Pilot Testing of Electrokinetic Remediation to Facilitate Nitrate-Enhanced Bioremediation of Gasoline Contamination in a Clay Aquitard

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Problem Statement

- Subsurface remediation is a contact sport
- Must bring remedial amendments into contact with contaminants
- How can you do this in low porosity soils?
Presentation Outline

• Site description
• Pilot test design, operation, and results
• Takeaways and lessons learned
Pilot Location and Site History

- Former retail gas station in central British Columbia
- Operated from 1986 until it was decommissioned in 2011 when the building, pump islands, and USTs removed
Pilot Area Geology

- Confined Aquifer
- Aquitard
- Sandy SAND and Gravel Fill
- LACUSTRINE Silty Clay
- Silty SAND and Gravel

Depth Ranges:
- ~3 to 4 mbgs
- ~3.5 to 4 m thick
Electrokinetic-Enhanced Bioremediation (EK-Bio)
Pilot Test Overview

• Pilot test area – approximately 100 m²
• Eight electrode wells, 4 injection wells, 6 monitoring wells
• 49 day duration; October through December 2016
• Approximately 12,600 L nutrient solution injected
  – Ammonium nitrate at approximately 22,000 mg/L
  – Biodegradable surfactant
  – Rhodamine dye tracer
• Injection largely by gravity; short periods of pumping
• Biweekly groundwater monitoring and sampling
• Soil borings collected following injection to evaluate performance
Pilot Test Objectives

• Can we inject into the aquitard by pumping, and at what rate?
• Can we inject into the aquitard by gravity, and at what rate?
• How does well diameter affect injection rate?
• How does EK impact nitrate migration rates within the clay?
• Does EK affect soil properties (i.e. cause dewatering, compaction)?
• What is the rate of water production at the cathodes?
• How much water needs to be injected at the anodes?
Pilot Area – Plan View

Electrode Well
1.5” Injection Well
4” Injection Well

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Pilot Area – Plan View

Electrode Well

1.5” Injection Well

4” Injection Well

Monitoring Well

+ Anode

- Cathode

H₂O

NO₃⁻

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Injection and Monitoring Wells

- Three 1.5-inch Geoprobe
- One 4-inch Hollow-Stem
- 1.5 m screens
- 1.8 to 2.7 m sand pack
- Screen and sand pack entirely within clay
Electrode Wells

- Bare steel “electrodes” spanning 1.8 to 2.9 m within clay with 0.3 to 0.6 m of clay above and below
- Backfilled with carbon coke from 0.3 m above the bare steel

2-inch steel casing

Epoxy coated above electrode

Carbon coke

Perforated bare steel
Soil BTEX Concentrations in Pilot Area

- **Contaminants:** Benzene, Ethylbenzene, Toluene, Xylenes
- **Criteria:**
  - Benzene: 0.03 mg/L
  - Ethylbenzene: 10 mg/kg
  - Toluene: 0.3 mg/kg
  - Xylenes: 4.5 mg/kg
- **Avg. Concentration:**
  - Benzene: 6.8 mg/L
  - Ethylbenzene: 9.5 mg/kg
  - Toluene: 47 mg/kg
  - Xylenes: 57 mg/kg

*Strictest CSR Schedule 3.1 Criteria
Red – above criteria
Pilot Setup Photos

- Looking West
- Electrode wells visible
- Control building in place
- Fuel cube being delivered
Pilot Setup Photos

- Looking East
- Injection tanks visible and plumbed to wells
- All connections wrapped in insulation, heat traced
Applied Voltage

- Applied voltage ranged from approximately 70 to 90 Volts
- Monitored for evidence of consolidation and the need to add water at the anodes
- No evidence of compaction and no water added at anodes
Groundwater Monitoring Data

- Groundwater temperatures increased from approximately 10°C to a high of 39°C
- No discernable trends in conductivity, pH, dissolved oxygen, or ORP
Groundwater Monitoring Data

- No rhodamine or nitrate detected at any monitoring well at any point during the pilot
  - Monitoring wells were within what would be the estimated radius of influence based on the volume of liquid injected
- No evidence of BTEX degradation or desorption from soil
Injection Volumes and Rates

<table>
<thead>
<tr>
<th>Well Diameter</th>
<th>Volume Injected/Well</th>
<th>Injection Rate by Gravity</th>
<th>Injection Rate by Pumping*</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-inch</td>
<td>7,585 L</td>
<td>164 L/day</td>
<td>1,322 L/day</td>
</tr>
<tr>
<td>1.5-inch</td>
<td>1,672 L</td>
<td>23 L/day</td>
<td>451 L/day</td>
</tr>
</tbody>
</table>

*pumping only occurred for short durations, sustainability of rates shown is unknown

- Approximately 12,600 L of nitrate solution were injected
- Approximately 14,000 L water extracted at cathodes
- The 4-inch well accepted more solution at a higher injection rate than the 1.5-inch wells
- Injection rates were higher while pumping
Confirmation Boreholes

- Electrode Well
- Monitoring Well
- Confirmation BH
- Injection Well

SCALE

0 2 4 6 m

E1, E2, E3, E4, E5, E6, E7, E8, MW16-1, MW16-2, MW16-4, MW16-5, MW16-6, BH16-1, BH16-2, BH16-3, BH16-4, BH16-5a, BH16-5b, BH16-6, BH16-6a, BH16-6b, BH16-9, BH16-10a, BH16-11a, IW16-1, IW16-2, IW16-3, IW16-4, IW16-5, IW16-6
Confirmation Boreholes

- Rhodamine difficult to see in soil, but towels help
- Samples collected for analysis of BTEX and nitrate
  - 42 “paired” before and after samples collected at same depth, similar location
  - BTEX lower in “after” sample in 32 of 42 pairs
Soil Nitrate Concentrations (mg/kg)

<table>
<thead>
<tr>
<th>Electrode Well</th>
<th>Monitoring Well</th>
<th>Injection Well</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>372</td>
<td>480</td>
<td>30</td>
</tr>
<tr>
<td>160</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>76</td>
<td>39</td>
<td>5</td>
</tr>
</tbody>
</table>

5 Soil NO₃ (mg/kg)
Soil Nitrate Contours (mg/kg)

- Electrode Well
- Monitoring Well
- Injection Well

Scale: 0 - 6 M

Contours (mg/kg):
- 5
- 4
- 3
- 2
- 1
- 0
- 1
- 2
- 3
- 4
- 5
- 6

Locations:
- MW16-1
- MW16-2
- MW16-3
- MW16-4
- MW16-5
- MW16-6
- IW16-1
- IW16-2
- IW16-3
- IW16-4
- E1
- E2
- E3
- E4
- E5
- E6
- E7
- E8
Comparison to Hydraulic ROI

- Soil NO$_3$ (mg/kg)

Electrode Well
Monitoring Well
Injection Well

5

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Inferred Nitrate Migration Rates (cm/day)

- Inferred rate (cm/d)
- No discernable migration

**Electrode Well**

**Monitoring Well**

**Injection Well**

**SCALE**

**N**

**E1**

**E2**

**E3**

**E4**

**E5**

**E6**

**E7**

**E8**

**MW16-1**

**MW16-2**

**MW16-3**

**MW16-4**

**MW16-5**

**MW16-6**

**BH16-2**

**BH16-3**

**BH16-4**

**BH16-5a**

**BH16-5b**

**BH16-6**

**BH16-9**

**BH16-10a**

**BH16-11a**

**IW16-1**

**IW16-2**

**IW16-3**

**IW16-4**

**IW16-5**

**IW16-6**
Summary of Findings and Takeaways

- Larger diameter wells performed better
- Injection rates were significantly higher with pumping, but sustainability unknown
- Injection rates by gravity were higher than anticipated
  - Extent to which EK influenced injection rate unknown
- Nitrate demand from the contaminants was high, significantly impacting area of influence of injections
- Rhodamine not an ideal tracer for this application, bromide may be better suited
• EK resulted in a significant increase in temperature, and required more power than anticipated
• EK did appear to influence distribution of nitrate within the clay
• Based on observed rates of migration, it would take approximately 80 day to move nitrate 3 meters, which is slower than hoped given the high cost of operating the EK system
• Worthwhile to look at migration rates without applying EK and do a cost/benefit assessment
Questions

Acknowledgements

- Kyum Shogren
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