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SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

Emerging Technology Summary

Development of Electro-Acoustic Soil Decontamination (ESD) Process for In Situ Applications

Laboratory studies were conducted on clayey soils contaminated with decane (organic), zinc chloride (inorganic), and a mixture of zinc and cadmium chlorides to evaluate the effect of electro-acoustics to decontaminate these soils. The objectives of the study were to develop an electro-acoustic leaching process that has the potential to :

- **Decontaminate soils containing hazardous organics in situ by the application of d.c. electrical and acoustic fields.**
- **Decontaminate soils containing heavy metals by the application of d.c. electric and acoustic fields.**

Using the electro-acoustic leaching process it was demonstrated that :

- **Removal of decane from clayey soils was not feasible.**
- **Up to 90 percent removal/ concentration of zinc and cadmium from soils was achieved.**

This report represents the first phase of the ESD process development aimed at decontamination of soils contaminated with organics such as decane and inorganics such as zinc and cadmium in fulfillment of a SITE cooperative agreement by Battelle under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period September 1988 to December 1989.

This Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Many sites in the U.S. are contaminated with nonaqueous phase liquids (NAPL) and heavy metals. The U.S. EPA has estimated that 189,000 underground storage tanks are leaking at retail fuel outlets alone. NAPL contamination in the form of coal tars and petroleum sludges from above-ground tanks is also a significant problem. Following an NAPL spill or release, the liquid typically migrates to the water table where it spreads out and floats, since it is lighter than water.

Moreover, improper disposal of industrial wastes containing heavy metals has created a serious problem in a number of locations. Because of increasing proliferation of these wastes, contamination of the ground and ground-

water at a number of locations is causing a serious threat to the environment.

The current state-of-the-art in remediating these sites is to recover all pumpable separate phase organic liquids and then treat the residuals either in situ (via bioreclamation, soil venting, or soil washing or flushing) to pump and treat or to excavate. The initial recovery of pumpable product, depending upon the site, is typically limited to 20-25 percent recovery and in many cases even less.

Background

The electro-acoustic soil decontamination process is based on the synergistic application of a d.c. electric field and an acoustic field to contaminated soils to increase the transport of leachants through the soils.

Acoustics, when properly applied in conjunction with electroseparation and waterflow, enhances dewatering or leaching. The phenomena that augment dewatering when using the combined technique are not understood fully. However, we have developed some hypotheses about possible mechanisms.

It is theorized that, in the presence of a liquid phase continuum, the acoustic phenomena (e.g., inertial and cavitational forces) that separate the liquid from the solid into the continuum are facilitated by the electric field and a pressure differential to enhance dewatering by means of one or more of the electroseparation phenomena. There is also evidence of synergistic effects of the combined approach. In addition, as the cake densifies (by sequestration and electroosmosis), the liquid continuum normally would be lost, but it is believed that by channelling, on a microscale, acoustic energy delays the loss of the continuum, making additional leaching possible.

Besides electroosmosis, passage of d.c. current through a wet soil also produces effects such as ion exchange, development of pH gradients, electrolysis, gas generation, oxidation and reduction, and heat generation. It is conceivable that the heavy metals present in contaminated soils can be precipitated out of solution by electrolysis, oxidation and reduction reactions, or ionic migration. The contaminants in the soil may be cations, such as Cd^{++}, Cr^{+++}, and Pb^{++++}, or anions, such as CN^-, CrO_4^-, and $Cr_2O_7^{2-}$.

The existence of these ions in their respective states depends upon the local pH and concentration gradients existing in the soil systems. Application of an electric field is expected to increase the leaching rate and precipitate the respective heavy metals out of solution by establishing appropriate pH and osmotic gradients. For example, $CdCl_2$ in solution can be precipitated out as $Cd(OH)_2$ at the cathode due to the generation of (OH) ion at the cathode and flushed out of the ground and separated by conventional techniques.

Test Equipment and Procedures

The test unit design was developed primarily to accommodate the introduction and characterization of the acoustical energy. The test unit is shown in Figure 1. The intent was to reasonably simulate the field conditions under which the acoustics would be applied. That is, the design was to simulate the earth as much as could be expected in a laboratory apparatus.

Relatively low frequencies were chosen to penetrate the earth an appreciable distance. The unit was designed to generate plane-wave acoustics in which points of constant phase form a plane. The direction of propagation is normal to the plane.

This approach reduces the acoustics system to a one-directional case and the acoustic field can be accurately characterized with a few point measurements. This is an equivalent situation to the electric field formed by the two parallel-plate electrodes.

The acoustic instrumentation includes an acoustic shaker, a load cell, an accelerometer, and two hydrophones. The acoustic source is an Unholtz-Dickie Model 1 electro-magnetic shaker*. This shaker is the source of the acoustic excitation. Acoustic data were acquired during testing with the four channel analyzer. This was under computer control to automate acoustic data collection and storage. Two test cells, 3-inch internal diameter, 4 and 6 inches high made of acrylic tubing were used to hold the contaminated soil. The cell consisted of two electrodes, an anode at the top and a cathode at the bottom. The anode is a 3-inch diameter, 100-mesh stainless steel screen, whereas the cathode is a perforated s.s. supporting plate. The cathode is supported by four s.s. rods. A leachate collecting chamber was placed under the cathode. Leachate from the soil was drained through pipes to the leachate collecting pans. Distance between two electrodes represented the sample cake thickness, which was varied from 2 inches to 4.5 inches depending on the contaminated soil type used during the experiment. Leachate from the soil was drained through pipes to the leachate collecting pans.

Zinc Tests

The soil sample was prepared in the lab by spiking 2,000 mg/kg of zinc ($ZnCl_2$) on a dry weight basis. Experimental results showed substantial removal of zinc by the ESD process. In one extended test, more than 90 percent zinc removal from approximately 3/4 of the soil sample was obtained in 100 hours of operation. The voltage gradient increased from 0.3 volt/inch at the start of this test to 20 volts/inch at the end to maintain a constant current at 50 milliamps. The average electrical power consumed during the test was 1.423 watts. Zinc accumulated in 1/4 of the soil sample next to the cathode. Accumulation of zinc was caused by precipitation of zinc hydroxide from reaction of zinc ions with hydroxyl ions generated at the cathode. By neutralizing the hydroxyl ions, precipitation of zinc hydroxide can be prevented and zinc can be flushed out from the cathode.

Zinc and Cadmium Tests

A soil sample was prepared in the laboratory by spiking 11,000 mg/kg zinc ($ZnCl_2$) and 1,000 mg/kg cadmium ($CdCl_2$) on a dry basis. One test was conducted to demonstrate that a mixture of ion contaminants in the soil can be transported in the presence of electric field. The treated cake (4.5 inches) was divided into five layers to monitor the ions removal from each layer. Layer thickness and gradient are shown in Table 1. Test results confirm that ESD is effective in moving both zinc and cadmium ions from the layer in contact with the anode to the layer in contact with the cathode. For example, cake gradient 1 (layer in contact with anode) shows a removal of 97.05 percent cadmium and 85.09 percent zinc. Also, there was zinc and cadmium removal from the rest of all layers except the layer in contact with the cathode (0.4 inch thick). This analysis indicates that both zinc and cadmium removal occurred in more than 90 percent of the treated cake.

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

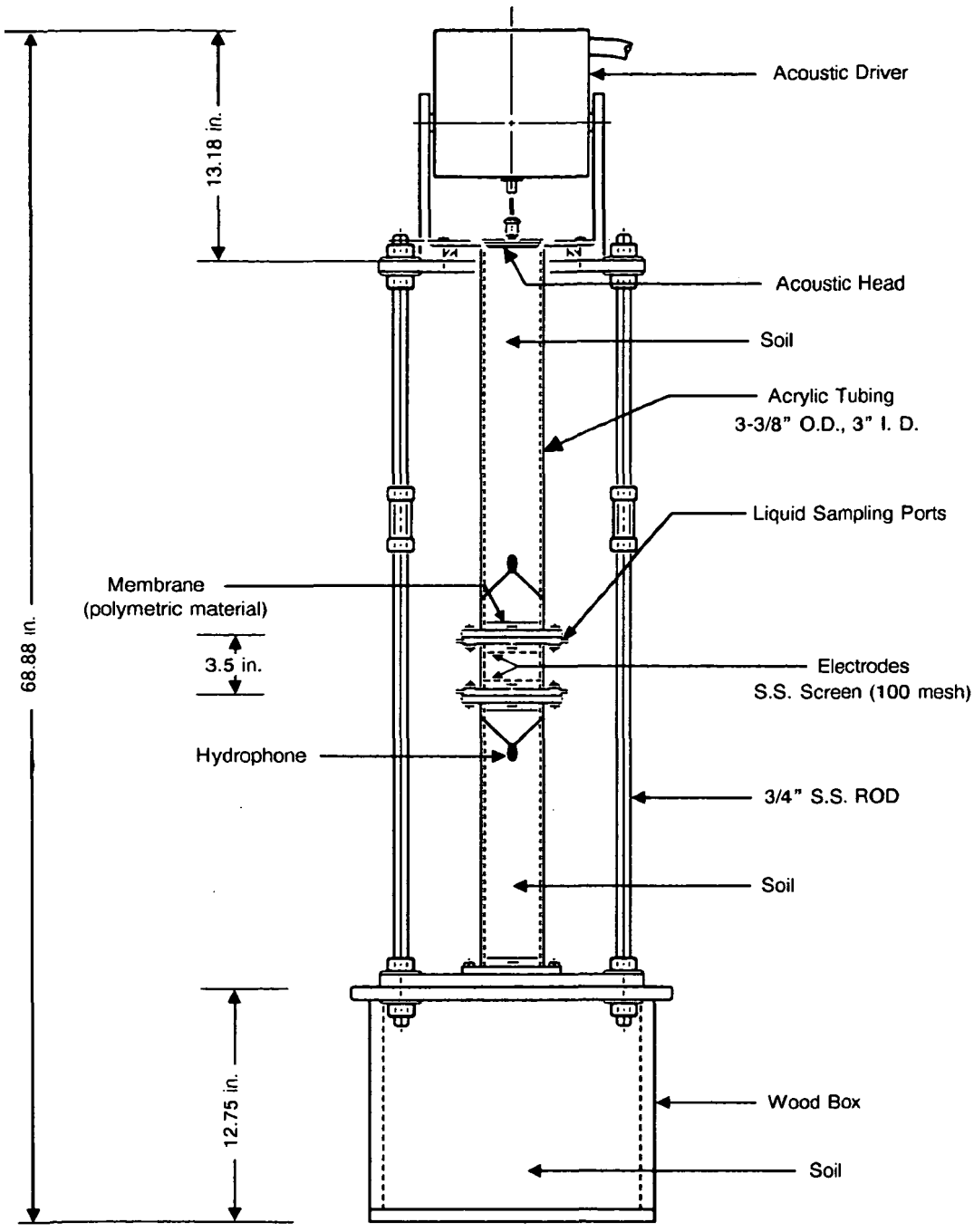

Figure 1. *Schematic of laboratory test cell.*

Decane Tests

Batch ESD tests were conducted on a decane-contaminated soil sample. The soil sample was spiked with 8 percent decane (dry weight). Tap water was added to moisten the soil to 45 percent moisture (net). Decane analysis on the ESD-treated soil was performed by both EPA and Zande Laboratories. Results from the decane experiments were inconclusive because of substantial experimental uncertainty in decane analysis from the two labs and also possibly in experimental procedures. However, based on a few tests in which the decane values from the two labs were relatively close, the data indicated between 10-25 percent decane removal.

Conclusions

(1) Electro-acoustic decontamination of soil in a laboratory mode was proven technically feasible for inorganic contaminants.

(2) Zinc removal/concentration (80-90 percent) was observed in the presence of the electric field.

(3) There appears to be a combined electric and acoustics effect during zinc removal. However, further testing is required to accurately determine the magnitude of the effect.

(4) Longer leaching times yielded higher zinc removal efficiencies.

(5) Higher power levels yielded higher zinc removal rates.

(6) Cadmium/zinc removal/concentration (90-95 percent) was observed in the presence of the electric field.

(7) Since a large variability in analytical determination of decane in the soil was observed, no definitive con-clusions can be drawn on the effect of electro-acoustics on decane removal from soils.

Recommendations

Based on Phase I laboratory experimental results for decontamination of heavy metals in clayey soil, a study is recommended and should be conducted to further evaluate the ESD process in field conditions. Such a study would validate the Phase I results and would provide the basis for developing design and operational changes for successful field applications.

We also recommend no additional work on the decane contaminated soil until the analytical and experimental problem can be solved. The results from the decane experiments were inconclusive because of substantial experimental uncertainty in the decane analysis and also possibly in experimental procedures.

The full report was submitted in fulfillment of Cooperative Agreement No. CR-815324-01-0 by Battelle under the sponsorship of the U.S. Environmental Protection Agency.

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Table 1. *Performance of EAD Process on Zinc/Cadmium Soil*

Cake Gradient	Layer Thickness (in.)	pH	Zinc Concentration (mg/kg) dry soil			Percent Zinc Removed	Cadmium Concentration (mg/kg) dry soil			Percent Cadmium Removed
			Zande	EPA	Ave		Zande	EPA	Ave	
0 ANode (+)	0		0	0	0	100	0	0	0	100
1	1	3.65	167	158	163	85.09	29.2	25	27.1	97.05
2	1	3.55	182	167	175	83.99	26.0	22	24.0	97.39
3	1	3.64	207	197	202	81.52	53.5	51	52.3	94.32
3.5	0.6	4.12	409	344	377	65.51	207	208	207.5	77.45
4 Cathode (-)	0.4	7.66-9.2	7755	7180	7468	-	6187	6310	6249	-

Initial Sample Solids % = 56.73%
Initial Zinc Concentration = 1093 mg/kg dry soil (see Table 7)
Initial Cadmium Concentration = 920 mg/kg dry soil (see Table 7)

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The complete report, entitled "Development of Electro-Acoustic Soil Decontamination (ESD) Process for In Situ Applications" (Order No. PB 90-204 728/AS; Cost: $23.00, subject to change) will be available only from:
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