Remedial Screening of Horizontal Injection Wells and Vertical Injection Wells for In-Situ Chemical Oxidation (ISCO) of Petroleum Hydrocarbons

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Presentation Overview

• Chemical Oxidation
  – What is it?
  – What are reactions?
  – What type of equipment is needed?

• Performing Effective Injections
  – What are concerns?
  – How are concerns mitigated?

• Case Studies
Experience with ISCO

California, Connecticut,
Delaware, Georgia, Florida,
Illinois, Louisiana, Maryland,
Michigan, Mississippi, New
York, New Jersey, Ohio,
Pennsylvania, Texas, Virginia
and West Virginia
Example: Remedial Alternatives

• **Multi-Phase Extraction Events**
  – did not effectively remove contaminant mass

• **Natural Attenuation**
  – not feasible, concentrations too high

• **Excavate Soil**
  – limited space, proximity to buildings, potential soil exposure

• **In-Situ (or in place) Chemical Oxidation (ISCO)**
  – Pilot Test approved by regulatory agency
In-Situ Chemical Oxidation

ISCO is where oxidants are introduced into subsurface to chemically oxidize contaminants into harmless substances. Some oxidants include:

- Permanganate (MnO$_4^-$)
- Fenton’s (hydrogen peroxide [H$_2$O$_2$] and Ferrous iron [Fe$^{+2}$]) or catalyzed hydrogen peroxide (CHP)
- Ozone (O$_3$)
- Persulfate (S$_2$O$_8^{2-}$)

Oxidants + Petroleum Compounds (carbon) $\rightarrow$ CO$_2$ + H$_2$O

Note: Once oxidants are injected via injection wells, monitoring surrounding wells will gauge effectiveness

**Will it work on my site?**
1. Hydrogen peroxide will react with iron to form hydroxyl radicals:

\[ \text{H}_2\text{O}_2 + \text{C} \rightarrow \cdot\text{OH} + \text{OH}^- + \text{C}^+ \]

\(\text{C} = \text{Iron or Metal Catalyst; OH} = \text{Hydroxyl Radicals}\)

2. Hydrogen peroxide will react with persulfate to form sulfate radicals and hydroxyl radicals:

\[ \text{S}_2\text{O}_8^{2-} + \text{H}_2\text{O}_2 \rightarrow 2\text{SO}_4\cdot + 2(\cdot\text{OH}) \]

3. Hydrogen peroxide will react with ozone to form hydroxyl radicals:

\[ 2\text{O}_3 + \text{H}_2\text{O}_2 \rightarrow 2(\cdot\text{OH}) + 3\text{O}_2 \]

Note: Addition of persulfate can lower local pH, which will enhance first and second chemical reactions above.
## Oxidation Potential

<table>
<thead>
<tr>
<th>Oxidizing Species</th>
<th>Oxidation Potential (Volts)</th>
<th>Relative Oxidation Power (Chlorine as reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroxyl Radical</td>
<td>2.80</td>
<td>2.05</td>
</tr>
<tr>
<td>Activated Persulfate</td>
<td>2.60</td>
<td>1.88</td>
</tr>
<tr>
<td>Ozone</td>
<td>2.07</td>
<td>1.52</td>
</tr>
<tr>
<td>Persulfate</td>
<td>2.01</td>
<td>1.46</td>
</tr>
<tr>
<td><strong>Hydrogen Peroxide</strong></td>
<td><strong>1.77</strong></td>
<td><strong>1.30</strong></td>
</tr>
<tr>
<td>Perhydroxyl Radical</td>
<td>1.70</td>
<td>1.25</td>
</tr>
<tr>
<td>Permanganate</td>
<td>1.69</td>
<td>1.24</td>
</tr>
<tr>
<td>Chlorine</td>
<td>1.38</td>
<td>1.00</td>
</tr>
<tr>
<td>Oxygen</td>
<td>1.20</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Ref: Solvey Interox., Hydrogen Peroxide, Fenton’s Reagent, 6/93
Example Site: Horizontal Wells

- Typical highway utility crossing
- Traffic was not disrupted
Example Site: Horizontal Wells

- Access inside this government facility was denied
Example Site: Horizontal Wells

- Traditional vertical equipment could not fit in tight spacing
Example Site: Horizontal Wells

- Typical utility installation
  - Traffic was allowed to continue
  - Pristine urban revitalization was preserved
Example Site: Horizontal Wells

Fast track environmental project required mandatory cleanup
$40 Billion project in South Korea
Example Site: Horizontal Wells

Site constraints – wells had to terminate within property boundaries
Example Site: Horizontal Wells

- Social Impacts
- Tight Set-Up Areas
Horizontal vs. Vertical

- HRWs can run parallel or perpendicular to the plume
- HRWs can run through the plume, under the plume or over the plume
- HRW can curve to follow the plumes path
- HRWs can get right to the source
- Smear Zone
- HRWs can use a variety of well materials
Ground Conditions

- Have to think linear – not point to point
- What can happen bgs over 450’ or 1,000’ of well screen
- Change in the geology
- Be prepared for a change in the geology with horizontal drilling and well placement
- Obstacles – left, right, up, down
- Change in the groundwater table
Site Conditions/Restraints

HRW vs Vertical Wells

• Wire line locating technology can be used if access to the building is not possible
• Small compact directional drilling rigs can accommodate sites with low ceiling clearance
• HRWs can be installed from discrete locations so that commercial activities can continue
• Minimum site restoration is required
• Fewer if any conveyance lines are needed
Site Conditions/Restraints

**HRW vs Vertical Wells**

- Horizontal Remediation Well requirements
  - 5:1 ratio to achieve depth
  - Can overcome this with design modifications
  - Entry/Exit well or blind well
  - No room for exit point will require blind well
Case Study

- Release history – multiple UST releases
- Remediation history – mass excavation, but significant impacted material left
- Recontamination of site from residuals
Selecting the Remedy

Feasibility Study Assessed:
- Excavation
  - Cost prohibitive – business interruption losses alone would exceed $10K per day
  - No guarantee of achieving NFA
Selecting the Remedy

• Feasibility Study Assessed:
  • Proven technology
  • Suitable for site’s subsurface conditions
  • Business interruptions reduced to loss of one dispenser island during vertical system installation

— Decision: select AS/SVE
Vertical AS/SVE System

Conceptual Layout

- 10 vertical wells with sufficient ZOI overlap to cover the entire impacted area
- Projected time to NFA: 3-5 years
Vertical AS/SVE System Costs

- Well installation: $300K – approximately half ($150K) for soft-dig trenching for interconnecting piping
- Treatment system: $100K
- 5 years O & M @ $40K/yr.: $200K
- Total estimated project life cycle costs: $600K
- Estimated lost business revenue due to dispenser island shutdown: $7.5K/day X 15 days = $112.5K
Cost Assessment

- Client’s lost business revenue due to dispenser island shut-down of approximately $112.5K was intolerable
- Cannot justify a $150K expenditure for soft-dig trenching for interconnecting piping
Technology Reassessment

- How to implement a remedy without shutting down the business?
- Solution: Horizontal Remediation Wells
3 Horizontal Remediation Wells
- 2 HRWs along north and south flanks of plume – overall length 175 ft.; screen length 135 ft.
- 1 HRW well between the 2 HRWs wells along plume centerline – overall length 175 ft.; screen length 135 ft.
- 3” diameter Sch. 40 PVC
- Blind completions
Site Design
Horizontal Remediation Well

Estimated Installation Cost

- $150K, including well screen design, materials, mob/demob, well installation, well development
Horizontal AS/SVE System Costs

- Well installation: $150K
- Treatment system: $100K
- 1 year O & M @ $40K/yr.: $40K
- Total project life cycle costs: approx. $290K
- Avoided costs:
  - $150K soft-dig trenching
  - $160K O & M (4 years)
- Total savings: approx. $210K
- Avoided business loss: $112.5K
## Cost Summary

<table>
<thead>
<tr>
<th></th>
<th>Horizontal Wells</th>
<th>Vertical Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well Installation</td>
<td>150,000</td>
<td>300,000 includes trenching</td>
</tr>
<tr>
<td>Treatment</td>
<td>100,000</td>
<td>100,000</td>
</tr>
<tr>
<td>O &amp; M : 1\textsuperscript{st} year</td>
<td>40,000</td>
<td>40,000</td>
</tr>
<tr>
<td>2\textsuperscript{nd} year</td>
<td>0</td>
<td>40,000</td>
</tr>
<tr>
<td>3\textsuperscript{rd} year</td>
<td>0</td>
<td>40,000</td>
</tr>
<tr>
<td>4\textsuperscript{th} year</td>
<td>0</td>
<td>40,000</td>
</tr>
<tr>
<td>5\textsuperscript{th} year</td>
<td>0</td>
<td>40,000</td>
</tr>
<tr>
<td>Total estimated life cycle project costs</td>
<td>$290,000</td>
<td>$600,000</td>
</tr>
<tr>
<td>Interruption of business</td>
<td>0</td>
<td>$112,500</td>
</tr>
</tbody>
</table>
Summary

• Avoided approximately $290K in program costs
• Avoided at least $100K in lost revenue for client by allowing business to continue during remedial construction
• Avoided street closures and police details
• Cleaned up site in 1 year vs. 5 years
ISCO Evaluation

Remediation Cost Options Over Time

- Hydrogen Peroxide
- Ozone
- Ozone + Hydrogen Peroxide
- Sodium Persulfate

Directional Technologies, Inc
Horizontal Drilling Services
Planning
Planning

Chemical Management Persulfate
Planning

Chemical Management Tankers
**SUBSURFACE REACTIONS**

**Constantly monitor injection process**
- Volume, flow and pressure of oxidants

**Constantly monitor subsurface effects**
- Groundwater levels, pH, temperature, ORP, DO and oxidant concentrations
- PID, % LEL and % O₂

**During injections, vacuum applied to well closest to injection point**
- Recovers any potential vapors, if any
- Vapors treated via carbon, as necessary
Case Study: HRW Injection
Conceptual Model

- Site Soils: Silty Sand to 65 feet
- Groundwater Flow Rate: 0.2 to 0.4 fpd
- Low Soil Oxidant Demand: 1.5 to 2.0 g/kg
- Contaminated Groundwater Zone: ≈25 to 55 feet bgs
Plume Cross-Section
Horizontal Well Design Layout
Horizontal Screen Design

- Modeling to achieve uniform distribution of oxidant through length of well screen
- 3D finite difference flow and transport model to design screen pattern
- MODFLOW
- Design specifies percent open area of well screen to generate uniform distribution
Horizontal Screen Design

- Model simulates injection fluid moving down the well, through screen slots, and into and through formation.

- Open area requirements for well screens ranged from 0.0357 to 0.0429 percent open area.

- Required number of slots were calculated for each length of screen at slot width of 0.02-inch.
Horizontal Well Installation

- Design: 7 rows of Horizontal Remediation Wells
- Some rows used two wells at various depths (≈30 and 40 feet bgs)
- Installation completed in 35 days (3,870 feet of drilling)
ISCO 1st Injection Event

- Injection into 10 Horizontal Wells (total of 2,330 feet of screen)
- Flow Rate: 11.7 GPM per well (average)
- Batch Process: 10,000 Gallons per Batch
- Injection Time: 85 Minutes per Batch
- ISCO 1st Injection Event: 340,000 gallons
Oxidant Mixing Station
ISCO 2nd Injection Event

- ISCO 2nd Injection Event: 1,032,333 gallons
- Average Injection Rate: 38,235 gallons per 10-Hour Shift
- Maximum Injection Rate: 55,000 gallons in 10-Hour Shift
- 81 Tons of Oxidant Chemicals Injected in 26 Days
Oxidant Distribution at Initiation of Injection
Oxidant Distribution at 90 Days After Injection
Concentration Reductions

• Source Area MWs
  Pre-Treatment Concentrations: as high as 13,000 ppb
  Post-Treatment Concentrations: from ND to 400 ppb

• Downgradient MWs
  Pre-Treatment Concentrations: as high as 8,000 ppb
  Post-Treatment Concentrations: from ND to 1,840 ppb
Summary of Advantages: Horizontal Remediation Wells

- Length of screen allows for higher volume injections
  - faster, less costly injection process
- Reduces effect of oxidant clogging
- Allow injections in areas where streets, utilities and buildings interfere with vertical wells
- HRWs are typically more effective than vertical wells
- HRWs are flexible technology that allows for many possible designs, applications and combinations
- Traditional vertical remedies can be transferred to HRWs
Questions?

Founded in 1992, Directional Technologies, Inc. has installed over 1,000 horizontal remediation wells throughout the world.

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