DPT Jet Injection for Remediation in Low-Permeability Source Zones: Full-Scale Treatment Demonstrated by 4 Years of High Resolution Performance Monitoring

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Two Key Take Home Points

Jet Injection Provides:

1) Control delivery of remediation amendments in tough geologic settings:
   - Clay, till, saprolite, weathered bedrock

2) Competitive costs for treatment:
   - $60-150/CY for ZVI treatment
Problem Statement: Treat Contaminants in Low Permeability Formations

Low permeability formations $+$ solvents $=$ long-term source zones

- Redox Boundary
- Silty Sand
- Dense Gray Till
- Sand Aquifer
Problem Statement:
Develop Better Injection Technology to Treat Contaminants in Clay

Method development partially funded by Danish government. Why?

- 40% Denmark covered in clay till.

Applicability in US and Canada:

Remediating low-permeability sites is a major challenge for US and Canadian Sites.

Source:
http://ftp.maps.canada.ca/pub/nrcan_rncan/publications/ess_sst/295/295462/gscgmr%5f195%5fb%5f2014%5fmm01pth.pdf
Jet Injection Compared to Traditional DPT Injections

- Injecting remediation amendment slurries using traditional direct push methods often results in uncontrolled fracturing of the subsurface.

- DPT Jet Injection overcomes this limitation.
DPT Jet Injection – How does it work?
DPT Jet Injection – How Does it Work?

Direct push tooling advancement
DPT Jet Injection – How Does it Work?

10,000 psi water jetting
DPT Jet Injection – How Does it Work?

10,000 psi water jetting

Path of jet cutting across saprolite
DPT Jet Injection – How Does it Work?

100 to 400+ psi slurry injection
Slurry contains solid proppant which is emplaced to create a reactive and more permeable zone.
Jet Injection – Treatment Concepts
Conceptual Model – Treatment with DPT Jet Injection

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Objective
CASE STUDY: Full-scale Source Treatment in Denmark
Case Study: Remedial Design

- 700 sq meter Target Treatment Area (TTA)
- 4 m design ROI
- 21 injection locations with 121 individual injections
- 5-7 discrete injection depths
- 50 tonnes mZVI (Hepure Ferox Flow)
- 25 tonnes sand

5 to 80 mg/kg VOCs (mostly TCE)
Case Study: Denmark – ZVI Distribution
Case Study: Surfacing

Surfacing limited to 4 known historical borings and 2 other locations during 121 injections.

Surfacing during slurry injection can be controlled!
Case Study – Lateral Fracture Distribution

• Advanced 80 borings in Target Treatment Area (TTA)

• Confirmed that we met our 4 m design ROI
Case Study: Tracing Single Fractures

Depth below ground surface (meters)

Distance from the injection point (meters)

- Distance 3 m
- Distance 2.5 m
- Distance 1.25 m
- Distance 0.25 m
- Distance 2 m
- Distance 4.7 m

Thickness 3 mm
Thickness 5 mm
Thickness 11 mm
Thickness 8 mm
Thickness 6 mm
Thickness 1 mm
METHODOLOGY

- 3D modeling (EVS software) was utilized to interpolate magnetic susceptibility (MS) readings.

- Interpolated MS readings >$1 \times 10^{-3}$ were generally co-located with visual identification of ZVI-filled fractures.
Case Study – 3-D Print of Distribution

Virtual 3-D Model (EVS)

3-D Printed Model
Demonstrated mZVI distribution, but what about VOC treatment?

- Groundwater sampling two times per year at ~13 well clusters (3 wells per cluster)
- Total VOC mass discharge analysis using transect method
- Soil sampling annually at ~14 locations
- Total VOC mass calculations using EVS
VOCs in Soil – 6, 18, 30, & 42 months Post-Treatment Profiles

Decreases in VOCs correlated with observed ZVI fracture depths
TCE in Soil – Baseline

![Graph showing TCE (mg/kg) vs. Depth (m bgs) for PRE mZVI (n = 315).]
TCE in Soil – Baseline vs Year 1

PRE mZVI (n = 315)  POST mZVI Y1 (n = 293)
TCE in Soil – Baseline vs. Year 2

PRE mZVI (n = 315)  POST mZVI Y2 (n = 435)
TCE in Soil – Baseline vs. Year 3

![Graph showing TCE VOC (mg/kg) vs. Depth (m bgs) for PRE mZVI (n = 315) vs. POST mZVI Y3 (n = 390).]

![Graph showing TCE VOC (mg/kg) vs. Depth (m bgs) for PRE mZVI (n = 315) vs. POST mZVI Y3 (n = 390).]
TCE in Soil – Comparison All Years

Depth (m bgs) vs. TCE VOC (mg/kg)

- PRE mZVI (n = 315)
- POST mZVI Y1 (n = 293)
- POST mZVI Y2 (n = 435)
- POST mZVI Y3 (n = 390)
- POST mZVI (n = 414)
Distribution of Total VOCs in Soil – Baseline to 4 years Post-Treatment

Nov 2014 (Baseline)  
- 67% Reduction in 6 months

June 2015  
- 58% Reduction in 18 months

June 2016  
- 78% Reduction in 30 months

June 2017  
- 85% Reduction in 42 months

June 2018
Distribution of Total VOCs in Soil – Baseline to 4 years Post-Treatment

3-D model shows decrease in magnitude and extent of Total VOCs in soil.

85% total mass decrease.
Distribution of Total VOCs in Soil – 4 years Post-Treatment

Remaining TVOC mass in soil is generally located in thin discrete layers.
Mass Discharge VOCs in Groundwater from TTA

92% Reduction in Total VOCs over 4 years

Downgradient Fenceline (S1/S2)

kg/yr (as TCE)

- TCE
- cis-DCE
- VC
- Ethene & Ethane
Mass Discharge VOCs in Groundwater from TTA

**Downgradient Fenceline (S1/S2)**

- **kg/yr (as TCE)**
  - 0.0
  - 0.5
  - 1.0
  - 1.5
  - 2.0
  - 2.5
  - 3.0
  - 3.5
  - 4.0

- **Months/Timepoints:**
  - Sept-Nov 2014
  - June 2015
  - Nov 2015
  - June 2016
  - Nov 2016
  - June 2017
  - Nov 2017
  - June 2018

- **VOCs:**
  - TCE
  - cis-DCE
  - VC
  - Ethane + Ethene
Case Study Conclusions – DPT Jet Injection in Denmark

• **Distribution of mZVI with DPT Jet Injection demonstrated be extremely effective in highly fractured clay till.**

  - Total TCE mass in soil decreased by 94% after 4 years.
  - Total VOC mass in soil decreased by 85% after 4 years.
  - Total VOC mass discharge in groundwater decreased by 92% after 4 years.
  - Increasing ethane/ethene concentrations demonstrate complete degradation (max. ethane conc. in 2018 = ~7 mg/L).
Thank you!