In-Situ Chemical Oxidation of TCE in Clay Using Rotating Dual Axis Soil Blending Technology

RemTech October 17-19, 2012

WILL CALDICOTT ISOTEC
ISCO at High Concentration Source Area Sites

• Generally effective in treating COCs (dissolved phase and lower concentration chemicals)

• Most effective in treating higher permeability soil types

• Limited effectiveness in treating NAPL, viscous products, and coal tar

• Success or failure of ISCO treatment is largely dependent on:
  – Sound conceptual site model
  – Development of site-specific treatment goals
  – Oxidant type
  – Reagent delivery method
  – Contact of chemical reagent with COCs
Traditional Subsurface Delivery Methods

• Direct Injection
  – Temporary injection points (e.g., DPT borings, Geoprobe®)
  – Fixed injection wells (e.g., screened wells)
  – Bedrock injection wells (e.g., inflatable isolation packers)
  – Trenches and horizontal well systems

• Soil Mixing
  – Backhoe methods
  – Auger methods
ISCO Application Challenges in Source Areas

• High concentration sites often require large quantities of reagent:
  » **HIGH** oxidant demand = **LARGE** oxidant volume
  » Numerous injection rounds are typically required

• Reagent delivery by injection is limited by soil pore space
  – Difficult injecting large oxidant volume

• Reagent short-circuiting/ surfacing

• Contaminant displacement

• **Reagent contact with COC is critical**
Auger Mixing Unit
Detail of Auger
Key components and benefits

• Dual–axis rotation (optimal soil mixing performance)
• Reagent application at point of mixing (maximize chemical contact)
• Large amounts of reagent introduced in a single application
• Control of chemical dosing
• Appropriate for most soil, COC, and oxidant types
Dual Axis Soil Blending Technology

- Site conditions favorable for technology
  - Variable soil types
  - Shallow or moderately deep soil and groundwater impacts
  - Dissolved fraction and higher concentration contaminants (COC < $C_{\text{sat}}$)

- Less favorable site conditions
  - Limited working space availability
  - Bedrock/ subsurface obstructions
  - Significant NAPL (COC > $C_{\text{sat}}$)
Technology Considerations

• Persulfate corrosion testing
### Design and Implementation Techniques

#### Example of reagent distribution plan and treatment grid

|   | A   | B   | C   | D   | E   | F   | G   | H   | I   | J   | K   | L   | M   | N   | O   | P   | Q   | R   | S   | T   | U   |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 |     |     |     |     |     |     |     |     |     |     |     |     | 10 ft x 10 ft Treatment Cells |     |     |     |     |     |     |
| 2 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 3 |     |     |     |     |     |     |     |     |     |     |     |     |     | SP 278 Na 196 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 586 Na 394 | SP 586 Na 394 | SP 388 Na 200 | SP 776 Na 399 | SP 776 Na 399 | SP 841 Na 432 | SP 933 Na 442 | SP 933 Na 442 |
| 4 |     |     |     |     |     |     |     |     |     |     |     |     | SP 278 Na 196 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 776 Na 399 | SP 776 Na 399 | SP 776 Na 399 | SP 841 Na 432 | SP 933 Na 442 | SP 933 Na 442 |
| 5 |     |     |     |     |     |     |     |     |     |     |     |     | SP 278 Na 196 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 776 Na 399 | SP 776 Na 399 | SP 776 Na 399 | SP 841 Na 432 | SP 933 Na 442 | SP 933 Na 442 |
| 6 |     |     |     |     |     |     |     |     |     |     |     |     | SP 278 Na 196 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 776 Na 399 | SP 776 Na 399 | SP 776 Na 399 | SP 841 Na 432 | SP 933 Na 442 | SP 933 Na 442 |
| 7 |     |     |     |     |     |     |     |     |     |     |     |     | SP 278 Na 196 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 776 Na 399 | SP 776 Na 399 | SP 776 Na 399 | SP 841 Na 432 | SP 933 Na 442 | SP 933 Na 442 |
| 8 |     |     |     |     |     |     |     |     |     |     |     |     | SP 278 Na 196 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 776 Na 399 | SP 776 Na 399 | SP 776 Na 399 | SP 841 Na 432 | SP 933 Na 442 | SP 933 Na 442 |
| 9 |     |     |     |     |     |     |     |     |     |     |     |     | SP 278 Na 196 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 776 Na 399 | SP 776 Na 399 | SP 776 Na 399 | SP 841 Na 432 | SP 933 Na 442 | SP 933 Na 442 |
| 10|     |     |     |     |     |     |     |     |     |     |     |     | SP 278 Na 196 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 776 Na 399 | SP 776 Na 399 | SP 776 Na 399 | SP 841 Na 432 | SP 933 Na 442 | SP 933 Na 442 |
| 11|     |     |     |     |     |     |     |     |     |     |     |     | SP 278 Na 196 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 776 Na 399 | SP 776 Na 399 | SP 776 Na 399 | SP 841 Na 432 | SP 933 Na 442 | SP 933 Na 442 |
| 12|     |     |     |     |     |     |     |     |     |     |     |     | SP 278 Na 196 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 776 Na 399 | SP 776 Na 399 | SP 776 Na 399 | SP 841 Na 432 | SP 933 Na 442 | SP 933 Na 442 |
| 13|     |     |     |     |     |     |     |     |     |     |     |     | SP 278 Na 196 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 510 Na 359 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 586 Na 394 | SP 776 Na 399 | SP 776 Na 399 | SP 776 Na 399 | SP 841 Na 432 | SP 933 Na 442 | SP 933 Na 442 |

**Pre-Treatment VOC Concentration**

- <7,000 ppb
- 7,000-20,000 ppb
- >20,000 ppb
- >25,000 ppb
Dual Axis Soil Blending Technology

- Control of blending location with GPS
- On-board GPS with 3-D visualization
Health and Safety

- Operator communication – overcoming equipment noise
- Hazardous chemicals – handling and management of chemicals and daily residuals
Site Preparation – Overburden Removed & Stockpiled
Site Preparation – Dike Construction
Example of Clay Soil
Dual-Axis Mixer
Mixing Unit Treating in Deep Zone
Mixing Unit Treating in Deep Zone, cont.
Mixing Unit Treating in Deep Zone, cont.
Mixing Unit Treating in Deep Zone, cont.
Design and Implementation Techniques

• Soil treatment verification sampling
Decision Factors Affecting Performance

- Real-time soil treatment verification sampling
- Adjusting mixing duration and/or reagent dosage

- Soil management
- Chemical supply logistics
- Chemical mixing quality control
Backfilling Stockpiled Overburden
Technology Considerations

• Re-blending limitations
• Large rocks or boulders

• Poor drainage in fine-grained soil (ponding of water and chemical reagents)
• Soil expansion
• Post-blending soil structure – site redevelopment considerations
Underground Obstructions Result in Maintenance
Underground Obstructions Result in Lost Time
Soil Blending/Mixing Effectiveness

Soil Void Ratio Comparison
Pre-Blending vs. Post Blending

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<tr>
<th>Void Ratio</th>
<th>Clay Pre-Blending</th>
<th>Clay Post-Blending</th>
<th>Clay Pre-Blending</th>
<th>Clay Post-Blending</th>
<th>Clay Pre-Blending</th>
<th>Clay Post-Blending</th>
<th>Sand Post-Blending</th>
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Soil Blending/Mixing Effectiveness

Pre-blending Soil Porosity

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<th>Clays</th>
<th>Clays</th>
<th>Clays</th>
<th>Sand</th>
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### Treatment Design Matrix & Introduced Reagent Volumes

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<tr>
<th>Date</th>
<th>Klozur (lbs.)</th>
<th>Persulfate (Gallons)</th>
<th>Activator (Gallons)</th>
<th>Cell Locations</th>
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<td>4,653</td>
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<tr>
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<td>7,454</td>
<td>5,228</td>
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</table>

**Note:**
- **Klozur lbs.** = Pounds of FMC Klozur (sodium persulfate powder) utilized per day within 15% liquid sodium persulfate mixture.
- **Persulfate** = Volume of liquid sodium persulfate solution (~15%) consisting of water, FMC Klozur (dry powder) and sodium hydroxide activator (~20-25% concentration), that was mixed/blended into the treatment cells.
- **Activator** = Volume of sodium hydroxide (~20-25% concentration) solution that was mixed/blended into the treatment cells after sodium persulfate solution was mixed/blended into the treatment cells.
- **Cell Locations** = ID locations of the treatment cells that were mixed/blended on that given day.
# TCE Remediation Results Using Dual Axis Soil Blending Technology

<table>
<thead>
<tr>
<th>Boring Location</th>
<th>Sample ID</th>
<th>Sample Collection Date</th>
<th>Sample Depth Interval (feet bgs)</th>
<th>TCE (ug/kg)</th>
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</tr>
<tr>
<td></td>
<td>VS12B</td>
<td>2/21/2012</td>
<td>8 10</td>
<td>&lt;30</td>
</tr>
<tr>
<td>MW-3PR</td>
<td>MW-3PRA</td>
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<td>2 4</td>
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<td>MW-3PRB</td>
<td>2/20/2012</td>
<td>11 13</td>
<td>43 J</td>
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<tr>
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<td>MW-3PRC</td>
<td>2/20/2012</td>
<td>25 27</td>
<td>&lt;29</td>
</tr>
</tbody>
</table>

**Notes:**
- **TCE** trichloroethylene
- **ug/kg** micrograms per kilogram
- **J** Results reported between the Method Detection Limit and Limit of Quantitation
- **bgs** Below ground surface (post remediation elevations)
- Clay unit depth is 0 to 15 ft bgs and lower sand unit is greater than 15 ft

Concentration in bold exceeds the cleanup goal of 1,500 ug/kg established based on direct contact criteria.

All samples were analyzed for the full VOC suite.
Only TCE was detected above laboratory detection limits.
### TCE Remediation Results Using Dual Axis Soil Blending Technology

#### Pre-Remediation TCE Soil Concentrations

<table>
<thead>
<tr>
<th>Boring Location</th>
<th>Sample Collection Date</th>
<th>Sample Depth Interval (Elevation in ft msl)</th>
<th>TCE (ug/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B-26</td>
<td>10/16/2007</td>
<td>829.3-827.3</td>
<td>&lt;32</td>
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<tr>
<td>TB2P</td>
<td>11/13/2000</td>
<td>820.3-818.3</td>
<td>1680</td>
</tr>
<tr>
<td>None</td>
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<td>-</td>
</tr>
<tr>
<td>B-34</td>
<td>10/17/2007</td>
<td>837.24-835.24</td>
<td>2800</td>
</tr>
<tr>
<td>GP-7</td>
<td>1/25/2000</td>
<td>833.23-831.23</td>
<td>6880</td>
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<tr>
<td>None</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B-22</td>
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<td>831.128-829.128</td>
<td>140000</td>
</tr>
<tr>
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<td>1/25/2000</td>
<td>821.26-819.26</td>
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<td>836.16-835.16</td>
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<td>7/26/2007</td>
<td>831.438-829.438</td>
<td>2400</td>
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<tr>
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<td>-</td>
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<tr>
<td>B-68</td>
<td>7/16/2010</td>
<td>830.16-829.16</td>
<td>12000</td>
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<tr>
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</tr>
<tr>
<td>B-73</td>
<td>1/25/2000</td>
<td>837.16-835.16</td>
<td>24500</td>
</tr>
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<td>GP-1</td>
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<td>821.16-819.16</td>
<td>18500</td>
</tr>
<tr>
<td>B-67</td>
<td>8/20/2010</td>
<td>836.16-835.16</td>
<td>1500</td>
</tr>
<tr>
<td>B-72</td>
<td>8/19/2010</td>
<td>836.16-835.16</td>
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<tr>
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<tr>
<td>B-31</td>
<td>10/16/2010</td>
<td>837.18-829.18</td>
<td>1100</td>
</tr>
<tr>
<td>MW-3P</td>
<td>4/25/2000</td>
<td>816.32-814.32</td>
<td>27500</td>
</tr>
</tbody>
</table>

#### Notes:
- ug/kg: micrograms per kilogram
- J: Results reported between the Method Detection Limit and Limit of Quantitation
- ft msl: Feet above mean sea level.
- Concentration in bold exceeds the cleanup goal of 1,500 ug/kg established based on direct contact criteria.
- NA: Not applicable; no pre-remediation soil samples collected at similar location and/or depth.
- NC: No change; both pre- and post-remediation samples were below laboratory detection limits.
- Average pre-remediation ground surface elevation was approximately 840 ft msl.
- For the purposes of this comparison, a elevation variation of less than 4 feet was used for comparing pre- and post-remediation TCE concentrations.
- Negative % change reflects a reduction in concentrations when comparing pre- and post-remediation TCE concentrations.

Where the TCE concentration was less than the detection limit, the detection limit was used to calculate the reduction.
TCE Remediation Results Using Dual Axis Soil Blending Technology

• Average TCE concentration in upper clay reduced from 13,300 ug/kg to 84 ug/kg
• Up to 99.4% mass reduction in TCE from pre-remedial estimates in upper clay soil
• Average TCE concentration in lower sand reduced from 10,200 ug/kg to 321 ug/kg
• Up to 96.3% mass reduction in TCE in lower sand unit
• Met TCE mass reduction goal established for site (>95%)
• 36 out of 37 post-remediation soil verification samples were below the treatment goal of 1,500 ug/kg TCE
## Cost of Dual-Axis Blending Technology

Example for ~15,000 CY soil treatment volume using alkaline activated sodium persulfate (2011)

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Cost Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soil Blending</strong></td>
<td></td>
</tr>
<tr>
<td>&lt; 15 feet depth (no soil excavation)</td>
<td>$38 to $40/ yd³</td>
</tr>
<tr>
<td>&gt; 15 feet and &lt; 30 ft depth (with soil excavation)</td>
<td>$43 to $46/ yd³</td>
</tr>
<tr>
<td><strong>Chemical Reagents (Alkaline activated sodium persulfate)</strong></td>
<td></td>
</tr>
<tr>
<td>Klozur ® Sodium Persulfate</td>
<td>$1.90 to $2.10/ lb</td>
</tr>
<tr>
<td>50% Sodium Hydroxide Solution</td>
<td>$3.00 to $4.00/ gallon</td>
</tr>
<tr>
<td>Municipal Water</td>
<td>$0.35 to $0.45/ yd³ of soil treated</td>
</tr>
<tr>
<td><strong>Equipment Mobilization and Demobilization</strong></td>
<td></td>
</tr>
<tr>
<td>~400 mi radius</td>
<td>$30,000 to $40,000</td>
</tr>
<tr>
<td><strong>Ancillary Project Costs</strong></td>
<td></td>
</tr>
<tr>
<td>Sediment and Erosion Controls</td>
<td>$1,500 to $2,000/ acre</td>
</tr>
<tr>
<td>Temporary facilities, perimeter fencing, decon pad</td>
<td>$1.00 to $1.25/ sq. ft of treatment area</td>
</tr>
<tr>
<td>Site grading, topsoil placement, seeding and mulch</td>
<td>$10,000 to $12,000/ acre</td>
</tr>
</tbody>
</table>
Observations/Lessons Learned

• Site planning is critical

• Requires application flexibility
  – Adjust dosing rates based on field/laboratory test results
  – Soil management

• May require significant mixing water to be added – delays site restoration

• Resulting soil structure will make redevelopment efforts more complex

• Schedule should allow for downtime (e.g. large boulders break teeth on rotating mixer head)

• Customized sampling equipment/techniques are beneficial

• Odor controls must be considered at some sites

• Reagent contact with COCs is maximized!
Site Conditions Post Treatment
Thank You

Acknowledgements
Scott Tarmann
Prasad Kakarla
Ed Brady