Integration of Chemical and Biological Technologies for Remediation of Contaminated Soil and Groundwater

Leonard Chan, M.Sc

Canada Colors and Chemicals Limited
About Canada Colors

- Sole Distributor for Regenesis Products in Canada
- Largest independent distributor in Canada
- Full service provider of over 5,000 commodity and specialty products
  - Environmental & Water Treatment
  - Industrial Solvents
  - Food and Fine chemicals
  - Coatings & Polymer additives
  - Oil & Gas
  - Soap & Detergent
  - Mining
  - Pulp & Paper
In-Situ Chemical Oxidation (ISCO)

- Chemical oxidation reaction involves the breaking of chemical bonds and the removal of electrons
- Electrons are transferred from the contaminant to the oxidant
- The contaminant is oxidized and the oxidant (electron acceptor) is reduced
Bioremediation

• The process of using microorganisms, fungi, or enzymes to treat environmental contaminants

• Aerobic degradation
  — BTEX, TPH, PAHs

• Anaerobic degradation
  — PCE, TCE, DCE, TCA, DCA

• Biostimulation: the addition of nutrients to stimulate bioremediation
**In-Situ Remedial Design**

- Oxidants or substrates typically injected using direct-push equipment
- Spacing of injection points is dependent on:
  - Geology
  - Plume Size
  - Product
- Product is injected across the vertical length of the contaminated saturated zone
  - Include the smear zone
- When treating soil, spacing must be closer and water should be added
  - Water is the transport medium
A key to success...

CONTACT!
RegenOx™
CHEMICAL OXIDATION REDEFINED...

Part A: Sodium Percarbonate
Part B: Catalyst and Silica
Oxidizer Complex

Activator Complex

Contaminant Oxidation

Oxidizer Complex

Contaminant
ORC releases oxygen in the subsurface over a period of a year
- Oxygen is used by microorganisms in the aerobic degradation of compounds
- ORC can treat TPH, BTEX, DCE, and VC

- ORC comes in pails as a white powder
- ORC can be applied to the subsurface:
  - By injection
  - Using ORC socks (left)
  - Application in trenches or excavation backfill
Controlled Release Technology (CRT)

- Unintercalated peryxogen is subject to “oxygen lock-up”

Commodity Chemicals

MgO₂ or CaO₂

“Rind Formation”

Mg(OH)₂

O₂ Trapped

Unintercalated

O₂ Released

Intercalated

This unique process separates ORC from commodity magnesium and calcium peroxides in form and function!
- Chemical Oxidation
- Concentration in ppm
- Reaction times weeks to month

- Biological Oxidation
- Concentration in ppb
- Reaction times months to year
Combined Remedies: Chem to Bio (Oxidation)

• Chemical Oxidation
  – Establishes high ORP
  – Results in high dissolved O₂
  – Colorless, non-toxic, mineral-like residuals (RegenOx™)

• Aerobic Bioremediation
  – Biological Oxidation process
  – Enhanced by adding O₂
  – ORC-A can be co-applied directly after or with RegenOx™

*Coupling of the two oxidations is seamless*
RegenOx does not inhibit microbial growth

**Biomass in MW-3 before and 130 days after RegenOx injection**

- Before: $1.0 \times 10^9$
- After: $1.0 \times 10^9$

**Community structure in MW-3 before and 130 days after RegenOx injection**

- **Eukarotes (polyenoics)**
- **General (Nsats)**
- **SRBs/Actinomycetes (MidBrSats)**
- **Anaerobic metal reducers (BrMonos)**
- **Proteobacteria (Monos)**
- **Firmicutes (TerBrSats)**
Typical Application

Direct Push

For RegenOx
• 10-20 lbs/ft.
• 20-60 gal./ft.
• 5-10 ft. Spacing

For ORC/ORC-A
• 4-10 lbs./ft.
• 1-3 gal./ft.
• 10-30 ft. Spacing
Mix the RegenOx Part A into water until it dissolves into a milky liquid
Add Part A and Part B together to form a slurry
Mix the two parts thoroughly
Mix the ORC-A into the RegenOx
Site 1: Manufacturing Facility

- BTEX Contamination, 46 ppm
- Excavation Treatment
- Source/Plume Treatment
- Treatment area: 9,800 ft$^2 \times 12$ ft
- Depth to GW: 5-7 ft
- Soil Type: Sand
- GW Velocity: 0.33 ft/d
Remediation Approach

- **Solution**: RegenOx & ORC Advanced
- **Application Type**:
  - RegenOx: Direct Push Injection
  - ORC Advanced: Direct Push and Excavation Backfill
- **Quantity Applied**:
  - RegenOx: 12,480 lbs
  - ORC Advanced: 6,350 lbs
• Treatment Area:
  – ORC-Advanced in the plume: 9,800 ft²
  – ORC Advanced in excavation pit: 2,200 ft²
  – RegenOx + ORC-Advanced in the Source: 1000 ft²
## Contaminant Concentrations

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>2.62 μg/L</td>
</tr>
<tr>
<td>Toluene</td>
<td>21,400 μg/L</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>4,200 μg/L</td>
</tr>
<tr>
<td>Xylenes</td>
<td>20,500 μg/L</td>
</tr>
<tr>
<td><strong>Total BTEX</strong></td>
<td><strong>46 ppm</strong></td>
</tr>
</tbody>
</table>

Well MW-1 Pre-treatment Concentrations
Application

• After Excavation, 950 lbs ORC-Advanced applied to pit
• RegenOx applied in source area (downgradient edge of pit)
• 6 RegenOx Applications, through November 2006
• 6th injection: RegenOx + ORC-Advanced in source area
• ORC-Advanced injected across entire plume
# Results: January, 2007

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Initial Concentration</th>
<th>Post Concentration</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>3</td>
<td>BQL</td>
<td>-</td>
</tr>
<tr>
<td>Toluene</td>
<td>21,400</td>
<td>BQL</td>
<td>&gt;98 %</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>4,200</td>
<td>730</td>
<td>82%</td>
</tr>
<tr>
<td>Xylenes</td>
<td>20,500</td>
<td>2,000</td>
<td>90%</td>
</tr>
</tbody>
</table>

Source Area

Goals

<table>
<thead>
<tr>
<th></th>
<th>1700</th>
<th>320</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Area</td>
<td>630</td>
<td></td>
</tr>
</tbody>
</table>
# Results: January, 2007

## MW-2 Results (ppb)

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Initial Concentration</th>
<th>Post Concentration</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>BQL</td>
<td>BQL</td>
<td>-</td>
</tr>
<tr>
<td>Toluene</td>
<td>BQL</td>
<td>BQL</td>
<td>-</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>672</td>
<td>364</td>
<td>46%</td>
</tr>
<tr>
<td>Xylenes</td>
<td>2,570</td>
<td>91</td>
<td>96%</td>
</tr>
</tbody>
</table>

### Goals

- Plume Area: 1700
- 320
- 630

Plume Area
Summary

• Combined RegenOx/ORC-Advanced application
• 2 months into bioremediation phase, BTEX levels at or near goals in all wells.
• In hottest well, total BTEX from 46 ppm to 2.7 ppm
• GW concentrations indicate that contaminant mass reduced significantly
Site 2: LUST Site in Alabama
Site Characteristics

- Service Station in Central Alabama
- Tanks excavated years before RegenOx and ORC-A injections
- Shallow silt overlying silty sand
- Depth to water – 5 ft bgs
- Treatment thickness – 12 feet (5-17 ft bgs)

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Baseline (MW-2)</th>
<th>Baseline (MW-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total BTEX</td>
<td>17.5 mg/L</td>
<td>0.220 mg/L</td>
</tr>
</tbody>
</table>
Remediation Approach

• Direct-push injection

<table>
<thead>
<tr>
<th>Product</th>
<th>Vertical Thickness</th>
<th>Inj. Pts</th>
<th>Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegenOx</td>
<td>12 ft</td>
<td>28</td>
<td>8 x 8 ft</td>
</tr>
<tr>
<td>ORC Advanced</td>
<td>12 ft</td>
<td>20</td>
<td>8 x 10 ft</td>
</tr>
</tbody>
</table>

• Product Amounts
  – RegenOx – 4,650 lbs
  – ORC Advanced – 1,200 lbs

• Product Cost
  – RegenOx – $9,068
  – ORC Advanced – $10,500
Remediation Timeline

<table>
<thead>
<tr>
<th></th>
<th>RegenOx</th>
<th>ORC Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>January '06</td>
<td>1350 lbs</td>
<td></td>
</tr>
<tr>
<td>Feb '06</td>
<td>1630 lbs</td>
<td>600 lbs</td>
</tr>
<tr>
<td>October '06</td>
<td>1680 lbs</td>
<td></td>
</tr>
<tr>
<td>November '06</td>
<td></td>
<td>600 lbs</td>
</tr>
</tbody>
</table>

Ground Water Results

**MW-2**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>BTEX</td>
<td>17.5 mg/L</td>
<td>10.90 mg/L</td>
<td>0.973 mg/L</td>
<td>0.588 mg/L</td>
</tr>
</tbody>
</table>

**MW-3**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>BTEX</td>
<td>0.220 mg/L</td>
<td>0.128 mg/L</td>
<td>0.242 mg/L</td>
<td>0.042 mg/L</td>
</tr>
<tr>
<td>Contaminant</td>
<td>Pre-Treatment Concentration (ppm)</td>
<td>Post-Treatment Concentration (ppm)</td>
<td>Cleanup Goal</td>
<td>Percent Reduction</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------------------------</td>
<td>-----------------------------------</td>
<td>--------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Benzene</td>
<td>2.4</td>
<td>0.001</td>
<td>0.99</td>
<td>99%</td>
</tr>
<tr>
<td>BTEX</td>
<td>17.5</td>
<td>0.004</td>
<td>NA</td>
<td>99%</td>
</tr>
</tbody>
</table>

![MW-2 Benzene Concentration Graph](image-url)
Conclusions

- Clean-up goals reached within 6-months
- BTEX level maintained for 1½ years
- Closure was granted and the property has been redeveloped
Conclusions

• Chemical oxidation (RegenOx) is good at reducing mass quickly and effectively
• Bioremediation (ORC) is a good polishing step
• The combination of these two technologies is an effective, low-cost solution for treating aerobically degradable compounds