Research Paper

Electrokinetic Remediation of Dye Contaminated Clay Soil

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ABSTRACT: *The objective of this study is to evaluate the suitability and efficiency of electrokinetic remediation treatment technique for the removal of crystal violet dye from clay soil. An electrokinetic remediation cell (45cm length) equipped with a DC electric current with the maximum values of 30 V, stainless steel electrodes used as anode and cathode were set up for two weeks operation. Sodium dihydrogen phosphate (NaH_2PO_4) was used as the processing fluid (electrolyte) and was inserted to the electrode chamber to enhance the electrical conductivity of the system and to increase the transportation rate of the contaminant from clay soil. The effects of initial dye concentration (200 mg/kg, 400 mg/kg, 600 mg/kg, 800 mg/kg, 1000 mg/kg) and applied voltage (30 V, 10 V), were investigated with time. Experimental results showed that, dye removal efficiency were largely dependent on initial dye concentration. The removal efficiencies of the dye increase from 45.5% to 81.1% with increasing time at 30 V when the initial concentration of dye decrease from 1000 mg/kg to 200 mg/kg. The optimum efficiency of dye removal which was obtained at voltage of 30 V, initial concentration of 200 mg/kg, contact time of 24 h was equal to 81.1%. The results showed that electrokinetic remediation treatment technique has the potential and it is suitable for the removal of dye from clay soil.*
KEYWORDS: *Electrokinetic Remediation, Removal Efficiency, Suitability, Crystal Violet Dye, Clay Soil*

I. INTRODUCTION

Environmental pollution, especially soil pollution is challenging and there are considerations on protecting soils from contamination caused by rapid industrialization and urbanization. Soil contamination is associated with industrial activities, mining exploitations and waste dumping. It is considered a serious problem since it affects not only the environment, living organisms and human health, but also the economic activities associated with the use of soil (Wania, 1999).

The effluents discharged from textile factories are a mixture of dyes, metals and other contaminants (Yaseen & Scholz, 2019). The textile dyes and dye intermediates with high aromaticity and low biodegradability have emerged as major environmental pollutants (Arslan, Balcioglu & Bahnemann, 2000) and nearly 10-15% of the dye is lost in the dyeing process and is released in the wastewater which is an important source of environmental contamination (Jayanthy, Geetha, Rajendran, Prabhavathi, Sundaram, Kumar & Santhanam, 2014). Textile effluent components such as carboxylate, anthraquinone, naphthalene, azo and amine based compounds; salts like SO^2_4 and Cl inhibit the plant growth and affect the food chain (Kumar, Bhora & Singh, 2003; Nupur, Pradeep, Pankaj & Mahendra, 2005). The United Nations Environment Program (UNEP) estimated that approximately 20% of agricultural land and 50% of crop land in the world are salt stressed (Saichek & Reddy, 2005). Sometimes, spilling and bad management of these effluents provoke the pollution of soils with this kind of organic pollutants which in turn limits the use of soil for agriculture, civil construction and it is also considered an economical problem (Pazos, Cameselle & Sanromán, 2008). Clays are resistant to remediation with traditional technologies because of their low hydraulic conductivities.

Accordingly, the development of a low cost alternative, environmental friendly and efficient treatment technique has been the focus of sustained research. Electrokinetics remediation which is an effective soil remediation technique that allows the *insitu* transportation and removal of contaminants from soils, resulting in potentially significant cost savings and less destruction of soil matrix could provide the useful means for in-situ remediation of low-permeable soils. The principle of electrokinetic remediation is based on the application of a low-intensity direct current through the soil, between two electrodes (anode and cathode) which are inserted into

the soil matrix, normally inside a chamber which is fill with water or the appropriate solution to enhance the removal of dye (Yeung, 2006).

In the present study, electokinetic treatment techniques was employed to clean soil contaminated by organic compound using model sample of clay contaminated with crystal violet dye. The effect of initial dye amounts and voltage variations were evaluated for increasing the removal efficiency.

II. MATERIALS AND METHODS

2.1 Material Preparations

Soil was obtained from Abakaliki. Ebonyi State, Nigeria. Crystal violet dye was obtained from Firmtech biosciences, and was used as contaminant dye for the experiment. All reagents used were sodium dihydrogen phosphate (NaH_2PO_4) (manufactured by Guangdong Guanghua Sci Tech Co. Limited, China), sodium hydroxide (NaOH) solution (manufactured by Trust Chemical Laboratories) and potassium chloride (KCl) (manufactured by BDH Chemicals Limited, England). Perforated stainless steel electrodes of diameter 1cm and length 10cm, purchased from Jumia services were used for both anode and cathode and were connected to a direct current (LW$^{®}$ Longwei 30 V) power supply. Soil pH was measured by a portable Hanna Instrument pH meter manufactured by Hanna Equipments India Private Limited, Mumbai. UV analysis was carried out using a UV-Spectrophotometer (Lasany$^{®}$Visible Spectrophotometer L1-722) manufactured by Labtech Holdings Incorporated, China. A 1000 KVA Inverter was used for uninterrupted power supply.

Soil Preparation

The soil sample was spread on the laboratory table to air dry naturally for 48h. They were ground to pass through a 2 mm sieve and a homogenized soil was obtained. Contaminated clay sample in this study was prepared by mixing. The soil was spiked with crystal violet dye. The crystal violet dye in the concentrations; 200 mg/kg, 400 mg/kg, 600 mg/Kg, 800 mg/kg and 1000 mg/Kg was added to 600 g of soil respectively. The mixtures were stirred to make the sample homogeneous and allowed to stand for 24 h at ambient temperature for the drying procedure to allow sorption of the dye to the surface of the clay particles. All mixing operations were performed in glass beakers with a stirring rod. A sample of each mixture was taken for the initial analysis of dye concentration.

2.2 Electokinetic Experiment
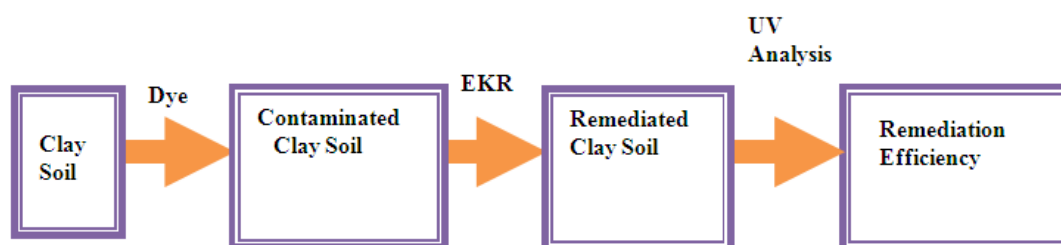
Scheme1: Experimental approach for electrokinetic treatment of clay

The experiments were performed in a specially fabricated rectangular cell made of acrylic material. The cell measures approximately 45cm length, 10cm width, and 11cm height. The sample of crystal violet spiked clay (dry weight) was introduced in the central tube. The two electrode chambers are placed at each end of the sample compartment isolated from each one by a paper filter. Stainless steel electrodes were used for both anode and cathode. Sodium dihydrogen phosphate (NaH_2PO_4) was used as the processing fluid (electrolyte) and was inserted to the electrode chamber solution to enhance the electrical conductivity of the system, improving desorption of dye from clay particles, and to increase the transportation rate of the pollutants from clay. The pH in both chambers was controlled by 0.1 NaOH solutions. A DC voltage of 30 V was applied between the anode and cathode and monitoring data was taken periodically.

After the completion of the electrokinetic treatment, the soil was taken from the soil chambers carefully, divided into three sections, and labeled as S1, S2 and S3 from the anode to the cathode direction. The sample soil was left to dry for 24 hours prior to analysis. The effects of dye amount (200 mg/kg, 400 mg/kg, 600 mg/kg, 800 mg/kg and varying voltage at 30 V and 10 V were evaluated.

2.3 Dye Analysis

Dye analysis was carried out using UV-Spectrophotometer. For the determination of dye amount in soil, 2 g of soil samples were added into 16 ml of 0.1 M Sodium dihydrogen phosphate (NaH_2PO_4) in the ratio

1g of dry soil per 8 ml (Pazos *et al*, 2008), shaked for 1 hour and then centrifuged at 4000 rpm for 10-15 minutes. Finally, the dye concentrations were determined by absorbance measurements using UV-Visible Spectrophotometer at 590 nm as the maximum wavelength for a crystal violet dye. The dye removal percentage was obtained using the formula;

$$\% \; CV \; Removal \; = \; \frac{C_0 - C_f \times 100\%}{C_0} \qquad (1)$$

Where: C_o and C_f are the initial and final concentrations of dye solution (mg/kg).

III.   RESULTS AND DISCUSSION

This study aims to evaluate the efficiency of the electrokinetic treatment technique for clay sample contaminated with crystal violet dye. Therefore, certain amounts of clay sample contaminated with initial dye amounts (200 mg/kg, 400 mg/kg, 600 mg/kg, 800 mg/kg and 1000 mg/kg) were inserted to the electrokinetic chamber. All equipments were set up and run for 24 h. Mobilization and distribution of dye remained in all sections after the electroknetic treatment process were determined. The results of eletrokinetic remediation of dye contaminated clay soil conducted in an electrokinetic cell divided into three sections, S1. S2 and S3 from anode to cathode are presented.

3.1 Effect of initial dye amount

The relationship between initial dye amount, dye remained in the soil and removal efficiency was investigated. According to the results, the concentration of dye remained in the anode (S1), middle (S2) and cathode (S3) sections after electrokinetic treatment increased with increasing initial dye amount (Fig. 1, Fig. 2 & Fig. 3)
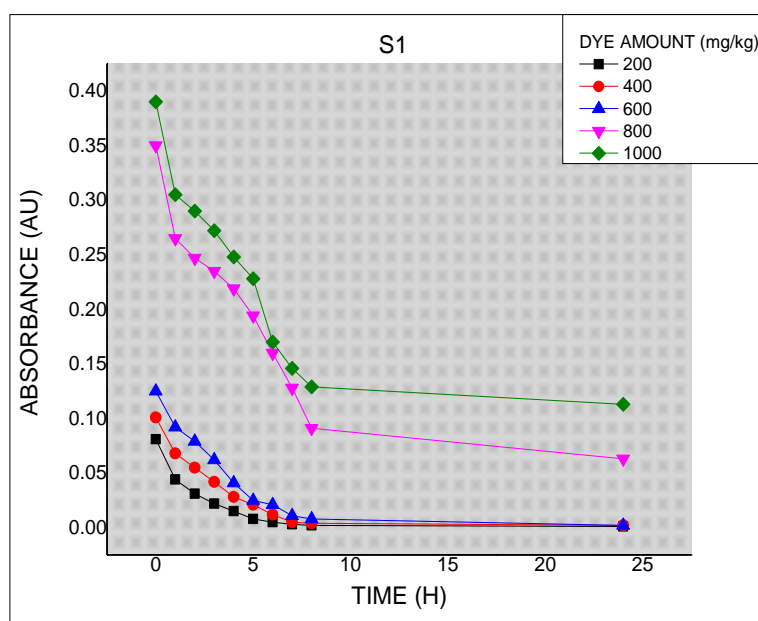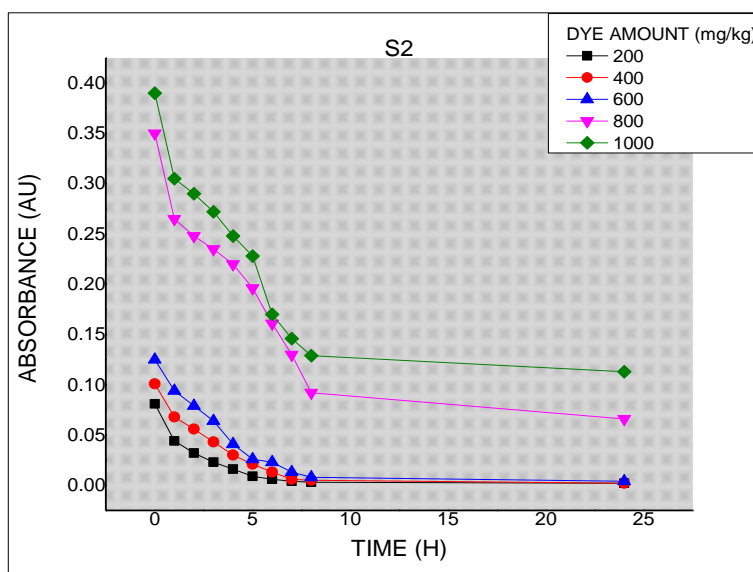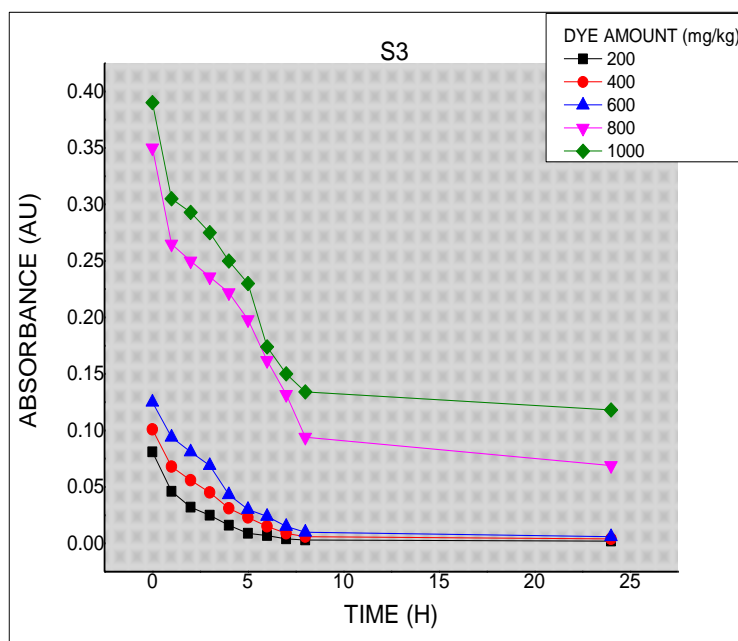

Figure1: Effect of initial dye amount on dye removal rate on electrokinetic remediation at the anode (S1)

Figure 2: Effect of initial dye amount on dye removal rate on electrokinetic remediation at the middle (S2)

Figure 3: Effect of initial dye amount on dye removal rate on electrokinetic remediation at the cathode (S3).

The corresponding effect of initial dye amount on the dye removal efficiency is presented in Fig. 4, Fig. 5 and Fig. 6. The result indicated that the percentage of dye removal decreases with an increase in the initial dye amount with function of time. In this study, 81.1%, 72.9%, 68.0%, 48.5% and 45.5% removal was achieved for initial dye amount of 200 mg/kg, 400mg/kg, 600mg/kg, 800mg/kg and 1000mg/kg respectively. As the result indicated, the dye removal efficiency decreased with an increase in initial dye amount i.e. dye removal decreases from 81.1% to 45.5% when dye concentration was increased from 200 mg/kg to 1000mg/kg at 30 V. Highest removal was achieved for initial dye amount of 200 mg/kg. This is due to the fact that the clay soil is constant and thus has a fixed number of active sites; therefore at low concentration of dye more dye can be removed from the abundant active site of the soil but the active site gets saturated at higher dye concentration, leading to less

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removal of crystal violet dye. Hence, 81.1% dye removal was obtained in quick time compared to higher concentration at 30 V. Tehenna (2015) reported similar results and stated that the dye removal will decrease with increase in initial dye concentration.
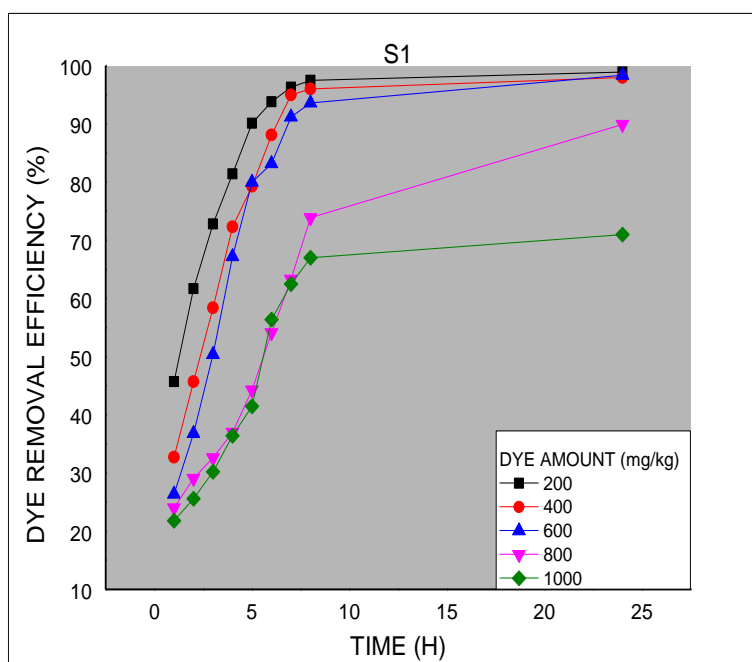

Figure 4: Effect of initial dye amount on dye removal efficiency on electrokinetic remediation at the anode (S1).
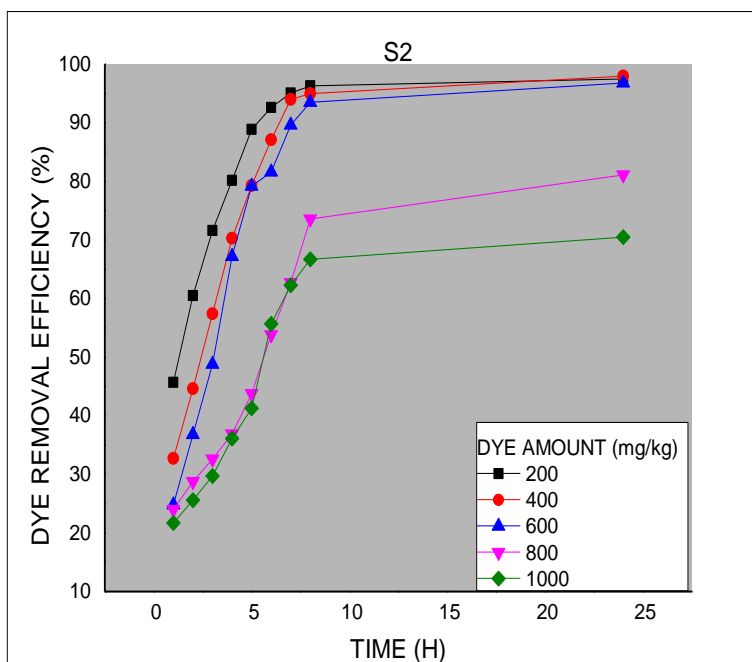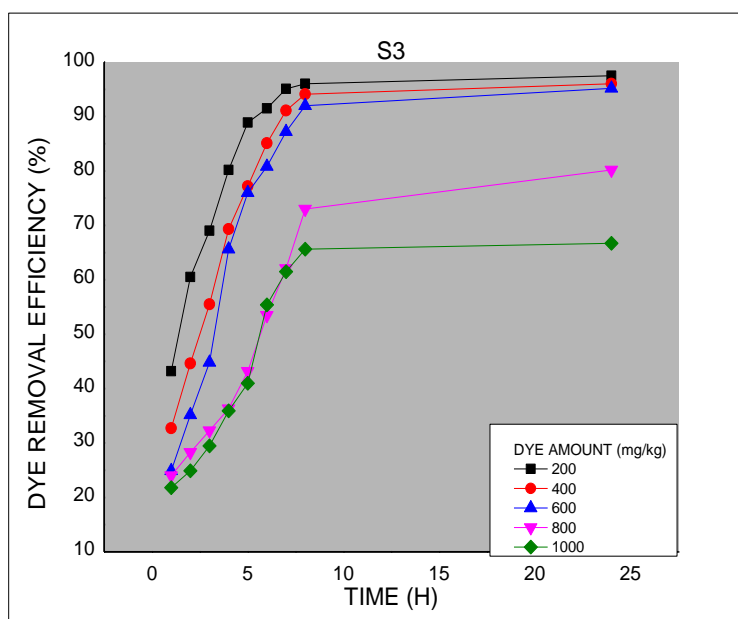

Figure 5: Effect of initial dye amount on dye removal efficiency on electrokinetic remediation at the middle (S2).

Figure 6: Effect of initial dye amount on dye removal efficiency on electrokinetic remediation at the cathode (S3).

KEY:
S1 = Anode compartment
S2 = Middle region
S3 = Cathode compartment

3.2 Effect of Voltage Variations

The effect of voltage variations on electrokinetic treatment efficiency is presented in Fig. 7(a) and 7 (b). From the results, there was optimum dye removal efficiency at 30 V than at 10 V. In all the cases the dye removal efficiency increases with increasing voltage at any given dye amount with time. This may be because as the voltage increases, the charged dye ions particles attracted toward cathode also significantly increases and because of which dye concentration decreases with voltage. If concentration of the contaminants is high in the soil, the increase of voltage is expected to drag more contaminants towards the anodic and cathodic points at less time interval depends on positive or negative charges of the contaminants. The average removal efficiency of dye for 30 V and 10 V is 63.2% and 48.2% respectively. Reddy *et al.* (2003) obtained a maximum of 77% of mercury reduction removed from glacial till after electrokinetic treatment using higher iodide concentration and high voltage gradient. Meng *et al*. (2011) had similar result to the experimental study on the effect of applied voltage on electrokinetic removal of chromium from kaolin at laboratory scale. Their results indicate that removal efficiencies increase with the increase of applied voltage. The electric energy consumptions also increase significantly due to the increase in applied voltage.
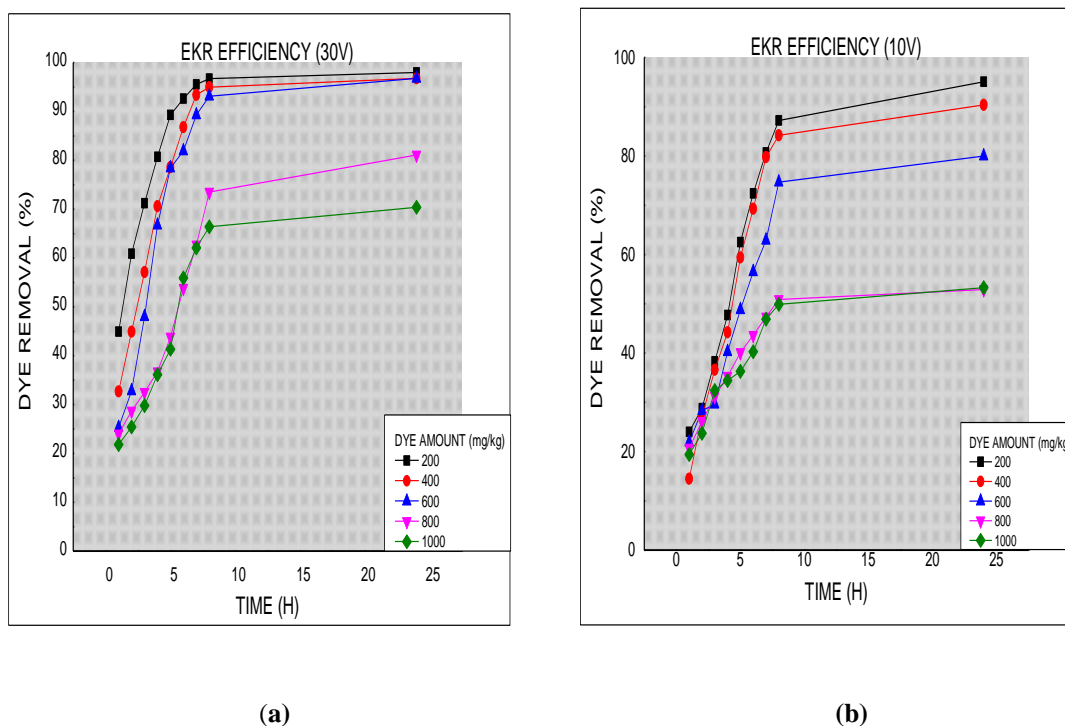
(a)   (b)

Figure 7: Effect of applied voltage on electrokinetics remediation efficiency at 30V(a) and 10V(b)

IV.   CONCLUSIONS

This study investigated the efficiency of electrokinetic treatment in the remediation of organic contamination from a low permeability soil. Crystal violet dye was chosen as the representative organic contaminant and clay as the low permeability soil. The effects of the initial dye amount and applied have been studied. From the experimental observation, the initial dye amount is an important input parameter that can seriously affect the remediation effectiveness. Removal efficiency decreased with increasing initial dye amount. The lower the amount of dye, the higher the percentage removal. Electokinetics could reduce the dye contamination in low permeability soils. The dye removal efficiency increases at higher increasing voltage. For higher removal, a higher voltage should be considered for remediation efficiency. Remediation time increased the removal efficiency. Longer remediation time facilitates dye removal. In this study, the dye removal efficiency increased with increasing remediation time from1h through 8h and highest removal was obtained at 24h. Considering the achieved results in this study, the electrokinetic remediation treatment is a promising treatment technique for the remediation method for soil contaminated with organic compounds including dyes.

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