Understanding In-situ Thermal Treatment Application and Performance

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Agenda

- Source Treatment Continuum
- What is In-situ Thermal Treatment & What It Can Offer
- Technology Overview
- Performance Monitoring Concepts and Strategies
- Performance Examples Similar to Velsicol Site
  - Solvents
  - Pesticides
  - Combined Remedies
- Closing Thoughts
Source Treatment Continuum

**Containment and long-term management**
- Hydraulic containment (P&T)
- Physical Containment
- Plume Management (In-situ bio; PRBs)
  - Timeframe: many decades to centuries

**Partial source removal plus containment/long-term management**
- Hydraulic displacement, ISCO, ISSM, plus containment and long-term management options
  - Timeframe: many decades to centuries

**Complete or near complete source removal**
- In-situ Thermal Treatment
- Excavation
  - Plus polishing techniques
  - Timeframe: 1 to a few decades
What is Thermal Treatment?

- Subsurface heating for remediation of soil and groundwater
  - Optimal application is treatment of NAPL source zones
  - Three demonstrated methods; one additional considered emerging
  - Coupled with fluid extraction for contaminant source removal & recovery

- In-situ thermal treatment (ISTT) is a mature technology
  - Evolved to a group of powerful and robust remediation technologies
  - Applications number in the 100’s; mainly for chlorinated solvents

- Coming Soon to St. Louis
  - Selected for NAPL/DBCP Area 1 and 2 on the former plant site
  - Proposed for use at the former burn pit area
Subsurface Heating Effects

- **Accelerate Mass Transfer**
  - Vaporization
  - Increased solubility
  - Enhanced desorption

- **Physical Removal**
  - Stripping
  - Displacement
  - NAPL Viscosity reduction

- **Secondary**
  - Chemical destruction
    - Hydrolysis
    - Oxidation
  - Microbial degradation

![Graph showing temperature and pressure impacts on different substances](image)
What Can Thermal Treatment Offer?

- Contaminant source removal
  - Minimum residual mobility
- Mass flux reduction
- Synergy with remedies
- Rapid implementation
- Lower sensitivity to
  - Contaminant mass
  - Subsurface conditions
- Treatment in a variety of geologic settings
- Implementation around structures
  - Even ones that are occupied (with appropriate care)
- Controlled extraction and treatment of contaminants
Some Disadvantages of In Situ Thermal

- High price point and cost variability
- Mechanically complex
- Limited commercial suppliers (and they are often busy)
- Typically area cannot be used during treatment
- Can be impacted by high permeability zones; cold water inflow
- Performance variability
- Energy availability
Just the Facts

- **In-situ Thermal Treatment Key Components:**
  - Heat delivery technology
  - Fluid extraction for contaminant recovery from groundwater and vapor
  - Extracted fluid treatment equipment
  - In-situ temperature monitoring systems
Many Process Options to Consider

Steam Enhanced Extraction (SEE)

Electrical Resistance Heating (ERH)
- Electro-Thermal Dynamic Stripping (ET-DSP™)
- Six phase heating (SPH)

Thermal Conduction Heating (TCH)
- In-situ Thermal Desorption (ISTD)
- Gas Thermal Remediation (GTR)

Emerging Heating Approach
- Self-Sustaining Treatment for Active Remediation (STAR)

High Permeability Formations
(10^{-2} cm/s)

Low Permeability Formations
(10^{-8} cm/s)

~10^{-4} cm/s
Electrical Resistance Heating

- Soil electrical conductivity and water boiling point govern heating
- Heating process
  - Alternating current supplied to subsurface electrodes
  - Electrical resistance of soil generates heat
- Temperature limited to boiling point of water at local pressure
- Specific heating approaches vary by technology provider
Thermal Conduction Heating

- Thermal conductivity governs subsurface heating
- Heating process
  - Accomplished using subsurface high temperature heaters.
  - Transfer heat by conduction to the surrounding formation
- Treatment temperatures > 100°C are readily attained
- Specific heating approaches vary by technology provider

- Ex-situ heating is also feasible
  - In constructed concrete cells
  - In covered soil piles
TCH - In-situ Thermal Desorption

- Electrical heaters (~800°C) provide subsurface energy.
Liquid or gaseous fuels provide subsurface thermal energy.

Soil and groundwater are heated to temperatures of 100-400°C by conduction.

Volatilized contaminants are collected by soil vapor extraction and treated ex-situ.
Vapor Extraction & Treatment is Required

- Primary condensation
- Low mass - GAC
- High mass
  - Thermal oxidation
  - GEO Compression/Condensation
So Which Technology Works Best?

- All heating technologies yield excellent results
  - With proper method selection and performance monitoring
  - All excel at source removal

- Design considerations
  - Contaminant characteristics
  - Remediation objectives
  - Treatment volume
  - Lithology
  - Site conditions
  - Treatment time

- Performance monitoring
Subsurface Conditions Matter

ERH or TCH are likely candidates for these conditions

TCH may be the only viable candidate for sites with buried metal
Thermal Treatment Systems are Readily Adapted to Site Conditions

OCCUPIED RESIDENCE

TREATMENT ZONE

EXTRACTED FLUID TREATMENT SYSTEMS
Privacy Screen to Minimize Visual Impacts of Treatment Area
Urban Applications are Well Documented

- Thermal treatment in proximity to many residential receptors
- Cap, insulation and aggressive fluid extraction limit heating of exterior walls
Performance Monitoring Concepts and Strategies
Monitoring Treatment Performance

- Subsurface temperature
  - Lateral and vertical measurement
  - Real time monitoring

- Temporal measurement
  - In-situ pressure
  - Groundwater elevation
  - Vapor concentration
  - Process parameters
    - Vapor, temperature, flow

- Discrete sampling
  - Extracted vapor concentration
  - Extracted liquid concentration

- Post treatment sampling
  - Soil and groundwater

- Contaminant removal is assessed in many ways using multiple lines of evidence
Process Monitoring
Demonstrates Mass Removal

Cumulative Mass Removed (lbs) vs. Mass Removal Rate (lbs/day)

- Cumulative Mass Removed (lbs)
- Mass Removal Rate (lbs/day)

- Chart shows mass removal rates from 5/1/2010 to 9/13/2011.
- Graph displays cumulative mass removed and mass removal rates over time.

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Post-Treatment Sampling
Thermal Monitoring Tells All

Temperature at Elevation 1163 ft MSL

Temperature at Elevation 1175 ft MSL
Temperature and Time Control Treatment Performance

Temperature achieved, average (deg C)

Fraction of total operations period (%)
Treatment Temperature and Mass Removal are Directly Correlated

Data by TerraTherm, Inc.

- Skuldelev % of total mass recovered [%]
- Knollen % of total mass recovered [%]
- Endicott % of total mass recovered [%]
- South Carolina % of total mass recovered [%]

Mass Recovered [% of total]

Average Treatment Zone Temperature [°C]
Soil Sampling Confirms Mass Removal Observations

Concentration Skuldelev [mg/kg]

Dybde [m u.t.]

PCE in soil pre treatment [mg/kg]
PCE in soil post treatment [mg/kg]

Detection

Soil MCL

Clean-up Goal

Data by TerraTherm, Inc.
Different Site – Similar Results

Concentration Reerslev [mg/kg]

Depth [m bgs.]

Detection limit
Clean-up goal
Soil MCL

Data by TerraTherm, Inc.
Temperature and time control technology performance
- Thermal monitoring data document target temperature achievement
- Operation time at target temperature drives contaminant removal

Instantaneous mass removal rate is measured with time
- Mass removal typically peaks around co-boiling temperature
- With increasing time and temperature removal rates decline

Rate analysis yields cumulative contaminant mass removed
- Total mass removed approaches asymptotic conditions with time

The simultaneous evaluation of temperature, time and contaminant mass removal form the basis of the diminishing returns analysis
- Results are the first line of evidence that treatment is complete
Performance Examples
Solvent Treatment
Performance Data Illustrates Thermal Treatment Endpoint
Average Treatment Zone Temperature as a Function of Time

MW00-312
MW00-313
MW00-314
MW00-318

(73 C) TCE & Water Co-Boiling Point
Soil Borings Confirm Performance

Soil Sample Results MW00-318 / SB05-247

-40 -35 -30 -25 -20 -15 -10 -5 0

Depth Below Ground Surface (feet)

0.00 0.01 0.10 1.00 10.00 100.00 1000.00

TCE Concentration (mg/kg)

Post Treatment

Pretreatment
Results Are Spatially Consistent

Soil Sample Results MW00-314 / SB05-246

-40
-35
-30
-25
-20
-15
-10
-5
0
0.00 0.01 0.10 1.00 10.00 100.00 1000.00

TCE Concentration (mg/kg)

Depth Below Ground Surface (feet)

Post Treatment

Pretreatment
Concentration Reduction = Removal

Soil Sample Results MW00-313 / SB05-245

Post Treatment

Pretreatment

TCE Concentration (mg/kg)

Depth Below Ground Surface (feet)
Performance Example
Pesticide Treatment
Mass Removal Follows Heating

- Graph showing vapor concentration (µg/m³) over time from 7/26 to 2/11.
- Temperature (°C) and depth (feet bgs) plotted against each other.

Legend:
- Outside Treatment Volume

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Soil Treatment Performance Summary

Concentration (µg/kg)

Pre-ISTT

Cleanup Goal

Post-ISTT

DCP  EDB  DBCP  TCP

0.1  1  10  100  1000  10000  100000  1000000

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Post-ISTT: All Wells Below Cleanup Goals
Performance Example
Combined Remedies
Oregon Solvent Site

- Voluntary cleanup of an active manufacturing site
- Solvent release to shallow groundwater
  - NAPL source contaminates groundwater
  - Dissolved contaminants migrate off site > 1000 feet
- In-situ thermal treatment selected for source removal
- Containment system installed for interim plume control
- Groundwater remedy deferred until ISTT was complete
  - Source removal by ISTT was successful
  - Removal immediately apparent on site groundwater
  - Containment no longer needed; Natural in-situ biological processes took over following contaminant source removal
- Combined remedy delivers No Further Action determination
Combined Remedy Approach
Example

Voluntary Cleanup Program – Private Industrial Site (Oregon)

TCE Concentration (µg/L)

- **MCL = 5 µg/L**

- **STEAM INJECTION**
- **HYDRAULIC CONTAINMENT**
- **IN-SITU BIOTREATMENT**

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Closing Thoughts for In-situ Thermal Treatment

- Demonstrated and proven technology
  - Applications number in the 100s
  - Powerful treatment approach but highly site specific
  - Big hammer
  - Mechanically complex
  - Among the most effective strategies for controlled source removal

- Time and temperature control performance
  - Methods to reliably monitor spatial performance are well documented

- Discrete treatment footprint
  - Minimizes disruption to surrounding setting
  - Source removal occurs with the highest degree of control

- Source contaminants are removed and destroyed
  - Statutory preference for treatment is fulfilled