Enhanced Bioremediation for Treatment of Chlorinated Solvent Residual Source Areas – Case Study and Implications

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Bioremediation Background

• In Situ Bioremediation of chlorinated solvents:
  – Solvents utilized as electron acceptors by indigenous microorganisms
  – Chlorine atoms sequentially replaced with hydrogen through “reductive dechlorination”
Microbial Metabolism

Electron Acceptor + Electron Donor → O₂

Electron Acceptor + Electron Donor → Respiration Products + Energy

Electron Acceptor + Electron Donor → Food

Electron Acceptor + Electron Donor → Energy
Bioremediation Metabolism

Electron Acceptor: \( \text{O}_2, \text{NO}_3^-, \text{etc.} \)
Electron Donor: BTEX

Electron Acceptor: Chlorinated Solvents
Electron Donor: Food (Organic Compound)
Reductive Dechlorination Pathway

Modified from Wiedemeier et al., 1996
A Paradigm Shift?

• Conventional applications for in situ bioremediation limited to dissolved phase for two primary reasons:
  – Concerns about toxicity
  – Impact on nonaqueous sources thought to be no better than pump and treat

• New research reveals that in situ bioremediation may be extremely effective for chlorinated solvent source areas
Enhanced Mass Transfer

• In situ bioremediation can enhance mass transfer, addressing the concerns previously thought to limit bioremediation applications:
  – Many investigators have shown that dechlorinating bacteria actually have an ecological niche in high concentration areas
  – Several studies have shown that in situ bioremediation enhances mass transfer of contaminants through at least three mechanisms
Mechanisms of Enhanced Mass Transfer

• Mechanisms for enhanced mass transfer
  – Bioremediation removes contaminants from the aqueous phase, thereby increasing the driving force for mass transfer = $k(C_s - C)$
  – Increasing solubility of reductive dechlorination degradation products greatly increases the maximum aqueous contaminant loading
  – The electron donor solution can be used to decrease interfacial tension, thereby increasing the effective solubility
Enhanced Mass Transfer: Mechanisms 1 and 2

- Enhanced mass transfer of chlorinated solvent NAPLs due to reductive dechlorination has been demonstrated in at least two laboratory batch studies:
  - Yang and McCarty (2000) showed enhanced PCE dissolution up to a factor of 5 higher than without reductive dechlorination
  - Carr et al. (2000) showed reductions in NAPL longevity of 83% due to reductive dechlorination in continuously stirred tank reactors
Enhanced Mass Transfer: Mechanisms 1 and 2

• Enhanced mass transfer of chlorinated solvent NAPLs due to reductive dechlorination has been demonstrated in at least one laboratory column study:
  – Cope and Hughes (2001) demonstrated total chlorinated ethene removal was 5 to 6 times higher with reductive dechlorination as compared to abiotic washout
Enhanced Mass Transfer: Mechanisms 1 and 2

- Enhanced chlorinated ethene removal due to reductive dechlorination in columns with PCE DNAPL (Courtesy of Joe Hughes)
Enhanced Mass Transfer:  Mechanism 3

- The impact of sodium lactate and other electron donor solutions on water-TCE interfacial tension was investigated in unpublished laboratory studies.
- The results supported a pending patent for the Idaho National Engineering and Environmental Laboratory.
- The process is referred to as Bioavailability Enhancement Technology™ (B.E.T.™).
Impact of Electron Donor Solutions on Interfacial Tension

Interfacial Tension (dyne/cm)

Lactate Concentration (%)

0% Solution B
0.1% Solution B
1% Solution B
10% Solution B
Enhanced Mass Transfer: Mechanism 3

- Enhanced mass transfer due to electron donor solution interaction with nonaqueous TCE, followed by complete reductive dechlorination has been observed in at least one field study:
  - Sorenson (2000, in press) showed that TCE concentrations were greatly enhanced due to facilitated transport associated with the electron donor solution (high concentration sodium lactate)
  - This work will serve as our case study
Test Area North (TAN) Background

• Industrial wastewater (including solvents), low-level radioactive wastes, and sanitary sewage were injected directly to the Snake River Plain Aquifer from the late 1950s to 1972
• TCE plume is nearly 2 miles long
• Residual source area is about 100 ft in diameter
• Contaminated aquifer is about 200-400 ft deep
• Aquifer is comprised of fractured basalt
Record of Decision (1995)

- Pump and treat selected as default remedy
- Treatability studies established for alternative technologies:
  - zero-valent iron
  - monolithic confinement
  - in situ chemical oxidation
  - in situ bioremediation
  - natural attenuation
- 100-year remedial time frame
Objectives for the 1-year In Situ Bioremediation Field Evaluation

• Primary Objective: Demonstrate that biodegradation of TCE can be significantly enhanced through electron donor addition
• Create hydraulic “treatment cell” to maintain hydraulic containment of the source area and control residence time
• Determine controls on process efficiency through extensive monitoring
Electron Donor Distribution

Electron Donor in TAN-25

Electron Donor in TAN-37A

Electron Donor in TAN-26

Electron Donor in TAN-37B (275') and C (379')
Redox Indicators in TAN-37B (275') and C (379')

Date
Nitrate and Iron (mg/L)
0 1 2 3 4 5 6

Sulfate and Methane (mg/L)
0 10 20 30 40

Redox Indicators in TAN-25

Date
Nitrate and Iron (mg/L)
0 1 2 3 4 5 6

Sulfate and Methane (mg/L)
0 10 20 30 40

Redox Indicators in TAN-26

Date
Nitrate and Iron (mg/L)
0 1 2 3 4 5 6

Sulfate and Methane (mg/L)
0 10 20 30 40

Redox Indicators in TAN-37A

Date
Nitrate and Iron (mg/L)
0 1 2 3 4 5 6

Sulfate and Methane (mg/L)
0 10 20 30 40

Redox Indicators in TAN-37B (275') and C (379')

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Redox Indicators in TAN-26

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Redox Indicators in TAN-37B (275') and C (379')

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Long-Term Dechlorination

TAN-25

TCE

cis-DCE

trans-DCE

VC

Ethene

TAN-26

TCE

cis-DCE

trans-DCE

VC

Ethene

TAN-27

TCE

cis-DCE

trans-DCE

VC

Ethene

TAN-37A

TCE

cis-DCE

trans-DCE

VC

Ethene

TAN-37B

TCE

cis-DCE

trans-DCE

VC

Ethene

TAN-37C

TCE

cis-DCE

trans-DCE

VC

Ethene
Enhanced Mass Transfer from DNAPL Source Area

![Graph showing enhanced mass transfer from DNAPL source area with data points for Ethenes (mol/L) and dates from 1/6/99 to 3/6/00.](image)
TAN 25 chloroethenes

Concentration (ppb)

Days of injection

$\delta^{13}C$

Days

TCE
t-DCE
c-DCE

VC

Ethene

TCE
t-DCE
c-DCE

Ethene
Status of Enhanced In Situ Bioremediation at TAN

- Formal regulatory approval to implement bioremediation at the TAN DNAPL source area as a replacement for the default remedy has been granted. A ROD amendment was signed in 2001.
Ft. Lewis ESTCP Demonstration

- The project will use two in situ treatment cells to quantitatively demonstrate the enhanced mass transfer and degradation that occurs due to in situ bioremediation in a chlorinated solvent source area
- One cell will be operated to test the first two mass transfer mechanisms, while the other will add the third mechanism
- Project planning is underway; field work is scheduled to begin in January 2003