Accelerated Site Cleanup Using a Sulfate-Enhanced *In Situ* Remediation Strategy

By: Sheri Knox, Tim Parker, & Mei Yeh
About EOS Remediation

- U.S.-based bioremediation company

- Proven products used worldwide
  - Every continent except Antarctica

Green states & provinces - EOS® implemented
## Our Family of Products

### Soil & Groundwater Bioremediation Products

<table>
<thead>
<tr>
<th>Category</th>
<th>Product Name</th>
<th>Target Contaminants</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biostimulation (Anaerobic)</strong></td>
<td>EOS®, EVO™, AquaBu$pH^{®}$, VOS <em>(under development)</em></td>
<td>Chlorinated Solvents, Perchlorate, Chromate, Explosives, Radionuclides, Acid Mine Drainage</td>
</tr>
<tr>
<td></td>
<td>EAS™</td>
<td>Petroleum Hydrocarbons</td>
</tr>
<tr>
<td><strong>Biostimulation (Aerobic)</strong></td>
<td>EOx™</td>
<td>Petroleum Hydrocarbons</td>
</tr>
<tr>
<td><strong>Bioaugmentation</strong></td>
<td>BAC-9™</td>
<td>Chlorinated Solvents</td>
</tr>
<tr>
<td></td>
<td>ENV-TCA20™</td>
<td>Chlorinated Alkanes</td>
</tr>
<tr>
<td></td>
<td>PJKS-1™</td>
<td>Chlorinated Solvents</td>
</tr>
</tbody>
</table>
Presentation Overview

- Introduction to Bioremediation
- What is EAS™?
- Why add sulfate?
- What contaminants can be addressed?
- Case Study
- Conclusion
In Situ Bioremediation

In Situ → Bio → Remediation
In Place → Microbial → Method to Fix

Microorganisms are used to Clean up Pollution in the Environment

Reference: Lisa Alvarez-Cohen, Civil and Environmental Engineering University of California, Berkeley, Earth Science Division, LBNL
Microbial World: The Unseen Majority

- ~20,000 strains/species of bacteria in 1g topsoil
- Bacteria in 5g topsoil = ~total human population of Earth
- Total bacterial population of Earth = ~5 x 10^{30} cells
- >90% of bacteria are in the subsurface below 30 feet

How Does It Work?

- How does *in situ* bioremediation clean up pollution?
  - Soil microbes are remarkably versatile!
  - They eat (electron donor) and breathe (electron acceptor) many types of organic and inorganic chemicals to generate energy to live.
    
    (Gasoline, oil, chromium, iron, solvents, perchlorate, nitrate, ammonia, MTBE, etc)

- They live in complex communities capable of degrading many contaminants.

Reference: Lisa Alvarez-Cohen, Civil and Environmental Engineering University of California, Berkeley, Earth Science Division, LBNL
How Does It Work?

- Growth-Promoting Biological Reduction

- Electron Donor (Food)
  - +

- Electron Acceptor (something to breathe)
  - $[O_2, NO_3, SO_4, TCE, etc.]$

- Waste Products
  - $[CO_2, N_2, FeS_2, Cl^-]$

- Energy

(Drawing Modified from AFCEE and Wiedemeier)
Applying *In Situ* Bioremediation

- **Natural Attenuation** – biotransformation occurs naturally: indigenous microbes present, substrates & nutrients present (can be MNA)

- **Biostimulation** – indigenous microbes present, substrates &/or nutrients must be added

- **Bioaugmentation** – indigenous microbes not present, organisms are added
Why Bioremediation?

Remediation Costs:

- Enhanced Bioremediation $29/yd^3
- Thermal Treatment $88/yd^3
- Chemical Oxidation $125/yd^3
- Surfactant Co-solvent Flushing $385/yd^3

What is EAS?

- **Electron Acceptor Solution**
- A soluble product for anaerobic biodegradation of petroleum hydrocarbon
- Stimulates microbial growth
Typical Petroleum Release

Vadose Zone (oxidized)

Residual Hydrocarbon

Aquifer (reduced)

NAPL

Residual sulfide oxidized to sulfate

\[ \text{H}_2\text{S}_{(g)} + 2\text{O}_2(g) \rightarrow \text{SO}_4^{2-} + 2\text{H}^+ \]

Sulfate reduction

Fe(II) on sediments

\[ \text{H}_2\text{S}_{(aq)} + \text{Fe(II)}_{(s)} \rightarrow \text{FeS}_{(s)} + 2\text{H}^+_{(aq)} \]

Sulfide sequestered as iron sulfides

\[ \text{FeS} + \text{S}_0 \rightarrow \text{Fe}_2\text{S}_3 \]

Reference; Kolhatkar, R and Taggart, D, 2004
Hydrocarbon Impacted Aquifers

After Chapelle (2001)
Conventional Wisdom

➢ Add Oxygen

Electron Acceptors
1. Oxygen
2. Nitrate
3. Fe(III)
4. Mn(IV)
5. Sulfate
6. CO₂ or fermentation

Products
Water, CO₂
Nitrogen, CO₂
Fe(II), CO₂
Mn(II), CO₂
Sulfide, CO₂
Methane

Aerobic
Anaerobic

High
Energy Yield
Fast
Kinetics (Lab Experiments)

Low
Slow
Sulfate-Utilizing Microbes Dominate Process

EPA-BP Study at 74 Sites

AFCEE Study at 42 Sites

Ref: Wiedemeier, T.H et al. at 38 Sites

- sulfate reduction
- methanogenesis
- nitrate reduction
- aerobic oxidation
- iron reduction
### Why EAS™?

<table>
<thead>
<tr>
<th>Electron Acceptor (EA)</th>
<th>Maximum Concentration (mg/L)</th>
<th>Mass of Benzene Degraded per Unit Mass of EA</th>
<th>Potential Benzene Degraded (mg/L)</th>
<th>Issues</th>
</tr>
</thead>
</table>
| Oxygen (in air)        | 9 – 10                       | 0.33                                        | 3.0 – 3.3                        | • Limited solubility  
• Numerous oxygen sinks  
• Potential aquifer clogging  
• Biofouling near injection point |
| Pure Oxygen            | 60 – 70                      | 0.33                                        | 19.8 – 23.1                      |        |
| EAS™                   | >1,000                       | 0.22                                        | >220                             | • Hydrogen sulfide; never documented as an issue in the field |
How Does EAS™ Work?

Growth-Promoting Biological Reduction

- Electron Donor (Food)
- Electron Acceptor (something to breathe) [$O_2$, $NO_3$, $SO_4$, TCE, etc.]
- Waste Products [$CO_2$, $N_2$, FeS$_2$, Cl$^-$]

(Drawing Modified from AFCEE and Wiedemeier)

www.EOSRemediation.com

Copyright © 2010 EOS Remediation, LLC
Sulfate-Reducing Bacteria (SRB) Reaction

Petroleum Hydrocarbon + EAS™
+ Dissolved Iron → Iron Sulfide + H₂O + MgCO₃ + CO₂

Iron Sulfide and Magnesium Carbonate are insoluble and immobile.
Why EAS™ Enhancement?

- Accelerates site cleanup
- *In Situ*
  - Minimal Disruption & O&M
- Cost effective
- “Green Technology”
- Proven
Typical EAS™ Project

- Removed leaking tank
- Injection Point
- Inject EAS™ into contaminant plume
- Unsaturated zone
- Saturated zone
- Groundwater flow
- Plume of dissolved contaminants

(Drawing Modified from ITRC and Koenigsberg 2007)
Contaminants that can be Treated with EAS™

- Petroleum Hydrocarbons
  - Aromatic Hydrocarbons
  - Total Petroleum Hydrocarbons (TPH)
  - Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX)
  - Methyl tert-butyl ether (MTBE)
  - tert-Butyl Alcohol (TBA)
How Much EAS™ is Required?

- Generally 3-4 EAS™ applications
- Utilization factor
  - 4.7 grams of sulfate consumed per gram of BTEX degraded (Reference: Wiedemeier et al.)
Case Studies

Courtesy of James F. Cuthbertson, Senior Consultant
Delta Consultants, an Oranjewoud N.V. Company

YOUR NATURAL SOLUTIONS
Patented Methods for In Situ Bioremediation
Former Gasoline Service Station
Potterville, MI

- Confirmed releases in 1992 and 2001
- Prior remedies:
  - High vacuum total fluids extraction, oxygen bio-sparging, bioaugmentation & MNA
- Geology:
  - Silty clay with granular fill material
  - Perched groundwater 1 to 2 feet bgs
- Liquid phase hydrocarbon (LPH) was last encountered in March 2003
- Sulfate enhancement was pursued as the lowest cost alternative to accelerate remediation and respond to a potential sensitive receptor (wetland area)
Results

Potterville, MI Source Area/Tank Cavity B,T,E,X vs. Sulfate

- Benzene, Toluene, Xylene Concentration (µg/l)
- Sulfate Concentration (mg/l)
- Ethylbenzene Concentration (µg/l)

Date: 4/6/2001 to 4/6/2006

Application and Cleanup Target
Midland, MI Case Study

- Confirmed releases in 1988 and 2000
- Primarily Sands with granular fill material to 8 feet bgs with clay to maximum explored depth
- Groundwater approximately 6 to 8 feet bgs
Midland, MI Site Map

OW-3AR
(Within Treatment Zone)

OW-19
(Compliance Well)
Monitoring Well Within Treatment Zone

Midland, MI
Observation Well OW-3AR
Sulfate vs. Total BTEX Concentrations

Total BTEX (ug/l)
Sulfate Concentration (mg/l)

02/06/03 05/16/03 07/30/03 11/14/03 02/24/04 05/03/04 08/17/04 11/10/04 01/11/05 06/28/05 08/02/05 11/01/05

0 50 100 150 200 250 300 350 400 450 500

0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

Total BTEX
Sulfate Applications
Sulfate Concentrations
Compliance Well

Midland, MI
Observation Well OW-19
Sulfate vs. Total BTEX Concentrations

Total BTEX (ug/l)

Sulfate Concentration (mg/l)

05/16/03  07/30/03  11/14/03  02/24/04  05/03/04  08/17/04  11/10/04  01/10/05  06/28/05  08/02/05  10/31/05

0.0  500.0  1,000.0  1,500.0  2,000.0  2,500.0  3,000.0

0  20  40  60  80  100  120  140
Example Closure / NFA Projects


Application Overview

- After an EAS™ application, sulfate levels initially rise and then decrease in conjunction with the reduction of contamination levels.

- If the contaminant is still present and sulfate is at background levels, another application may be needed.
Recognizing significant contributions in the pollution control industry

REMEDICATION

EOS Remediation

EAS Biodegradation Stimulator
Application Experience

- Applied at over 200 sites
  - FL, CA, MI, IN, IL, WV, VA, IA, GA & NY

- Method of Injection & application
  - Infiltration trenches
  - Vertical wells
  - Surficial spreading
  - Former recovery wells
  - Former SVE wells
  - Temporary Geoprobe® points

- Variety of geological and hydrogeological settings
Benefits of EAS™

- Minimal site disruption
  - *In situ* approach with no ongoing O&M activities
- Cost effective
Benefits of EAS™

- Safe
- Green – Natural Process
Benefits of EAS™

- Accelerated cleanup
  - Information gained significantly strengthens advocacy position with regulatory agencies
  - Monitoring frequency showed no lag time for acclimation of native sulfate reducing bacteria
Overview of Patented Process

  - Issued November 21, 2006

- Patent issued for:
  - A process that enhances the environmental conditions existing within a contaminant plume by replenishing a natural groundwater compound required by bacteria to degrade the contaminants.
  - Sulfate solution in excess of 1,000 ppm
  - Covers all pollutants that can be degraded by sulfate-reducing microorganisms
Conclusion

- Enhancement of biodegradation with the addition of EAS™ is a viable technique to safely and aggressively remediate BTEX, MTBE and petroleum impacted groundwater
- Design, implement and monitoring is a relative easy process
Thank you for attending … Questions?

J&L Environmental Technology CO., LTD
森品環境科技股份有限公司
Contact: Kevin Liu (劉 瑞文)
Phone: (07) 6162. 000 • kevin@jletco.com.tw
www.jletco.com.tw

YOUR NATURAL SOLUTIONS
Patented Methods for In Situ Bioremediation

Contact: Sheri Knox or Tim Parker
Phone: 919.873.2204
sknox@eosremediation.com • Skype: sheri.knox