ENV 504
Remediation of soils and groundwater
Final exam
December 3rd, 2025
8:15am-12:00 pm
Prof. Rizlan Bernier-Latmani

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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 : 100 points

Question 1: _____/ 50 points
Question 2: _____ / 20 points
Question 3: _____ / 30 points

Total number of pages: 9

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Problem 1: Treatment of 1,4-dioxane (50 points)

1,4-dioxane (dioxane, $C_4H_8O_2$), a probable carcinogen, is used in the textile and paper industry. It is a challenging contaminant to remediate due to its high solubility (1,000 g/L) and its low Henry's Law constant ($4.8* 10^{-3}$ atm.L/mol). A groundwater was contaminated with 1,000 µg/L of dioxane. The goal is to reach a concentration of 10 µg/L to reach the legal limit. Three treatment options were considered: (1) *in situ* direct biodegradation; (2) Cometabolic biodegradation with toluene; (3) pump-and-treat with GAC adsorption.



Figure 1: The 1,4-dioxane molecule

Note: This problem has several numerical dependencies. If you have trouble with any part, assume a value and continue your work. I will weigh the approach more highly than the numerical results (particularly the ones dependent on a previous result).

1. Partitioning:

The contaminated groundwater is cylindrical in shape with a height of 20m and a diameter of 2m. 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 0.4. Dioxane adsorbs to the aquifer material with a K_D= 10^{-6} m^3/kg.

A- Calculate the total mass of dioxane in the contaminated zone.
B- What is the mass and concentration of dioxane associated with the solid phase?
C- What is the mass of dioxane in the aqueous phase?

2. *In situ* biodegradation:

The bacterium *Pseudonocardia dioxanivorans* CB1190 uses dioxane as a sole carbon source and electron donor with O_2 as the electron acceptor. In addition, the bacterium *Burkholdaria cepacia* G4 can degrade dioxane cometabolically with toluene (C_7H_8) as the primary substrate and O_2, the electron acceptor.

A. How much mass of O_2 is needed for the biodegradation of dioxane by CB1190?
B. Assuming 5 toluene molecules are biodegraded per dioxane biodegraded, how much mass of O_2 is needed for the cometabolic biodegradation of dioxane by G4?
C. Calculate C_{min} for direct aerobic oxidation of dioxane. What is the half-life of dioxane? Is this metabolism a feasible bioremediation option?
D. What is the half-life of toluene?
E. Assuming dioxane is oxidized 5x more slowly than toluene in the cometabolism case, which is the best metabolism to stimulate in the aquifer: direct or cometabolic degradation?

Toluene molecular weight= 92 g/mol; Dioxane molecular weight= 88 g/mol
Dioxygen molecular weight= 32 g/mol.

P. dioxanivorans CB1190: decay rate 0.001 d^{-1}; half velocity constant= 1 mg/L; growth yield= 0.09 mg protein/mg dioxane; degradation rate constant= 1.1 mg dioxane/(mg protein. d). The estimated biomass content in the aquifer is 100 mg protein/L of groundwater.
B. cepacia G4: degradation rate constant= 0.08 mg toluene/(mg protein. h); half velocity constant= 22 mg/L. The estimated biomass content in the aquifer is 1,000 mg protein/L of groundwater.

3. Pump-and-treat with GAC adsorption

Treatment is also considered with pump-and-treat with a pumping rate of 20 L/min and treatment with GAC. Dioxane can adsorb to GAC with a Freudlich-type isotherm with $K=1.18*10^4$ (cm^3/g) and n=1.01[-] with C_s in mg/g and C_{aq} in mg/cm^3. The volume of the GAC bed is 0.05 m^3 and the bulk density of the GAC is 500 kg/m^3.

A- How long will it take to reach breakthrough (assuming 75% usage of the bed to reach 1% of the influent concentration in the effluent)?
B- How much sorbent is needed to treat the entire contaminated zone? Would you revise the volume of the bed with this knowledge (yes or no and why)?
C- How long will it take to treat to entire contaminated zone?

4. Overall comparison

How do these four approaches (considering direct and cometabolic biodegradation as separate approaches) compare? Fill out the table below indicating the pros and cons for each method.

Method	Pros	Cons
Direct biological oxidation		
Cometabolic biodegradation		
Pump-and-treat with GAC		

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Problem 2: Slurry (20 points)

A contaminated soil is to be remediated in a single batch slurry reactor with a 10 m^3 volume. Assume there is no gas phase in the reactor. The dry solids density (ρ_s) of the contaminated soil is 2,600 kg dry solids/m^3 dry solids.
The soil contaminant concentration, measured as COD, is 600 mg/kg dry soil and the allowable concentration (because of toxicity) is 60 mg/kg.
Based on laboratory studies, K_D= 0.2 m^3/kg and biodegradation can be described as a first-order function of the dissolved COD concentration.
A value of the first order rate coefficient of 0.5 per day has been determined. Adequate mixing can be achieved at a concentration of suspended solids (C_{SS}) of 10 kg dry soil/m^3 slurry.

$\mu_{s,max}$= 0.29 h^{-1} K_s= 2.12 $mg.g^{-1}$ X_w= 2 $mg.L^{-1}$

K_w= 1.99 $mg.L^{-1}$ Y= 0.34 mg cells/mg substrate

K_b= 0.167 $L.g^{-1}$

Determine the residence time in the reactor required to remediate the soil

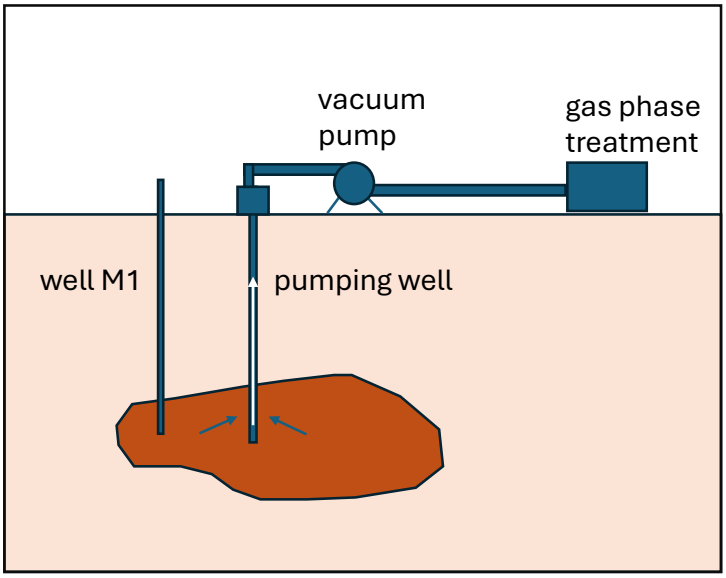
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Problem 3: SVE (30 points)

A site contaminated with petroleum hydrocarbons is considered for soil vapor extraction (SVE) and a feasibility study was done (see schematic below). Air is drawn from an extraction well (diameter 0.2 m) at a flow rate of Q and at a pressure of 3 $*10^5$ g/(cm.s^2). Based on this study, the pressure at well M1 was measured to be 8 $*10^5$ g/(cm.s^2). Well M1 is 2.5 m from the extraction well. Given that the contamination covers a surface area of 10 m^2 and a depth of 2 m, how many wells need to be put in?

1. Calculate the radius of influence
2. Calculate the flow rate needed inside the well
3. Calculate the number of wells needed to cover the surface area

Height of screen=8m
Soil porosity=0.4
Soil volumetric moisture content (θ)= 0.2
Soil wet bulk density=1.40 g/cm^3
Soil dry bulk density= 1.20 g/cm^3
Permeability of the formation = 10^{-10} m^2
Viscosity of air = $1.8*10^{-4}$ g/cm.sec
Ambient pressure=1.013 $*10^6$ g/(cm.s^2)= 1 atm



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