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Enhanced Electrokinetic Remediation of Cadmium Contaminated Soil

Okeke, P. N.
Department of Environmental Technology,
Federal University of Technology P.M.B 1526, Owerri, Nigeria
E-mail: nduokeke100@yahoo.com

Abstract

In an attempt to remediate contaminated soil, a new technique of purging cadmium from soil is examined by enhanced electrokinetic method. It involves the passage of low level direct current between two electrodes in the soil to remove contaminant. An apparatus consisting of four principal parts; soil cell, electrode compartments, electrolyte solution reservoir and power supply unit, was designed and constructed. A 2 kg sample of clay soil with background cadmium concentration of 0.08 mg/kg, was artificially contaminated to the tone of 38.45 mg/kg as its cadmium concentration and then treated in the electrokinetic apparatus over a period of 2 days. Samples were collected from 4 points from the soil at intervals of 3cm from the anode electrode and analyzed for cadmium. Results indicate a 76.2%, 52.3%, 42.4%, 18.16% removal efficiency of cadmium from respective distances of 3cm, 6cm, 8cm and 12cm from the anode. The enhanced electrokinetic soil remediation technique is an emerging technology *for treating both polar and non-polar contaminants in soils, with promising prospects as a soil remediation process as it has high removal efficiency and time effectiveness*.

Introduction

Recent advancements in technology have led to high levels of industrialization, and its resultant increase in waste discharge into the environment. Some of these wastes contain heavy metal such as cadmium.

Cadmium is used in industries for the manufacture of batteries, electronic components etc. Warren (1981) noted that. Various activities of man in recent years have increased the quantity and distribution of cadmium in the atmosphere, land and water bodies. In municipal sewage cadmium content is often adsorbed on the sewage sludge or solids; so when the sludge is disposed off to farmland, the cadmium is desorbed and taken up by plants in some amounts and stored in the roots, shoots and storage organs, depending on the plant species in various proportions (Wild, 1996). The heavy metal is highly toxic to plants and animals; it bio-accumulates in man's organs by the food chain and the cumulative effects in humans include tubular and glomerus damage, protenuria, slight anaemia (Zeilhuis, 1979).

In view of the consequences of cadmium contamination, it becomes imperative for man to begin the development of remediation techniques, which has recently emerged as an important tool for natural resource management. Soil remediation techniques are fast growing into vital options in modern environmental friendly economy.

Reclamation techniques are aimed at returning land to beneficial use or to prevent contamination in the soil from causing further damage. Electrokinetic technique involves the use of direct current to remove organic, inorganic and heavy metal particles from the soil by electric potential (Acar et al, 1993; Lyer, 2001; Wada et al., 2001).

Some of the advantages of this technique are that remediation can be conducted in situ (within the remediation site) to treat contaminants in low permeability zones to overcome accessibility of contaminants or delivery of treatment (Ho et al., 1995); remediation can occur despite soil stratification or homogeinity (Sharma, 2004). Also the technique has low cost of operation and potential applicability to a wide range of contaminant types (kin et al., 2000). According to Acar et al. (1995), and Virk et al (2002), electrokinetic technique has been applied in the treatment of soils contaminated with mercury, zinc, iron, lead, copper and manganese.

The objective of this study therefore is to explore the degree of effectiveness of electrokinetic technique in the removal of cadmium in contaminated soil.

Materials and Method

This experiment was conducted in the laboratory of the Department of Environmental Technology, Federal University of technology, Owerri, Nigeria. It relies upon the application of a low intensity direct current through the soil between ceramic electrodes that are divided into a cathode and an anode array (FRTR, 2003).

Experimental Apparatus

A schematic diagram of the experimental apparatus used in this study is shown in figure 1. The apparatus consists of four principal parts; soil cell, electrode compartments, electriolyte solutions reservoirs and the power supply unit. The soil cell has a dimension of 9 x 9 x 15cm, with each end of the soil cell having 81 holes to enhance uniform electro-osmotic flow. At both sides of the soil cell, two sheets of filter paper were inserted to prevent clay particles from flowing into the electrode compartments.

Platinum wire that was plated like a net of 9cm x 9cm with interval of 1cm was used as the anode to prevent electrode electrolysis reaction, and carbon rods, 11cm x 11cm, was used as the cathode. The electrode compartments contained 400ml of electrolyte solution ensuring that sufficient volume was present to avoid sudden variations of electrolyte solution. Two mass cylinders were used as electrolyte solution reservoirs. The electrolyte solutions were re-circulated in both electrode compartments by peristaltic pumps, using DC power supply.

Soil Contamination

Twenty grams of sieved clay soil sample was analysed for initial pH and cadmium concentration before contamination.

After the analyses the soil sample was artificially contaminated with 100mg/l of Cd $(NO_3)_2$, by mixing 2kg of the air dried soil sample with the prepared solution of 100mg/l Cd (II) at 50% water content. The slurry of the soil sample was afterward mixed mechanically for one hour with a stirrer, and the mixture was allowed to settle down for 3 days to attain the uniform distribution of contaminant and to complete adsorption in the soil sample.

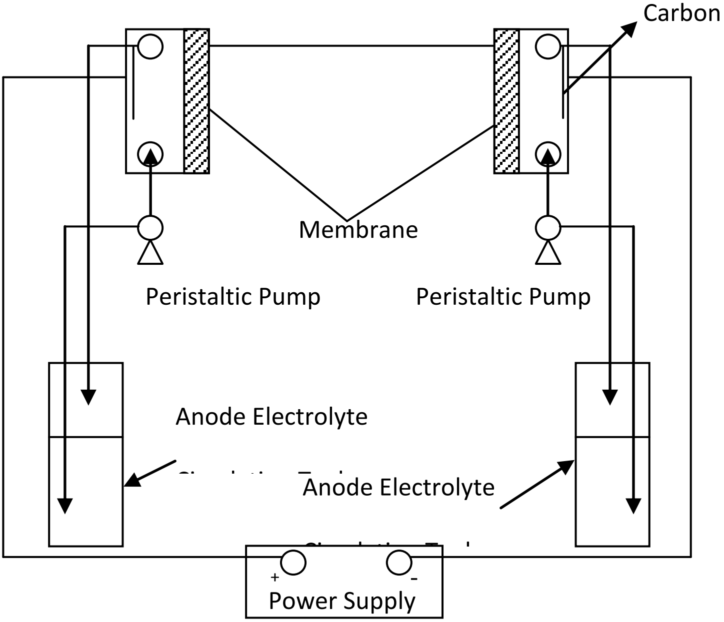

Fig. 1 Schematic diagram of experimental apparatus

Electrolyte Solution and Removal Tests

Anode purging solutions of 0.005N H_2S0_4 solution (2L) and IL of 0.5N H_2S0_4 solutions as cathode electrolyte solution were used.

A test was conducted for the removal of cadmium from the soil by electrokinetic soil processing technique. Direct current was used to keep the net rates of the electrolysis reaction constant.

Measurement, Sampling and Analysis

The prepared soil sample was packed into the soil cell and the cover was set on the packed soil cell. The anode and cathode electrolyte solutions were pumped into the electrode compartments for 30 minutes without electric current to equalize the electrolyte solutions.

After the experiment, four samples were obtained from the soil bed using a stainless steel sampler at every 3cm distance to analyze the concentrations of cadmium and soil pH. The duration of the test was two days.

Determination of pH and Cd concentrations in the soil sample

The pH of the sample was determined using a mettler Toledo 320 electronic pH meter according to Miller and Donahue (1992) while Cd concentrations were analysed by atomic absorbortion spectrophoto photometer as described by Houba et al (1989).

Results and Discussion

The concentrations of cadmium reduced generally on processing the soil in the electrokinetic equipment (Table 1). The baseline Cd concentration was 0.08mg/l (A). After contamination, it rose to 38.45mg/l (B). The treatment reduced the Cd concentrations from 38.45mg/kg to 31.28, 22.16, 18.35 and 9.16mg/kg represented by C, D, E, F respectively and which indicate various distances from the anode. Table 2 shows the standard deviation of Cd concentration from the mean value.

Table 1: Cd concentration and pH values of the soil samples

Soil sample	Cd concentration (mg/kg)	pH
A	0.8	6.8
B	38.45	6.2
C	31.28	6.3
D	22.16	5.9
E	18.35	5.8
F	9.16	6.0

A = Sample of background soil
B = Sample of soil after contamination with Cd
C Soil sample at 12cm from anode after treatment
D = Soil sample at 9cm from anode after treatment
E = Soil sample at 6cm from anode after treatment
F = Soil sample at 3cm from anode after treatment.

Table 2: Cd concentrations of treated soil samples with the mean value and standard deviation

Soil sample	Cd concentration mg/kg	Standard deviation
F	9.16	5.54
E	18.35	0.96
D	22.16	0.99
C	31.28	5.52

Mean = 20.24

A significant ($p = 0.05$) removal of 76.2% at point F indicates a high degree of efficiency of this method. Soon-oh kim et al. (2000) reported a similar higher percentage. The higher values observed in this study is probably as a result of having to remove only one contaminant (cd) as against other studies which attempted to remove more number of heavy metals.

As shown in figure 2, there was a movement of Cd ions from the anode to the cathode, resulting in low concentration of Cd towards the anode and higher concentrations around the cathode. The reason for this movement is because the electrolysis of water produces hydrogen ions in the anode compartment and the acid front migrates across the soil cell and makes Cd desorb from the soil surface, resulting in the initiation of electromigration, i.e the transport of ions and polar molecules in electric field (EPA, 1996).

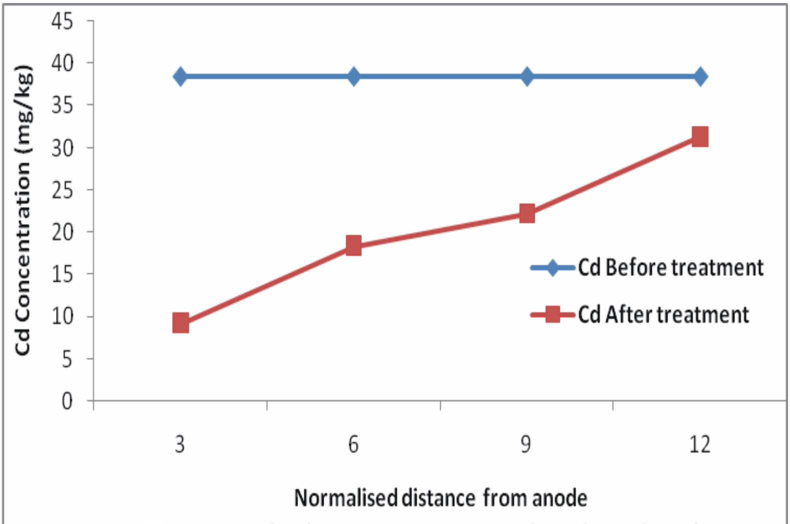

Fig. 2. Variation of cadmium concentration in the soil sample with distance from anode

pH variation in the soil samples

It was observed that the acidity of the soil cell increased from the cathode to the anode (Fig.3). This can be linked also to the electrolysis of water in the anode compartment generating hydrogen ions, which migrated from the anode to the cathode. The overall pH of the soil cell decreased, but the decrease was less marked towards the cathode compartment as a result of the production of hydroxyl ions. It is this migration of the acid front that made the soil pH to decrease.

This result is consistent with fig 2, because at a lower pH Cd is more available.

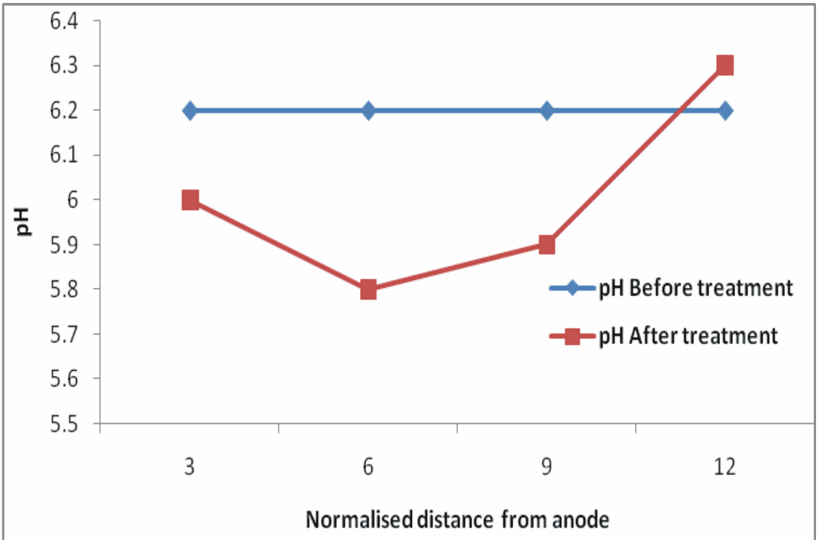

Fig. 3. Variation of pH with distance from anode

Conclusion

The enhanced electrokinetic technique is effective in reducing the level of Cd concentration in Cd-contaminated soil sample. Cadmium concentration was significantly reduced from 38.45mg/kg to 9.16mg/kg which is 76.2% reduction.

In addition, this procedure is environmentally friendly and relatively faster than bioremediation.

According to EPA (2004), the technique has an advantage of cost effectiveness and its ability to leave the soil in its original conditions, as an in-situ technique. It is gradually being recognized as an emerging solution to soils contaminated with heavy metals.

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