

Electrical Resistance Heating: a Hot New Approach to Soil and Groundwater Remediation
By Greg Beyke¹

Electrical Resistance Heating (ERH) is an aggressive remediation technology that can quickly reduce the mass of volatile organic compounds (VOCs) in soil and groundwater by over 99%. The process is often used to clean sites where other technologies have had limited success. Larger ERH sites are cleaned within 6 to 12 months and smaller sites can be cleaned in half that time or less.

The technology is not affected by soil type and can be applied almost anywhere, even under operating facilities and public areas. Currently, no other technology can offer equal levels of chlorinated non-aqueous phase liquids (NAPLs) cleanup in the same time frame and for the same price as ERH. Because ERH is so robust, it is possible for site owners to obtain price and performance guarantees for most site cleanups.

ERH quickly and evenly heats the subsurface to the boiling point of water by passing electrical current through contaminated soil and groundwater. This gentle heating evaporates volatile contaminants *in situ* and steam strips them from the subsurface. Vapors and steam are then extracted, cooled, and treated using standard methods. The technology has been demonstrated as an effective method for the removal of volatile and semivolatile chlorinated and petroleum hydrocarbons from both vadose and saturated zones regardless of soil permeability or heterogeneity².

Developed for the US Department of Energy in the early 1990s by Battelle NW Laboratories, ERH can be applied using three or six phases of electricity. Three-phase heating is generally more applicable for full-scale treatments and the general term “electrical resistance heating” is now used to describe the remediation technique regardless of the electrical phases used. About 50 ERH remediations have now been completed.

ERH can be used to steam strip volatile organic compounds (VOCs) from the subsurface, enhance vapor and multi-phase extraction systems, and increase biological degradation and chemical dechlorination reaction rates. During a typical ERH site remediation, all of these processes are utilized to ensure an effective and lasting remediation is achieved.

Deploying ERH requires a power control unit (PCU) to condition and control the application of power, electrodes to deliver power to the subsurface, recovery wells to collect steam and contaminant vapors, a steam condenser, a vapor treatment system, and control and data acquisition systems. The training and experience of the personnel applying the technology is critical to a successful deployment.

The ERH process

Resistance to the flow of electrical current between electrodes warms the treated soil until a portion of the soil moisture is converted into steam. This *in situ* steam generation occurs in all soil types as well as in fractured or porous rock. The electrical energy evaporates the target contaminants and also produces steam as a carrier gas to sweep the vapors to the recovery wells for capture and eventual treatment at the surface.

Electrodes are placed in the subsurface throughout the remediation area using standard drilling or pile driving techniques. The spacing between the electrodes is usually 14 to 22 feet. The depth at which electrodes may be placed at a given site is only dependant upon the depth to which drilling can be accomplished. Electrodes can be constructed with multiple elements in a single borehole. These electrode elements can then be used to vary the flow of electrical current, and thus the level of heating, at different subsurface depths.

Electrodes are really just remediation wells with the added capability to direct electrical current to the proper depth for subsurface heating. Electrodes can serve as vapor and steam recovery points, or can operate as multiphase extraction wells for the recovery of vapor, steam, water and NAPL from the subsurface.

The PCU directs three-phase electricity from municipal power lines to the electrodes. The electricity may be directed to groups of electrodes, or electrode depth intervals, either simultaneously or sequentially depending on the size of the volume being treated, or the desired heating pattern.

Subsurface temperature, voltage, airflow, and pressure data are collected automatically and uploaded to the PCU computer. The PCU computer is used to both monitor and control site activities and may be accessed directly or remotely. Subsurface temperatures are measured using thermocouples set at predetermined subsurface locations.

The overall ERH heating pattern is remarkably even. However, while all soil in the targeted treatment volume is heated simultaneously, electricity prefers to take pathways of lower resistance when moving between electrodes and these pathways are heated slightly faster. Examples of low resistance pathways in the subsurface include silt or clay lenses and areas of higher free ion content.

As chlorinated contaminants sink through the lithology, they tend to become trapped on silt and clay lenses. Over time, trapped solvents undergo natural dehalogenation processes that produce daughter compounds and free chloride ions. Thus, at chlorinated hydrocarbon sites, the most impacted portions of the subsurface are also the low resistance electrical pathways that are preferentially treated by ERH. Subsequently, low permeability soils and solvent concentration spots heat, and clean up, slightly faster than other locations during ERH remediation.

By increasing subsurface temperatures to the boiling point of water, ERH speeds removal of contaminants by two primary mechanisms: increased volatilization and *in situ* steam stripping. As subsurface temperatures begin to climb, contaminant vapor pressure, and the corresponding rate of contaminant extraction, typically increases by a factor of about 30.

However, the ability of ERH to produce steam *in situ* represents its most significant advantage over other subsurface heating techniques. Through preferential heating, ERH creates steam from within silt and clay stringers and lenses. The physical action of steam escaping these tight soil lenses drives contaminants out of those portions of the soil matrix that tend to lock in contamination via low permeability or capillary forces. Released steam then acts as a carrier gas, sweeping contaminants to vapor or multiphase extraction wells constructed in the saturated and vadose zones.

The boiling points of most common VOCs in air are either below or just slightly above the boiling point of water (100°C). However, when a VOC is immersed or dissolved in water, its boiling point is depressed, because a low solubility VOC/water mixture boils when the vapor pressure of the VOC plus the vapor pressure of water is equal to the ambient pressure as described by Dalton's Law of Partial Pressures. An example of this effect is perchloroethylene (PCE), which has a boiling point in air of 121°C. The boiling point of PCE in contact with water or moist soil is 88°C, allowing its effective remediation by ERH.

Once subsurface heating starts, the boiling point of various VOC/water mixtures is reached in the following order: NAPL in contact with water or moist soil, groundwater containing dissolved VOCs, and then pure groundwater. This is advantageous for remediation because contaminated water will boil off before uncontaminated water, reducing the time and energy required to complete treatment.

Although volatilization is usually the primary removal mechanism for VOCs during ERH, VOCs are also degraded in place by *in situ* processes. These *in situ* processes include bio-attenuation, hydrolysis, and reductive dehalogenation by zero valent iron.

The biodegradation of chlorinated solvents is most commonly an anaerobic process. Heating increases the degradation rate far beyond what is typically observed under ambient conditions. Heating is especially important at sites with high levels of total organic carbon (TOC), which provide a carbon source for an electron donor. Boiling of the site converts a portion of the natural TOC into water soluble forms and therefore makes the TOC more bio-available. In essence, even heterogeneous sites are uniformly bioamended without the injection of amendments.

Economics

No matter what technologies are employed, remediation cost accounting is site specific and dependent on the shape and volume of the treatment area, the target contaminants

and level of contaminant reduction required and the TOC content of the soil. Cost considerations should include both the direct costs to pay for application of the remediation technology and ongoing project costs such as real estate opportunity costs, interaction time with regulatory agencies, sampling and analysis, and reporting.

At sites where ERH is applicable, the time spent in remediation is typically reduced from years to months. For a typical commercial site requiring a 99% reduction of TCE in soil and groundwater, the total price for ERH remediation is currently about \$250,000, plus \$40-70 per cubic yard of treatment. For larger sites, the cost of ERH is about half that of excavation and disposal³.

A remediation guarantee typically adds 10-15% to the total cost. The simplest way to enforce a guarantee is to apply a relatively large retainage to the technology provider's invoices – perhaps 30%. The retainage is placed in an escrow account and the technology provider is paid the retainage only when the remedial goals have been met. Remedial goals can be based on soil samples, groundwater samples, or both.

Summary

ERH is now recognized as a proven and cost effective remediation tool capable of successfully cleaning sites where other technologies have had limited success. ERH is commonly selected as the preferred clean-up alternative for highly impacted sites, including those with NAPL sources, heterogeneous lithologies, and low permeability silt, clay, or rock. The technology is commonly applied under operating buildings and roads with limited impact to business operations or the public. About half of the current ERH remediation projects are being performed under contracts with guaranteed results.

¹Greg Beyke, P.E., is the Vice President of Engineering for Thermal Remediation Services. He directs environmental engineering for TRS out of their Franklin, TN office.

² US EPA Technology Innovation Office, Cost and Performance Report – *Six-Phase Heating™ (SPH) at a Former Manufacturing Facility Skokie, Illinois*, October 1999
http://www.thermalrs.com/TRS_docs/EPA%20Skokie%20Cost%20Perform%20Rpt.pdf

³ US EPA, EPA 542-R-04-010, *In Situ Thermal Treatment of Chlorinated Solvents Fundamentals and Field Applications*, March 2004
http://www.thermalrs.com/TRS_docs/epa542r04010.pdf