Optimizing *in situ* Bioremediation of Chlorinated Ethenes in Ontario’s Groundwater

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SiREM-Major Services/Products

*gene*trac®
*treatability* studies

Bioaugmentation Products

KB·1®
Advantages of Enhanced Bioremediation for Chlorinated Solvents

• **Cost Effective:** As little as 1/3rd the cost of other options

• **Destroys Contaminants:** doesn’t just move them

• **Prevents Rebound:** Once down concentrations tend to stay down

• **Sustainable:** low carbon footprint/natural process
EISB Tools

- **Biostimulation**: addition of nutrients to increase biodegradation of lactate, emulsified vegetable oils, etc.
- **Bioaugmentation**: addition of beneficial microorganisms to improve biodegradation.
- **KB-1®**: Canadian bioaugmentation culture for chlorinated ethenes
- **Enhanced Delivery**:
  - Groundwater recirculation
  - Hydraulic fracturing
  - Electrokinetics

**Injection of KB-1 each liter contains 100 billion Dehalococcoides cells**

**Dehalococcoides (Dhc) as Featured in Wired Magazine**
Introduction to *Dehalococcoides* (Dhc)

- One of the smallest free living microbes ~0.5 µm, disk shaped
- Obligate anaerobes
- Degrader of a range of chlorinated compounds (chlorinated ethenes, propanes, dioxins, PCB’s and more)
- Distributed throughout the world but not ubiquitous

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**Biodegradation of Chlorinated Ethenes**

By Reductive Dechlorination

Can accumulate if DHC are absent
lack VC-reductase *vcrA*

- *Dehalobacter*
- *Dehalospirillum*
- *Desulfitobacterium*
- *Desulfuromonas*

Only **Dehalococcoides**

Ethene (aka. ethylene) is non-toxic, produced by many fruit to stimulate ripening

+ **Dehalococcoides**
Optimal Site Conditions for Bioremediation of Chlorinated Ethenes

- pH 6.0-8.5-Southern Ontario generally well buffered
- Anaerobic/Reducing DO < 0.2 mg/L ORP <-75 mV often created by biostimulation
- Absence of high concentrations of inhibitory co-contaminants (1,1,1-TCA/chloroform/CFCs)
- Warmer groundwater = faster results Southern Ontario applications expect faster results than Northern ON (groundwater below 10°C)

TESTING AND BIOAUGMENTATION TO OPTIMIZE AND ASSESS REMEDIATION PERFORMANCE
• Commercial testing for *Dehalococcoides*, *Dehalobacter*, *Dehalogenimonas* and functional genes (e.g., *vcrA*) in groundwater

• Exclusive license agreements with DuPont and Stanford University for patented tests

• Routinely serving Canada, USA, Europe and Australia, plus South America and Africa

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**Why Quantify Dhc at a Site?**

• To determine if a site has *Dhc* (~ 40-50% don’t)

• To determine if type of *Dhc* dechlorinate to ethene? (~25% can’t don’t have *vcrA* gene)

• To predict effectiveness of enhanced bioremediation in advance of field application (To stall or not to stall)

• To confirm effectiveness of enhanced bio by quantifying growth and spread of *Dhc*
Treatability Testing

• Microcosms or columns constructed using site materials (soil, sediment or rock, and groundwater)

• Monitor contaminant reduction over time

• Customize treatment variables to meet site specific needs

Some Site Challenges Addressed Through Treatability Testing

• Low pH –and pH modification

• Dealing with contaminant concentrations & mixtures

• Requirement for bioaugmentation

• Electron donor choices etc.

To determine rate and extent of bioremediation under different scenarios
KB-1® (101)

- Anaerobic liquid bioaugmentation culture enriched from TCE site in SW Ontario

- Used to introduce $Dhc$ to sites
  Contains ~100 billion $Dhc$/Liter

- Consortium that contains ~40 different bacteria that grow symbiotically with $Dhc$

- Not genetically engineered/pathogen free

- Added at 1/35,000 dilution in groundwater

Bioaugmentation Kit

*Materials shipped to site- 20L vessel and injection tools*
Impact of KB-1 Bioaugmentation

Complete dechlorination of TCE to ethene only achieved after KB-1 added to groundwater
Why Bioaugment?

• Complete degradation of chlorinated solvents will simply not occur in the absence of the right microorganisms which are introduced by bioaugmentation

• Where the right type of indigenous microorganisms are present but at low concentrations/poorly distributed-bioaugmentation can decrease the time-frame and costs required for site cleanup

• By increasing the speed and effectiveness of bioremediation can increase efficiency of electron donor use and decrease O&M costs including monitoring

KB-1®/KB-1® Plus Bioaugmentation Locations

Over 350 sites have been bioaugmented with KB-1® & KB-1® Plus in North America Europe and Asia
KB-1® Bioaugmentation in Ontario

Between 2009-2013, ~10 Sites in Ontario were bioaugmented with KB-1

EISB FOR CHLORINATED SOLVENTS IN THE ONTARIO ENVIRONMENT
Ontario Regulatory Landscape

• Bioaugmentation cultures require approval under Federal NSN Regulation prior to use in Canada

• KB-1 only culture of its type approved for use in Canada

• SiREM has MOE Mobile Certificate of Approval for injection in ON

• EISB can meet or exceed MOE groundwater water regs (i.e., Table 1 Ground Water) for chlorinated compounds

First Injection of KB-1 in Canada, Thunder Bay ON, 2009—Photo Courtesy TEA Inc.

Common Ontario Geologies

• Fractured Rock (Canadian Shield/Niagara Escarpment)

• Low permeability glacial deposits/clay (Great Lakes/St. Lawrence Lowlands)

• Sites with above geologies often require specialized approaches to optimize bioremediation
EISB at Fractured Rock Site

EISB of fractured rock site in Fort Erie, Sustainable Development Technology Canada (SDTC) funded study

Groundwater Recirculation System, Fort Erie, ON

- Recirculation system controls groundwater flow and enhances flushing of source to reduce clean up times
- Ethanol and KB-1 were injected via recirculation system
- Recirculation contains nutrients and microbes in contaminated zones

Extraction Well Results Fractured Rock Site - Fort Erie, Ontario

- Accelerated decrease in DCE/VC and >4-fold increase in ethene observed after bioaugmentation
- Bioaugmentation effective even with indigenous Dhc at site
Amendment Distribution Challenges

- Ontario has low permeability glacial deposits/clay especially in industrialized areas (e.g. Golden Horseshoe)

- Spread of bioremediation amendments challenging under low permeability conditions

- Technical solutions to low permeability include:
  - High density direct push injection grids
  - Hydraulic fracturing
  - Electrokinetics

Hydraulic Fracturing for Dispersion of EISB Amendments

- High pressure injection of viscous liquid creates fractures (proppant e.g., sand) prevents fractures from closing

- Commonly used in oil & gas industry for enhanced hydrocarbon recovery

- Used to increase distribution of remediation amendments at low permeability sites

Distribution of permanganate around induced clay fracture at FEW AFB
-Courtesy URS Corp.
FE Warren Air Force Base, Wyoming
-Hydraulic Fracturing at Low Permeability Site

Fracing in progress

Application of KB-1

Pronghorn herd after installation of bioremediation remedy

Approach:
• Over 600 fractures emplaced with sand /electron donor mix
• KB-1 (380 liters) injected into 174 fractures
• Spread of Dhc up to 70 feet from injection points observed

Impact:
• “Remedy-In-Place” approved by Wisconsin DEQ/EPA within 2 years
• Colorado Engineering Excellence Award-2010

Distribution of Electron Donor at and KB-1 FEW AFB Using Hydraulic Fracturing

Figure Courtesy of URS Corp.
Electrokinetic (EK)-Bioremediation

Low voltage DC current applied to subsurface to move amendments with electricity.

**EK mechanisms:**
- **Ion migration:** charged particles move by ‘electrophoresis’
- **Electro-osmosis:** Charged water (H$_3$O$^+$) moves to negative electrode (moves non-charged particles by advection e.g., Dhc)

SiREM developing laboratory test methods in support of EK applications

Testing EK movement of amendments using site core in lab
Denmark Clay Site EK pilot:

- Lactate moved 2.5-5.0 cm/day
- Heat generation (~6 °C temp. increase) = improved degradation rates
- PCE dechlorination to ethene observed
- Energy used was equivalent to 10-100 W light bulbs
- Full scale EK-remedy currently in progress

Conclusions

- Bioaugmentation with KB-1 has regulatory approval and growing track record in Ontario
- Laboratory treatability testing and Dhc testing services for EISB optimization available in Ontario
- EISB of chlorinated ethene sites in common Ontario geologies could be facilitated by:
  - Groundwater recirculation approaches – especially fractured rock
  - Hydraulic fracturing
  - Electrokinetic bioremediation

Low Permeability Materials
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