RESTORE: Research for Subsurface Transport and Remediation

# ELECTROKINETICALLY-EMPLACED AMENDMENTS FOR ENHANCED BIOREMEDIATION OF CHLORINATED SOLVENTS IN CLAY: A PILOT FIELD TEST


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## 1. Introduction

- Bioaugmentation, the injection of dechlorinating bacterial cultures, and biostimulation, the injection of electron donors, result in anaerobic degradation of chlorinated solvents
- Challenges in low permeability soils due to the difficulties in amendment delivery
- Electrokinetics (EK) has been proposed for the delivery of amendments into silts and clays
- Use of EK to deliver lactate and bacterial cultures has been studied at the lab scale (Wu et al., 2007; Mao et al., 2012)
- A pilot field test was conducted to evaluate EK-enhanced anaerobic dechlorination of chlorinated solvents in clay

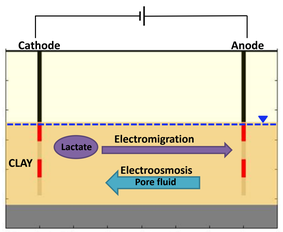


*Figure 1. EK transport mechanisms.*

**OBJECTIVES:**

**1) Evaluate the use of EK to enhance the delivery of lactate through clayey soil at a field scale**

**2) Determine whether EK emplaced amendments result in chlorinated solvent degradation**

## 2. Site Description

- The site was located on a former chlorinated solvent production facility in South-Western Ontario, Canada
- The subsurface of the site was characterized by approximately 3m of weathered brown clay underlain by gray clay (Fig 2)
- Ambient groundwater flow on the site was calculated to be $1.4x10^{-3}$ cm/day toward the north
- The clay is contaminated with chlorinated solvents, in particular 1,2-dichloroethane (1,2-DCA) (Fig 3)
- A test cell with lactate injection and applied EK (EK-Bio) and a cell with no amendment injection and no EK (Control) were installed in the clay

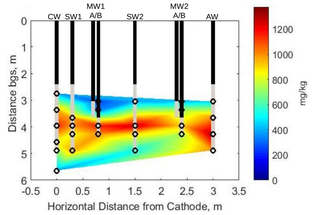


*Figure 3. Background EK-Bio soil 1,2-DCA concentrations.*

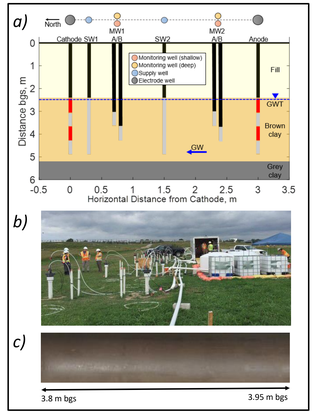


*Figure 2. a) Plan view and cross section of EK-Bio, where red indicates the mixed metal oxide electrodes and grey indicates the screened intervals (Control cell located 16 m east) b) Actual site layout c) Site brown clay core*

## 3. Site Sampling Methodology

**Aqueous and soil sampling:**

- Monitoring wells were purged then allowed to recover for one week before sampling (due to slow recovery times)
- First 200 mL of water was discarded then samples are collected for cVOC and dissolved organic carbon analysis
- Groundwater is filtered through Sterivex filters then frozen until DNA is extracted for further lab analysis
- Soil samples for cVOC analysis were taken from cores obtained with direct push drilling

## 4. EK Operation and Amendment Injection

- EK phase migration from Sept 28, 2016 to Dec 6, 2016
  - Total calendar days of DC applied: 71 days
  - Actual days DC power on: 45 days (See Figure 4)
  - Time weighted average voltage gradient of 0.078 V/cm
- Amendment injection into supply wells for 71 days (See Table 1 for amendment information)

*Table 1. Summary of injected amendments*

| Cell | Amendment Injected | Injected Mass [g] | Injected Volume [L] | Injected Conc. [g/L] | DOC Conc. [g/L] |
|---|---|---|---|---|---|
| EK-Bio | Lactate | 60000 | 1490 | 40 | 11.5 |
| | KB-1 | - | 2 * | - | - |

*1 L of KB-1 added to each well at beginning of EK phase

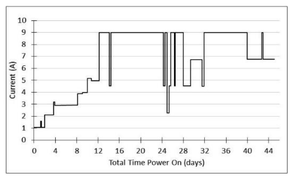


*Figure 4. Applied current (DC) shared across 4 EK transects.*


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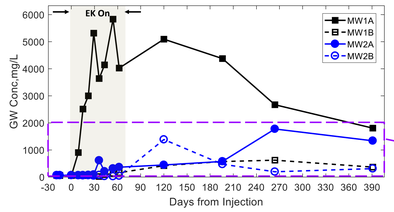
## 5.1 Results: Groundwater




Day 0: EK is initiated and injection of lactate begins*
*Note power was not on continuously for the 71 days

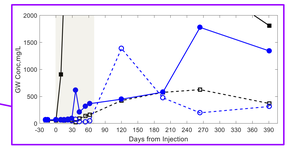



*Figure 5. EK-Bio dissolved organic carbon (DOC) concentrations.* DOC was measured to indicate lactate presence. There was evidence of lactate breakthrough at all monitoring locations, with about 50% breakthrough at MW1A. DOC in Control cell remained below 40 mg/L. The evidence of lactate breakthrough corresponds with observed lactate transport rates between 1.3 cm/day and 7.4 cm/day.

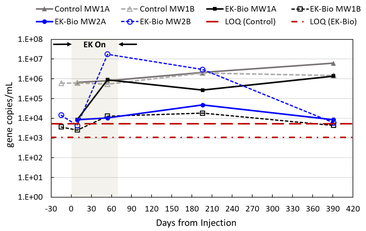



*Figure 6. General bacteria concentrations.* Results were obtained through quantitative polymerase chain reaction (qPCR). There were 2 and 3 order of magnitude increases in MW1A and MW2B respectively.

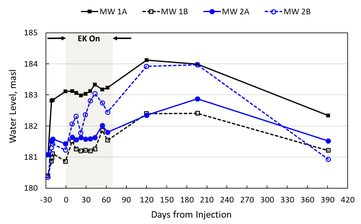



*Figure 7. Water levels in EK-Bio cell.* Low initial water levels due to slow recovery of newly developed wells. Water levels were the highest in MW1A and MW2B.

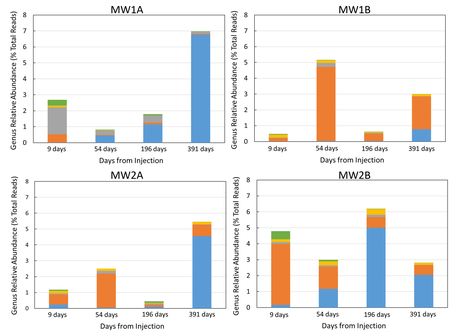



*Figure 8. Relative abundance of the top 5 organohalide respiring bacteria genera in the EK-Bio cell.* Results were obtained through 16S metagenomic sequencing performed on the Illumina MiSeq system following Illumina standard protocol. Increases in relative abundance of *Desulfitobacterium* was observed in MW1A and MW2B by 54 days while this increase was not observed until 391 days in MW1B and MW2A. *Desulfitobacterium* has the ability to anaerobically degrade chlorinated ethenes and ethanes including 1,2-DCA.

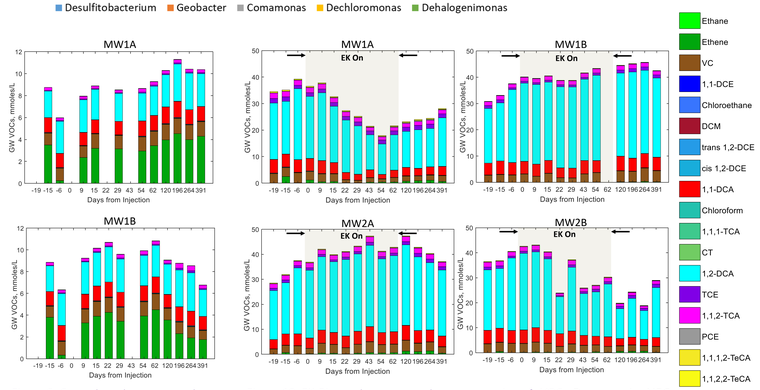



*Figure 9. Control total aqueous molar concentration of cVOCs:* No clear change in cVOC concentrations over time in the control cell.

*Figure 10. EK-Bio total aqueous molar concentration of cVOCs.* Decreases in cVOC concentrations evident in MW1A and MW2B during EK application. These are the same locations where microbial abundance increased (Fig 6) and microbial community structure shifted to favourable dechlorinators (Fig 8). These also match with locations with highest water levels.

## 5.2 Results: Soil

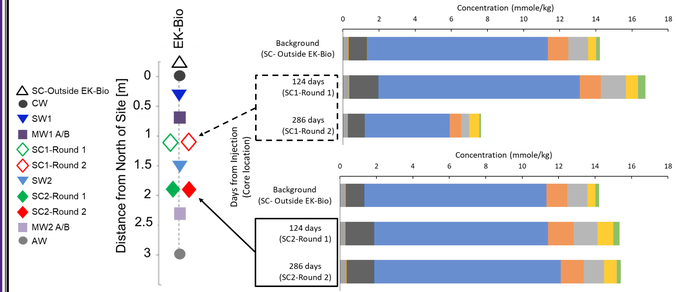



*Figure 11. EK-Bio cell layout with soil borehole sample locations.*

*Figure 12. EK-Bio total soil molar concentration of cVOCs for sampling rounds post-EK application and sample location outside EK-application. This is an average concentration over the same set of sample depths at each location (Samples collected at 2.9 m, 3.35 m, 3.66 m, 3.96 m, 4.27 m and 4.72 m bgs).* Between 124 and 286 days, soil cVOC concentrations decreased by about 50% at the north drilling location, SC1, while the more southern location, SC2, saw no obvious change in concentrations during this time.




*Figure 13. EK-Bio 1,2-DCA soil concentration profile for each sampling time and location.* Background 1,2-DCA concentrations were similar to concentrations 124 days since initial EK application. Soil 1,2-DCA concentrations from 124 days to 286 days decreased at most depths at location SC1 but stayed relatively constant at location SC2.

## 6. Conclusions

- Significant lactate migration in clay observed in the field due to electrokinetic enhancement (3 orders of magnitude larger than groundwater velocity)
- Significant heterogeneity observed in electrical, microbial, and remedial performance
- Increased total bacterial abundance in some locations where lactate migration was successful
- Bacterial community shifted towards favourable conditions for biodegradation where lactate migration was successful
- Decreased cVOCs, in particular 1,2-DCA, in some locations where lactate migration was successful (same locations as increased bacterial abundance)

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## References


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- Wu, X.; Alshawabkeh, A., Gent, D., Larson, S., & Davis, J., (2007). Lactate Transport in Soil by DC Fields. *Journal of Geotechnical and Geoenvironmental Engineering, 133* (12), 1587-1596.