Anaerobic Bioremediation of Chlorinated Solvents in Groundwater Using Edible Oil Substrate EOS®

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- Jeff Baker (Vironex, Inc.),
- John Sankey, P.Eng. (True Blue Technologies Inc.).

Given by
John Sankey, P.Eng.,
True Blue Technologies
From this…
...to this in 18 months!
Anaerobic Bioremediation of Chlorinated Solvents in Groundwater Using Edible Oil Substrate EOS®

Site Intro

Anaerobic Bioremediation– Few slides

Options: What ferments to hydrogen?

Designing the Project

Preparing and Injecting Substrate

Results

Ground Water Characterization--What to Monitor?
Site Intro: Dry Cleaners Site  
Located in San Jose, California

Highest PCE and TCE concentrations in the January 2005 were 8,500 µg/L.

After evaluating several alternatives, in situ bioremediation was selected.

The goal was to find a substrate that was long lasting and easily distributed into the saturated soils.
How Does Anaerobic Bio Work?

- **Growth-Promoting Biological Reduction**

Energy

Electron Donor (Food)

Electron Acceptor (something to breathe) [O\textsubscript{2}, NO\textsubscript{3}, SO\textsubscript{4}, TCE, etc.]

Waste Products [CO\textsubscript{2}, N\textsubscript{2}, FeS\textsubscript{2}, Cl\textsuperscript{-}]

Energy

(Drawing Modified from AFCEE and Wiedemeier)
What is Needed for Effective Anaerobic Bioremediation?

- Organic substrates that ferment to:
  - Acetate
  - Hydrogen (H₂)
- Strongly reducing conditions (Sulfate Reducing or Methanogenic)
- Right halorespiring bacteria (Dehalococcoides for DCE / VC)
- Nutrients
  - Vitamins and trace minerals to stimulate Dehalococcoides growth

Source: AFCEE, Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents, August 2004
OPTIONS:

What quickly ferments to hydrogen?

• Soluble substrates (e.g., lactate, butyrate, propionate, acetate, molasses, and sugars).

• Solid substrates (e.g., bark mulch, compost, chitin and peat).

• Slow release substrates such as vegetable oil.
What lasts longer in-situ?

• Soybean oil

• $C_{56}H_{100}O_6$ (soybean oil$^1$) + 50 H$_2$O $\rightarrow$ 28 CH$_3$COOH (acetic acid) + 44 H$_2$

$^1$Represents weighted average of constituent fatty acids and glycerol.
# How Many Electrons Can We Pump into the Ground?

<table>
<thead>
<tr>
<th></th>
<th>$e^-$ Released</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>per mole</td>
<td>per lb</td>
</tr>
<tr>
<td>Acetate</td>
<td>8</td>
<td>0.13</td>
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<tr>
<td>Lactate</td>
<td>12</td>
<td>0.13</td>
</tr>
<tr>
<td>Glucose</td>
<td>24</td>
<td>0.13</td>
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<tr>
<td>Soybean Oil</td>
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<tr>
<td>Canola Oil</td>
<td>319</td>
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</tr>
<tr>
<td>Lard</td>
<td>311</td>
<td>0.36</td>
</tr>
</tbody>
</table>
Soy/Lactate Emulsions

- Blender
- Lab Homogenizer
- Silverson High Shear Mixer
- EOS
The Secret of Good Oil Distribution
“Emulsions that do NOT Flocculate”

Dispersed Oil Droplets

Flocculated Oil Droplets
Secrets of Good Emulsion Distribution
“Use Emulsions that do NOT Flocculate”

Clogged pore
Technology Choice--EOS®

Why?

- Slow release substrate
  - Emulsified soybean oil (GRAS)
  - Small, uniform droplets
  - Negative surface charge

- Easily biodegradable substrate
  - Lactate

- Micronutrients
  - Amino acids, Trace nutrients, Vitamins

- Easy to inject and distributed throughout treatment area

- Solid reputation

- Cost
Technology Choice—Proposed Cost

EOS598 B42 Cost-6600 lbs

- $19,000

Drilling 12 points, injected 4,400 gallons of EOS mix and 22,700 gallons of flush water over a period of 6 days.

- $30,000

Plus monitoring and engineering
Designing the Injection at The Dry Cleaner Site

“You need to make contact…with the contaminant
Radius of Influence?
10ft to 100ft with EOS

From This

.....To This

EOS Treatment Zone

Peroxate (CrO₇⁻)
Nitrates
TNT, RDX, HMX
Chlorinated Solvents
Acid Rock Drainage

Chloride (Cl⁻)
N₂
Ethene/Ethane
Metal Precipitates
Increased pH

True Blue Technologies Inc.
Source Treatment with Barriers

• Barriers 0.5 to 1 year apart

• Advantages
  – Low cost
    • Fewer injection points
    • Less oil and water
  – Release of TOC enhances downgradient biodegradation
  – Aquifer remains permeable

• Disadvantage
  – Longer clean-up time
Source Area Treatment
• How much do we inject?
Treatment Zone Dimensions

- **Source Area**
- **EOS® Emulsion & Chase Water**
- **Injection Point**
- **Groundwater Flow**
- **Barrier**: Make barrier wider than plume width
Design Tool Used

- Substrate needed for biodegradation
  - Flow rate through barrier
  - Pollutant concentrations
  - Competing electron acceptors (O₂, NO₃, SO₄)
  - Theoretical substrate life (5 to 10 years)

- Oil retention by aquifer
  - Higher retention with fine grained materials
Determining Injection Well Spacing

• Tradeoff between
  – Well installation cost
  – Labor cost for injection
  – Material cost for emulsion
Enhanced Anaerobic Bioremediation Using Emulsified Edible Oils

• Preparing and Injecting Emulsions
Injection System Design Options

• Direct-push technology
  – Using pressure
• Injection wells
  – Gravity feed
  – Low pressure
Emulsion Dilution Options

• Continuous injection of dilute emulsion without chase water
  – Dilution ratios range from 1:10 to 1:30
  – Depends on effective porosity

• Injected 4,400 gallons of EOS mix and 22,700 gallons of chase water

• Chase water used to distribute emulsion out into the formation
Emulsion Dilution

- In-line metering system
  - Eliminates labor and equipment for field blending
  - Adjustable dilution ratio
Ground Water Characterization
What to Monitor

Indicator Parameters
- Electron acceptors (O$_2$, NO$_3$, SO$_4$)
  - Low levels of O$_2$ are not a major problem
  - High levels of SO$_4$ increase substrate demand
- Electron donors (Mn, Fe, CH$_4$, TOC)
- ORP, PH
- Degradation products
- See EPA / AFCEE protocol for MNA of Chlorinated Solvents
Degradation products

Degradation products involve the breakdown of compounds like PCE, TCE, and ethene into simpler molecules, including vinyl chloride and ethane. The process is driven by electron flow, leading to complete mineralization.

(Drawing Modified from AFCEE, Technology Transfer Division)
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• Results
PLUME OF THE MAJOR CONTAMINANTS
Pre-Injection (injection April 2005)
PLUME OF THE MAJOR CONTAMINANTS
6-months post-injection
PLUME OF THE MAJOR CONTAMINANTS
9-months post-injection
PLUME OF THE MAJOR CONTAMINANTS
12-months post-injection
PLUME OF THE MAJOR CONTAMINANTS
15-months post-injection
PLUME OF THE MAJOR CONTAMINANTS
18-months post-injection
RESULTS: CHART 1: MW-1A ANALYTICAL RESULTS VERSES TIME

Volatile Organic Compounds

Methane, Ethane, and Ethene

MW-1A Total Organic Carbon (TOC) and Dissolved Oxygen (DO)

Oxygen Reduction Potential (ORP) and pH
Project Conclusions

- EOS® effectively distributed throughout treatment area
- Quickly established favorable geochemistry for reductive dechlorination.
- Dramatic improvements in groundwater conditions compared to prior technologies
- Substantial reductions in TCE observed.
- Apply for decrease monitoring to every 6 months.
- Apply for closure this year.
I would like to thank:

Matt Sedor, M.S., Yonathon Yoseph, P.G., C.H.G. (Remediation Sciences, Inc.)
Jeff Baker (Vironex, Inc.)
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Visit www.eosremediation.com
•  Design Tool, Case Studies
•  Complete Product Line
  –  Chlorinated Solvent Site Remediation
    •  EOS ® ,  emulsified soybean oil, for enhanced in situ bioremediation
    •  BAC 9, microbes for bioaugmentation
  –  Petroleum Site Cleanup Remediation
    •  EOx™, a calcium-based oxygen releasing substrate for aerobic bioremediation