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In Situ Remediation Technology Status Report:

Thermal Enhancements

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office
Washington, DC 20460

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Notice

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Foreword

The purpose of this document is to describe recent field demonstrations, commercial applications, and research on technologies that either treat soil and ground water in place or increase the solubility and mobility of contaminants to improve their removal by pump-and-treat remediation. It is hoped that this information will allow more regular consideration of new, less costly, and more effective technologies to address the problems associated with hazardous waste sites and petroleum contamination.

This document is one in a series of reports on demonstrations and applications of in situ treatment technologies. To order other documents in the series, contact the National Center for Environmental Publications and Information (NCEPI) at (513) 489-8190 or fax your request to NCEPI at (513) 489-8655. Refer to the document numbers below when ordering.

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EPA542-K-94-009 Thermal Enhancements

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Contents

Abbreviations

BTEX = Benzene, Ethylbenzene, Toluene, Xylene
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act
DNAPL = Dense Non-Aqueous Phase Liquid
DOE = Department of Energy
PAH = Poly-Aromatic Hydrocarbon
PCE = Tetrachloroethylene
RCRA = Resource Conservation and Recovery Act
SITE = Superfund Innovative Technology Evaluation Program
SVE = Soil Vapor Extraction
SVOC = Semi-Volatile Organic Compound
TCA = 1,1,1-Trichloroethane
TCE = Trichloroethylene
TPH = Total Petroleum Hydrocarbon
VOC = Volatile Organic Compound

Introduction

Purpose and Process

This document describes the development and application of in situ thermal enhancement as a technology to remove contaminants from soils and ground water at waste disposal and spill sites. The activities described include research, demonstrations, and field applications of the technology.

Information in this report was found in computerized databases such as the Environmental Protection Agency's (EPA) Vendor Information System for Innovative Treatment Technologies (VISITT) and Alternative Treatment Technologies Information Center (ATTIC) and the Dialog Information Services; and in publications such as the Hazardous Substance Research Center Annual Reports, the Superfund Innovative Technology Evaluation Technology Profiles and the Department of Energy's Office of Technology Development Program Summary. The review also included conference summaries, proceedings and compendiums. It was supplemented with personal interviews and discussions with representatives of other federal agencies, academic research centers and hazardous waste remediation consulting firms. In some cases, the data concerning the performance of the technology were provided by the technology vendor.

Technology Needs

Numerous hazardous waste sites have significant concentrations of organic contaminants in saturated and unsaturated soils. In a permeable matrix, soil vapor extraction (SVE) in the unsaturated zone, and air sparging in the saturated zone, appear to be successful in removing some of the volatile phase of the contaminant. However, limiting factors to the success of these two techniques include the rate of phase transformation between solid and vapor and the limited permeability of clays and organic soils which restrict removal of the volatile contaminants. With these limitations, substantial removal of contaminants by soil vacuum extraction may be long and costly. By selectively heating the soils, the rate of volatilization is increased and the release of contaminants from the soil can be improved significantly.

Technology Descriptions

Both radio frequency (RF) and electrical resistance (alternating current or AC) heating are effective in expelling organic contaminants from soil even in low permeability, clay-rich zones. The electrical properties of the clay zones have been shown to preferentially capture the RF or AC energy, focusing the power in the target zones. By selectively heating the clays to temperatures at or above 100°C, the release and transport of organics can be enhanced by: (1) an increase in the contaminant vapor pressure and diffusivity; (2) an increase in the effective permeability of the clay with the release of water vapor and contaminant; (3) an increase in the volatility of the contaminant from in situ steam stripping by the water vapor; and, (4) a decrease in the viscosity which improves mobility. The technology is self limiting; as the clays heat and dry, current will stop flowing.

In sandy, more permeable formations, steam can be injected. The advancing pressure front displaces soil, water, and contaminants by vaporization. The organics are transported in the vapor-phase to the condensation front where they condense and can be removed by pumping. The injection of moderately hot water (50°C) in a contaminated zone can increase the solubility of many free-phase organics which improves their removal by pumping. However, a more important mechanism may be the reduction of viscosity of these free-phase liquids allowing the hot water to displace them. Hot water does not create as harsh an environment as other heating methods and the biomass may be enhanced to remove residuals.

Ongoing or Future Demonstrations and Commercial Applications

Steam Heating with SVE and Bioremediation
AT&T

Description of Demonstration: The demonstration is taking place at a site in the Midwest—not RCRA or CERCLA. The site has moderately tight soil configuration with undissolved or dense non-aqueous phase liquids. Steam is injected into areas of highest contamination to volatilize and mobilize the volatile components. A shallow SVE system is designed and installed to capture the volatiles. Extraction wells collect and control the mobilized contaminants. At the outer fringes of the contaminant zone, where concentrations were lowest, enhanced biotransformation was performed using an injected nutrient slurry. The nutrient slurry was heated to promote the biotransformation and maintained between 20°C and 40°C for optimal growth of bacteria.

Wastes Treated: TCE and TCA

Status: The facility began using the technology in early 1991 and, as of early 1994, is still in full operation with the median concentration in the ground water reduced to below cleanup criteria.

Preliminary Results: Initially, to determine the effectiveness of biotransformation, ratios of the "daughter" and "parent" compounds were compared. Biotransformation rates have been observed to be highly temperature and concentration dependent. Maintaining optimal temperatures has been observed to promote the ground-water cleanup.

Greater than 18,000 pounds of solvent have been removed in 3½ years through vapor and ground water extraction.

Quarterly sampling of the ground water shows that the plume has been reduced in size. Utilizing the technology concepts and final tuning of the system have shown to expedite removal from the remaining source areas indicated by the data.

Monitoring for cleanup at one location for six months shows that where cleanup has been attained for all chlorinated aliphatic compounds, concentration rebound was not observed.

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Basile, A.J. and Smith, G. "Innovative Treatment Combination Rings Bell for AT&T." *HazMat World* March 1994, p 52-53.

Brodhead Creek Superfund Site, Stroudsburg, PA
Steam Heating and Hot Water Displacement
(Contained Recovery of Oily Wastes (CROW™))
Western Research Institute

Description of Demonstration: Hot water displacement is used to move accumulated oily wastes and water to production wells for above-ground treatment. Hot water is injected through six wells below and in the contaminants in the ground water to dislodge them from the soil matrix. The wells at this site were placed at a depth of 27 feet to 35 feet and hot water was injected at a total rate of 100 gallons per minute. The mobilized wastes are then displaced toward two pumping wells by the hot water. The residues then may be treated by bioremediation.

Wastes Treated: PAHs (coal tars, pentachlorophenol, creosote, and petroleum by-products)

Status: The technology was tested both in the laboratory and pilot-scale and is being demonstrated and used as a remediation technology at the Pennsylvania Power and Light Brodhead Creek Superfund site. The demonstration should be completed in August 1995.

Demonstration Results: None yet.

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Bell Lumber and Pole, New Brighton, MN
Steam Heating and Hot Water Displacement (CROW™)
Western Research Institute

Description of Demonstration: Hot water displacement is used to move accumulated oily wastes and water to production wells for above-ground treatment. Hot water is injected and withdrawn at three groupings of four injection wells and one production well. The groupings or "patterns" are operated one at time. The injection rate for one pattern is 25 gallons per minute. Hot water is injected below and in the contaminants in the ground water to dislodge them from the soil matrix. The mobilized wastes are then displaced toward a pumping well by the hot water. The residues then may be treated by bioremediation.

Wastes Treated: Pentachlorophenol, creosote, and petroleum by-products

Status: Construction for full-scale demonstration began in early 1994. As of April 1995, the system is in operation and is scheduled to operate for 18 months.

Preliminary Results: Over 80% of the nonaqueous phase liquids were removed in the pilot test. A 500 fold decrease in pentachlorophenol also was noted in the pilot.

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Rocky Flats (DOE), CO
Electrical Resistance Heating with SVE

Description of Demonstration: Researchers are planning to use the Six Phase Array very similar to the Savannah River demonstration. The demonstration may extend to the water table which is less than 30 feet from the surface. The target contaminants are in the free phase.

Wastes Treated: TCE, PCE and mixed oils

Status: The demonstration is scheduled for the summer of 1995.

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Hill Air Force Base, Utah
In Situ Thermal Extraction Process
Praxis Environmental Technologies, Inc.

Description of Demonstration: The in situ thermal extraction process enhances other processes such as pump-and-treat and soil vapor extraction. Steam is introduced to the soil through injection wells screened in contaminated zones both above and below the water table. The steam flow sweeps contaminants to extraction wells. The extracted vapors and liquids are treated above ground.

Wastes Treated: VOCs and SVOCs such as gasoline, diesel and jet fuel, and solvents such as TCE and PCE

Status: The technology is scheduled to be demonstrated under the SITE program in the summer of 1995 at Hill Air Force Base in Utah.

Demonstration Results: None yet.

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References:
Stewart, L.D. and Udell, K.S. "The Effects of Gravity and Multiphase Flow on the Stability of Steam Condensation Fronts in Porous Media," *Multiphase Transport in Porous Media,* ASME HTD, 127, December 1989.

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Udell, K.S. and Stewart, L.D. "Mechanisms of In Situ Remediation of Soil and Groundwater Contamination by Combined Steam Injection and Vacuum Extraction," Paper No. 119d presented at the Symposium on Thermal Treatment of Radioactive and Hazardous Waste at the AIChE Annual Meeting, San Francisco, November 1989.

ANNEX Terminal, San Pedro, CA
Steam Heating with Soil Vapor Extraction
NOVATERRA, Inc.

Description of the Demonstration: The ANNEX terminal site was an industrial chemical storage facility where soil, clay, and harborfill are contaminated with volatile organics. The process includes two counter-rotating hollow-stem drills capable of operating up to 30 feet deep. Each drill stem contains two pipes, one inside the other, connected to five-foot cutting bits. The inner pipe delivers steam; the outer pipe heated air. The steam and air volatilize the contaminants which then migrate to the surface along a specially created pathway next to each drill Kelly (drill stem). A shroud seals the process area above the drilling area to prevent escape of vapors. At this site, the contaminants were treated in the vadose and saturation zones down to 10 feet.

Wastes Treated: Volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs)

Status: An EPA SITE demonstration was conducted at the ANNEX Terminal in 1989 and a final report published in June 1991. Small-scale field and laboratory tests have been conducted since then and two demonstrations have been scheduled for the summer of 1994.

Demonstration Results: At the ANNEX Terminal, more than 85% of the VOCs and 55% of the SVOCs were removed at a rate of three cubic yards of soil per hour. Fugitive air emissions were very low and no downward migration of contaminants was detected. At the completion of the project the Responsible Party received written notification from the state that the soil cleanup objective had been met by the process.

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U.S. Environmental Protection Agency. *Toxic Treatments (USA), In Situ Steam/Hot Air Stripping Applications Analysis Report*, EPA/540/A5-90/008, 1990.

Huntington Beach, CA
Steam Heating with Soil Vapor Extraction
Hughes Environmental Systems, Inc.

Description of Demonstration: The technology was applied to the site (2.3 acres) with 35 steam injection wells and 38 liquid/vapor extraction wells. The wells were placed in a repeating pattern of four injection wells surrounding each extraction well. The distance between adjacent well/extraction well pairs was approximately 45 feet; between adjacent wells of the same type, the spacing was approximately 60 feet. The wells were approximately 40 feet deep. The steam pressure was approximately 15 psi.

Wastes Treated: BTEX

Status: The demonstration began in September 1991, and ended in September 1993. Hughes Environmental Systems, Inc., operated the technology, however, they are no longer in the environmental remediation business. Since the technology requires commonly available process equipment, the technology can be designed and operated by other consultants knowledgeable of the process.

Demonstration Results: The removal of contamination was less successful than originally anticipated. Forty-five% of the post-treatment soil samples were above cleanup criteria (1,000 ppm TPH). Approximately 16,000 gallons of diesel were removed of an estimated spill volume of 70,000 to 135,000 gallons. The recovery represents a reduction of approximately 12% to 24%.

All major equipment systems experienced problems, often leading to downtime. The demonstration had an on-line factor of 50% but subsequent applications of the technology are expected to be higher since this was the first full-scale application. Heating the soil took much longer than predicted and high soil temperatures were not maintained in many areas. This may have been due to the way the process was operated initially (16 hours per day, five days per week) and to excessive operational downtime. The heating rate improved later in the application when the process operation went to a 24-hour per day, 6-day per week cycle. These factors may have contributed to the technology not achieving the cleanup criteria.

Operating costs were relatively low. Actual costs were estimated to be $46/cubic yard, assuming a 50% on-line factor. Under idealized conditions, which assumes a 100% on-line factor, the technology could have cost as little as $29/cubic yard.

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U.S. Environmental Protection Agency, Risk Reduction Engineering Laboratory. *In Situ Steam Enhanced Recovery Process, Innovative Technology Evaluation Report*, February 1994.

Solvent Service, Inc., CA
Steam Heating with SVE
Berkeley Environmental Restoration Center

Description of Demonstration: This study was conducted in unsaturated sediments within 20 feet from the surface. One recovery well was surrounded by six injection wells within a 13 by 13 foot plot. The first phase obtained information from vacuum extraction alone, the second phase used injected steam to volatilize and mobilize organic contaminants.

Wastes Treated: VOCs and SVOCs

Status: The demonstration was conducted in August 1988, by the Sanitary Engineering and Environmental Health Research Laboratory, University of California, Berkeley.

Demonstration Results: Vacuum extraction alone removed 72% of the recovered contaminants. After five days of steam injection, four contaminants (acetone, 2-butanone, 1,2-dichloroethene and xylene) were reduced by 90% to 99.9% in laboratory studies. Contaminant concentrations remained high in areas with high water content and low mass transfer rates. Although some of the more volatile compounds were showing a decrease in concentration by the end of the field demonstration, most of the contaminant concentrations were holding steady or increasing at the time the demonstration was terminated. Thus, a longer treatment time may have reduced the remaining contaminants even more.

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Kelly AFB, TX
Radio Frequency (RF) Heating with SVE
KAI Technologies, Inc. and IIT Research Institute

Description of Demonstration: Radio Frequency technology is used for the removal and reclamation of petroleum-oil-lubricant (POL) hydrocarbon components, mainly from soils and other kinds of geological formations above the water table. It is particularly attractive to engineers needing a rapid, in situ treatment technology to avoid expensive excavation and treatment methods to meet near-term regulatory requirements. Much like a microwave oven heating approach, an electrical field is created at an ISM (industrial, scientific, medicine) frequency of 6.68, 13.56, 27.12, or 40.68 megahertz. Specially designed electrode rods can be placed in vertical or directionally drilled holes for optimal “excitation” of the contaminated treatment zone, vaporizing hydrocarbons beyond their boiling points for capture in a vacuum extraction system. POLs and other contaminants which have been vaporized are then transported to condensate and vapor treatment systems on- or off-site.

This demonstration was conducted at a site that was used for temporary storage of waste oils and industrial solvents prior to off-base disposal. Ground water was relatively shallow. Dewatering wells were used continuously to attempt to minimize water intrusion into the test. About 115 cubic yards of clayey soil were heated to 150°C for over 60 days.

Soil vapor was collected at the surface by trenches and pipes placed beneath a shroud of heavy, moisture-proof metallic ground cloth that prevents the vapors from escaping.

Wastes Treated: BTEX, VOCs

Status: The use of radio frequency for the thermal desorption of hydrocarbons first came to the attention of Air Force site restoration R&D project engineering management about ten years ago. At that time, the technology was found to have been previously tried by the Illinois Institute of Technology Research Institute (IITRI) to remove crude oil fairly successfully from shale oil rock formations in eastern Utah.

The Air Force Civil Engineering Laboratory at Tyndall AFB, Florida, followed up with further investigations of different IITRI system applications to remove POL contaminants: first from a contaminated sandy soil matrix in a fire training pit at Volk Field, Wisconsin, and the other a clay soil matrix contaminated with fuels and solvents at an abandoned storage site at Kelly AFB, Texas. While at Kelly, another RF design by KAI Technologies of Woburn, Massachusetts, was tested for comparison purposes at the same site.

Demonstration Results: The latest demonstrations were concluded in July 1993 for the IITRI Tri-Plate Capacitor System (TPCS) and June 1994 for the KAI Dipole Antenna System. Preliminary results indicated that both systems reached desirable operational temperatures necessary to remove volatiles and semi-volatiles in clay. The 1993-94 IITRI and KAI field tests at Kelly are still being analyzed. Vapor extraction analysis confirmed the extraction of chlorinated and nonchlorinated hydrocarbons common in the fuels and solvents known to be in the test volumes from previous soil and water sampling; however, total contaminant removal efficiency is still under investigation. A partial remediation of the Kelly contaminated site was achieved after some 100 tons of clay soil were thermally desorbed and vapor extracted. On-site destruction of vacuum extracted vapors was accomplished by flare. Contaminated water from the dewatering system and vapor steam moisture condensate was drummed for later treatment at a nearby industrial wastewater treatment plant. These investigations have prompted further consideration by Air Force engineers to use an ultraviolet-catalytic treatment system for integration into future RF emissions treatment for on-site destruction of chlorinated and nonchlorinated hydrocarbons. One UV/Catalytic system already was used successfully for treatment of vapor stream emissions on air stripper at Dover AFB, Delaware.

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References:

Marley, M.C.; Kasevich, R.; and Price, S.L. "Enhancing Site Remediation Through Radio Frequency Heating" American Institute of Chemical Engineers 1993 Annual Meeting, St. Louis, Missouri, November 1993, p 7-12.

"Radio Frequency Heating Process Heats Organic Materials," *Waste Treatment Technology News*, 6 (3) January 1992, p 3.

Savannah River, GA (DOE)
Radio Frequency Heating with SVE
KAI Technologies, Inc.

Description of Demonstration: A field demonstration of in-situ radio frequency heating was performed at the Savannah River Site (SRS) as part of the U.S. Department of Energy—Office of Technology Development's Integrated Demonstration. The objective of the demonstration was to investigate the effectiveness of in situ radio frequency (RF) heating as an enhancement to vacuum extraction techniques of residual solvents held in vadose zone clay deposits. Conventional soil vacuum extraction techniques are mass transfer limited because of the low permeabilities of the clays. By selectively heating the clays to temperatures at or above 100°C, the release or transport of the solvent vapors will be enhanced as a result of several factors including an increase in the contaminant vapor pressure and diffusivity and an increase in the effective permeability of the formation with the release of water vapor.

The in situ heating demonstration at the Savannah River site integrated RF applicator technology and vacuum extraction from a single, horizontal well. The horizontal well was drilled through a shallow, contaminated, subsurface clay layer at a depth of approximately 40 feet and was continuously screened over a 300 foot horizontal section. The applicator, approximately 17 feet long, operated at a maximum power output of 25 kW and a frequency of 13.56 MHz. The applicator was inserted to a location approximately 100 feet from the start of the screened zone to heat one section of the well. The vacuum extraction system consisted of a rotary lobe blower capable of providing a flow of approximately 150 cfm at 6" Hg vacuum. Offgases drawn from the well were destroyed with a skid-mounted, thermal-catalytic oxidation system. Several vertical boreholes were placed both in and adjacent to the expected heated zone and in a “cold” control zone to monitor temperatures, pressures, and soil gas concentrations.

Wastes Treated: TCE and PCE

Status: The demonstration was conducted in March and April, 1993. A similar demonstration was conducted in May and June, 1994 at Kelly AFB in conjunction with the SITE program.

Demonstration Results: The heating stage of the test was conducted over a 34-day period with approximately 27 days of operation. Offgas concentrations from the well rose steadily during the initial stage (first 15 days) to levels ranging from 150 to 200 ppm of perchloroethylene and from 20 to 30 ppmv of trichloroethylene. These levels were sustained over the latter half of the heating stage and appeared to correlate directly with periods of applicator power output. The maximum soil temperature at approximately 6 feet from the center of the applicator reached 63°C from an initial ambient temperature slightly below 20°C. The RF power output was controlled using commercial fiber optic temperature sensors located on the applicator and at the screen wall. The control temperatures ranged from 100° to 130°C. Power output was cycled to maintain temperatures within these control values established by the limitations of the well casing material (fiberglass reinforced epoxy). The maximum RF output per cycle ranged from 10 to 25 kW.

The radio frequency energy was coupled efficiently to the targeted clay layer from a horizontal borehole. The single RF applicator delivered over 95% of its available power to the surrounding contaminated clayey sediments. The entire RF system was estimated to operate with an 80% delivered energy efficiency to the clay. During the demonstration period, greater than 11,000 kilowatt-hours of RF energy were successfully coupled to the subsurface sediments and heated a soil volume of approximately 2000 cubic feet to temperatures greater than 60°C.

Over 170 kilograms of chlorinated solvents were successfully extracted from the sediments over the course of the demonstration. The thermal catalytic oxidation system destroyed the contaminants with an efficiency ranging from 80 to 95%. All discharges to the environment were well within the permissible guidelines required by the state of South Carolina.

Due to the problems encountered with the integration of RF heating using a borehole applicator combined with vacuum extraction from a single horizontal well, the results of the demonstration did not provide enough data to adequately assess the feasibility of applying the technology for thermally enhanced remediation of contaminated clays in the unsaturated zone. The demonstration provided a greater understanding of the important component and system designs, the critical operating parameters, and the essential site characterization requirements for in situ RF heating applications. The results and insights from this demonstration also have led to selecting specific solutions to address the problems encountered. The primary limitations resulted from the use of a relatively long, single horizontal well design screened within a low-permeable clay formation. A horizontal borehole application is advantageous for vadose zone remediation as the applicator can be moved through the well, heating a progressively larger volume of the contaminated tabular clays. However, such an application must consider the proper choice of well completion materials that are compatible with the installation technique, and the expected temperatures.

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References:
Final Report: In Situ Radio Frequency Heating Demonstration. Westinghouse Savannah River Company Technical Report, WSRC-TR-93-673, Rev. 0.

Rocky Mountain Arsenal Basin F
Radio Frequency Heating with SVE
IIT Research Institute

Description of Demonstration: This was a pilot-scale demonstration to test the ability of RF heating to heat clayey soils to over 250°C and, in the process, reduce organochloro pesticide (OCP) concentrations. Researchers used the Triplate Array on 50 cubic yards at a maximum depth of 16 feet.

Wastes Treated: Organochloro pesticides (aldrin, dieldrin, endrin)

Status: The demonstration was held in the summer of 1992 and lasted one month.

Demonstration Results: Destruction efficiencies in the soil heated to 250°C or higher were 97% to 99%, from initial concentrations which were up to 5,000 mg/kg.

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References:
Snow, R.H.; Sresty, G.C.; Conroy, C.; Collins, R.; and Kilgannon, T. "Test of Radio Frequency In Situ Heating for Treatment of Soil at RMA." *Proceedings of the XIV Superfund Conference*, HMCRI, 1993.

Volk Air National Guard Base, WI
Radio Frequency Heating with SVE
IIT Research Institute

Description of Demonstration: The field test took place at a former fire training pit contaminated with JP-4 jet fuel spilled during routine fire training exercises. The soil was 98% silica sand. The ITT Research Institute used the Triplate Array at this field test. Nineteen cubic yards of sandy soil were heated to an average depth of seven feet. The area of the heated zone was 72 square feet. The soil was heated to a temperature range of 150° to 160°C in eight days with a 40 kW RF power source. The treatment temperature was maintained for four days.

Wastes Treated: BTEX

Status: This field experiment was held in 1987 and the test completed in 12 days. IITRI has subsequently demonstrated the Triplate Array at other sites (Kelly AFB, Rocky Mountain Arsenal).

Demonstration Results: At least 99% of the volatile hydrocarbons and 94% to 99% of the semivolatile hydrocarbons were removed from the site. Hexadecane, with a normal boiling point of 289°C, was used as a target compound to represent the semi-volatile aliphatic compounds. On the average, 83% removal of hexadecane was achieved.

A tracer injection study was performed to determine the flow of soil fluids. Approximately 2.6 grams of Halon 2402 were injected at a depth of six feet and at a distance of four feet outside the heated zone. The hot gases leaving the treatment zone were sampled and analyzed for the tracer. The tracer was detected in the hot gases approximately 100 minutes after the tracer was injected.

Soil samples obtained from the immediate surrounding vicinity of the heated zone indicated a net loss of contaminants. Together with the results of the tracer study, it was concluded that no net outward migration of the contaminants occurred during the experiment.

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References:

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Report Number: EPA/600/A-93/273, 1993, 9p.

Kirkland AFB
Radio Frequency/Electrical Resistance Heating with SVE
IIT Research Institute

Description of Demonstration: The demonstration used the Triplate Array which is similar to the one used at Kelly AFB. However, at Kirkland, researchers used low frequency alternating current initially to heat the soil to 80° to 90° and then used radio frequency heating to heat it to 150°C. The treatment zone was approximately 550 cubic yards of silty soil containing solvents, petroleum hydrocarbons, and heat transfer fluids at maximum depth of 25 feet. The system was in operation 24 hours a day, seven days a week. The concentration of hydrocarbons in the soil effluent was monitored continuously.

Wastes Treated: A mixture of VOCs and SVOCs

Status: The demonstration was completed in April 1995 after operating for approximately 90 days.

Preliminary Results: The concentration of the hydrocarbons, as measured by the area counts of the chromatograms, increased by about two orders of magnitude after the application of the radio frequency heating. After the soil has cooled, the rate of removal of individual target compounds and the residual soil concentrations will be quantified. Results are expected during the summer of 1995.

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References:
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Savannah River, GA (DOE)
Electrical Resistance Heating with SVE

Description of Demonstration: Researchers used the Six Phase Array in which six electrodes were placed around a central vent. Each electrode is equipped with a separate transformer wired to provide each electrode with a separate phase. This ensures a more uniform distribution of electrical current in the soil. Because the key to resistive heating is to maintain a small amount of moisture in the zone to conduct the electricity, splitting the current into six phases prevents overheating and excessive drying around the electrodes. Resistive heating dissipates the electrical energy in the contaminated zone and vapor is withdrawn from the central vent.

The Six Phase heating process does not require large energy resources compared to incineration and other thermal treatment methods, as the need to heat soils past 100°C is unnecessary.

The target contaminated zone was a 10 foot thick clay layer approximately 40 feet below the surface. The electrode array was circular with a 30 foot diameter.

Wastes Treated: Dissolved TCE and PCE

Status: The demonstration was conducted in November 1993.

Demonstration Results: The demonstration lasted 25 days. Of this, it took 10 days to reach the treatment temperature of 100°C which was maintained for the following 15 days. The demonstration was 99.99% successful reducing contaminants from 100–200 ppm to less than 1 ppm.

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Lawrence Livermore National Laboratory
Steam and SVE with Electrical Resistance Heating
Berkeley Environmental Restoration Center

Description of Demonstration: The contaminant plume was surrounded by six injection wells, with three extraction wells located in the center. The injection wells located in the areas of more permeable soil are screened for steam injection. The wells in the less permeable areas are equipped with conductive packing material and a stainless steel electrode to provide electrical current. Remediation begins with pumping the extraction wells followed by steam injection in the permeable zones.

The steam creates a pressure front where the organics are distilled into the vapor phase and transported to the steam condensation front where they are condensed. The advancing steam zone displaces the condensed liquids, moving them toward a recovery well.

As steam input stops, the electrode assemblies heat up the clays and cause water and contaminants trapped there to vaporize and be forced into the steam zones where vacuum extraction removes them.

Wastes Treated: BTEX

Status: A full-scale demonstration on a gasoline spill was completed in the summer of 1993.

Demonstration Results: Researchers expected to reclaim about 6,200 gallons of spilled gasoline, but they actually recovered 8,000 gallons. The steam distribution was controlled well. The special needs of the project (such as the harsh environment for the pneumatic pumps) led to the development of new high-tech, low cost monitoring tools.

There is preliminary evidence that soil bacteria capable of biodegrading residual contaminants survived the steam treatment. Researchers are monitoring the population to see if it rebounds.

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Naval Air Station, Lemoore, California
Steam Injection and Vacuum Extraction (SIVE)
Naval Facilities Engineering Service Center

Description of Demonstration: The soil and ground water on the three-acre test site were contaminated with approximately 200,000 gallons of JP-5. The average water table was at 16 feet below the ground surface. A clay layer acts as a lower bound to the permeable layers containing the jet fuel. The SIVE system consisted of eight dual vapor/ground-water extraction wells, two steam injection wells and 14 temperature monitoring wells were installed at the site in June 1994.

This demonstration is being conducted under an interagency agreement with the U.S. Environmental Protection Agency. The University of California (Udell Tech) and OHM are the contractors responsible for the SIVE system design and operation.

Wastes Treated: BTEX

Status: The system was in operation from July to September 1994.

Demonstration Results: Preliminary results show 94,000 gallons of JP-5 free product has been recovered from the test site.

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Current Research

Rutgers University

Description of Research: Ahlert is conducting laboratory-column and pilot-scale tests to determine the effects of humidity on the recovery of VOCs during vapor extraction. The injection of heated, humidified air enhances VOC vapor recovery by decreasing surface tensions of coexisting water/DNAPL phases, shifting the vapor-liquid equilibria in favor of the vapor phase, and yielding aqueous condensate to displace formerly trapped pure organics. Injecting energetic steam with a high heat capacity and controlling the humidity level to prevent excessive condensation should further enhance VOC vapor recovery. Ahlert's current research is aimed at explaining why some chlorinated solvents (methylethyl ketone, for example) are easily mobilized with this technology and why others (such as chloroform) are not. He is looking for a site on the East Coast that is willing to support a demonstration.

Wastes Treated: VOCs

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R.S. Kerr Environmental Research Laboratory

Description of Research: The purpose of this research is to demonstrate the use of moderately hot water to lower the viscosity of oil and increase its mobility to improve the remediation of subsurface contamination. Experimental results have shown that as the temperature increases, the oil recovery also increases, reducing the oil saturation by 33% after the injection of 10 pore volumes of water.

Although the use of hot water produced a significant reduction in the amount of residual oil in the pores, the remaining residual is still likely to be above cleanup goals. Thus, it is likely that additional treatment, such as biodegradation, will be required. However, this substantial reduction should significantly reduce the time and expense required for bioremediation, and the overall time for cleanup.

One of the advantages of the hot water process over processes such as surfactant and cosolvent flooding is that hot water does not require the injection of potentially harmful chemicals. When compared to steam injection, the advantages include the significantly lower temperatures and pressures which are easier to produce and handle in the injection equipment and wells. In contrast to the high temperatures used for steam injection which are very detrimental to the microorganisms commonly found in the subsurface, the moderate temperatures of Davis's hot water process may be beneficial to subsequent bioremediation.

Wastes Treated: BTEX

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