Electrical Resistive Heating

For In Situ Remediation of Soil & Groundwater

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Dry Cleaner Remediation: Suburban Chicago

Maximum PCE Concentration: 13,000 mg/kg
Hydraulic Conductivity: $10^{-8}$ cm/sec
Soil Contamination Depth: 4 to 20 feet
Contaminant Scenario

- Ruptured sewer line released PCE to soil 300 ft. downgradient from the drycleaner.
- Impacted sediments are clayey glacial till deposit with very low permeability.
- VOC mass in unsaturated soil: 3150 lbs., estimated.
- Average Initial Concentration: 1400 mg/kg.
Site Description

- Infrastructure
  
  Sewer lines, water line, natural gas, and electrical conduits.

- Building Foundations

- Remediation Zone
  
  60 feet x 25 feet with treatment from 4 to 20 feet bgs.
  Groundwater is encountered below 50 feet.
Remedial Objective

- Remove residual DNAPL in soil to below 529 mg/kg., (the project’s calculated saturation limit for site-specific soil with total organic carbon content > 1.6%).
Remedial Alternatives

- **Excavation: Eliminated**
  Excavation would have required relocating infrastructure elements and extensively shoring the foundation.

- **SVE: Attempted**
  - Initial remediation consisted of 70 4-inch diameter SVE wells operated for 5 years.
  - The SVE system captured 200 pounds of total VOCs
  - Confirmation samples showed an apparent increase in PCE concentrations.

- **Electrical Resistive Heating: Selected**
  - Based on cost, timeliness, and ease of implementation.
Cost Comparison

- Excavation and Disposal
  - Estimated Cost for shoring of building, utility relocation, soil removal, disposal as a hazardous waste, and soil replacement: $1.1 million

- Resistive Heating
  - Total fixed price, guaranteed remediation: $0.695 million
About Electrical Resistive Heating

• ERH Takes common 3-phase electricity and directs it into the subsurface through electrodes
• Electrodes are placed vertically to any depth, or may be placed horizontally
• Once in the subsurface, the electrical energy resistively heats soil and groundwater
• Contaminants are removed by direct volatilization and in situ steam stripping
• A Soil Vapor Extraction (SVE) System collects and treats the VOCs
Electrical Resistive Heating

13.8 kV Local Service
480 V Alternate Power Supply
Instrumentation and Control

Voltage Control System
Vacuum Removes Vapor
Off-Gas System Vacuum Extraction

Contaminated Zone

Groundwater

Courtesy of the U.S. Department of Energy
Applications

- Low permeability & heterogeneous lithologies
- DNAPL & LNAPL clean-ups by heating the aquifer and the smear zone
- Bioremediation enhancement
- Remediation underneath operating facilities, in the presence of buried utilities and hazardous waste drums
- Heavy hydrocarbon mobilization
Advantage of Electrical Resistive Heating

- Heating is typically uniform without bypassed regions
- Heating is rapid – months vs. years
- Steam is produced *in situ*
- Preferentially heats tight soil lenses and DNAPL hot spots
- Costs: most commercial, full-scale sites range from $57 to $130 per yds$^3$
Typical Three-Phase Pattern

Uniform, Efficient Heating

No Hot Spots

No Cold Regions
Surface Equipment

- 500 kW PCU
- Air Cooling Tower
- Emergency Shutoff
- Steam Condenser Skid
- Operating Electrode

Photo Courtesy of Brown and Caldwell
ERH 2000 kW PCU
ERH Remediation Beneath a Building

Limited overhead access

Electrode Co-located w/ Recovery Well

Vapor Recovery Line

Electrode

Photo Courtesy of Brown and Caldwell
Multi-Phase Extraction Well: Steam Enhanced LNAPL Removal

Photo Courtesy of TRS
ERH Electrode
In Situ Steam Generation

1. Soil grains act as electrical resistors
2. Steam generation is uniform through the heated zone
3. Discrete intervals can be heated
General Heating and Cooling Times (7,000 yd volume)

Figure 2 - Expected Subsurface Temperatures

- Saturated zone
- Vadose zone

Days after start-up vs. degrees C
Temperature Increases as Detected in the Treatment Area

Temperature Vs Depth
9/09/02

Temperature (C)

Depth (ft-bgs)

TMP4
TMP5
TMP6
TMP7
TMP8
TMP9
TMP10
TMP11
TMP12
TMP13
TMP14
Site Avg
W/O Pilot Area

W/O Pilot Area

Clayton GROUP SERVICES
Dry Cleaner Remediation: Suburban Chicago in December
Electrode Array
Common Utility Trench

- Electrical Connections
- SVE Piping
- Water Connections etc.
Remedial System

- Electrical Transformer and SVE enclosures