

ELECTRORECLAMATION

During the past five years, electroreclamation technology has been developed by the Geokinetics company and applied in The Netherlands. Some field trials and actual cleanup projects using this new technology have removed toxic heavy metals from soil and groundwater. The method is based on electrokinetic phenomena that occur when the soil is charged by means of several electroarrays—hence the term electroreclamation. This technique can be applied in situ, on site, and off site. Additionally, the electrokinetic phenomena that occur when the soil is electrically charged can be used to fence off hazardous waste sites or hazardous industrial sites. Electrodes can be installed horizontally and vertically in deep, directionally drilled tunnels or in trenches around sites polluted by leaking storage tanks; by spillage from industrial processes; by leachate from agricultural lands, landfills, and mine tailings; and by deposition from the air and subsequent leaching into the soil and groundwater. Electrokinetic fencing combines containment, remediation, and prevention. [Electrokinetic remediation principles are described in the feature by Yalcin Acar on p. 2638.]

Recent laboratory experiments show that this technique can be used in combination with other re-

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Applications in The Netherlands

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mediation techniques such as pumping, biodegradation, and vacuum extraction. When combined with electrical heating, this electrokinetic technique can also be used to remove polar and nonpolar organic chemicals from soil and groundwater.

Field experiments and projects

A pilot test of the electroreclamation process was conducted in 1987 at the site of a former paint factory in Groningen, The Netherlands. This first field experiment took place in the peat soil alongside part of a water-bearing ditch, bordered on one side by the factory and on the other side by open grassland. Pollution in this area consisted of heavy metals, such as lead and copper, which had leached down into the soil from sludge that had been dredged from the ditch and dumped on the bordering grassland. The sludge was heavily polluted with metals in the form of paint residues (solid particles). The lead concentration range was 300 to > 5000 ppm, and copper concentrations

were on the order of 500–1000 ppm.

The test area was 70 m long and 3 m wide. Electrode setup consisted of one horizontal cathode at 0.5 m below ground surface and a row of vertical anodes installed at a depth of up to 1 m and spaced 1 m apart. Changes in lead and copper concentrations were monitored at 26 sampling locations, spaced at regular intervals and at several depths (10, 20, 30, 40, and 50 cm below ground surface). Current was applied 10 h per day for 43 days, after which lead was reduced by up to 70%, while copper concentrations were reduced by 80%. Energy consumption was 65 kWh/m³ or 38 kWh/ton. In the layer just underneath the sludge, metal concentrations were observed to increase as a result of additional dissolution of the paint particles.

We concluded from this test that the relatively low pH of the peat soil (pH 4) facilitated mobilization of the heavy metals greatly, necessitating a low energy inducement. The already acid environment was acidified further through electrokinetic inducement of H⁺, resulting in the dissolution of paint particles, which then acted as new sources of pollution. To successfully remediate the site by electroreclamation, the sludge layer containing the solid paint particles should have been removed. The energy consumption needed to reach Dutch reference levels for lead and copper is estimated to be 85 kWh/m³.

The second project

A second project pilot test was conducted at the site of a galvanizing plant in Delft, The Netherlands. For the experiment we selected an area 15 × 6 × 1 m. Power was sup-

A current electroreclamation project at the airbase in Woensdrecht, The Netherlands. The right building container is for conditioning; the middle and left ones are for treatment of the electrode solutions. The yellow tanks are buffer tanks for the electrolytes coming from the field; the black pipes are part of the anode circulation system. The cathodes are horizontally installed in between the anode rows and are not visible. The soil is covered with plastic sheets to prevent rainwater from entering the circulation system (excess water causes the system to stop automatically, as the conditioning container can handle a limited volume per unit of time). The energy container (with transformers and rectifiers) is not visible.



plied by a 100-kVA generating set. Electrode setup was three horizontal cathodes at a depth of 0.5 m and three rows of anodes installed up to 1 m below ground surface. The resistivity of the clay soil was 5 ohm per meter (Ω/m) at the beginning of the test but decreased to 2.5 Ω/m after two weeks as a consequence of increases in temperature and ionic strength. Current density was 8 A/m^2 of soil, and the potential drop 20–40 V/m. The effective energy consumption per 1000 kg of soil amounted to 160 kWh during the eight-week period.

Changes in zinc concentration were monitored at 12 locations, which were sampled at three different depths (10, 30, and 50 cm). Changes in groundwater concentration were monitored in two observation wells. At the beginning of the test the highest measured zinc concentration was 7010 ppm with an average of 2410 ppm over the whole area. At the end of the test the highest measured zinc concentration was 5300 ppm, and the average had been reduced to 1620 ppm.

We concluded from the second test that, even after a relatively high

energy inducement of 160 kWh per ton, the remediation objective of 200 ppm was not achieved. This was caused by the high buffering capacity of the soil and by the presence of ammonia and ammonium chloride, as shown during additional analysis of the soil. To mobilize all zinc by the electrokinetic reduction of pH to a level of 3–4 would require an additional energy inducement of some 320 kWh per ton. With the existing power supply of 100 kVA (kilowatt amperes), this would mean tripling the treatment duration from eight to 24 weeks.

A third project

The third project was the actual cleanup at the site of a former timber impregnation plant in Loppersum, The Netherlands, in 1989. The site was underlain by heavy clay soil containing arsenic levels up to 400–500 ppm to a maximum depth of 2 m. The source of the pollution was attributed to $Na_2HAsO_4 \cdot 7H_2O$, or "Superwolmansalt D," used for impregnation. The pollution was confined to an area 10×10 m, contaminated to a depth of 2 m, and an adjoining area 10×5 m, contami-

nated to a depth of 1 m.

When this project began, the resistivity of the clay was 10 Ω/m and soil temperature at a depth of 0.5 m was 7 °C. After 3 to 4 weeks the temperature had risen to an average of 50 °C, while resistivity decreased to 5 Ω/m . The original potential drop of 40 V/m decreased subsequently to 20 V/m with an average current strength of 4 A/m^2 (the total cross-sectional area being 110 m^2).

Changes in arsenic concentrations were monitored at 10 fixed sampling locations and numerous randomly distributed points. After 65 days roughly three-quarters of the area showed arsenic concentrations below the remediation objective of 30 ppm. During the remediation process it had been observed that in the remaining one quarter of the area the decrease in arsenic concentration proceeded much more slowly than at other locations. Temperature at the location rose to a maximum of 60 °C. Because of time constraints it was decided to stop the electroreclamation process and excavate the remainder of the soil, which showed arsenic concentrations above reference levels.

Electroreclamation at a glance

The electroreclamation process in situ or in temporary landfills can effectively clean up soil contaminated with heavy metals and other inorganics.

Boundary conditions:

- The contaminant can be brought into solution (liquid phase) at pH 4–5,
- The soil material should not contain metal or isolating objects,
- The contamination does not occur as concretions or in other solid form (e.g., paint residuary).

If these conditions are not met, the polluted soil material should be pretreated and remediated in an open temporary landfill or electrokinetic batch installation (this means excavation of the soil).

Pretreatment consists of:

- sieving, sorting, and homogenizing
- mixing with organic or inorganic acid or with complexing agents
- posttreatment to neutralize.

Depending on the available electrical power the pretreated material can be remediated:

- in temporary landfills; large volumes at the same time during a longer time period, using a relatively low energy supply per cubic meter, or
- in batch installations; smaller volumes during short periods using a relatively high energy supply per cubic meter. The advantage of the latter is that it allows for almost immediate intervention the moment deviations occur and more efficient control of the electroreclamation process.

never been observed. The CdS, not readily soluble, went into solution under the influence of the electrokinetic processes, thus functioning as additional point sources of cadmium. These concretions, spread over the whole depot, impeded the decrease of the cadmium concentration to the desired level (2 mg/kg Cd) within the planned 300 days. The cadmium concentration at the end of the two-year period varied from < 1 to 40 mg/kg.

The most important conclusion of this project was that the cadmium in the CdS could be brought into solution much faster by conditioning the soil with acid during a pretreatment phase. The cadmium concretions should also be removed by sieving the soil during a pretreatment phase.

Additional experiments with pretreated soil (sieved and mixed with acid) in a so-called batch installation (open containers with fixed electrode compartments) yielded the results shown in Table 1.

A fifth project

This cleanup project is currently in operation at the site of a temporary depot at the air base of Woensdrecht in The Netherlands. The depot measures 90 × 20 × 2.5 m and is filled with 2500 m³ clay and peat dredged from a natural pond. The soil material contains heavy metals like cadmium (660 mg/kg), lead (730 mg/kg), copper (770 mg/kg), nickel (860 mg/kg), chromium (7300 mg/kg), and zinc (2600 mg/kg) from a former galvanizing plant. The soil material has been preacidified. Remediation takes place in two batches. Results may be published after termination of this project in early 1994.

TABLE 1
Results of electroreclamation project, Stadskanaal, The Netherlands

Energy (kWh/m ³)	Concentration (mg/kg)		
	Cadmium	Lead	Zinc
0	300	210	480
20	150	120	320
65	50	90	120
180	< 2	< 10	< 10

During excavation, many metal objects such as tins, barrels, and reinforcing rods were found—shiny, without any rust, and in many cases partly dissolved. These objects functioned as preferential flow paths for the electrical current, thereby delaying the movement of the pollutants in their vicinity, until the objects had been dissolved. Some 40 m³ of soil had to be excavated. Periodic treatment of the electrode solutions yielded 800 kg of filtrate. Meanwhile the site has become a residential area.

A main conclusion from the third project was that metallic objects > 10 cm should be removed whenever possible, because they interfere with the electric current. Insulating objects such as wooden beams, plastic sheets, and concrete blocks also interfere with the process. The presence and location of subsurface

pipes and cables should be found out in advance, so appropriate measures can be taken to protect them.

A fourth project

The fourth project was the cleanup of a temporary landfill in Stadskanaal, The Netherlands in 1990–1992. The upper part of this depot measured 70 × 40 × 2.6 m. It had been filled in with soil and sludge contaminated with cadmium and other heavy metals. Cadmium was present in the form of cadmium sulfide (CdS). We planned to remediate the upper part, containing approximately 2300 m³, in two sections within 300 days. Cadmium concentrations in the first section averaged 11 mg/kg with a range of 74–2 mg/kg. In the second section concentrations averaged 30 mg/kg and ranged from 3400 to 20 mg/kg. Cathodes were installed horizontally, anodes vertically. During the first two months of the project (April and May 1991), concentrations decreased according to plan, using 5 kWh per 1 mg/kg of cadmium. In June, however, a relatively strong increase in cadmium concentrations was observed at the sampling points. Additional survey and analysis of the soil material uncovered concretions of CdS. The size of these concretions varied from millimeters to several centimeters, with concentrations up to 5000 mg/kg. During earlier laboratory tests these concretions had