Modeling Multi-Component Transport and Enhanced Anaerobic Dechlorination in a Single Fracture – Clay Matrix System

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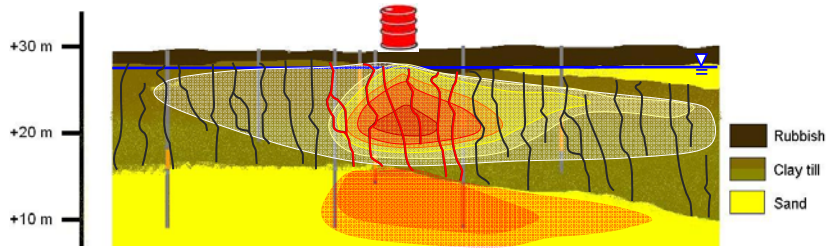
Department of Environmental Engineering

Background

Contamination source leaching pollutant



Fracture mapping at a field site in Denmark, Christiansen and Wood, 2006

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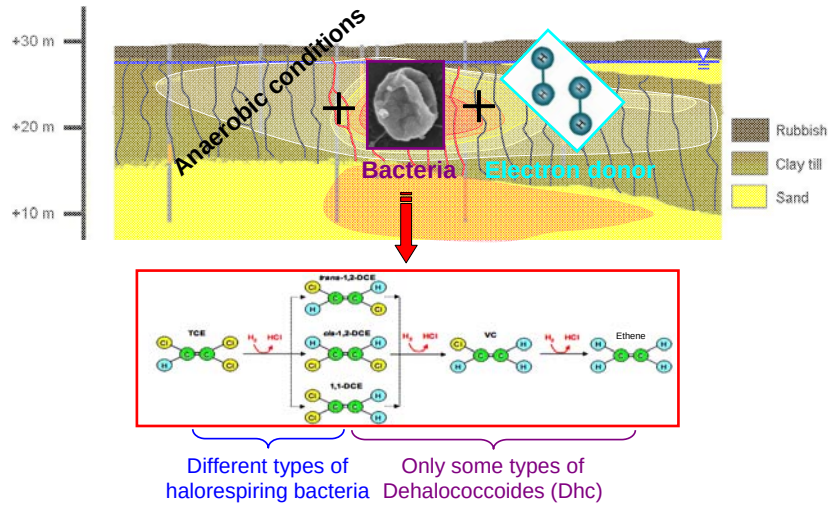
Background

Anaerobic dechlorination



Different types of halorespiring bacteria

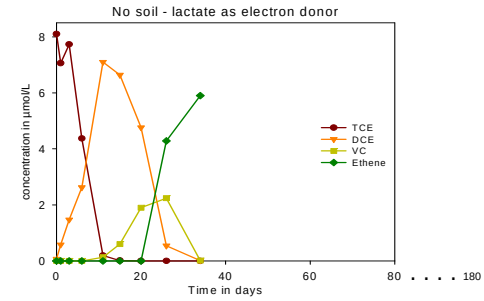
Only some types of Dehalococcoides (Dhc)

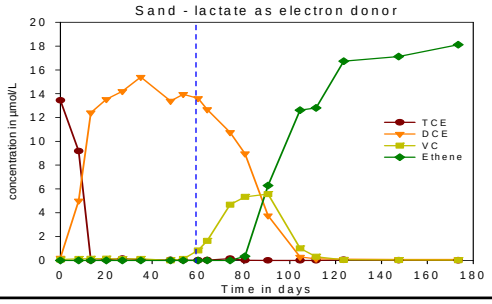
Objectives

- Combine fracture/matrix model with chlorinated hydrocarbon degradation
- Different diffusion and sorption properties for the compounds
- Study where degradation takes place in fractured clay till
- Assessment of contaminant flux from fractured clays
- Perspectives for reductive anaerobic dechlorination
  - Clean-up times for fractured clay systems

Anaerobic dechlorination

- Monod kinetics model
- Two sets of experiments
  - No soil
  - Sand from a field site (treatability study)
- Same bacteria culture KB-1™
- Two electron donors
  - Lactate (fast hydrogen releaser)
  - Propionate (slow hydrogen releaser)





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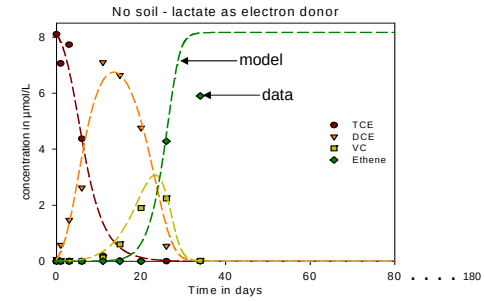
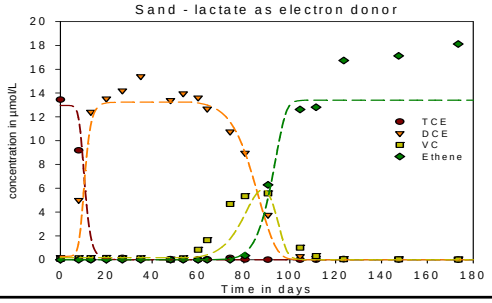
Anaerobic dechlorination - data

- Monod kinetics model
- Two sets of experiments
  - No soil
  - Sand from a field site (treatability study)
- Same bacteria culture KB-1™
- Two electron donors
  - Lactate (fast hydrogen releaser)
  - Propionate (slow hydrogen releaser)
- Optimization of most sensitive parameters (lactate, no soil)
  - Use of the same parameters for the experiments with sand and GW





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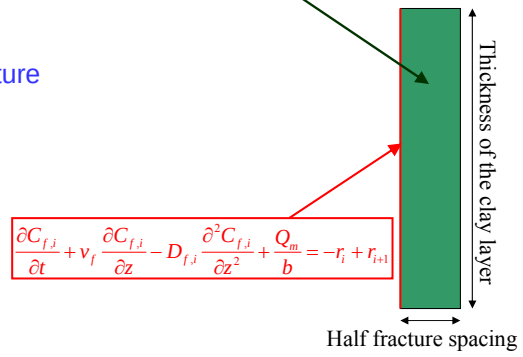
Single fracture model - equations

- Conceptual model based on Sudicky and Frind, 1982
- Symmetry in geometry
  - Half matrix and half fracture
- Transport equations
  - Diffusion/Sorption
  - Advection/Dispersion
- Coupling fracture/matrix
  - Concentration continuity
  - Flux $Q_m = -\phi_m D_m \frac{\partial C_m}{\partial z}$

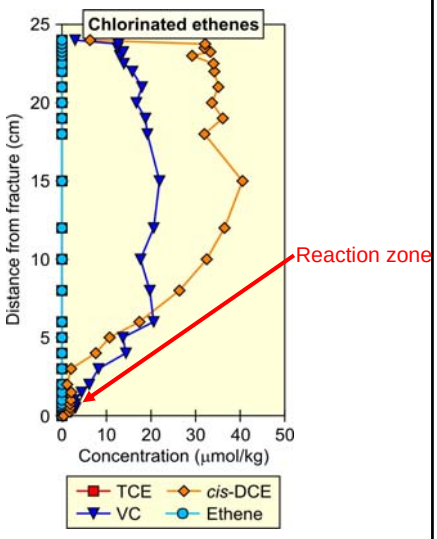
$$R_{m,i}\frac{\partial C_{m,i}}{\partial t} = D_{m,i}\left(\frac{\partial^2 C_{m,i}}{\partial x^2} + \frac{\partial^2 C_{m,i}}{\partial z^2}\right) - r_i + r_{i+1}$$

$$\frac{\partial C_{f,i}}{\partial t} + v_f\frac{\partial C_{f,i}}{\partial z} - D_{f,i}\frac{\partial^2 C_{f,i}}{\partial z^2} + \frac{Q_m}{b} = -r_i + r_{i+1}$$



Single fracture model - dechlorination

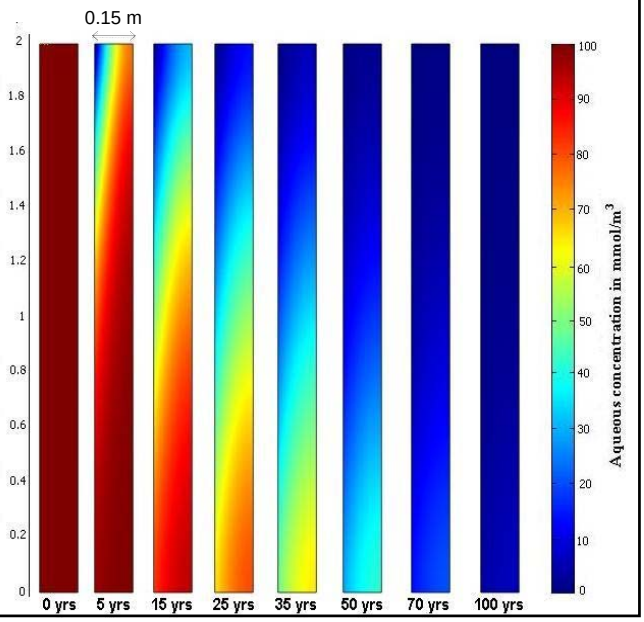
- Monod kinetics with previous parameters
  - Constant biomass
- Degradation location
  - Fracture
  - Matrix?
  - From literature and field data, reaction zone is limited at the fracture – clay interface



Scheutz et al., 2006

Single fracture model - outputs

- Contaminant distribution in the matrix



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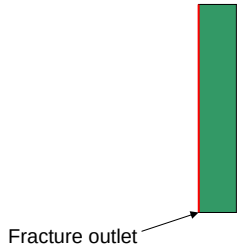
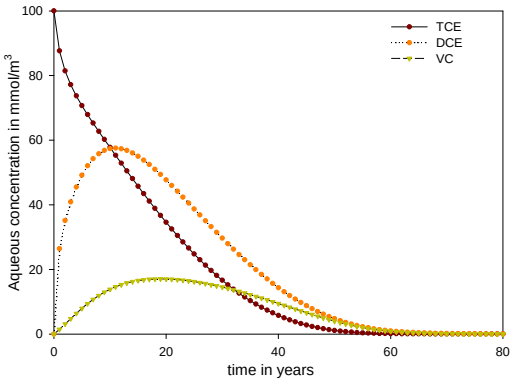
Single fracture model - outputs

- Contaminant distribution in the matrix
- Contaminant concentration at the fracture outlet





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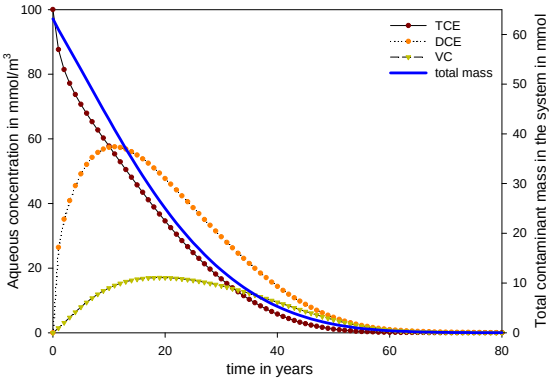
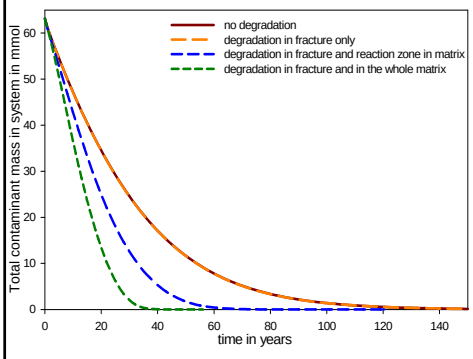
Single fracture model - outputs

- Contaminant distribution in the matrix
- Contaminant concentration at the fracture outlet
- Total mass of contaminant in the system

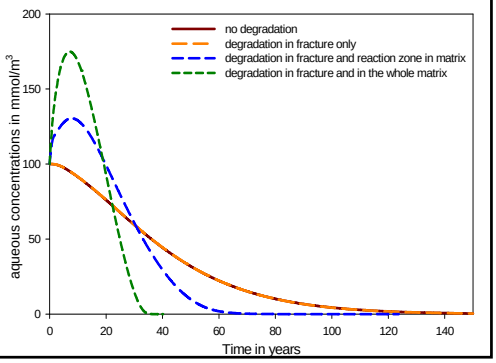


Different degradation scenarios

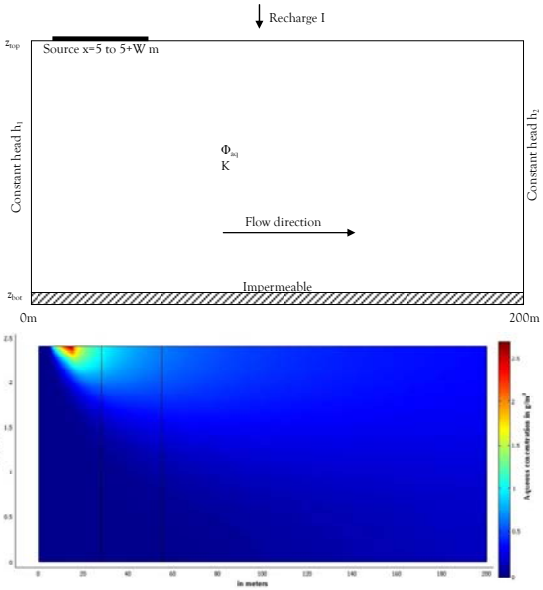


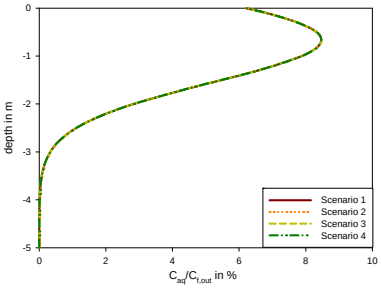
Total mass of contaminant

TCE, DCE + VC at the fracture outlet

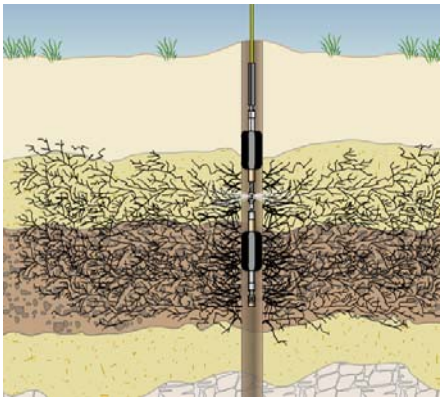


Coupling to underlying aquifer

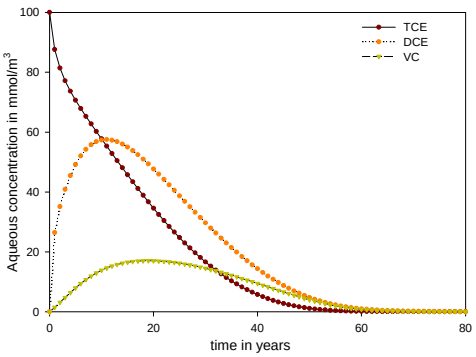




Remediation perspectives



Pneumatic fracturing



➔ Reduce clean-up times

Picture from ARS Technologies

Conclusions - Perspectives

- Single fracture – matrix model combined with complex dechlorination model
  - Clean-up times
- Improvement of the dechlorination model
  - Biomass growth
  - Limiting substrate
  - Fermentation process
- Improvement of the geometry
  - Horizontal fractures
  - Heterogeneous fracture networks
- Simulation of enhanced bioremediation system design