TechData Sheet

Naval Facilities Engineering Service Center
Port Hueneme, California 93043-4370

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Removal of Heavy Metals from Contaminated Soils at a former Naval Air Station

A Demonstration of Electrokinetic Remediation

Conducted by:
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In cooperation with:
Bay Area Defense Conversion Action Team Environmental Technology Partnership

Introduction

The Navy is conducting a treatability study of electrokinetic remediation of soil contaminated with heavy metals. The process uses a direct-current electric field in the soil to move metals to electrodes where they are removed. The study is for the Navy Installation Restoration Program to evaluate the technology for site use. The Bay Area Defense Conversion Action Team (BADCAT) Environmental Technology Partnership (ETP) will also evaluate the technology for regional use.

BADCAT ETP is a public/private partnership of the Bay Area Economic Forum, Bay Area Regional Technology Alliance, California Environmental Protection Agency, San Francisco State University Center for Public Environmental Oversight, U. S. Environmental Protection Agency, U. S. Navy, Chevron Research and Technology Company, and other technical experts working to expedite the cleanup and conversion of Bay Area closing bases through the application of innovative environmental technologies.

Purpose of the Demonstration

The demonstration is designed to show that electrokinetics removes heavy metal contamination from alkaline soils. The objective of the demonstration is to reduce chromium concentrations in the soil to achieve U. S. EPA Region IX preliminary remediation goals for residential use and to develop reliable cost and performance data.

Site Description

The demonstration site is a former naval air station plating shop. Activities during operations between 1942 and 1990 included degreasing, caustic and acid etching, metal stripping and cleaning, and plating of chrome, nickel, silver, cadmium, and copper. Two sumps were used to collect wastewater discharged from the plating process lines. Soil cores have shown chromium levels up to 2060 mg/kg.

Electrokinetic Demonstration Site

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Advantages of Electrokinetics

Electrokinetics offers advantages over other technologies currently available for metals remediation, specifically:

- Electrokinetics is an in-situ technology that has much less impact on existing landscaping, buildings or structures than ex-situ technologies dig and haul or soil washing.
- Unlike acid flushing, the process exploits induced localized pH alterations to mobilize metal ions so the soil matrix is not destroyed and the process is not limited by low soil permeability.
- The metals are actually removed from the soil unlike chemical stabilization, which incorporates metals into a compound with low solubility.

Process Fundamentals

Electrokinetic remediation is a process in which an electric field is applied across contaminated soil with low-voltage direct-current electrical power. This field causes the movement of ions such as heavy metals to the electrodes. The principles behind electrokinetic remediation are those of the electrolytic cell where ions in a liquid will migrate under the influence of electricity. A detailed description of the process follows. First a few definitions:

Electrolyte: technically, a substance that dissociates in solution into positive and negative ions but this term is most often used to refer to an *electrolytic solution*, which is an aqueous solution of an electrolyte.

Electrolysis: the passage of an electric current through an electrolyte caused by an external voltage source. Negative ions (anions) are attracted to the anode, where they are oxidized (lose electrons). Positive ions (cations) are attracted to the cathode, where they are reduced (gain electrons).

Electrokinetics: the movement of ions in a liquid caused by electrolysis.

Electrolytic Cell: a voltage source with a positive electrode (*anode)* and a negative electrode (*cathode)* placed in an electrolyte (see Figure 1). Note that these electrode definitions are the opposite of galvanic cell terminals such as a lead-acid battery.

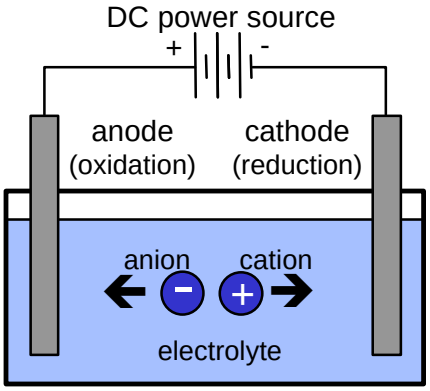


Figure 1. Electrolytic Cell

Electrical current is the flow of electrical charge. Unlike the electrical current in a wire, which is the movement of free electrons, the current in an electrolyte is the movement of ions to the electrodes. Metal ions such as chromium are generally positive ions. Metals also exist as negative ionic compounds such as chromates (chromium-oxide ions). If these ions are in an electrolyte and DC power is applied, the positive ions will migrate to the cathode and negative ions will migrate to the anode.

Soil Remediation

A contaminated soil matrix can be thought of as an electrolyte (pore water) surrounding soil particles. This simplified model is applicable both above and below the water table. Below the water table all of the soil void spaces are filled with pore water. Above the water table, soil typically contains 5% to 20% water. This water resides as a thin coating clinging to soil particles by surface tension forming a continuous medium through which ions can travel to the electrodes.

Heavy metal contamination typically exists in one of three forms:

- as precipitates, such as metal hydroxides and metal carbonates
- as a metal cation which is adsorbed to the surface of a negatively charged soil particle
- as a dissolved ion or in a dissolved ionic compound within the pore water.

The ratio of metal contamination in each of these three states is dependent on many factors. Soil properties such as pH and buffer capacity and contaminant properties are the most important.

To recover metal contamination from soil, it must first be converted into a dissolved ionic form. Typically this requires an adjustment of the soil pH and sometimes modification of the pore water chemistry. Electrokinetics was developed to address these issues in an elegant and practical manner. The key elements discussed in the following paragraphs.

Electrodes are not just put into the contaminated soil, they are immersed in circulating electrolyte held in semi-permeable casings (see Figure 2). The casings contain the electrode electrolyte (catholyte for the cathode and anolyte for the anode) but allow for the passage of ions and maintain hydraulic continuity between the electrolyte and the soil moisture.

When the electrodes are energized, electrolysis of water inside the casings results in the formation of H+ ions at the anodes and OH- ions at the cathodes. Essentially, each anode is a source of acid (H+) and each cathode is source of base (OH-). The electrodes and circulating electrolyte are used to supply and remove ions from the soil/water matrix. Careful selection and management of the electrolyte pH and chemistry allows the properties of the soil/water matrix to be adjusted to maximize contaminant solubility.

Once the contaminant is dissolved, it may freely migrate to the anode or cathode under the influence of the electrical field. At the electrode surface, the contamination passes through the

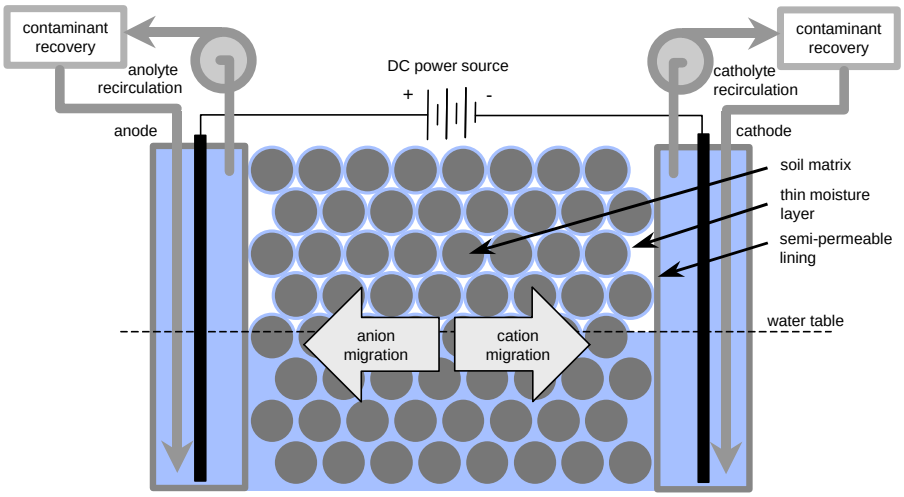


Figure 2. Electrokinetic Treatment System

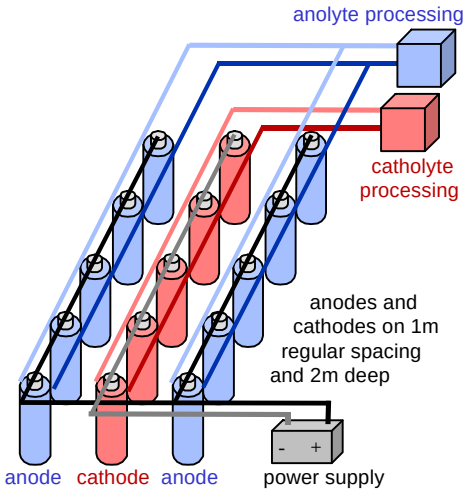


Figure 3. Demo Site Equipment

electrode membrane and into the electrode solution and is removed from the ground for further processing and recovery.

Technology Limitations

The buffer capacity of the soil and the specific form of the contamination influences electrokinetics. During the early development of the technology, alkaline soils presented a significant problem. However, modeling of transient processes resulted in the development of sophisticated electrolyte management that greatly enhances performance under these difficult conditions. Moreover, if the ground and contamination chemistry are known a potential site can now be accurately modeled to determine the appropriateness of the process. One of the objectives of the demonstration is to validate performance model.

More critical concerns include the presence of solid metallic contamination, for which electrokinetics is inappropriate, and metallic underground services which, if not compensated for, will act as preferential current paths.

The key deployment issue concerns the available time to remediate a site. Although this may be counter intuitive, the total cost of electrokinetics can be shown to decrease with the time available because less costly equipment is required. For most practical in-situ applications this results in a minimum treatment time of six to nine months. In one case optimal performance and cost was determined to be two to three years.

Demonstration Description

The demonstration layout consists of two rows of five anodes on either side of a row of five cathodes (Figure 3). The electrodes are placed on a one-meter regular spacing and two meters deep.

The target of the demonstration is the recovery hexavalent chromium (Cr6+) that exists in the form of negatively charged chromates. To achieve this, the anolyte and catholyte are maintained at pH between four and five. This reduces the soil pH from seven to five by the migration of a mild acid front from the anodes to the cathodes. The acid front increases the solubility of the Cr6+ ions, which then migrate to the anodes. When the dissolved Cr6+ ions reach the electrode casings they pass through the casing membrane and into the anolyte solution and out of the ground for recovery. Treatment time is expected to be approximately four months.

Previous Projects

Several demonstration and full-scale electrokinetic projects have been successfully conducted by Geokinetics. The full-scale projects to date have been conducted in Europe. The results are summarized in Table 1.

At the site of a former paint factory, a pilot test of electrokinetics was employed to remove lead and copper that had leached into the soil from a sludge pile. The soil was characterized as acidic and the lead and copper were easily mobilized. Lead and copper were reduced by 70% and 80%, respectively, in only 43 days.

Another pilot project was used to remove zinc at a galvanizing plant site. This site had a higher pH and ammonia content in which zinc is less soluble. Accordingly, nearly nine months were required to achieve the 200-mg/kg objective.

At a former timber treatment plant, arsenic levels were reduced below the objective 30-mg/kg level for 75% of the site treated. Levels in the remaining 25% were observed to decrease much more slowly so the remaining soil excavated. A later unearthed drum of arsenic solution was determined to be the problem.

A temporary landfill was used to receive and treat dredged material contaminated with cadmium, zinc, lead and other heavy metals. A two-year treatment period was specified based on site data that failed to identify the presence of “nodules” of cadmium concretions. After two years the cadmium levels had been reduced from 4,000 mg/kg to 40 mg/kg. Although this remained higher than the two-mg/kg goal, the lack of mobility of the remaining cadmium allowed the soil to be used as capping material for a landfill.

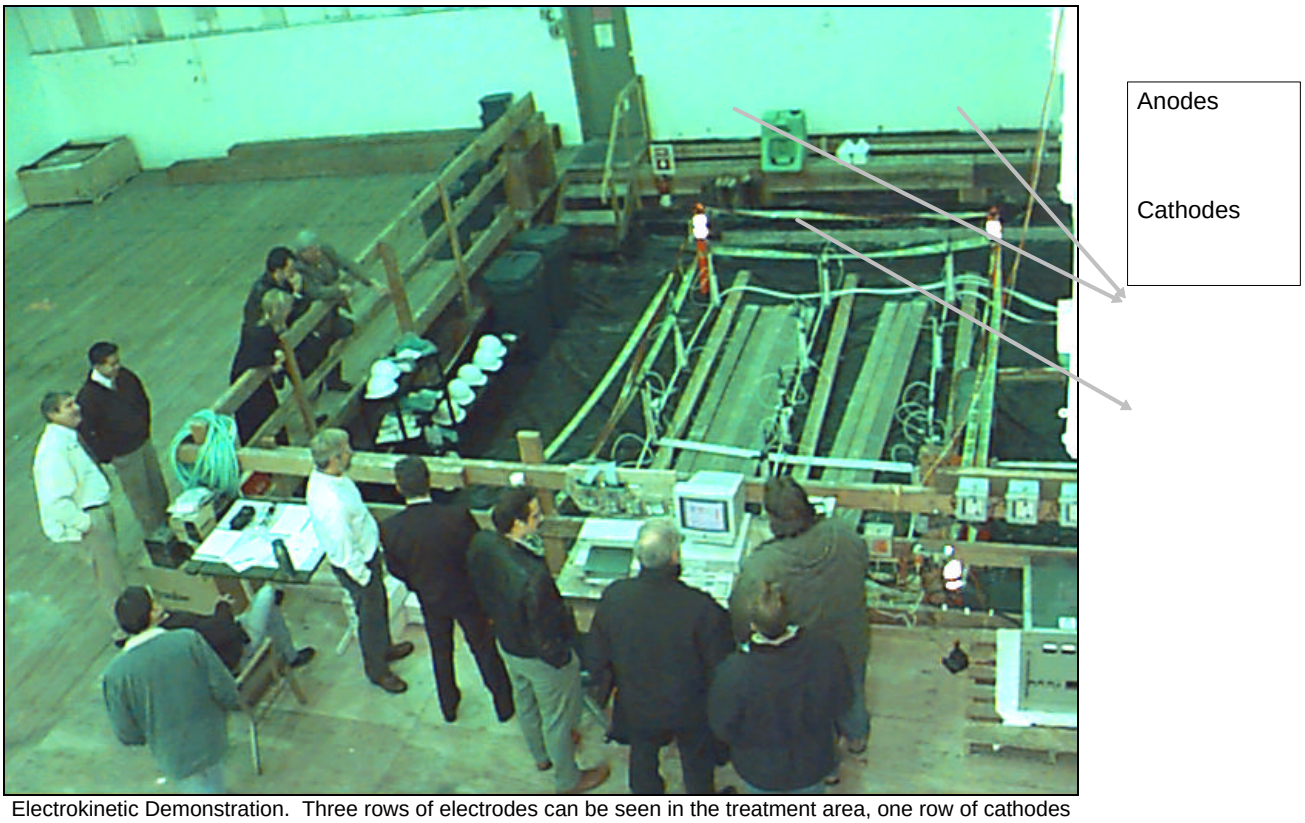
At a former Dutch Air Force base, contamination from several metals contaminated zones was consolidated into a large lagoon and processed over two years with some acid pre-treatment. Reduction of zinc, lead, copper, arsenic and cadmium was achieved to acceptable levels.

Costs

Stated costs for small, "turn key" remediation projects of nine months duration are in the range of $120 to $170 per cubic yard. For large projects, or extended time scales, costs should be significantly lower. This demonstration will help to provide cost information for this technology and validation of cost modeling.

Project	Soil Type	Volume (yd^3)	Initial (mg/kg)		Final (mg/kg)	
Paint Factory	Peat/Clay	300	Cu	>1,220	Cu	<200
			Pb	>3,780	Pb	<280
Galvanizing Plant	Clay	50	Zn	1,400	Zn	600
Timber Plant	Heavy Clay	250	As	> 260	As	<30
Temporary Landfill	Sand	4,000	Cd	>180	Cd	<40
Military Airbase Galvanizing Plant	Clay	2,500	Cr	7,300	Cr	755
			Ni	860	Ni	80
			Cu	770	Cu	98
			Zn	2,600	Zn	289
			Pb	730	Pb	108
			Cd	660	Cd	47

Table 1. Projects completed by Geokinetics



Electrokinetic Demonstration. Three rows of electrodes can be seen in the treatment area, one row of cathodes in the middle with two rows of anodes on the outside. The computer in the foreground is the control system.

For more information about BADCAT ETP and Electrokinetics, contact:

Engineering Field Activity West (650)244-2539	**Naval Facilities Engineering Service Center** (805) 982-2631/DSN 551-2631
U.S. Environmental Protection Agency (415) 744-2334	**Bay Area Defense Conversion Action Team** (510) 628-8330

This document is for informational purposes only and makes no endorsements. Applicability for remediation must be evaluated on a site-specific basis.