ENV 504
Remediation of soils and groundwater
Final exam
November 27th, 2024
8:15am-12:00 pm
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Name

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Instructions:
This is an open book examination. You are allowed the course notes but not the homework problems or solutions. To get partial credit, be sure to show your work and to justify your answers. Sign the Honor code pledge. Please work in the blank pages provided.

I will abide by the EPFL Honor code ______________________________

Total : 80 points

Question 1: ________/ 40 points
Question 2: ________/ 20 points
Question 3: ________/ 20 points

Total number of pages: 7

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Problem 1: Bioremediation and air stripping (40 points)

Groundwater contaminated with 1,000 μg/L of trichloroethylene (TCE) was treated *in situ* through the continuous injection of 10 mg/L toluene ($C_6H_5CH_3$) as well as oxygen for the cometabolic aerobic degradation of TCE. For toluene, the growth yield (Y) was 0.007 g cells/mg, the decay coefficient (b) was 0.0001/d, the maximum primary substrate utilization rate (k) was -0.05 mg of toluene/(day. g cells), the half-velocity constant K_S is 0.1 mg toluene/L. The initial solid-associated biomass concentration is equivalent to 1,000 mg cells/L groundwater. [Note: the biomass is high because of an initial 20-day injection of higher toluene (100 mg/L) concentrations to build-up biomass].
Given the high concentration provided, we assume no adsorption of toluene to the aquifer materials.

1. Please define cometabolic degradation of TCE with toluene. What does it entail?
2. What concentration of oxygen is needed for the complete oxidation of toluene to CO_2 (neglecting toluene used for biomass generation)?
3. What is the concentration of toluene after 200 days?

The aquifer consists of fine to medium-sized sand with some silt. It has a dry bulk density of 1.75 g/cm^3, a porosity of 0.3. TCE can adsorb to the aquifer with a partitioning coefficient (K_D) of 0.1 mL/g. Desorption is rapid (98% can desorb in less than 1 min). The second-order rate coefficient for TCE biodegradation was 0.07 L/(mg. d).

4. What is the total mass of TCE in 1 m^3 of aquifer?
5. Considering the aquifer as a batch reactor (with no solid phase), what is the concentration of TCE after 200 days in 1 m^3 of groundwater?
6. How much TCE is left after 200 days?

Instead of *in situ* cometabolic bioremediation, it is also possible to use air stripping to remove TCE.

7. Given the specifications below, what is the effluent concentration of TCE from the tower assuming a temperature of 20 ºC?
8. Which approach would you choose? Provide a detailed justification of the pros and cons of each.

Air stripping tower:
Diameter= 0.6 m
Height= 5.5 m
Air-to-water ratio 160:1
Henry's constant (dimensionless): 0.415
Water flow rate Q_w= 60 L/sec
Liquid diffusion coefficient D_L= 5.3 *10^{-4} m^2/s
TCE molecular weight= 131.4 g/mol
TCE molar volume= 256 cm^3/mol
Packing material, 12 mm Berl Saddles
Toluene molecular weight= 92 g/mol

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Problem 2: Adsorption (20 points)

Particulate activated carbon (PAC, density 2 g/cm^3) is increasingly used to remove trace organic contaminants from wastewater treatment plant effluents. An EPFL environmental engineering graduate would like to try this strategy for groundwater treatment, specifically for the removal of diclofenac. PAC adsorption takes place in a batch system. The water is equilibrated with PAC for 2 min and separated via advanced filtration.
Preliminary tests conducted with 2.7 mg/L of PAC show that diclofenac adsorption to PAC follows a Freundlich isotherm with a slope of 0.85 and an intercept of 0.008 on a log-log plot with units of μg/L for the aqueous concentration and mg/mg PAC for the adsorbed fraction.
The diclofenac concentration in groundwater is 6 μg/L and the legal limit is 0.05 μg/L. PAC is to be used 1,000 times prior to regeneration to be economically feasible.

1. Is this a feasible strategy?
2. If not, what concentration of PAC should be used to achieve the desired removal?

Solution:

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Problem 3: Biopiles (20 points)

A mineral soil is contaminated with benzene (2,000 kg of benzene). The contamination is sufficiently shallow and limited in space that excavation followed by biopile treatment is deemed a feasible option. The target concentration is 30 mg/kg dry soil. The volume of soil to be treated is 10,000 m^3 (wet soil) with a soil moisture content of θ= 10 % and a wet bulk density of 1,875 kg/m^3.

The biopiles will have a volume of 500 m^3 each. The rate of degradation (assumed to be constant under optimal conditions) was determined to be 1 mg/(kg dry soil.day). We target 80% of field capacity and field capacity represents 20% water by volume.

1. Calculate the volume of water to be added to each biopile.
2. With a target of an initial molar ratio of C: N: P = 120:10:1, what mass of ammonium sulfate and trisodium phosphate should be added to each biopile?
3. If this is a static biopile, is the amount of O_2 present sufficient for the degradation of benzene (assuming no other sinks for O_2 and atmosphere O_2 and O_2-saturated water)?
4. If a dynamic biopile, how many air volumes will need to be pumped to degrade benzene?
5. How long will it take to treat the entire amount of contaminated soil assuming sufficient O_2 and nutrient supply?

Benzene C_6H_6
Wet soil bulk density ρ_{wb}=1,875 kg/m^3
Solid density ρ_s=2,500 kg/m^3
Soil moisture content in situ θ= 10 %
Density of benzene ρ_{benz}=786 kg/m^3
MW benzene MW= 78 g/mol
Ammonium sulfate ($(NH_4)_2SO_4$) MW= 132 g/mol
Trisodium phosphate ($Na_3PO_4 \bullet 12H_2O$) MW= 380 g/mol
Molar volume of O_2 (standard conditions) =22.4 L
Aqueous concentration of O_2 in saturated water =9.2 mg/L
Benzene K_D=0.03 m^3/kg
Benzene K_H=2.08[-]

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