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In Situ Remediation Technology:

Electrokinetics

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

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For more information about this project, contact:

Rich Steimle
U.S. Environmental Protection Agency (5102W)
Technology Innovation Office
401 M Street, SW
Washington, DC 20460
703-308-8846

Notice

This material has been funded by the United States Environmental Protection Agency under contract number 68-W2-0004. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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 at (513) 489-8190 or fax your request to NCEPI at (513) 489-8695. Refer to the document numbers below when ordering.

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Walter W. Kovalick, Jr., Ph.D.
Director, Technology Innovation Office

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

The purpose of this document is to describe demonstrations, field applications, and research on electrokinetics for remediating contaminated soils and ground water at waste disposal and spill sites.

Information for this report came from computerized databases such as the Dialog Information Services and the Environmental Protection Agency's (EPA) Vendor Information System for Innovative Treatment Technologies (VISITT) and Alternative Treatment Technologies Information Center (ATTIC). Additional materials were obtained from publications such as the Hazardous Substance Research Center Annual Reports, Superfund Innovative Technology Evaluation Technology Profiles and Department of Energy's Office of Technology Development Program Summary as well as conference summaries, proceedings and compendiums. Personal interviews and discussions with representatives of other federal agencies, academic research centers, and hazardous waste remediation consulting firms provided supplementary information.

Technology Needs

Although clay and silt tend to sequester large quantities of organic and inorganic contaminants, they are resistant to remediation with traditional technologies because of their low hydraulic conductivities. Recently, attention has focused on developing in situ electrokinetic techniques for the treatment of low permeable soils contaminated with heavy metals, radionuclides, and selected organic pollutants. Although electrokinetics has been used for decades in the oil recovery industry and to remove water from soils, in situ applications of electrokinetics to remediate contaminated soil is new.

Technology Descriptions

Electrokinetics is a process that separates and extracts heavy metals, radionuclides, and organic contaminants from saturated or unsaturated soils, sludges, and sediments. A low intensity direct current is applied across electrode pairs that have been implanted in the ground on each side of the contaminated soil mass. The electrical current causes electroosmosis and ion migration, which move the aqueous phase contaminants in the subsurface from one electrode to the other. Contaminants in the aqueous phase or contaminants desorbed from the soil surface are transported towards respective electrodes depending on their charge. The contaminants may then be extracted to a recovery system or deposited at the electrode. Surfactants and complexing agents can be used to increase solubility and assist in the movement of the contaminant. Also, reagents may be introduced at the electrodes to enhance contaminant removal rates.

The following pages contain descriptions of completed, on-going, and future demonstrations and current research on electrokinetics in the United States. Electrokinetics is being used commercially in Europe to remove heavy metal contaminants such as uranium, mercury, and metal mixtures.

Ongoing and Future Demonstrations

Old TNX Basin, Savannah River Site, South Carolina
Isotron Corporation
Electrokinetic Remediation

Description of Demonstration: The purpose of this demonstration is to remediate mercury contamination in unsaturated soil consisting primarily of sand and kaolinite. Isotron Corporation is using an Electrosorb® process with a patented cylinder to control buffering conditions in situ and an ion exchange polymer matrix called Isolock® to trap metal ions.

Wastes Treated: Mercury, lead, chrome

Status: This ongoing demonstration involving Isotron Corporation and Westinghouse Savannah River Company is supported by the Department of Energy's Office of Technology Development.

Demonstration Results: Although mercury is the target contaminant in this demonstration, preliminary results indicate that at the 5 ppm mercury concentrations found at the site and other conditions, mercury will be difficult to remediate in the Basin. However, the process is showing good results on lead and chrome in the Basin.

Contacts:

Henry L. Lomasney
Isotron Corporation
13152 Chef Menteur Hwy
New Orleans, LA 70129
504-254-4624
Fax: 504-254-5172

Jane P. Bibler
Westinghouse Savannah River Company
803-725-5276

References:

Bibler, J.P.; Meaker, T.F.; and O'Steen, A.B. *Electrokinetic Migration Studies on Removal of Chromium and Uranyl Ions from 904-A Trench Soil*. U.S. Department of Energy, WSCR-RP-92-1207. NTIS #: DE93005074, 1992.

Oak Ridge K-25 Facility, Tennessee
Isotron Corporation
Electrokinetic Extraction

Description of Demonstration: The objective is to demonstrate the effectiveness of electrokinetics to move and capture uranium and organic contaminants in soil. The process involves the application of a direct current across the soil and patented system to capture the radionuclide.

Wastes Treated: Uranium and organic contaminants

Status: A pilot-scale demonstration, supported by the Department of Energy's Office of Technology Development, is underway. Laboratory tests completed in 1994 using site soil showed that the process could move and capture uranium.

Demonstration Results: None.

Contact:
Henry L. Lomasney
Isotron Corporation
13152 Chef Menteur Highway
New Orleans, LA 70129
504-254-4624
Fax: 504-254-5172

References:
U.S. DOE. *In Situ Remediation Integrated Program: Technology Summary*. U.S. Department of Energy, Office of Environmental Management, Office of Technology Development, 1994.

DOE Gaseous Diffusion Plant, Paducah, Kentucky
In Situ Remediation Technology Consortium

Description of Demonstration: The demonstration will test the ability of an integrated technology to treat TCE in clay. Highly permeable subsurface sorption zones will be created in a vertical configuration by hydraulic fracturing or similar technology followed by the introduction of certain sorbents. The electrodes, placed vertically on either side of the contaminant plume, will flush contaminants by electro-osmotic flow into the sorption zones containing certain sorbents. (Electrodes and degradation zones may be constructed horizontally or vertically depending on the site and contaminant characteristics.)

Wastes Treated: TCE

Status: Preliminary field trials began in the summer 1994, and in November 1994 CDM Federal Programs Corporation installed field demonstration equipment. Bench and pilot scale experiments will be conducted in 1994-1995, and field demonstrations of the full process is planned for 1995-1996. Integrated in situ remediation technology is being developed by a consortium consisting of Monsanto with its trademark process Lasagna,™ E.I. DuPont de Nemours & Co., and General Electric with participation from the U.S. EPA and U.S. DOE.

Demonstration Results: None.

Contacts:
Sa Ho or B. Mason Hughes
Environmental Sciences Center
Monsanto Company
St. Louis, MO 63167
314-694-5179/314-694-1466
Fax: 314-694-1531

Steven J. Bossart
U.S. Department of Energy
304-285-4643
Fax: 304-285-4403

U.S. Army Waterways Experiment Station, Baton Rouge, Louisiana
Electrokinetics, Inc.
Electro-Klean™ Electrical Separation

Description of Demonstration: Electro-Klean™ is an in situ process that removes or captures heavy metals, radionuclides, and selected volatile organic pollutants from saturated or unsaturated sands, silts, fine-grained clays, and sediments. Electrodes are placed on each side of the contaminated soil mass, and direct current is applied. Conditioning fluids may be added or circulated at the electrodes to enhance the electrochemistry of the process. The concurrent mobility of the ions and pore fluid decontaminates the soil mass. Contaminants are electroplated on the electrodes or separated in a post-treatment unit.

Wastes Treated: Lead

Status: The field demonstration of the in situ pilot-scale Electro-Klean™ process for removing lead at a U.S. Army firing range is expected to be initiated by the Spring of 1995. Electrokinetics, Inc. and the U.S. Army are preparing construction guidelines, and design and analysis processes for the demonstration. Numerous bench-scale and pilot-scale laboratory studies involving the feasibility of removing lead, uranium, and thorium from kaolinite have been completed under the SITE Emerging Technology Program. Schemes which enhance transport and extraction of substances have been developed by Electrokinetics, Inc., in collaboration with and support from the U.S. Army. Pilot-scale studies with 1.5 ton samples of a soil retrieved from the Army firing range and contaminated with lead leached from bullets are ongoing. Electrokinetics, Inc.'s process was developed in conjunction with Louisiana Business and Technology Center at the Louisiana State University.

Demonstration Results: None.

Contact:
Robert Marks, General Manager
Electrokinetics, Inc.
Louisiana Business and Technology Center
Louisiana State University, Suite 155
South Stadium Drive
Baton Rouge, Louisiana 70803-6100
504-388-3992
Fax: 504-388-3928

References:

Acar, Y.B.; Puppala, S.; Marks, R.; Gale, R.J.; and Bricka, M. *Investigation of Selected Enhancement Techniques in Electrokinetic Remediation*. Report presented to US Army Waterways Experiment Station, Electrokinetics Inc., Baton Rouge, Louisiana, 1994, p 160.

U.S. Environmental Protection Agency, Office of Emergency and Remedial Response. *Superfund Engineering Issue: Treatment of Lead-Contaminated Soils*. EPA/540/2-91/009. April, 1991.

U.S. Environmental Protection Agency, Office of Research and Development. *Superfund Innovative Technology Evaluation Program Technology Profiles. 7th ed*. EPA/540/R-94/526. November, 1994. p 262-263.

U.S. Patent and Trademark Office. *Electrochemical Decontamination of Soils or Slurries*. Patent #5,137,608, August 11, 1992.

Sandia National Laboratories Chemical Waste Landfill
Sandia National Laboratories and Sat-Unsat, Inc.
In Situ Electrokinetic Extraction

Description of Demonstration: Three to five electrode pairs, supplied with water and neutralization chemicals, will be used to treat chromium-contaminated soil over a 120-day period. Between 25 and 120 kilograms of chromium are expected to be removed from 700 to 1,000 cubic feet of soil. Soluble chromium concentrations range from 25 (background) to 10,000 ppm with the upper limit at 15 feet below ground surface. Contaminants arriving at the electrodes will be removed using a vacuum system.

Wastes Treated: Chromium

Status: Sandia National Laboratories has requested that their planned field demonstration in the unlined chromic acid pit at the landfill be conducted under the SITE program. Research and demonstrations at the Sandia National Laboratories are supported by the U.S. Department of Energy.

Demonstration Results: None.

Contact:

Eric R. Lindgren
Sandia National Laboratory
P.O. Box 5800, Mail Stop 0727
Albuquerque, NM 87185
505-844-3820
Fax: 505-844-1480

References:

Lindgren, E.R. and Mattson, E.D. *SITE Demonstration Program Proposal: In Situ Electrokinetic Extraction System*. Sandia National Laboratories, New Mexico.

Completed Commercial Applications

An Underground Storage Tank Spill
Environment & Technology Services
Electrokinetic Enhancement

Description of Demonstration: Direct current was applied through 56 electrodes installed in the upper clay layer of this 2,400 square foot gasoline contaminated site to move contaminants and water down 15 feet into dense cemented conglomerate sandstone where contaminants were removed by bioventing. Electrolysis of some water molecules, resulting from the electrical gradient, was thought to have produced hydroxyl ions that promoted oxidation of the contaminants.

Wastes Treated: BTEX

Status: Completed.

Demonstration Results: Bioventing, enhanced by electrokinetics, reportedly reduced gasoline levels of 100-2,200 ppm to well below the target of 100 ppm after about 90 days at a cost of about $50/ton.

Contact:
Walter Loo
Environmental & Technology Services
2081 15th Street
San Francisco, CA 94114
415-861-0810
Fax: 415-861-3269

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"Firm Employs Electrokinetics to Assist Subsurface Cleanup" *HazTECH News*. 9(24) p 185 (1994).

Current Research

Electrokinetic Soil Remediation
Argonne National Laboratory

Description of Research: Investigators at Argonne National Laboratory are studying the effects of various system parameters such as temperature and applied voltage on the complex subsurface phenomena that occur during electrokinetics soil remediation. Initial studies have focussed on the effect of temperature on the removal/extraction of potassium dichromate from kaolinite soil.

Wastes Treated: Potassium dichromate

Contact:
Theodore R. Krause
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439
708-252-4356
Fax: 708-252-5912

References:
Krause, T.R. and Tarman, B. "Preliminary Results from the Investigation of Thermal Effects in Electrokinetics Soil Remediation." ANL/CMT/CP-79321. Conference Proceedings: Annual American Chemical Society Industrial and Engineering Chemistry Division Special Symposium on Emerging Technologies for Hazardous Waste Management, Atlanta Georgia. September 27-29, 1993. U.S. Department of Energy.

Electrokinetic Remediation
Louisiana State University and Electrokinetics, Inc.

Description of Research: The primary goal of past and ongoing research at Louisiana State University (LSU) is to explore, investigate, and use multi-species transport mechanisms in soils under electrical fields for developing techniques to remediate soils from inorganic and organic substances and radionuclides. The mission of Electrokinetics, Inc. is to translate the scientific knowledge developed by LSU and other researchers into practice by carrying out the essential developmental work in deployment and commercialization of the promising technologies.

Bench-scale studies are conducted at LSU to evaluate the feasibility of removing lead, chromium, cadmium, zinc, uranium, radium, and thorium from spiked and natural contaminated soils. Bench-scale studies also have been carried out to investigate the feasibility of transporting phenol, hexachlorobutadiene and trinitrotoluene (TNT). Both clays/granular soils and spiked/natural specimens have been used in testing. The feasibility and cost-effectiveness of electrokinetic remediation in extracting some of these inorganic species have been demonstrated. The efficiency of extraction relies upon several factors such as the type of species, their solubility chemistry in the specific soil, their electrical charge, their concentration relative to other species, their location and form in the soil, available counter ions in the soil, type of soil, availability of organic matter in the soil, processing parameters used, and the type of conditioning and enhancement scheme employed in the electrokinetic remediation process. Studies at LSU indicate that polar species such as phenol may be removed under electrical fields below their solubility limit, but removal of nonpolar species such as hexachlorobutadiene and TNT under electrical fields is possible only if aqueous surfactant solutions are used in order to increase the solubility of the organic species and to form charged micelles.

Pilot-scale studies have been conducted under a cooperative agreement between the U.S. EPA and Electrokinetics, Inc. of Baton Rouge. The efficiency and feasibility of removing lead from spiked one ton specimens of clay have been demonstrated in three separate pilot-scale tests. In research sponsored by the U.S. EPA, researchers at LSU have developed a theoretical model for multi-species transport in soils under electrical fields. The numerical implementation of the model has been verified through correlations with the results of the pilot-scale studies.

LSU researchers and Electrokinetics Inc. personnel, in a collaborative effort with the Department of Energy (DOE) and the U.S. EPA also have initiated a research and development program which aims to deploy multi-species transport processes under electrical fields in injection of process additives and nutrients for effective in situ bioremediation of organic species. Bench and pilot-scale studies investigating transport rates of selected species in heterogenous soil conditions are ongoing. Pilot-scale studies and field demonstration studies are planned.

Wastes Treated: Heavy metals, radionuclides, organics.

Contact:
Yalcin Acar
Louisiana State University
Department of Civil and Environmental Engineering
Center for Engineering and Business Administration
Baton Rouge, LA 70803-6100
504-388-8638
Fax: 504-388-8652

References:
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In Situ Electrokinetic Soil Processing
Electro-Petroleum, Inc. and Lehigh University

Description of Research: Laboratory studies conducted by Electro-Petroleum, Inc. and Lehigh University have shown mobilization of 15 metals and 6 organic compounds in five soil matrices with an electro-kinetic process developed by Electro-Petroleum, Inc. (Some of the research has been conducted under two contracts through the Argonne and Sandia National Laboratories.) The electrokinetic process can treat soils, sludges, and sediments contaminated with heavy metals and organic hydrocarbons but works best on clay-type soils with low hydraulic permeability. Electrokinetic permeabilities for aqueous systems in clays have been demonstrated to be up to one thousand times greater than normal hydraulic permeabilities, and some heavy metals have exhibited removal efficiencies of up to 100%. Based on laboratory-scale experiments, Electro-Petroleum, Inc. estimates the cost of in situ remediation should be approximately $50 per cubic yard.

The only field testing of Electro-Petroleum, Inc.'s electrokinetic process has been under confidentiality agreements in oil fields. Two full-scale systems are in the design phase of development.

Wastes Treated: Heavy metals, volatile and semivolatile organic compounds, solvents, BTEX, radioactive metals, inorganic cyanides

Contact:
J. Kenneth Wittle
Electro-Petroleum, Inc.
Suite 1118
996 Old Eagle School Road
Wayne, PA 19087
610-687-9070
Fax: 610-964-8570

References:
Khan, L.I.; Pamukcu, S.; Wittle, J.K.; and Titus, C.H. "Electrokinetic Treatment of Contaminated Soil." AIChE Meeting, Pittsburgh, PA, August 1991.

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Electrokinetic Soil Processing
Lehigh University

Description of Research: The critical parameters of electroosmosis and flow enhancing ions have been investigated in a series of laboratory experiments. The study demonstrated successful removal of 16 targeted PAH compounds from the soil (clay or granular) at a removal rate of 44 to 70% upon 2 to 9 pore volumes of electroosmotic water flow through the soil specimens. In general, the degree of success of decontamination by electrokinetic process appeared to be parameter specific; more dependent on the type of the contaminant to be removed than the type of medium being decontaminated. Electroosmosis appeared to be the dominant mechanism of transport when the contaminants present in the aqueous phase were nonpolar or nonionic, neutral micelles or surface-coated colloids.

Investigations of clay or clay mixtures and a known concentration of a selected heavy metal salt solution or an organic compound showed up to 99% heavy metal removal and high removal levels of some organic compounds such as phenol, acetic acid, and O-nitrophenol. Transient pH change through the soil had an effect on the metal movement as evidenced by accumulation of the metals at the discharge ends of the soil specimens. The accumulation was attributed to the precipitation of the metals and increased cation retention capacity of the clay in high pH environment at the cathode end. In general, precipitation, reduced mobility, and reduced dissociation of the ionic species as they encountered areas of higher ionic concentration in their path of migration resulted in the accumulation of the metals at the discharge ends of the soil specimens.

Wastes Treated: Coal tar, radionuclides, priority heavy metals

Contact:
Sibel Pamukcu
Lehigh University
Department of Civil and Environmental Engineering
Fritz Engineering Laboratory
13 East Packer Ave.
Bethlehem, PA 18015
610-758-3220
Fax: 610-758-4522
E-Mail: SP01@Lehigh.edu

References:

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Electroremediation
Massachusetts Institute of Technology

Description of Research: The purpose of the research is to develop and verify a mathematical model that can be used in identifying optimal operating conditions for electrokinetic decontamination of waste sites. The model is intended to take into account the complex interaction of subsurface effects that occur simultaneously when a direct current is applied in soil. Tests are being conducted in laboratory test cells to identify the multiple parameters that influence the electrokinetic process and to verify the model. Experimental results of up to 94% removal for some chemicals such as phenol or acetic acid and 98% removal of heavy metals such as zinc in compacted kaolin were in good agreement with model predictions when important parameters, such as electrode reactions and pH, were accounted for. This research, which is sponsored by the U.S. Department of Energy, is expected to improve the efficiency and reduce the cost of practical applications of the technology.

Wastes Treated: Heavy metals, organics

Contact:
Ronald F. Probstein
Massachusetts Institute of Technology
Department Mechanical Engineering
Cambridge, MA 02139
617-253-2240
Fax: 617-258-8559

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Electrokinetics
Sandia National Laboratories

Description of Research: The purpose of this research program is to develop an in situ electrokinetic process for remediating unsaturated soils contaminated with heavy metals. The results of laboratory electrokinetic studies on large anionic organic dyes in unsaturated soil (as low as about 25% saturation) indicate that electrokinetics is a feasible alternative for remediating in situ anionic heavy metals like chromate and uranium. In sandy soils with approximately 40 to 60% moisture saturation, the bench-scale electrokinetic process removed 75 to 90% of initial chromium.

Wastes Treated: Chromium

Contact:
Eric R. Lindgren
Sandia National Laboratory
P.O. Box 5800, Mail Stop 0727
Albuquerque, NM 87185
505-844-3820
Fax: 505-844-1480

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Electrokinetic Extraction
Texas A&M University

Description of Research: Researchers formulated a coupled flow theory for the transport of fluid, electricity, and contaminants under the combined influences of hydraulic, electrical, and chemical gradients to describe the contaminant transport during the electrokinetic extraction process. Electrochemical reactions associated with the processes and soil-contaminant interactions are also included. A numerical model was developed to simulate the contaminant transport, electrochemical reactions, and soil-contaminant interactions during the extraction processes. Bench scale experiments were performed to evaluate the validity of the theory and numerical model.

Wastes Treated: Sodium chloride, lead nitrate, phenol, acetic acid

Contact:
Albert T. Yeung
Department of Civil Engineering
Texas A&M University
College Station, TX 77843-3136
409-845-2538
Fax: 409-845-6554
E-mail: ALYEUNG@tamu.edu

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Electrokinetics
University of Massachusetts Lowell

Description of Research: Researchers have been conducting laboratory and bench-scale research on the effectiveness of electroosmosis for removing hydrocarbons and heavy metals from clay. Benzene, toluene, TCE, and m-xylene—all of which have relatively high water solubilities—were more easily removed from fine-grained soils than hexane and isooctane and other compounds with low water solubilities and high distribution coefficients. Researchers also are studying the physical and chemical characteristics of electroosmotic contaminant transport. The data are being used to gain insights into electroosmotic organic contaminant displacement and how soil and pore water characteristics affect the process.

Wastes Treated: BTEX, hexane, isooctane, other hydrocarbons, and lead

Contact:
Clifford J. Bruell
University of Massachusetts Lowell
Civil Engineering Department
One University Avenue
Lowell, MA 01854
508-934-2280
Fax: 508-934-3052

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In Situ Electrokinetics
West Virginia University

Description of Research: The Department of Energy has sponsored laboratory and bench-scale studies on the use of electrokinetics to remediate fine-grained soil contaminated with lead. The research included an evaluation of the impact of initial conditions on the efficiency of electrokinetics to drive liquids and contaminants through soil samples. An electrokinetic soil reactor designed to mimic in situ electrokinetic flushing was applied to silt loam artificially contaminated with lead. Studies of the removal of lead from soils indicate that the efficiency of lead removal is related to the flow of the acid front generated by the positive electrode.

Wastes Treated: Lead

Contact:
Brian Reed
West Virginia University
Department of Civil and Environmental Engineering
647 Engineering Science Building
Morgantown, WV 26506
304-293-3031 x613

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