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REVIEW ARTICLE

Electrochemical Remediation of Heavy Metal Contaminated Soils

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ABSTRACT

Soil contamination is causing human health at a greater risk and becoming a key environmental issue, due to its importance in ecosystems. It also has influence on the quality of soil, ground water, plants and food. This technology has been proved to be practical in many laboratory experiments. However, remediation studies at field soils are at infant stages owing to. Limited understanding of possible electrochemical reactions and soil contaminant interactions, therefore there is a need for further research to understand physicochemical changes in contaminated soils and efficiency of this technology both lab and at field level. Electrodialytic soil remediation can be used for stationary and water saturated soils. Remediation or faster dissolution of carbonates indicating a faster remediation in the stirred system. An increase in the voltage in removal efficiency of the contaminant remediation results increase.
Key words: *Soil Contamination, Heavy Metal and Environmental*

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INTRODUCTION

Soil is one of the important and valuable resources. Soils have become polluted with organic and inorganic contaminants from a variety of industrial waste and agricultural chemicals in recent years. Presence of heavy metals in soil beyond threshold limit of toxicity has a great concern with respect to human health and safety. Heavy metal contamination is a major social issue in the era of urbanization and industrialization; Industries are practicing open dumping since it is an economic means of waste disposal. Wastes which contain heavy metal will contaminate soil as well as ground water. The most important sources of heavy metals in the environment are the anthropogenic activities such as mining, smelting procedures, steel and iron industry, chemical industry, traffic, agriculture as well as domestic activities [8] Chemical and metallurgical industries are the most important sources of heavy metals in soils release high amounts of heavy metals into the biosphere.

Accumulation of heavy metals in crop plants is of great concern due to the probability of food contamination. Therefore determination of free metal ion concentrations in soil solution becomes important. So soil remediation is nowadays gaining importance. Not only industries, but also households and vehicles cause heavy metal contamination. A number of methods are available for soil contamination. But 100% removal is not possible. Remediation techniques deserve ever-growing attention in soils contaminated with heavy metals

In recent years, electrokinetics method has been considerable interest in the application of new and innovative ways for removal of pollutants from soil and groundwater, but most methods have high cost, and they are unsuitable in low permeability soils. Electrokinetic is a relatively new way to remove environmental pollutants from these soils. It is a developing technology that is intended to separate and extract heavy metals, radio nuclides and organic contaminants from saturated or unsaturated soils, sludges, sediments and groundwater.

Electrokinetic remediation method removes heavy metals effectively because en external energy is applied in the form of current. This method does not cause any secondary pollution. Various enhancement techniques are available to increase the removal efficiency.

CONTAMINATION

It is defined as the build-up of persistent toxic compounds, chemicals, salts, radioactive materials or disease causing agents in soil, which have adverse effects on plant growth and animal health.

How soil is contaminated

- Industrial seepage
- Solid waste materials
- Application of pesticides, herbicides or fertilizers
- Rapid industrialization
- Municipal sludge
- Waste-water
- Volcanic areas
- Mining

The most common chemicals involved in causing soil pollution are

- Petroleum hydrocarbons
- Pesticides
- Solvents

Heavy metals – definition, sources

Refers to any metallic chemical element that has a high specific gravity and high relative atomic mass is called as heavy metals.

Soil remediation method

Soil remediation implies the application of technology which is able to remove or eliminate the contaminants and also the restoration of the site to the original state.

Electrochemical remediation method

- **Electroremediation:** It is a technique of using direct electrical current to remove organic, inorganic and heavy metal particles from the soil by electric potential.

Principle of Electrokinetic Method

Technique which uses intensity of direct current (DC) or a low electric potential between the two electrodes placed in the soil, for removing organic, inorganic and heavy metal particles from low permeable soils, sludge, slurries, sediments and groundwater by electric potential. When a DC is applied to soil, it stimulates the migration of electricity, pore fluid, ions and fine particles across the soil towards the oppositely charged electrode. The migrated species can then be removed by several different methods such as electroplating, adsorption onto the electrode, precipitation and co precipitation at the electrode or pumping near the electrode.

Electrokinetic phenomena are

- **Electro chemically induced chemical reaction**
- **Electrolysis**

Electrolysis of water: At anode: $2H_20 \longrightarrow O_2 + 4H^+ + 4$

At cathode: $4H_2O + 4e^- \longrightarrow 2H_2 + 4OH^-$

- H^+ move from anode to cathode (acidic front)
- OH^- from cathode to anode (basic front)
  - The goal of Electrokinetic remediation is to effect the migration of contaminants in an imposed electric field. Under induced electrical potential, electrolysis reactions generate H+ ions and oxygen gas at the anode and OH- ions and hydrogen gas at the cathode.
  - The H+ ions create an acidic environment, pH 2–3, at the anode and the OH- ions create an alkaline environment, pH 10–12, at the cathode.
  - The migration of H+ ions from the anode towards the cathode produce an acid front which flushes across the soil. The contaminants in the soil are then transported towards either the cathode or the anode depending on their charge. This contaminant transport occurs primarily because of the three main mechanisms: electro-osmosis, electromigration and electrophoresis. Acidic solution generated at the anode typically migrates through the soil towards the cathode, thereby lowering the pH along most of the soil profile. Compared to H+ ions, OH− ions have larger ionic radii and a lower mobility and hence the H+ ions usually migrate faster through the soil.

Electrokinetic transport

Electroosmosis is the movement of the pore fluid which contains dissolved ionic and non-ionic species, relative to the stationary soil mass, toward the cathode due to the application of a low direct current or voltage gradient to the electrodes.The fluid migration occurs mostly from the anode to the cathode, due to the predominance of a negative charge on the soil particle surfaces. In fact, the electroosmotic flow is caused by the fact that when an electric field is applied to a soil, the excess of cations close to soil particles surface (double layer) tend to move towards the cathode. Hence, the electric field causes the pore fluid to flow from the anode compartment to the cathode, producing a flux and forcing the water table to arise in the cathode compartment [1]. The electroosmotic flow ceases when the counteracting flow, due to the hydraulic gradient between the anode and the cathode compartments, equals the electroosmotic force. [12] Reported that a laboratory investigation was performed for the removal of chromium by electrokinetic method from spiked soils (kaolin, loam, and sand). Electrokinatic experiments were conducted for chromium concentration of 500, 1000, 1500 mg/kg and a constant voltage gradient of 1.0 V DC/cm was supplied. The effect of enhanced oxalic acid on the electro kinetic remediation processes was supplied. The results showed that the percentage removal of Cr (VI) from the contaminated soils enhanced to 82, 63.8, and 69% for kaolin, loam and sand respectively when oxalic was used as purging solution.

Electromigration

The second transport mechanism generated by the voltage gradient, electromigration, is the movement of ions in the pore solution under the influence of an electric field. Positive ions (cations) migrate towards the cathode while negative ions (anions) are transported towards the anode. Because of electromigration ions tend to concentrate near the opposite charged electrode [1, 13, 11, 2, 6,] the electromigration of cations and anions towards the electrode opposite in charge is proportional to the ion concentration in the pore water solution and to the electric field strength.

[3] Indicated that Electrodialytic soil remediation can be used for remediation of stationary, water saturated soils (in-situ) or suspended soils (ex-situ). the first as in-situ or on-site treatment when there is no requirement for fast remediation, as the removal rate of the heavy metals are dependent on the distance between the electrodes (everything else equal) and in such application the electrode spacing must have a certain distance (often meters). In the stirred setup it is possible to shorten the transport route to few mm and to have a faster and continuous process.

Electrophoresis:

Electrophoresis consists in a movement of charged particles and colloids under the influence of an electrical field (Figure 1 (c) When a DC electric field is applied across a colloidal suspension, charged particles and colloids that are suspended in the pore fluid are electrostatically attracted to one of the electrodes and repelled from the other.

[10] Showed that electrokinetic experiments were conducted using same type of clay soil taken from the site. Initial total concentrations of lead (II) maintained at 1000mg/kg for each process. The clay soils were subjected to a voltage gradient of 1 V DC/cm for over 24 hrs, 36 hrs and 48 hrs. The result of this experiment indicate that Electrokinetic enhancement of contaminant transport in clay soils with different durations, increased duration (48 hrs) is best removal efficiency for comparing the other durations (24 hrs and 36 hrs).

HOW TO IMPROVE REMOVAL EFFICIENCY

Use of enhancing agents

- EDTA, oxalic acide, acetic acid, citric acid, NaOH, NaCl *etc.*
- Dosage of chelating agents to promote the contaminants solubilisation.
- Dosage of acid solutions at the cathode to prevent the formation of high pH conditions near the cathode due to water electrolysis reactions.Ion selective membrane around electrodes – Electrodialytic remediation.

[5] Evaluated that 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 3 cm from the anode electrode and analyzed for cadmium. Results indicated that 76.2, 52.3, 42.4, 18.16% removal efficiency of cadmium from respective distance of 3, 6, 8, 12 cm respectively from the anode. The enhanced electrokinetic technique was effective in reducing the level of Cd concentration in Cd contaminated soil samples. Cadmium concentration was significantly reduced from 38.45 mg/kg to 9.16 mg/kg which was 76.2% reduction.

ADVANTAGES

- Electro reclamation can treats contaminants at a wide range of concentrations.
- Many metal species can be simultaneously removed.
- Effective in low permeability soils.
- Organics, pesticide contaminants in soil can also be removed.
- Promising soil remediation technology and not affects indigenous microbial community.

- Provides an approach with minimum disturbance to the surface, while treating subsurface contaminants.

LIMITATIONS

- Oxidation/reduction reactions can form undesirable products (e.g. chlorine gas).
- Metallic electrodes may dissolve as a result of electrolysis and introduce corrosive products into the soil mass.
- The effectiveness is sharply reduced for wastes with a moisture content of less than 10 percent.
- Volatiles compounds are released into the soil air.
- The process may require an acid conditioning to solubilize the target compounds. If a proper solubilisation cannot be achieved, the treatment may fail in attaining a contaminant removal.

[4] Revealed in this study, we use enhanced electrokinetic to remove lead and zinc from an alkaline (pH=7.69) and natural polluted soil. We applied constant voltage of 25 volt and different chemical agents such as EDTA and ammonium citrate to enhance removal pollutants from soil. Experimental results have shown that ammonium citrate (pH=9) was more effective than EDTA in alkaline soil. Removal of lead in EDTA treatment was more than zinc and removal of zinc in ammonium citrate treatment was more than lead as a result of having high constant stability. PH Adjustment of anode solution is an important factor in Electrokinetic remediation.

[7] Assessed the Experiments have been conducted on Cr (VI) contaminated kaolin to determine the kinetics of electro remediation (ERM) and the associated rate controlling mechanism. ERM experiments of potassium dichromate contaminated kaolin show that approximately 15% chromium was removed in the first 20 h. Thereafter, there was a drastic reduction in the chromium removal rate. After 144 h, only 31% of Cr (VI) was removed from kaolin. Migration of the acid and base fronts leading to acid-base neutralization appears be the rate controlling step in the ERM of chromium. A significant fraction of chromium could not be remediated due to acidic conditions in kaolin. Results also show that the extent of both remediated and adsorbed (unremediated) chromium and power consumption increased with voltage.

CONCLUSION

- The electrokinetic remediation method is a new and innovative for remediation of heavy metal contaminated soils.
- This technology has been proved to be practical in many laboratory experiments. However, remediation studies at field soils are at infant stages owing to limited understanding of possible electrochemical reactions and soil contaminant interactions, therefore there is a need for further research to understand physicochemical changes in contaminated soils and efficiency of this technology both lab and at field level.

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