In-Situ Emplacement of Permanent Barriers in Earth Formations

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Ground Water Contamination

• A major Concern in the Oil Shale Industry

Solution: In Situ Barriers
• Block Flow
• Sequester
• Contain
Approach

- Uniformly Heat a Region
- Condition the Region
- Evaporate Water and Inject a Sealant
- Allow Time for Sealant Cooling
Selective Heating (RF Heating)

- Tri-plate Array Example Study (PyroArray)
- Confine and Apply Uniform Heating
- Uniform Temperature Distribution of 90° to 120°C
- Control Over Specific Volume
Soil Electric Conductivity

CONDUCTIVITY OF SOIL & CLAY AT 0.5 MHz & 10 MHz

- SOIL 10 MHz 16.5% H₂O
- SOIL 0.5 MHz 16.5% H₂O
- CLAY 10 MHz 15% H₂O
- CLAY 0.5 MHz 15% H₂O

TEMPERATURE °CENTIGRADE

10⁻⁷
10⁻⁶
10⁻⁵
10⁻⁴
10⁻³
10⁻²
10⁻¹
10⁰
Sealants

- Paraffins
  - Good melting point and good viscosity variation by temperature

- Waxes
  - Polyethylene waxes with molecular weights of 500-2000 have good permeation rates and great resistivity to benzene saturated water

- Resins
  - Low molecular weight resins possess excellent sealant properties

- Asphalt
  - Asphalt emulsion and Sodium Silicate solutions showed low permeation rate in dry and wet soils
Sealant Properties
(lab measurements)

- **Wax**
  - Melting temperature of 80 to 110°C
  - Viscosity less than 200 cP at 100°C
  - Density close to water (0.9 to 1.0 g/cm³)
  - Molecular Weight of 500 to 2000 Da
Lab Results on Permeability

- 100% decrease in permeability for wax injection in sandy soil sample
- More than 90% decrease in permeability for wax injection in clayey soil sample
- 95 to 97% decrease in permeability for wax injection in sandstone core samples
- In the above tests, permeabilities of 0 to 10 mD were achieved.
Vertical Barrier
Sealant Injection
Electrode Installation (Horizontal)
Experimental Setup
One Row of Alternating Electrodes

- RF Coaxial Cable
- Buried Perforated RF Electrodes
- Metallic Shield Covers Coax and Electrodes
- Connection & Sealant Injection Assembly
- Soil Media
Lab Results on Temperature

![Graph showing temperature changes with distance from center of array]

- **Temperature (°C)**: Y-axis
- **Distance from Center of Array [inches]**: X-axis
- **0.6 hour, 4 KWH** (Blue line)
- **15 hours, 66 KWH** (Red line)

Table:

<table>
<thead>
<tr>
<th>Time</th>
<th>kWh</th>
<th>Distance from Center of Array [inches]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6 hour</td>
<td>4</td>
<td>0.6</td>
</tr>
<tr>
<td>15 hours</td>
<td>66</td>
<td>10</td>
</tr>
</tbody>
</table>
Result

- Sealant well distributed throughout the heated zone
- Sealant solidified in a few days
Simulation Result

Case 1
Modeled Geometry
(One Row of Alternating Electrodes)
Model Geometry (Case 1)

Connection of Coax to Electrodes

Alternating Electrodes
Simulation Result (Case 1)  
(Heating for 3.5 Months)

Hot Region with Temperature more than 80°C Prepared for Sealant Injection
Simulation Result (Case 1)
(Cooling for 1 Month)

Region Cooled to Temperature less than 80°C in a month
Simulation Result (Case 1)
(Heating Period)
Simulation Result (Case 1) (Cooling Period)

Heating for 3.5 months

Cooling for 5 days

Cooling for 15 days

Cooling for 30 days

Cooling for 60 days
Simulation Result

Case 2
Model Geometry (Case 2)
Tri-plate Array (Three Rows of Electrodes)
Simulation Result (Case 2) (Heating for 3 Months)

Region with Temp. more than 80°C Prepared for Sealant Injection
Simulation Result (Case 2)  
(Cooling for 1 Month)

Region with Temp. more than 80°C  
(most of sealant is solidified in a month)
Simulation Result (Case 2) (Cooling Period)

- Heating for 3 months
- Cooling for 10 days
- Cooling for 30 days
- Cooling for 60 days
Conclusions

- Almost zero soil permeability observed after solidification of sealant in some lab tests
- Permanent barrier even after long time exposure to solvents and water
- Uniform heating around and along the RF electrodes
- Less than 3 months for heating and less than one month for cooling period
Conclusions for Oil Shale

- Sequester and contain
- Precludes contaminants into aquifers
- Precludes water from aquifer into in situ processes