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A REVIEW ON APPLICATION OF ELECTROREMEDIATION TECHNIQUE IN DIFFERENT ENVIRONMENTAL SAMPLES

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ABSTRACT

Advances in the industrial and urban sector has led to an increase in the release of contaminants into the environment. These activities can help in the growth of economy, but on the other hand, it leads to environmental problems and also has its effect on human health. To minimize these problems, remediation and reclamation is necessary. Remediation methods for soil/ sludge include physical, chemical and biological techniques. Biological methods such as phytoremediation and bioremediation are also adopted. A low cost treatment method known as electroremediation is an emerging technique in the remediation of marine sediments, soil contaminants, sludge and flyash. This technique uses low voltage direct current that is applied to the medium, which induces various physico-chemical reactions in the medium. This helps in the removal of oil hydrocarbons, and other pollutants. In this paper, the application of electroremediation in various environmental samples are discussed.

KEY WORDS : Sewage sludge, Contaminated soil, Marine sediment, Flyash, Electroremediation, Eectroremediation cell.

INTRODUCTION

Modern advances in urban and industrial sectors in recent decades led to an increase in soil pollution. Contaminated soils are of greater significance, as they cause environmental problems due to pollutants' persistence, which may accumulate in the soil, and the removal is not easy (Bocos *et al.*, 2015). Innumerable anthropogenic activities lead to the release of harmful pollutants, and contaminants that include heavy metals, pesticides, oil hydrocarbons into the environment. These activities can cause severe menace in all forms of life, environment and disrupts ecosystem health (Quintella *et al.*, 2019; Moraru *et al.*, 2014; Lãcãtu°u *et al.*, 2013; Cioca *et al.*, 2011). Remediation of contaminated soils helps in the reclamation of the geological environment, its functions and reduces the possible threats to environment and human health (Bartke 2011; Maliszewska *et al.*, 2000; Cocârtã *et al.*, 2016). Mutagenesis, carcinogenesis and other toxic effects are more prevalent in human beings (Kuppusamy *et al.*, 2020). To recover the contaminated environment's functions, application of remedial methods in contaminated sites is essential for the preservation of environmental health and urban development. Soil remediation processes include physical, chemical and biological methods (*in-situ* or *ex-situ* conditions). Biological methods include phytoremediation and bioremediation that help in the quick removal of contaminants than the existing techniques. These methods are environmental friendly and cost-effective (Kumar *et al.*, 2018; Soleimani, 2014)

Remediation of contaminated soils becomes problematic when the soil is clayey in nature and has a low permeability. Petroleum hydrocarbons and other pollutants have high adsorption rate than soil particles, which makes their removal difficult (Streche *et al.*, 2014; Istrate *et al.*, 2013; Chung and Kamon, 2005).

The process of Electroremediation uses low-

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intensity direct current and promotes the mobilization of toxic contaminatns in saturated and unsaturated soils (Tsai *et al*., 2010; Shenbagavalli and Mahimairaja, 2010; Acar *et al*., 1995). This process serves as an in-situ contaminant removal technique in soil compared with ex-situ treatment processes like soil washing and solidification.

Electroremediation helps remove numerous contaminants, including oil and petroleum hydrocarbons, radioactive compounds, phenols, heavy metals, inorganic pollutants from soil and groundwater (Kim *et al.,* 2011a; Shenbagavalli and Mahimairaja, 2010; Korolev, 2006; Doering *et al.,* 2001; Acar *et al*., 1995).

Process/ Functioning of Electroremediation cell

Electroremediation process involves applying an electric gradient or electric potential difference to the electrodes inserted in different profiles in the contaminated medium. The applied electric potential ranges from 1V/cm to 40V/cm, and the current density varies from 1mA/cm^2 (milliamperes/cm^2) to 200 cm^2 (Ribeiro *et al.,* 2016, Ibanez 2002, Yoo *et al*., 2015). When the flow of current starts, the medium undergoes several physical and chemical phenomena that include electrokinetic transport (electromigration, electrophoresis, electroosmosis), change in pH and water hydrolysis. These mechanisms help in the mobilization of pollutants to their respective electrodes bases on the charge. Electrooxidationis based on redox reactions, which induces immobile organic contaminants' mobilization (Ribeiro *et al*., 2016; Isosaari, 2007).

The toxicity of distinct pollutants can be significantly reduced due to the processes of oxidation and reduction (Röhrs *et al.,* 2002) that targets the contaminants, includinganions, metals and organic matter in the soil and sludge (Szpyrkowicz *et al.,* 2007). Applicability of this method in the removal of toxic contaminants, chlorophenols (Cong *et al*., 2005), polycyclic aromatic hydrocarbons (PAH's), chlorinated solvents (Ribeiro *et al*., 2016, Reddy *et al*., 2006; Estabragh *et al*., 2016; Zheng *et al.,* 2007) in contaminated soils and sediments are highlighted in various studies. This process helps in the mineralization of organic compounds under low power consumption (Ribeiro *et al*., 2016).

Advantages of Electroremediation

Niroumand *et al.,* (2012) have described the advantages of electroremediation as follows; (i) It helps in the simultaneous treatment of organic and inorganic compounds, (ii) shift in the pH due to electrolysis desorbs the contaminant ions effectively, (iii) this method induces the movement of ions, colloids and water through fine-grained sediment, (iv) it is one of the cost-effective and remediating technique compared to other treatment techniques. (v) Removal and recovery of heavy metals in a short period with high efficiency, which is not possible through soil incineration and bioremediation.

Application of Electroremediation in Environmental Samples

Contamination by total petroleum hydrocarbons (TPH) in the soil is mainly due to accidental spills of crude oil, gasoline, oil and lubricants. A typical example of soil contamination occurs in industries because of maintenance or impairment of the machinery, and the company's vehicles cause spillage of fuels and lubricating oils accidentally. The mining industry is not the exception; its many activities (operation and maintenance) causes soil contamination with diesel, fuel oil and residual oil. (N´apoles *et al.,* 2005; Unzueta-Medina 2010). Electroremediation uses the soil's conductive properties, which aims to separate and remove organic and inorganic (metals) contaminants of saturated and unsaturated soils, sludges and sediments, using an electric field that allows removing charged species (Martínez *et al.,* 2014).

In Contaminated Soils

Various anthropogenic activities lead to the contamination of soils by heavy metals. These metals are released from multiple sources like mining wastes, landfill leachates, accidental spills, improper treatment of industrial wastes (Kim *et al.,* 2005). These heavy metals find their way into the soils and become hazardous pollutants, as they are toxic even at lower concentrations and are not biodegradable. With changing pH or physicochemical conditions of soils, they mobilized (Stegmann *et al.,* 2001). Electroremediation is an efficient technology in the removal of contaminants and heavy metals from polluted soils (Gidarakos and Giannis, 2006). When a low-intensity electric current passes through the medium, electrolysis reactions occur at the electrodes. These reactions creates acidic front at anode and alkaline front at the cathode. Generation of H^+ ions at anode move towards the cathode by ion migration and enhances desorption of cations and dissolution of precipitated contaminants. Reduction reactions occur at the cathode, increasing pH, causing precipitation of metals. Due to ions' dissociation by electrolysis, the H^+ ions and OH^- ions move across the medium towards cathode or anode (Virkutyte *et al.,* 2002, Reddy *et al.,* 2004).In the process of electroremediation, soil pH plays a crucial role in solubilization and speciation of metal removal (Al-Hamdan and Reddy 2008).

In Marine Sediments

Marine sediments are contaminated with numerous hazardous pollutants that originate from harbour activities, ships, industrial effluents and municipal sewage, etc. These pollutants mainly include hydrocarbons and heavy metals (Yong, 2001). Some alternatives, such as open sea dumping and disposal at the shore, is done when there are no contamination or contaminant levels that comply with regulatory standards. Reuse of sediments in construction materials is also beneficial until they do not pose any environmental risk (Dubois *et al*., 2011). Many residues are deposited at disposal sites, the transfer of these contaminants is a risk to the environment, and thus sediment treatment is required (Ammami *et al*., 2015).

Heavy metal pollution is an essential issue in the remediation of marine sediments. These are mostly composed of organic matter and clay minerals, to which metals tend to bind, lowering their mobility in the medium (Feng Peng *et al.,* 2009). Parameters like high buffering capacity and low hydraulic permeability characterize the marine sediments (Reddy and Ala, 2006). The presence of these conditions may lower the remediation efficiency. In this context, electroremediation serves as an essential technique for removing organic and inorganic contaminants even materials which have very low-permeability (Virkutyte *et al*., 2002; Lageman, 1993; Probstein and Hicks, 1993; Reddy and Cameselle, 2009;Yeung, 2011).

In Sewage Sludge

Economic activity and population growth have a consequential effect on the increase of anthropogenic waste generation, which includes sewage sludge (Azizi *et al.,* 2013). Sewage treatment plants are engaged in lowering the impact of the release of these wastes into the environment. Sewage treatment plants produce a secondary known as sewage sludge, which is to be disposed off properly. Sewage sludge may interfere with the properties of soil and water bodies, induces the processes of food chain and disrupt ecosystem's balance (Wei *et al.,* 2014; Chen *et al.,* 2012). Sewage sludge is utilized as agricultural fertilizer, as it contains high amounts of nutrients and organic matter. On the other hand, these also include potential toxic metals and pathogens, when present in higher concentrations and are improperly disposed of without prior evaluation (Wong, 2005; Li *et al*., 2012; Wei *et al*., 2014; Camargo *et al.,* 2016).

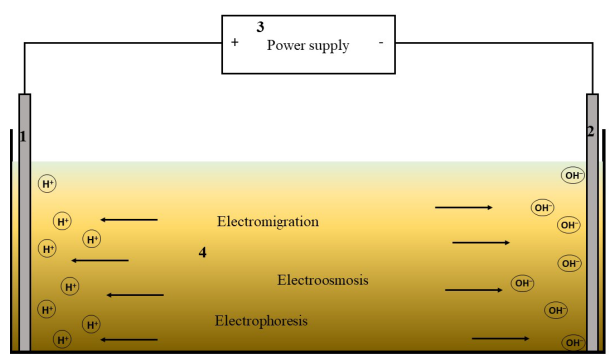
In sewage sludge, metals are considered the major inorganic contaminants and constitute about 0.5 to 4% of the dry weight (Wong, 2005). Depending on the origin and type of effluent, metals occur in different concentrations and forms. The presence of metals is considered as a limiting factor in application of sewage sludge as a source of nutrient and fertilizer (Ebbers *et al.,* 2015).

Electroremediation induces the pH, redox potential, chemical reactions and electrolyte concentrations in the medium. In electroremediation, direct current mineralizes organic compounds such as volatile organic compounds and removes metal toxicants (Hamdan *et al.,* 2008; Cameselle and Pena, 2016).

In Flyash

Fly ash is considered as one of the hazardous material due to its toxic nature and is oftnen enriched with heavy metals and volatile contaminants. This waste is mostly landfilled to stabilize this material. However, depending on the origin, it is reused in the forms of soil amendment and concrete applications (Ferreira *et al.,* 2003; Naik and Kraus, 2003) only after the removal of contaminants in it.

In addition to existing techniques for removing



1. Cathode, 2. Anode, 3. DC Regulated power supply, 4. Soil/sludge medium with water

Fig. 1. Typical representation of an electroremediation setup

Table 1. Different studies on electroremediation with different material types:

S. No.	Material type	Period of treatment	Experimental conditions	Type of electrodes used.	Results observed	Reference
1.	Contaminated soil (Cd and Zn)	14 – 18 days	38V, Citric acid, aceticacid and PDA are used as purging and washing solutions for Cd removal and enhancement	Graphite electrodes	90% cadmium removed with the use of acetic acid, 95% of cadmium removal observed with PDA, 96% of zinc removal observed when $Na_2S_2O_5$used.	Gidarakos and Giannis, 2006.
2.	Marine sediments	10 days	0.5V/cm, using 0.1M citric acid, 0.1M EDTA and tap water	Graphite electrodes	EDTA enhanced metal removal. Zn (9.5%), Pb (9.8%), V (17.5%), Ni (24.3%), Cu (27.3%). Other tests didn't show significant results.	Masi *et al.*, 2016.
3.	Sewage sludge	40 hours treatment (8 hours/ day for five days)	20V and 100mA	Graphite rod used as anode and stainless steel plate used as cathode	Removal of metals are as follows, Pb (72.49%), Cr (54.87%), Cu (55.42%), Zn (68.25%)	Elicker *et al.*, 2014.
4.	Flyash	10 – 14 days	A constant current of 40mA	Platinum electrodes	An increase in remediation time influenced removal efficiency and increasing dissolution leading to lower removal efficiency. A significant influence on Cd and Cu migration towards the cathode	Lima *et al.*, 2010.

metals from flyash, various researchers study alternative approaches such as cyclic voltammetry (CV), electrodialytic remediation (EDR), etc. The method is suitable for fly ash, which are rich in chloride that makes most of the metals available in the water-soluble chloride form (Ferreira *et al.*, 2005). Electroremediation helps in detoxification of fly ash, which separates the metals in the flyash through acidification, dissolution and membrane separation (Kirkelund *et al.,* 2013). Current density, period of remediation, L/S ratio, and assisting agents are the factors resposnsible for evaluation as contributors to the process's ef (Kirkelund *et al.*, 2013; Pedersen 2002, Kirkelund *et al.*, 2013; Pazos *et al.,* 2010).

CONCLUSION

Reclamation and preservation of contaminated soils and other environmental components is always necessary. Pollutants like hydrocarbons, phenols, heavy metals pose a severe threat due to their presence in soil, sludge and sediments. Evidences of different techniques (physical, chemical and biological) proved the efficiency of reclamation. Electroremediation is gaining importance as an environmental friendly and cost-effective technique,that can applied to various environmental samples, which include contaminated soils, sewage sludge emerging from sewage treatment plants, sediments collected from marine environment and flyash from industries. Under the influence of various experimental conditions (voltage, period of treatment, type of materials and electrodes used), there is a change in pH, electrical conductivity and removal efficiency of metals observed. Thus, electroremediation can be applied as an economical technique in the remediation of environmental samples.

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