Electrical Resistance Heating
Technology Overview and NASA KSC Case Study
Mississippi Tier II Meeting, July 2017
Presentation Content

• ERH Technology Overview

• NASA Kennedy Space Center Case Study
  – Site Background
  – ERH Treatment Performance Monitoring
  – Lessons Learned
  – Path Forward
How does ERH work?
- Electrical current passes from electrode to electrode
- Soil resistance heats subsurface to boiling point of water/VOC mixture
- Boiled water/VOC mixture captured through vapor recovery in vadose zone
- Vapors and moisture in steam cooled and separated
- Vapors treated through activated carbon or catalytic oxidation

Effective in heterogeneous conditions and bedrock
Addresses source zone matrix diffusion
Dissolves natural organic material for post-ERH biotic treatment
Can be applied at a lower intensity to enhance natural attenuation in dilute plumes or induce thermal hydrolysis
Electricity is directed into the subsurface area.

Courtesy of TRS
Many VOCs form a positive heteroazeotropic mixture with water

What is a positive heteroazeotrope?
- a mixture where the equilibrium vapor and liquid compositions are equal at a given pressure and temperature
- the vapor has the same composition as the liquid and the mixture boils at a temperature other than that of the pure components’ boiling points (positive azeotrope = lower boiling point)
Hydrolysis of Halogenated Alkanes and Pesticides

Hydrolysis Rates of Pesticides

- trichloropropane (pH 7)
- trichloropropane (pH 9)
- dieldrin
- aldrin
- toxaphene
- lindane
- DBCP
- 1,3-dichloropropane
- 1,2-DBA (EDB)
- pentachlorophenol
- DDT
- DDD
Common ERH Misnomers

• Expensive
  • In certain settings, competitive to less costly than other source removal technologies
  • Selection of technology based on site specific evaluation
  • Cost is generally a function of volume and geometry
  • Temporal benefit of 6-9 month treatment durations

• Temperature is the goal
  • Steam production is the goal
  • Reducing mass concentrations is the goal

• Electrical conductivity of matrix matters
  • ERH equipment has large dynamic range across many conductivities

• Water is problematic
  • Water (or moisture) conducts electricity

• Vadose zone is challenging
  • Originally developed for the vadose zone

• Only for VOCs
  • Can treat compounds such as chlorinated compounds, pesticides, and energetic compounds
Site Background

- Site: NASA Kennedy Space Center, Components Cleaning Facility
- Area developed in 1962 for cleaning and refurbishment of hardware and an associated analytical laboratory
- Designated Solid Waste Management Unit 030
- Currently site is vacant (buildings demolished ~2006)
- Groundwater plume co-mingled with Area South of K7-0526, SMWU 100
- Located northeast of intersection of Crawler Parkway and Fluid Servicing Road
HS2 Site Characterization

- Source zone site characterization:
  - Source zone definition of ~1% TCE solubility (11 mg/L)
  - Investigated by DPT sampling with on-site mobile lab
  - General 10’ source zone DPT spacing
  - 5’ vertical spacing
    - Selective 1’ intervals in semi-confining unit
  - Membrane interface probe borings
- Semi-confining, fine-grained unit from 49 to 61 feet bgs
  - 76% of TCE HS mass within fine-grained unit
    - Conceptual model “Storage” or back-diffusion layer
  - 23% of TCE HS mass 10’ above fine-grained unit
    - Conceptual model advective layer

<table>
<thead>
<tr>
<th>Interval (ft bgs)</th>
<th>TCE Dissolved (lb)</th>
<th>TCE Sorbed (lb)</th>
<th>TCE Total (lb)</th>
<th>cDCE Dissolved (lb)</th>
<th>cDCE Sorbed (lb)</th>
<th>cDCE Total (lb)</th>
<th>VC Dissolved (lb)</th>
<th>VC Sorbed (lb)</th>
<th>VC Total (lb)</th>
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<td>0 - 10</td>
<td>0.6</td>
<td>1.1</td>
<td>1.8</td>
<td>0%</td>
<td>1.0</td>
<td>0.8</td>
<td>1.8</td>
<td>3%</td>
<td>0.2</td>
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<td>10 - 20</td>
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<td>4.2</td>
<td>6.5</td>
<td>0%</td>
<td>4.4</td>
<td>3.4</td>
<td>7.7</td>
<td>12%</td>
<td>1.8</td>
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<td>1.7</td>
<td>0%</td>
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<td>2.8</td>
<td>6.5</td>
<td>10%</td>
<td>2.7</td>
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<td>4.4</td>
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<td>9.8</td>
<td>11.9</td>
<td>21.7</td>
<td>35%</td>
<td>3.9</td>
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<tr>
<td>50 - 60</td>
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<td>1106.3</td>
<td>1235.2</td>
<td>76%</td>
<td>3.2</td>
<td>11.4</td>
<td>14.5</td>
<td>23%</td>
<td>2.1</td>
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<tr>
<td>&gt;60</td>
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<td>0.1</td>
<td>0.2</td>
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<td>0.0</td>
<td>0.1</td>
<td>0%</td>
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<td>Totals</td>
<td>232</td>
<td>1399</td>
<td>1631</td>
<td>28</td>
<td>35</td>
<td>62</td>
<td>14</td>
<td>7</td>
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# IM Components

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<tr>
<th>Quantity</th>
<th>Component</th>
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<td>19</td>
<td>Vertically-bored electrodes (3 elements per electrode)</td>
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<tr>
<td>10</td>
<td>Horizontal vapor extraction (VE) points</td>
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<td>7</td>
<td>Temperature monitoring points (TMPs)</td>
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<td>Vapor monitoring probes (VMPs)</td>
</tr>
<tr>
<td>1</td>
<td>700-kW power control unit (PCU)</td>
</tr>
<tr>
<td>1</td>
<td>Condenser and cooling tower skid</td>
</tr>
<tr>
<td>1</td>
<td>Vapor recovery blower skid</td>
</tr>
<tr>
<td>3</td>
<td>2,000 lb. Vapor-phase granular activated carbon (VPGAC) units</td>
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<tr>
<td>2</td>
<td>400 lb. Liquid-phase granular activated carbon (LPGAC) units</td>
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<tr>
<td></td>
<td>Electrode field vapor cover</td>
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<tr>
<td></td>
<td>Motion sensing and security camera system</td>
</tr>
<tr>
<td></td>
<td>Vinyl coated perimeter fencing</td>
</tr>
<tr>
<td></td>
<td>Electrical and potable water utilities</td>
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</table>
IM Timeline

• November 2015: Pre-mobilization Activities
• December 2015: Mobilization Activities
• January to April 2016: IM Installation
• May 2016: Commissioning and Startup
• May 2016 to February 2017: OM&M
• March to April 2017: Demobilization
CCF Mass Recovery and Influent PID Concentration

Influent Concentrations and Mass Removal
### Field Temperatures

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<tr>
<th></th>
<th>B3</th>
<th>C3</th>
<th>D4</th>
<th>E3</th>
<th>F3</th>
<th>F4</th>
<th>G4</th>
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<tr>
<td>5 ft</td>
<td>99.1°C</td>
<td>102.7°C</td>
<td>99.0°C</td>
<td>98.5°C</td>
<td>99.7°C</td>
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<td>99.9°C</td>
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<tr>
<td>10 ft</td>
<td>102.9°C</td>
<td>106.6°C</td>
<td>105.8°C</td>
<td>103.1°C</td>
<td>106.5°C</td>
<td>102.7°C</td>
<td>104.0°C</td>
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<tr>
<td>15 ft</td>
<td>107.8°C</td>
<td>109.2°C</td>
<td>110.5°C</td>
<td>108.9°C</td>
<td>109.2°C</td>
<td>104.5°C</td>
<td>106.6°C</td>
</tr>
<tr>
<td>20 ft</td>
<td>110.0°C</td>
<td>110.2°C</td>
<td>110.7°C</td>
<td>112.9°C</td>
<td>112.2°C</td>
<td>114.0°C</td>
<td>111.1°C</td>
</tr>
<tr>
<td>25 ft</td>
<td>112.3°C</td>
<td>111.6°C</td>
<td>114.3°C</td>
<td>115.1°C</td>
<td>116.4°C</td>
<td>114.5°C</td>
<td>113.7°C</td>
</tr>
<tr>
<td>30 ft</td>
<td>115.5°C</td>
<td>116.5°C</td>
<td>114.9°C</td>
<td>117.7°C</td>
<td>118.4°C</td>
<td>118.3°C</td>
<td>107.2°C</td>
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<tr>
<td>35 ft</td>
<td>112.0°C</td>
<td>119.0°C</td>
<td>116.5°C</td>
<td>119.4°C</td>
<td>118.8°C</td>
<td>117.2°C</td>
<td>117.6°C</td>
</tr>
<tr>
<td>40 ft</td>
<td>118.9°C</td>
<td>121.0°C</td>
<td>101.3°C</td>
<td>122.3°C</td>
<td>122.8°C</td>
<td>122.1°C</td>
<td>111.6°C</td>
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<tr>
<td>45 ft</td>
<td>122.7°C</td>
<td>124.0°C</td>
<td>119.8°C</td>
<td>123.0°C</td>
<td>126.6°C</td>
<td>122.7°C</td>
<td>120.7°C</td>
</tr>
<tr>
<td>50 ft</td>
<td>125.7°C</td>
<td>126.6°C</td>
<td>126.8°C</td>
<td>125.1°C</td>
<td>127.5°C</td>
<td>126.8°C</td>
<td>126.7°C</td>
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<tr>
<td>55 ft</td>
<td>128.2°C</td>
<td>128.5°C</td>
<td>122.0°C</td>
<td>128.7°C</td>
<td>129.7°C</td>
<td>126.8°C</td>
<td>124.5°C</td>
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<tr>
<td>60 ft</td>
<td>130.5°C</td>
<td>129.3°C</td>
<td>125.4°C</td>
<td>119.1°C</td>
<td>122.7°C</td>
<td>128.2°C</td>
<td>128.9°C</td>
</tr>
</tbody>
</table>

### PCU

- **Main Contactor** (Green = Open, Red = Closed)
- **Total Uptime:** 1445 Hours
- **Electrode Voltage:** 127 VAC
- **Electrode Total Power:** 780 kW

### Field Data

- **Field Vacuum:** -2.00 PSia
- **Manifold Temp "Condenser IN":** 80.6°C
- **Manifold Temp "Condenser OUT":** 36.6°C

### Blower OUT Data

- **Manifold Temp:** 64.6°C
- **Manifold Pressure:** 2.756” WC
- **Humidity:** 34.6 % R.H.
- **Air Flow:** 336 SCFM
Temperature Monitoring Data

5/5/2016

Temperature Data Video

Note: Horizontal TMP distances not scaled.
Performance Monitoring

- Hot sampling techniques utilized
  - Stainless steel cooling coil in ice bath for sample cooling
  - Artesian conditions due to the difference in formation pressure/temperature at depth; traditional DPT methods were not used
  - Waterloo profiler with adaptive sample approach (focused sampling in 1’ increments)
- 3-man drill crew allowed resting and engineering controls to manage heat stress
- Sampling intervals and optimized based on data from round to round
Baseline DPT Sampling Results
TCE EVS Plumes, Baseline
TCE EVS Plumes, February 2017

TCE (02/2017): 3 µg/L
TCE (02/2017): 300 µg/L
TCE (02/2017): 11,000 µg/L
TCE (02/2017): 100,000 µg/L
TCE (02/2017): 300,000 µg/L
Baseline, November 2015

August 2016

November 2016

February 2017

EVS Depth Layers – 50 feet bls
Baseline, November 2015

August 2016

November 2016

February 2017

EVS Depth Layers – 55 feet bls
<table>
<thead>
<tr>
<th>PM DPT # (DPT-0)</th>
<th>Max TCE PM Result (µg/L)</th>
<th>Baseline DPT # (DPT-0)</th>
<th>Baseline TCE Result (µg/L)</th>
<th>% TCE Concentration Reduction</th>
<th>Orders of Magnitude Reduction</th>
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<tbody>
<tr>
<td>479</td>
<td>4</td>
<td>433</td>
<td>203,000</td>
<td>99.998%</td>
<td>4.7</td>
</tr>
<tr>
<td>480</td>
<td>230</td>
<td>434</td>
<td>459,000</td>
<td>99.950%</td>
<td>3.3</td>
</tr>
<tr>
<td>481</td>
<td>27</td>
<td>435</td>
<td>383,000</td>
<td>99.993%</td>
<td>4.2</td>
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<tr>
<td>482</td>
<td>130</td>
<td>436</td>
<td>1,430,000</td>
<td>99.991%</td>
<td>4.0</td>
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<tr>
<td>486</td>
<td>270</td>
<td>439</td>
<td>443,000</td>
<td>99.939%</td>
<td>3.2</td>
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<tr>
<td>487</td>
<td>2</td>
<td>393</td>
<td>241,000</td>
<td>99.999%</td>
<td>5.1</td>
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<td>441</td>
<td>116,000</td>
<td>99.999%</td>
<td>5.1</td>
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<td>431</td>
<td>40,000</td>
<td>99.933%</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Average % Reduction (of >100 ppm baseline locations): 99.981%

Average % Reduction (of <100 ppm baseline locations): 99.808%

Average % Reduction (overall): 99.918%
Lessons Learned

- Site conditions can change from investigation to design
  - Ensure the installation is appropriate for site conditions
  - DPT baseline sampling resulted in revision of treatment area and +2 electrodes
- Advocate $f_{oc}$ soil data in source area
  - orders of magnitude sensitivity in mass estimates
- Sonic electrode installation significantly reduced waste
  - Minimal drilling spoils; soil displaced outward in boring
  - Liquid IDW treated and discharged onsite with mobile air stripper
- Effective communication with facility and project stakeholders is paramount
- Continuous data review and subcontractor interaction an important aspect of efficiently optimizing ERH performance
- High resolution site monitoring provided effective optimization tools
- Performance based contract an effective risk management resource to secure key subcontractors to objectives
  - Without performance guarantee to ERH subcontractor, typical ERH contracts are based on subsurface energy delivery or temperature targets. In those cases, site objectives to $<$NADC levels (e.g., $<$300 ppb TCE) may not be accomplished.
Conclusions and Path Forward

- IM successfully removed TCE source zone and contaminant mass in fine grained and overlying units
- Operations terminated based on confirmation DPT sampling results and secondary lines of evidence such as temperature, mass removal trends, etc.
- Source zone transitioning to MNA
- Air sparging treatment planned for surrounding dilute plume

Thank you! Questions?

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