PRB Installation using Edible Oil Substrate (EOS®)

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- SERDP/ESTCP
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- AFCEE
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Enhanced Reductive Dechlorination using Slow Release Organic Substrates

- Oil-in-water emulsion prepared with food grade edible oils
- Use high mixing energy to achieve required droplet size
- All materials are FDA Generally Recognized as Safe (GRAS)
- Patent Issued June 4, 2002
Proposed Technology

Application Approach

- Source area injected to enhance degradation of NAPLs
- Distribution throughout plume to enhance MNA
- Barrier to cut off plume
 Barrier Approach

**Advantages**
- Limited source area delineation
- Low construction cost
- Minimal O&M cost
- Construction to ‘any’ depth required
- Construction in both sediments and fractured rock
PCE Biodegradation

Reductive Dechlorination

- Soybean Oil (C_{18}H_{32}O_{2}) ferments to H_{2} and simple organics

\[ C_{18}H_{32}O_{2} + 34 H_{2}O \rightarrow 18 \text{ CO}_2 + 50 \text{ H}_2 \]

- H_{2} and simple organics
  - Consume oxygen
  - Drive dechlorination
Possible Substrates

- Soluble Substrates
  - Lactate, molasses
  - Frequent addition required
  - Higher O&M Costs

- HRC
  - $12 per pound of organic substrate
    ($6/lb HRC – 50% water)
  - Lasts ~ 6 months then need to reinject
  - Very limited spread in aquifer
Possible Substrates

- EOS®
  - Longer lasting, lower need for reinjection
  - Effective distribution over much larger areas
  - Relatively low cost
    - Low cost substrate
    - Injection is more complicated
    - Frequent reinjection not required
Potential Concerns

- Absence of dehalogenating microorganisms
- Oil degrades too rapidly
- Limited oil distribution
- Aquifer permeability loss
How Long Will Oil Last?

- Microcosms built 3.5 years ago
- Originally fed 500 mg/L soybean oil
- Periodically respiked with 20 mg/L PCE
- Now on 8th respike
- Continue to see excellent PCE → ethene
Emulsion Transport in Aquifers

- Soo and Radke (‘84 – ‘86)
- Big droplets get removed by straining and cause large permeability loss
- Small droplets removed by sticking to solid surfaces and cause minor permeability loss

\[ K = 10^{-5} \text{ cm/s} \]
Making Emulsions with Little Droplets

Blender

Lab Homogenizer

Dairy Homogenizer

Field Preparation
Emulsion Transport in Aquifer Material

- Column tests to evaluate oil transport
- 80 cm long x 2.5 cm dia.
- Inject 0.05 PV oil
- Chase with 3 PV water
- Sediment
  - Sand
  - Sand & 5% Clay
  - Dover AFB Sediment \((K = 4 \times 10^{-4} \text{ cm/s})\)
- Treatments
  - NAPL Soybean Oil
  - Emulsified Soybean Oil
Permeability Loss

- Columns treated with oil then flushed with water

- Sediment
  - Concrete sand
    \( K_{\text{initial}} = 0.05 \text{ cm/s} \)
  - Concrete sand + 5% clay
    \( K_{\text{initial}} = 0.02 \text{ cm/s} \)
  - Natural field sand
    \( K_{\text{initial}} = 0.01 \text{ cm/s} \)
  - Dover sediment
    \( K_{\text{initial}} = 0.0005 \text{ cm/s} \)

- Treatments
  - NAPL Soybean Oil
  - Emulsified Soybean Oil

![K Change During Injection](image)

- Oil Inject.
- Water Flush
Transport in a 3-D Sandbox

- Radial flow sandbox
  - 1 m x 1 m x 1 m
  - Inject in corner
  - Sample at different depths / distances
  - Core box at end to determine oil distribution

- Treatments
  - Homogeneous sand
  - Layered sands
Transport in a 3-D Sandbox

- Heterogeneous K distribution
- Top field sand + 2.5% clay
- Middle field sand
- Bottom field sand + 5% clay
Transport in a 3-D Sandbox

- Good oil distribution throughout box
- Both high and low K layers
- No density effects
Field Evaluations of EOS™

- Dover AFB, DE – Pilot
- Edwards AFB, CA – Pilot
- Altus AFB, OK – Pilot
- Lumberton, NC – Full Scale
- Hamilton, NC – Full Scale
- Long Island, NY – Full Scale
Installing Injection Points
Oil Totes
Field Preparation
Emulsion Preparation
Altus AFB SS-17 Pilot

- SS-17 plume
  - Partial dechlorination of TCE to cDCE and VC
  - Plastic clay overlying weathered/fractured shale
  - Very high SO$_4$ (up to 2,000 mg/L)

- EOS™ injected into 6 wells

- Monitoring
  - Nov. 01 (pre-injection)
  - Dec. 02 (1 day after EOS™ injection)
  - April 02 (4 months after injection)
  - July 02 (8.5 months after injection)
Altus AFB SS-17 Pilot

- Inject wells space 7.5 ft O.C.
- Emulsion distributed 25 ft in high K zone
- Little distribution in low K zone
Altus AFB Injection Well 3

- Concentrations in µg/L
- TCE initially sorbs to oil
- Rebound as oil equilibrates with groundwater
- Production of ethene + ethane
Altus AFB Injection Well 3

- Same data as previous graph – conc. in µMole/L
- By 8.5 months, sorption is not significant
- Total ethenes > 90% of initial
- 93% decline in TCE
- > 70% of initial TCE recovered as ethene + ethane
Monitor Well 5
- 25 ft downgradient
- high K zone
- emulsion reached well
- TOC above 100 mg/L after 9 months

TCE is BDL

VC increase from 440 to 1185 µg/L
Altus AFB Conclusions

- EOS™ moved at least 25 feet in low K weathered - fractured shale
- EOS™ injection stimulated dechlorination
  - > 90% reduction in TCE
  - Large production of ethene and ethane
  - VC produced. May degrade further downgradient
- High sulfate (500 to 2000 mg/L) not major a problem
Benefit – Lower Lifecycle Costs

- 30 yr Net Present Value (Quinton et al.)
- 600 ft wide x 80 ft deep
- Every 5 yr
  - 25% engineering
  - Reinject oil
  - Replace 25% of wells
- Monitoring same as iron PRB