PILOT TEST OF
ELECTROKINETICALLY ENHANCED
BIOREMEDIATION (EK-BIO)
AS AN INNOVATIVE REMEDIAL APPROACH FOR PCE DNAPL

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EK-BIO PILOT TEST – THE TEAM

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PILOT TEST AREA
SKULDELEV, DENMARK

Pilot test area:

- Target depth 3-8 m bgs
- PCE DNAPL
- Tight clay till w/ high K sand stringers
EK-BIO – TAKING ON THE CHALLENGE OF PCE DNAPL IN CLAY

- Why EK-BIO?

✓ 100% PCE DNAPL degradation via enhanced reductive dechlorination possible with *Dehalococcoides (Dhc)*

- Effective delivery in heterogeneous clay till?

  - Fracturing
  - Direct push injections
  - Electrokinetics

  ✓ Transport drivers independent of K

  Non-uniform distribution – back-diffusion issues and long timeframes for clean-up
WHAT IS ELECTROKINETICS (EK)?

- EK = application of DC electric field to saturated subsurface system

- Primary EK-BIO transport drivers in clay till:
  - **Electro-migration (EM)** – movement of ions – substrate transport
  - **Electro-osmosis (EO)** – bulk movement of water – bacterial transport
As $K_h$ decreases, EK becomes the most efficient delivery method.
THE SKULDELEV PILOT TEST – WHAT’S NEW?

✓ Processes already shown to occur under EK conditions:
  ✓ Electron donor transport (2-5 cm/day in clay)
  ✓ Bacterial transport
  ✓ *Dehalococcoides* viability
  ✓ Transport of *Dehalococcoides* under EK conditions
  ✓ Bench-scale EK-BIO treatability study 2010*

? Field scale yet to be shown → Until this project!

*Test performed at Northeastern University (Akram Alshawabkeh and Xuhui Mao)

EK-BIO PILOT TEST – OBJECTIVES

1. Evaluate and demonstrate applicability of EK-BIO
2. Evaluate lactate transport rate
3. Evaluate viability and transport of \( Dhc \) in clay materials
4. Evaluate degradation of PCE w/in timeframe of pilot test
5. Gather site-specific field data and operational data for full-scale EK-BIO design
EK-BIO PILOT TEST – SYSTEM LAYOUT

- Pilot test area ~3x3 m
- Pilot test infrastructure
  - 3 cathode wells
  - 3 anode wells
  - 3 injection wells
  - 4 monitoring wells

3 cm/day x 60 days = 1.5 m
EK-BIO PILOT TEST – MONITORING PROGRAM

• **Electrical system**
  - 2-3 times weekly
    - Currents of power supplies
    - Current to individual electrodes
    - Electrical potential

  Monitored to ensure steady electric field

  Steady amendment transport

• **Groundwater**
  - Twice weekly:
    - Field measurements (ORP, DO, EC, T)
  - Weekly:
    - VFAs
  - Baseline and monthly:
    - CVOCs, redox sensitive species (NO$_3^-$, SO$_4^{2-}$, Fe, Mn, NVOC), dissolved gasses (incl. CH$_4$), Dhc, vcrA, Cl

  Monitored to document progress of

  • amendment distribution
  • contaminant degradation

• **Soil cores**
  - Baseline, post-test, 7 mo post-test:
    - CVOCs, TOC, vcrA, cations, anions
EK-BIO PILOT TEST – TIMELINE

Monitoring after operation:
- Groundwater – 3 & 6 months post-test
- Soil cores – 7 months post-test

Operation: August-Nov. 2011
Monitoring: Nov. 2011- May 2012
EK-BIO PILOT TEST –
RESULTS, OPERATIONAL PARAMETERS

- Power supplies operated w/ constant current
- Even distribution of power to all electrodes
  - 6A applied to top electrodes
  - 8A applied to lower electrodes
- Cumulative total system energy supply for the whole pilot test operation: **1950 kW-hr** or **29 kW-hr** per m³ of “treated” aquifer materials

![Cumulative System Energy Diagram](image)
EK-BIO PILOT TEST – RESULTS, OPERATIONAL PARAMETERS

- Chemical amendment dosing:
  
  - Injection wells and anode wells:
    - Lactate ~ 5,900 liters total (6 g/l)
    - NaOH ~ 1,100 liters total (0.5 mol/l)
  
  - Cathode wells:
    - Lactic acid ~ 250 liters total (0.05 mol/l)
  
  - All wells:
    - KB-1 ~ 21 liters total

- Recirculation between cathodes and anodes for pH control in electrode wells as in treatability test
Monitoring showed:

- Neutral pH
- Negative ORP
- Slight increase in temperature (~5 °C), which may benefit biological activities
EK-BIO PILOT TEST –
KEY RESULTS, SUBSTRATE TRANSPORT

→ Lactate transport rate ~ 2.5 - 5 cm/day (~ same as 3.2 cm/day found in treatability test)

→ Substrate deficiency 3 months after operation
EK-BIO PILOT TEST – KEY RESULTS, REDUCTIVE DECHLORINATION

**Groundwater baseline**

**Groundwater 1 mo operation**

**Groundwater 2 mo operation**

**Groundwater 3 mo after operation**

**Groundwater 6 mo after operation**

- Ethan
- Ethen
- VC
- cis DCE
- TCE
- PCE

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EK-BIO PILOT TEST

NORDROCS, 2012
• Increase in vcrA in all wells, also post test
• Increase in ethene 3 mo and 6 mo after pilot test - max 3,700 µg/l
✓ confirms ongoing complete reductive dechlorination by Dehalococcoides
• Increase in PCE and Chloride (~190 mg/L PCE degraded)
✓ DNAPL dissolution and desorption
Post test soil cores sampled 63 days after bioaugmentation

High concentrations of vcrA in samples from clay till --> *Dhc* transport into clay due to EK-processes
• Reductive dechlorination in soil cores post test
• Few samples unaffected by degradation
• Degradation observed in cores w *Dehalococcoides* (vcrA)
• Decrease in total CVOC concentrations in most samples
KEY CONCLUSIONS OF THE EK-BIO PILOT TEST

1. EK-BIO works!

2. EK transport of lactate through clay till ~ 2.5 to 5 cm/day

3. Evident increases of *Dehalococcoides* and *vcrA* in groundwater and clay till matrix within pilot test area

4. Groundwater and core data show PCE dechlorination to vinyl chloride and ethene by end of pilot test
   - Increasing dissolved PCE concentrations ⇔ dissolution/desorption of PCE DNAPL
   - Increasing ethene concentrations and *Dhc/vcrA* numbers ⇔ sustained ERD

5. Stable electric field in test area

EK-BIO is an effective method for achieving good distribution of sub-strate and bacteria for the purpose of enhancing PCE dechlorination!
WHAT’S NEXT?

- Full-scale implementation in Hot Spot IV starting up in December 2012
- Expected remediation time 3-5 years
QUESTIONS / COMMENTS?
THANK YOU!


X. Wu, (2005), Tetrachloroethylene Bioremediation by Lactate Injection under Direct Electric Currents, Doctoral Dissertation, Northeastern University, Boston, MA, USA.

