \text{ soil} * \text{day}} \right) \\ = \frac{k_B (g \text{ C} / kg \text{ wet soil. day}) * \rho_{wb} (kg \text{ wet soil} / m^3 \text{ soil})}{D_{O_2} (g O_2 / m^3 O_2) * R_{C/O} (g \text{ C} / g O_2)} \end{aligned}$$

We have the following information:

$$\rho_{wb} = 1.45 \text{ g/cm}^3 = 1450 \text{ kg/m}^3$$

$$k_B = 0.05 \text{ g C} / (\text{kg wet soil.day})$$

$$D_{O_2} = 1.33 \text{ g O}_2 / \text{L O}_2 = 1.33 \frac{g O_2}{L} * \frac{1000 L}{1 m^3} = 1330 \frac{g O_2}{m^3}$$

First, we must determine the value of $R_{C/O}$



MW hexane = 86 g/mol and O₂ = 32 g/mol

For each mole of C₆H₁₄ there are 6 moles of C (6*12 = 72g) and 9.5 moles of O₂ are consumed (=304 g).

Therefore C = 72/304 => $R_{C/O} = 0.24 \text{ g C/g O}_2$

$$k_{O_2} \left(\frac{m^3 O_2}{m^3 \text{ soil} * \text{ day}} \right) = \frac{0.05 (g C / kg \text{ wet soil. day}) * 1450 (kg \text{ wet soil} / m^3 \text{ wet soil})}{1330 (g O_2 / m^3 O_2) * 0.24 (g C / g O_2)}$$

$$k_{O_2} \left(\frac{L O_2}{m^3 \text{ soil} * \text{ day}} \right) = 0.227 m^3 O_2 / (m^3 \text{ wet soil. day})$$

Air stripping example

First, all units should be consistent:

Vol: m³; distance: m, time: s; mass, g.

$$S = \pi r^2 = 0.50 m^2$$

$$L = \frac{Q_w \times \rho_L}{S} = \frac{5 \frac{m^3}{s} \times 998,200 \frac{g}{m^3}}{0.50 m^2} = 9.93 * 10^6 \frac{g}{m^2 s}$$

$$R = \frac{K_H Q_A}{Q_w} = 0.27 * 20 = 5.4$$

$$L_M = \frac{L}{MW_{water}} = \frac{9.93 * 10^6 \frac{g}{m^2 s}}{18 \frac{g}{mol}} = 5.52 * 10^5 \frac{mol}{m^2 s}$$

$$HTU = \frac{L_M}{M_w K_L a} = \frac{5.52 * 10^5 \frac{mol}{m^2 s}}{55600 \frac{mol}{m^3} \times 16 \frac{1}{s}} = 0.62 m$$

$$NTU = \left(\frac{R}{R-1} \right) \ln \left(\frac{c_{in} \times (R-1) + 1}{c_{out} R} \right) = 3.87$$

$$Z = HTU \times NTU = 2.4 m$$