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INDIANA DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

In-Situ Thermal Treatment

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Notice

IDEM Technology Evaluation Group (TEG) completed this evaluation of In-Situ Thermal Treatment based on review of items listed in the "References" section of this document. The IDEM OLQ technical memorandum *Submittal Guidance for Evaluation of Remediation Technologies* describes criteria for performing these evaluations.

This evaluation does not approve this technology nor does it verify its effectiveness in conditions not identified here. Mention of trade names or commercial products does not constitute endorsement or recommendation by IDEM for use.

In-Situ Thermal Treatment Background and Technology Description

In-situ thermal technology involves the addition of heat below the surface to increase the solubility or vapor pressure of contaminants, facilitating faster and more complete removal. A significant advantage of thermal technology is effective removal of non-aqueous phase liquid (NAPL) source zones in soil and groundwater, which can be difficult to accomplish with other technologies currently available. Dissolved and adsorbed contaminants are also reduced to very low levels. Furthermore, thermal technology can aid removal when the subsurface permeability limits traditional extraction.

Heating enhances treatment through three pathways:

1. Heating can increase mobility by inducing physical changes, for example decreasing the viscosity or vaporizing the contaminant, etc. Vaporization is the dominant removal method for most chlorinated and volatile contaminants. In general, density, viscosity, surface tension, and other physical properties vary somewhat with temperature, but vapor pressure and Henry's law constants increase substantially with temperature. Pneumatic or hydraulic extraction can capture contaminants once they are mobilized. This is the primary method of treatment for most thermal technologies.
2. Heating can enhance chemical reactions by increasing the rate of reaction as temperature rises.

3. Heating can enhance biological reactions by increasing the rate of biological reactions and changing the organisms present.

The primary implementations of the thermal technology concept are steam enhanced extraction, electrical resistance heating (ERH) and thermal conduction heating (TCH). A brief description of each follows. For most contaminants, increased mobility is the primary remedial enhancement.

Steam Enhanced Extraction

The first step of steam enhanced extraction is steam injection through horizontal or vertical injection wells causing increased pressure gradients and decreased viscosity of the NAPL and pushes the NAPL towards extraction wells. This technology has been used in both saturated and unsaturated zones. Additional removal occurs through volatilization, evaporation, and steam distillation of volatile and semi-volatile compounds. Liquid phase compounds with boiling points less than water are nearly completely removed while the process is considered effective for liquid hydrocarbons with boiling points up to 175° C.

Steam enhanced extraction has been used for chlorinated solvents, petroleum, and some wood treatment waste. Permeability should be high enough to allow the steam to permeate. Steam generating capacity from on-site operations may make it more cost effective. The combination of electrical heating and steam stripping is termed Dynamic Underground Stripping.

Electrical Resistance Heating (ERH)

Electrical resistance heating involves passing current between electrodes using either six phase or three phase electrical heating; three phase involves a triangular electrode pattern more suited to larger sites and six phase is implemented in a hexagonal pattern more suited to smaller sites since a large network of hexagonal electrodes will have substantial dead zones where current does not flow. Voltage damping is used to reduce voltage at the surface and outside the treatment area for safety.

Electrodes are generally spaced from 8 to 20 feet apart for three phase heating; for six phase heating the hexagon diameter is generally 17 to 40 feet. Resistance to the current flow between electrodes warms the soil and boils a portion of the water. Measured resistance levels in the range of 5 to 400 ohm-meters are favorable for ERH. In the area of the electrodes, water may need to be added to ensure electrical current conduction. ERH generally requires around two weeks to reach the boiling point of water. The steam generated from the boiling water carries the volatilized contaminants to recovery wells. As water boils away in the most conductive zones, less conductive zones heat up leading to relatively uniform heating; silts and clays are generally more conductive than gravel and sands. Target temperatures are the boiling point of the subsurface water, which is somewhat contaminant, and pressure dependent (as depth increases so will boiling point). Most contaminants are recovered as a vapor instead of being mineralized. ERH has been most widely used to treat VOCs (TCE, PCE, methylene chloride) (USACE, 2014).

Thermal Conduction Heating (TCH) Combined with Vacuum: In-Situ Thermal Desorption (ISTD)

Thermal conduction heating is the application of heat to subsurface soils via conduction. Thermal wells or blankets are used as the heat source. Thermal conductivity is relatively consistent over a wide range of soils leading to uniform heat propagation. Operating temperatures can reach 1400-1500° F. Discrete subsurface layers can be heated by placing conductive heaters at desired intervals; the practical minimum thickness is 8 feet (USACE, 2014).

TCH has been used for PCBs in soil, manufactured gas plant coal tars, pesticide residues, chlorinated solvents, creosote contamination, and semi-volatiles.

Technology Selection

The physical properties of the contaminant, the geology of the site, and the available time frame for cleanup should be evaluated before thermal enhancement is chosen for a site. A US Air Force study (AFCEE, 2005) evaluated 27 sites where thermal technology was used and found widely inconclusive results on both the cost and remedial effectiveness of the technology. If a contaminant has a relatively high vapor pressure, alternate technologies may be just as effective in achieving cleanup. If low permeability limits typical extraction technologies, then thermal treatment may increase extraction rates. If a short time frame is required, then thermal technology may aid in this remedial goal.

At many sites, thermal treatment may only be appropriate in source areas or for partial cleanup (see remedial goals below). However, due to the high costs associated with installation of the power control unit, the site size should be balanced with cost per cubic yard for treatment. Many sites may simply be too small to justify the startup cost unless extenuating circumstances exist. Combinations of systems may be useful if site stratigraphy is varied. For example, steam stripping along with ERH may be used in areas that are more permeable while using ERH alone in less permeable layers of a site.

Treatment Objectives

Thermal technology can significantly alter existing site conditions during operation. Consequently, the technology typically includes more than one treatment objective. However, achieving diminishing returns in extracted mass may be a primary objective.

Additional or supplemental objectives may include:

- Maintaining a site-specific temperature range throughout operation.

- Achieving a total electrical power objective, such as a 100% MW-hour limit (estimated from pre-design modeling).
- Measuring contaminant concentrations in recovered vapors or groundwater and ceasing operations when these concentrations decrease by a predetermined percent (ex 80%).
- Soil or groundwater concentrations or mass estimates during operation.

<u>Note Soil and Groundwater / Mass:</u> Soil or groundwater concentrations or mass estimates are supplemental objectives and not primary objectives. Objectives based on these parameters alone may cause unnecessary and expensive contingency measures.

Soil and groundwater concentration measurements during operation are prone to inaccuracy and may not be representative of post-treatment concentrations. Mass estimates are interpolated from soil and groundwater concentrations and as such are inherently less accurate. While sampling heated media during operation, following all aspects of proper sampling methodology is difficult, and high temperatures change the ratio between vapor and liquid phase concentrations. Significant rebound may also occur following media cool down. However, a concentration indicating the absence of NAPL may be a reasonable supplemental objective. For example, achieving a groundwater TCE concentration below 1% of the solubility limit indicates an absence of TCE NAPL.

System Design

In-situ thermal treatment systems are complex and intricate. Operational design details are best left to experienced contractors. Due to the alteration of multiple existing site conditions, pre-design testing of temperature control, hydraulic and pneumatic control, or other performance parameters may be conducted. If adequate pre-design testing is performed, larger scale pilot testing may not be necessary, particularly if the full-scale treatment zones are only marginally larger than a pilot zone. Pre-design modeling of system performance is also often performed to enhance system design. Modeling is useful in estimating the treatment time frame as well as the total cost. However, the following design guidelines apply to all thermal treatment sites.

<u>For pilot tests and for full scale treatment design plans:</u>
The performance monitoring zone can contain monitoring points which are located inside the treatment footprint and in the area beyond and surrounding the treatment footprint. Performance points can be selected to verify the estimated zone of influence, and to observe the effects of treatment in a reasonable timeframe. During treatment and during the post-treatment period, performance measurement can include driving contaminants[1] and treatment indicators. Treatment indicators may include driving contaminant concentrations, temperature, resistivity, power consumption, subsurface

[1] A **driving contaminant** is a chemical having a significantly higher risk compared to other chemicals, thereby having a higher influence on risk-based decisions. A primary driving criterion is a <u>screening ratio</u>, which is the ratio of a sample concentration to a screening threshold level.

vacuum or pressure, injection flow rate, and extraction flow rate. Installation of additional performance monitoring points may be needed based on ongoing results.

Plan view and cross section drawings can be provided showing the spatial extent of driving contaminants and performance indicators, along with estimated zones of system influence (such as temperature, vacuum, voltage) and system components.

Several representative cross section(s) can show the system components (electrodes, conduits/piping, etc.), horizontal and vertical extent of driving contaminants, soil types, groundwater levels, seasonal groundwater range, boring depths, sample locations, screen intervals, field screening levels in borings (such as PID/FID readings), utility lines, utility trenches, and building foundations. Screen intervals include screens for monitoring wells, extraction wells, and vapor sample points.

Considerations:
A basic design feature is the depth and location of the heated intervals. These intervals are chosen such that mobilization upon heating occurs in the direction of the contaminant capture system. Hydraulic and pneumatic control can be demonstrated before heating commences. A vapor cap is considered to minimize fugitive emission of surface vapors and to make extraction more efficient. Perimeter and bottom heating prior to sitewide heating is effective at minimizing the risk of contaminants spreading.

Water management during thermal treatment typically involves extracting and treating existing groundwater in the treatment zone. Additional water may also be injected into the treatment zone to generate steam, to cool components, or to create electrical conductivity. At some sites, large volumes of extracted water may be recirculated into the treatment zone, and a portion of this water is typically discharged to a water treatment facility or, through a permitted outfall, into nearby surface water.

To control groundwater hydraulic flow, extraction systems are designed to extract injected water as well as to extract outside groundwater entering the zone of hydraulic control. This is accomplished when the extraction to injection ratio is greater than 1.0, and the ratio is increased to account for influent groundwater.

Water management can be cost effective. The specific heat capacity of water (4.21kJ/kg C) is more than four times that of rock or soil (~1 kJ/kg C). To minimize treatment costs, it is important to minimize the amount of water to be heated if possible and to impede the flux of groundwater into treatment zones. At some sites, dewatering may be needed to minimize costs.

Note that during steam stripping, cycling subsurface pressure can maximize the mass of contaminants removed; reducing the pressure in the steam zone leaves fluid in that zone slightly superheated leading to enhanced volatilization shortening the remediation time. (USDOE; 2003, Joplin, 2006)

Costs and treatment time frame should always be considered. The high cost of a power control unit in conjunction with substantial electrical costs to run thermal treatment systems makes the technology inappropriate for many sites. The cost of most implementations is well over $1 million. Turning systems on and off is also expensive. In general, if short time frames or treatment in heterogeneous zones are required, the cost may be justified. For most systems, thermal operation generally meets treatment objectives within several to six months.

Operational Monitoring

System performance can be assessed during operation. System wide monitoring can include real time and remote monitoring due to the potential for explosive conditions or excessive heat or steam being generated. Keep updated plan view and cross section drawings noting significant changes to the extent of contamination, performance parameters, site structures, and system components.

Subsurface temperature monitoring is necessary. For heterogeneous sites, thermocouples are placed no more than 1.5 meters apart vertically. Analysis of system wide parameters during operation can identify dead spots or hot spots in the zones of influence allowing them to be adjusted or targeted as operation continues.

<u>Permitting:</u> Highly contaminated sites can be expected to generate significant quantities of volatile chemicals. Air or water treatment components of the thermal system need to be specified. Estimates of air emissions and water discharge concentrations are evaluated for permitting requirements. If the responsible party feels that the system will be exempt from permitting and/or treatment requirements, submit detailed supporting calculations including an appropriate start up sampling plan to verify that their calculations are correct. The IDEM Office of Air or Water Quality may need to be consulted to be exempt from permitting requirements.

Post-treatment Performance Assessment

Post-treatment sampling and assessment is always performed to assess treatment performance. The assessment evaluates the applicable exposure pathways, and whether additional treatment technologies are needed. Post-treatment sampling plans and activities are coordinated with and compared to the pre-treatment, and operating period sampling results. Collect post-treatment sampling after temperatures, groundwater parameters, and other applicable site conditions have returned to pre-treatment conditions.

<u>Advantages</u>

- More complete reduction of many recalcitrant contaminants.
- Faster cleanups.
- Enhanced bioremediation may occur in areas outside the heated source area due to elevated temperatures and decreasing contaminant concentrations.

- Can treat DNAPL in saturated zones and at great depths.
- Areas containing underground utilities and beneath structures can be treated, however treatment may proceed with caution.
- Useful in low permeability silts and clays where typical extraction technologies fail due to low hydraulic conductivity. TCH is applicable when low conductivity prohibits traditional technologies.

Limitations

- System operating costs, especially electrical costs, are substantial.
- Safety hazards including electrocution, scalding and pressure induced ruptures are more likely than with conventional technologies. Please see safety section.
- PVC will melt at the temperatures of some thermal treatment systems. Conductive material cannot be used in the presence of ERH systems. Potential damage to utility corridors.
- Mobilized contaminants may migrate off site. Demonstrate hydraulic and pneumatic control before commencement of in-situ thermal desorption or extraction methods.
- If contaminants are destroyed, daughter and reaction products should also be characterized. Contaminants that can be expected to generate low pH waste streams as they volatilize (ex. many chlorinated solvents) require corrosive resistant alloys in system components.
- Vapors condense around unheated extraction wells. Vapor samples drawn from these wells will underestimate concentrations being removed.

Safety Issues

The main physical safety issues associated with thermal extraction methods revolve around the fact that electricity is invisible and hot material often has the same appearance as cold material but can cause severe burns.

Skilled contractors are required with this technology. OSHA regulations require surface voltage less than 50 V but most ERH systems operate at less than 15V as an added safety measure. Isolation transformers force current to flow only between electrodes.

Drilling into the subsurface to sample during active treatment is possible but creates safety concerns due to the pressure buildup and possibility of steam eruptions. Monitoring wells can become geysers and erupt upon opening the well.

Confirmatory VOC sampling is hindered by elevated temperatures at the immediate conclusion of operations. Safety precautions are necessary to deal with the extremely high temperatures likely to be encountered. The system is shut down in advance to dissipate subsurface pressure, but the possibility of steam flashing will still exist. Technicians should wear protective clothing and goggles. Permanent dedicated tubing accessible without opening the well cap may be installed in each well and run through an ice bath before collecting a sample (USACE, 2014).

Thermally enhanced SVE systems may incorporate the use of steam to heat soils to be treated. Pressure caused by plugged steam lines may cause a rupture or an explosion in the system. System controls can be in place to monitor the pressure.

Conclusion

Thermal extraction is a viable technology that can facilitate and/or expedite cleanup at many contaminated sites. The increased energy costs and safety costs may be considered when choosing this technology. This technology may be appropriate at sites where traditional extraction technologies fail. Establishing hydraulic and pneumatic control of the site is necessary before heating.

Further Information

If you have any additional information regarding in-situ thermal technology or any questions about the evaluation, please contact the Office of Land Quality, Science Services Branch at (317) 232-3215. IDEM TEG will update this technical guidance document periodically or on receipt of new information.

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