EMULSIFIED ZERO-VALENT IRON TREATMENT OF CHLORINATED SOLVENT DNAPL SOURCE AREAS

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Technology Rationale

• ZVI is an accepted technology for the reductive dehalogenation of dissolved CVOCs such as PCE and TCE to ethene.

• ZVI PRBs are effective in treating dissolved CVOCs but:
  • are dependent on dissolution and transport of CVOCs; and
  • do little to reduce the clean up time and long-term monitoring costs.
Since exterior oil membrane of emulsion droplets have hydrophobic properties similar to DNAPL, the emulsion is miscible with the DNAPL.

CVOCs in DNAPL diffuse through the oil membrane and undergo reductive dechlorination in the presence of the ZVI in the interior aqueous phase.

In addition to abiotic degradation due to ZVI, EZVI contains vegetable oil and surfactant which will act as long-term electron donors and promotes anaerobic biodegradation.
Properties of EZVI
In Contact with DNAPL

DNAPL dyed red

DNAPL with micro-scale ZVI

DNAPL with EZVI
• Demonstration conducted at NASA LC34.

• Pilot test area (PTA) was inside of a building and was 15 ft by 10 ft.
  • hydraulically controlled for containment and to maintain consistent groundwater velocity in treatment zone.

• Performance evaluation based on GW mass flux and TCE mass in pre- and post-treatment soil cores

• Monitored changes in CVOCs in:
  • GW (5 depth intervals, 2 upgradient and 2 downgradient wells); and
  • soil cores (8 depth intervals, 6 locations).
Monitoring and Injection Locations

- Extraction well (recirculation well)
- EZVI injection well (1/2 screen)
- EZVI injection well (full screen)
- Injection well (recirculation well)
- Monitoring well
- Multi-level monitoring well
- Orientation of screen

- E-W-1, E-W-2
- PP-3, PP-4
- EML-3, EML-4
- PA-23
- PP-7
- PP-8
- PP-9
- EML-1, EML-2, EML-3, EML-4
- E-EW-1, E-EW-2

- EML-1, EML-2
- PP-7
- PP-8
- PA-23
- EML-3, EML-4

- EZVI injection well (1/2 screen)
- EZVI injection well (full screen)
- Monitoring well
- Multi-level monitoring well
- Orientation of screen
EZVI Injection Set-Up Within PTA

- EZVI injected in 8 injection wells
- Injection wells along edge of plot directed inwards
- Injection wells in center were fully screened
- Injection at 2 discrete depth intervals in each well
Pressure Pulse Technology

Injection Head Apparatus
EZVI Drum
Water Line

No Pulsing

With Pulsing
EZVI Injection Set-Up Within PTA
Pre and Post-Demonstration Cores

- PP# - EZVI injection well (1/2 screen)
- PP# - EZVI injection well (full screen)
- Pre-demonstration soil boring
- Orientation of screen
- Extraction well (recirculation well)
- Injection well (recirculation well)
- Monitoring well
- Multi-level monitoring well

Interim soil boring
Post-demonstration soil boring
Results of Demo at LC34

• Soil Core Samples:
  • Stated objective of 50% removal of total TCE
  • Significant reduction of TCE (>80%) where EZVI was present
  • Average reduction of 58%
  • EZVI migrates to shallow intervals

EZVI in 1- to 3-inch thick stringer
## Results of Demo at LC34

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# Results of Demo at LC34

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Results of Demo at LC34

• Groundwater Samples:
  • Significant reduction (60 to 100%) of TCE in target depths.
  • Reduction of 56% in the Mass Flux.
    • from 19.2 mmoles/ft²/day down to 8.5 mmoles/ft²/day
  • 18 months after injection groundwater concentrations indicate that long term degradation due to bioremediation ongoing
Results of Demo at LC34

• Elevated cis-1,2-DCE, VC suggest biodegradation due to oil as an electron donor may also be significant

• Bioaugmentation may enhance complete degradation associated with biological component of process
Injection Techniques Field-tested at LC34-2004

- Pressure Pulsing
- Pneumatic Fracturing
- Hydraulic Fracturing
- Direct Injection
Field Test Objectives:

• Give each vendor 100 gallons of EZVI containing nanoscale iron.

• Inject at depths between 16 and 19 ft bls, depending on how the vendor intended to perform the test.

• Vendors should attempt to distribute over a narrow injection interval and achieve maximum ROI.

• Immediately following injection, soil cores and FLUTe® liners were used to evaluate where and how far the EZVI was distributed.
Pneumatic Injection

M = missed interval
Blue dots = sample locations
Hydraulic Fracturing
Hydraulic Fracturing
Pressure Pulsed Injection
Pressure Pulsing

Evidence suggests the EZVI found a path of least resistance somewhere between $R=0.75$ and $R=1.5$ feet and was not dispersed omni-directionally outwards.
Direct Push Injection
Conclusions:

• Pneumatic injection of EZVI in sandy soils looks promising. Able to disperse EZVI evenly and at target depths.

• Further testing using pneumatic injection concludes that micro-scale iron may be injected into sandy formations without emulsion deformation and a sufficient ROI is achievable. Saves $$

• Hydraulic fracturing of EZVI does not deform emulsion droplets. May have application in consolidated sediments or where tighter lithologies prevail.
Conclusions

• Pressure pulsing appears not to overcome soil heterogeneities enough for the highly viscous EZVI; approach may be suitable for aqueous-phase materials or pure vegetable oil.

• Direct push has application to small sites where a direct push rig can install a bunch of “columns” of EZVI in a single day, making it very cost competitive over injection technologies that seek larger ROIs.

• This is a NASA-patented Technology available for all US Government agencies to use royalty-free.
Upcoming Work
ESTCP Pilot Test Demonstration

• More research on determining % of degradation due to ZVI and % due to biodegradation.

• EZVI deployment in two pilot test areas within a DNAPL source zone using the two most promising EZVI injection technologies with the objective of providing cost and performance data.