In Situ Remediation of Soil & Groundwater using Electrical Resistance Heating (ERH)

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CarbonFree™ Partner

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How Likely is Matrix Diffusion after ERH?

Fluorescein E into mixed heterogeneity system with low permeability layers

Prolonged diffusion of Fluorescein E from low permeability layers occurs
ERH Remediation Effectiveness

- *In situ* soil and groundwater – preferential heating
- All soil types including fractured rock
- VOCs and semi-VOCs
- Methylene chloride - PCE
- Solid grease or oil tar as NAPL
- Heating is rapid and uniform - no soil desiccation
- Proven safe and effective
- Greatest reduction, fastest time, lowest cost
- Polishing effect – no rebound
TRS ERH PROCESS

Saturated Zone

Sand

Clay

Bedrock

Groundwater Flow
Electricity is directed into the subsurface area.
In-Situ Steam Generation during ERH

Current flowing between electrodes heats soil directly.
In-Situ Steam Generation during ERH

Reductive dehalogenation creates a “halo” of chloride ions in CVO hot spots
In-Situ Steam Generation during ERH

Uniform soils would lead to parallel ERH current lines
– but soils aren’t uniform
In-Situ Steam Generation during ERH

Low permeability lenses and CVOC hot spots attract current
In-Situ Steam Generation during ERH

Regions with higher current density heat slightly more quickly.

Steam bubbles form more quickly at NAPL due to interfacial tension and reduced boiling temperatures.
Heat Enhanced Remediation Mechanisms

- Hydrolysis
- Iron reductive dechlorination
- Enhanced bioremediation
- Viscosity change - multi-phase extraction
- Phase change - vapor recovery
- Heat activated persulfate
ERH Surface Equipment

500 kW PCU

STEAM CONDENSER

OPERATING ELECTRODE

Photo Courtesy of Brown and Caldwell
Electrode Designs

- Vertically Bored
- Angled
- Sheet Pile
- Horizontal
ERH under operating industrial plant

ELECTRODE HEAD
Guaranteed fixed price remediation
Greater than 99% reduction of PCE
in soil samples.
ERH vs ISTD
Why Uniform Heating is More Efficient

ERH
99% VOC Reduction
95-105°C
ERH energy input causes a 99% reduction

ISTD
200-300°C
20-30°C
(thermal conduction heating)
99.9999%
99.9%
30%
ISTD energy: (99.9999%+99.9%+30%)/3 = 77% average reduction

Shown at equal energy inputs
Underneath Building
Tucker, GA

- MeCl, PCE, TCE, and DCE
- 16,360 ft², 2 to 20 ft bgs, 11,852 yd³
- Silty-clay saprolite
- Inside and below the existing facility
- GAC for vapor treatment
- Baseline levels (µg/kg): MeCl = 110,000, PCE = 17,000, TCE = 840, DCE = 560
- Remedial goals (µg/kg): MeCl = 80, PCE = 180, TCE = 130, DCE = 530

“Short duration + more effective source removal = quick closure”
Average Reduction in VOCs in Soil
Tucker, GA

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Pre-ERH</th>
<th>Post-ERH</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCE</td>
<td>2.6</td>
<td>0.02</td>
<td>99.8%</td>
</tr>
<tr>
<td>MeCl</td>
<td>4.1</td>
<td>0.0007</td>
<td>99.992%</td>
</tr>
<tr>
<td>TCE</td>
<td>2.5</td>
<td>0.06</td>
<td>96%</td>
</tr>
<tr>
<td>DCE</td>
<td>2.2</td>
<td>0.10</td>
<td>98%</td>
</tr>
<tr>
<td>Total</td>
<td>11.4</td>
<td>0.0011</td>
<td>99.98%</td>
</tr>
</tbody>
</table>
Results
Tucker, GA

- 250 days of ERH operations
- 60 of 61 soil samples were non-detect (one sample had 13 μg/kg PCE)
- Average 99.98% reduction total CVOCs
- ~ 175.6 lbs of total CVOCs removed (estimate was 20 lbs)
- ERH Impact for Property Owner = Net increase of $10M in the property due to lack of environmental restrictions
Property Transfer
Northwest Atlanta, GA

- Standard Fixed Price
- Methylen Chloride (MeCl) and Trichlorethene (TCE) in soil and groundwater
- Treatment area 19,730 ft²; depth 0 to 70 ft bgs; 18,000 yd³
- Saprolite clay to 31 ft bgs. Groundwater at 15 ft bgs
- 86 electrodes – project in 3 phases
- GAC for vapor treatment
- Baseline MeCl (avg): 2,000 mg/kg in soil; 1,350,000 μg/l in groundwater
- Remedial goal: MeCl: soil <1 mg/kg, groundwater 120 μg/l; TCE (dissolved phase) < 5 μg/l
Site Photos
Continued Decline in MeCL in Groundwater
2 Years Post ERH - NW Atlanta, GA - 2008

Average Methylene Chloride (μg/l)

Shallow ERH

Deep ERH

Jan-06 Jul-06 Jan-07 Jul-07 Jan-08 Jul-08 Jan-09 Jul-09 Jan-10 Jul-10 Jan-11

440,200 116,158 3,168 671 27 14

266,657 142,614 8,645 28 27 14 10

Shallow Wells (99.999%)

Deep Wells (99.996%)
Results
Northwest Atlanta, GA

- October 9, 2006 – September 11, 2008 (3 phases = 369 days)
- Majority of electrodes installed through concrete floor – no subsidence or vapor intrusion
- \( \approx 2,000 \) lb mass removed
- MeCl: soil reductions = 99.95%, groundwater = 99.997%
- TCE: below drinking water standards
VOC Remediation Under Active Manufacturing Facility
Lockheed Martin Airforce Plant 6 - Marietta, GA

- PCE, TCA, DCE and Xylene
- 4,400 ft², 2 to 20 ft bgs, 3,100 yd³
- Silty clay with fine to medium sands
- Groundwater, 18 ft bgs
- GAC for vapor treatment
- Baseline levels (mg/kg): 847 mg/kg total VOCs
- Remedial goals (µg/kg): Reduce total VOCs by 95% within 6 months
Average Reduction in VOCs in Soil

Concentrations in Soil (µg/kg)

- Tetrachloroethene
- Trichloroethene
- cis 1,2-Dichloroethene
- 1,1,1-Trichloroethane
- 1,1-Dichloroethene
- Methylene Chloride
- Total CVOCs

Pre-ERH vs 100% Sample Event
Results
Marietta, GA

- 180 days of ERH operations
- Soil samples taken at 70% completion reported 99.2% reduction
- Final sampling = 98.5% reduction total CVOCs
- ~ 900 lbs of total CVOCs removed (estimate was 90 lbs)
Common ERH Sites

### Remediation Parameters

- **Size**: 200 sq ft – 3 acres
- **Depth interval**: 0 – 135 ft bgs
- **Volume**: 300 – 200k yd³
- **Unsaturated and saturated**: Both
- **Days of operations**: 60 - 365
- **Electricity**: Average 96%
- **Reduction achieved**: 88% - 99.9999%
- **Price**: $350K - $2.4M
TRS ERH Summary

- Rapid in situ remediation of soil and groundwater
- Volatiles and semi-volatiles
- Under buildings and structures – occupied, public places
- Fixed price, performance guarantee
- Results – contaminant reduction, energy use
- Synergies - combining technologies
- Largest capacity in the world
- Greatest reduction, quickest time, lowest cost
- Polishing effect – continued decline – no rebound
QUESTIONS?

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