In Situ Source Zone Remediation via ZVI-Clay Soil Mixing

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Topics

- Concept
- Equipment
- Laboratory Studies
- Field Performance
- Costs
“DNAPLs are notoriously difficult to locate, and yet the performance of most treatment technologies depends on **reasonably precise delivery** of remedial agents to the contaminants.”

“**Back diffusion** can limit performance of any technology based on advective transport...”
In Situ Source Zone Remediation via ZVI-Clay Soil Mixing

Soil mixing with delivery of ZVI and clay
- Homogenizes soils and contaminants
- Uniform reagent delivery
In Situ Source Zone Remediation via ZVI-Clay Soil Mixing

- Overlapping columns treat entire source zone
- ZVI degrades chlorinated solvents
- Clay lowers permeability, isolating treated soils
### ZVI-Clay v. Permeable Reactive Barriers

<table>
<thead>
<tr>
<th></th>
<th>PRB</th>
<th>ZVI-Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hydraulic conductivity</strong></td>
<td>$10^{-2}$ to $10^{-4}$ cm/s</td>
<td>$10^{-5}$ to $10^{-7}$ cm/s</td>
</tr>
<tr>
<td><strong>Residence time</strong></td>
<td>hours to days</td>
<td>years</td>
</tr>
<tr>
<td><strong>Concentrations</strong></td>
<td>only aqueous phase</td>
<td>any, including DNAPL</td>
</tr>
</tbody>
</table>

- **ZVI-Clay overview**

- **Colorado State University**
ZVI-Clay Projects

- Field project complete
- Field project pending
- Laboratory study

Map showing locations of field projects: Denmark and Australia.
Mixing Process

Before mixing

After mixing

Photos courtesy of TetraTech
Crane-Mounted Mixing Equipment

After Olson et al. 2012

Photos courtesy CH2M HILL
Backhoe Mounted
Backhoe Mounted Lang Tool

http://redox-tech.com/in_situ_blending.htm

Steve Day GeoSolutions Inc.
Grout Plant

ZVI
bentonite

water

grout

Steve Day GeoSolutions Inc

ZVI-Clay overview

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Laboratory Studies
Iron Size and Amount

• Size matters
• Pumpable
• Amount
  – 1% iron = 10% project cost
  – Safety factor (10 to 100 x stoichiometry)
Experimental Variables: Iron Type & Amount

**PCE**

<table>
<thead>
<tr>
<th>Iron Type</th>
<th>Half life (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3, 7, 8, 9, 10, 11, 10, 7, 10</td>
</tr>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
</tr>
<tr>
<td>E</td>
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<td>F</td>
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</tbody>
</table>

**ZVI amount**
- 1%
- 2%
- 3%
Soil Mixing of NAPL with Bentonite: Pickering Emulsion

Advantages of emulsification

- Prevents migration
- Enhances contact with iron particles
- Increases NAPL surface area

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ZVI-Clay overview
Longer Residence Time

Field groundwater data:
1,2-dichloroethane & dichloromethane

Half lives: on the order of 100 days
Field Application:
Site 89, Camp Lejeune, NC

- 30,000 yd³ to 25 ft. depth
- TCE & 1,1,2,2-TeCA DNAPL
- Treatment: 2% ZVI, 3% bentonite

Olson, et al. 2012 (in press), Ground Water Monitoring and Remediation, (see notes).
Site 89
Performance Monitoring Data

Groundwater data - a year later

![Bar chart showing total CVOCs in groundwater (µM) for different wells at Site 89. The chart compares data at time 0 and after 1 year. The wells are MW-1A to MW-3A.]
Site 89
Performance Monitoring Data

After one year...

- TCE
- cDCE
- tDCE
- VC
- Total CVOCs

Concentration (µM)

Time (d)
Site 89
Performance Monitoring Data

After 3 years

- TCE
- cDCE
- tDCE
- VC
--- Total CVOCs
Site 89: Flux reduction

• Hydraulic conductivity, $K$
  – Before mixing: $1.7 \times 10^{-3}$ cm/s
  – After mixing: $5.2 \times 10^{-6}$ cm/s
  – Average reduction by 99.7%

• Adveective flux, $J_{\text{adv}} = K \cdot C \cdot i$

• Theoretical flux reduction: $10^2$ to $10^7$?
Limitations

• Contaminants
• Access & mixability
• Geotechnical impacts
Post-Treatment Land Use

Site 88, Camp Lejeune after treatment
Implementation Costs: Mobilization, Materials, Mixing, Demob

Mixing cost ($/CY) vs Site size (CY)

- Overconsolidated clay to 50 ft
- Silty sands 18-35 ft

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ZVI-Clay overview
CSU Services

• Initial screening
• Laboratory studies
• Assistance with design, contracting & post-treatment monitoring
Closing Thoughts

• ZVI-Clay treats DNAPL/low-k zones
• Simultaneous reduction in k, concentration
• Field applications
  – Concentration reductions by 99+% 
  – Permeability reduction by 99+% 
  – Flux reduction > 99.9%
• Cost $75- $200 per yd$^3$
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