

Cadmium Removal from Contaminated Soil by Electro-Kinetic Method

Laith Hamdan Hawal^{1*}, Ali Omran Al-Sulttani², Jinan N. Hamza²

¹ Environmental Engineering Department, Mustansiriyah University, Baghdad, Iraq

² Water Resources Engineering Department, College of Engineering, University of Baghdad, Baghdad, Iraq

* Corresponding author's e-mail: laith.h@uomustansiriyah.edu.iq

ABSTRACT

For this study, an electro kinetic method used to eliminate cadmium from the polluted soil. This method is useful at low permeability medium. Several experiments were conducted with variable operating circumstances, using different pH purging solutions. Rice husks were used in this work as an adsorbent medium available and free of charge to counteract the reverse osmosis process that occurs and affects the work efficiency. The final results after the end of the practical experiments of this process showed that the percentages of the removal process began to increase after the pH gradually decreases. The pH of the solution for the three experiments conducted was 3, 6 and 9, respectively. The best removal rate was 68% in this process at pH 3 ; when compared with the second and third tests at pH 6 and 9, the removal ratios were 58% and 51.5%, respectively. It was discovered that the cadmium removal rate began to decrease along with voltage. At 30 volts the removal rates were 68%, whereas 20 volts they were 66%. Rice husks have been shown to be an effective adsorbent for counteracting reverse osmosis. Therefore, it can be successfully used as an adsorbent medium.

Keywords: electro-kinetic, cadmium, soil, removal rate, rice husks.

INTRODUCTION

The environmental contamination due to heavy metals is an important environmental issue caused by human actions, like agriculture, industry and mining (Laith et al. 2021). Heavy metals are considered dangerous pollutants in nature. They are widespread and the need to treat them is urgent. Therefore, there are efforts to remediate these contaminated sites, taking into account some physical and biological conditions related to the type of pollutants (Laith et al. 2021). The problem of soil pollution is one of the sensitive environmental issues for environmental scientists all over the world (Laith et al. 2021). Various techniques have been applied to remediate polluted places, and among these methods are biological treatment, chemical treatment and electro kinetic method. These technologies can be practically performed either on-site or off-site (Laith et al. 2021). Among the different technologies tested, the electro kinetic technology was interesting,

impressive and useful, for its applicability on site (Rosestolat et al. 2015.). It is considered environmentally friendly when compared with other methods (Voccianta et al. 2016). This technique is a modest method, two electrodes are installed in soil and an electric current is passed between these electrodes. One electrode was the cathode electrode and the other was the anode. When an applied current passes through a section of soil, a path that gives the ions free movement through section is created (Acar and Alshawabkeh 1993; Alshawabkeh et al. 1999; Lindgren et al. 1992).

The positives of this method are as follows: (1) little equipment is used, (2) this technology is used to remove many pollutants such as heavy metals, organic matter, radio nuclides and mixes of these contaminants, (3) this process considered safe for its employees as well as the people close to the work site, (4) low cost as it requires low electrical power, (5) it can be used on-site or off-site, (6) it is used for many polluted media such as ground water, soil and sludge.

The heavy metals in soils can be in the form of soluble compounds as ions or interchangeable shapes. Mostly, these metals are steady by interfering with various soil compartments and fractures such as hydroxide, oxide, carbonate and organic compound (Srivastava et al. 2007). The main sources of cadmium in soil are precipitation, mining, waste treatment, industrial waste and fertilizers, while the other non-point sources are atmospheric deposits and ecological pollution actions (Herngren et al. 2005). The appearance and form of cadmium in the soil is not related only to the content and nature of the metal itself, but also has to do with the geographical and physical circumstances of its presence, kind of the soil and its characteristics, soil structure (such as organic compound, carbonates, clay metals and microorganisms), soil ecological circumstances. Cadmium is subjected to adsorption, absorption, accumulation, complexation and dissolution after ingoing the soil, which leads to its presence in different shapes in the soil. Relative to the chemical composition, metal can be classified according to exchangeable condition: carbonate-linked condition, interchangeable condition and organic-linked state (Yang et al. 2012, Zhao et al. 2011, Tessier et al. 1979).

Cadmium is a toxic and unsafe metal for living organisms. It is of particular concern because it is an element that is difficult to decompose and is therefore stable (Rao et al. 2010). There were several objectives of this research, including the study of: (1) possibility of using this method to eliminate cadmium from the polluted soils, (2) influence of varying pH of the solution (household water) on the removal rate, (3) voltage change effect on the removal rate, (4) the extent of the effect of using some wastes such as rice husks as barrier inside the system to counter the occurrence of the reverse-osmosis throughout cell work.

MATERIALS AND METHOD

Soil

In this research, the polluting medium that was used is soil, a quantity of which was purchased from one of the nurseries in Iraq. Then, the soil was taken, washed, dry and sieved by (sieve 2 mm) to obtain a homogeneous soil sample. Then, it was contaminated by cadmium in the laboratory. Table 1 gives details of soil properties.

Cadmium contaminant

Cadmium in the amount of 14.75 was dissolved in distilled water with volume of 280 ml. Then, the solution was mixed with 600 gm of soil to obtain a soil sample with 30% moisture content and concentration of 400 mg per kg soil. After the process of the soil mixing well, soil was left (24 hrs.) to achieve the state of homogeneity between the components of the sample.

Rice husks

The rice husks were obtained from the nearby rice mills. Then these peels were washed with water and then dried in oven at a temperature of 90 °C for a period of about 26 hours to remove the moisture content in those peels. The treated rice husks are packed in a perforated bag and placed in the cell in a chamber with dimensions 4×10×10 cm.

Electro-kinetic cell

In Figure 1, the electro-kinetic cell used in this research is shown as a diagram. This cell is prepared of glass and has internal dimensions [40 cm (L) × 10 cm (H) × 10 cm (W)]. The soil dimensions in the cell were (20 cm (L) × 10 cm (W)). Rice husks were used as an adsorbent in the cell between chamber of the cathode and section of the soil with dimensions (4 cm (L) × 10 cm (W)). For the sections that contain the electrodes in the cell, there is a valve to adjust the outflow with filter paper and the electrodes are made of graphite. These parts that contain the electrodes are at both ends of the cell with dimensions of dimensions (8 cm (L)

Property	Value
Distribution of particle size (ASTM D 422)	
Sand (%)	65
Silt (%)	22.3
Clay (%)	12.7
Atterberg limits (ASTM D 2487)	
Liquid limit (%)	28
Plastic limit (%)	23
Plasticity index (%)	5
Specific gravity	2.54
Electric conductivity EC (μS/cm)	725
Organic content (%)	0.21
Primary pH	8.5
Porosity (n)	0.28
Soil classification (USDA)	Sandy silt soil

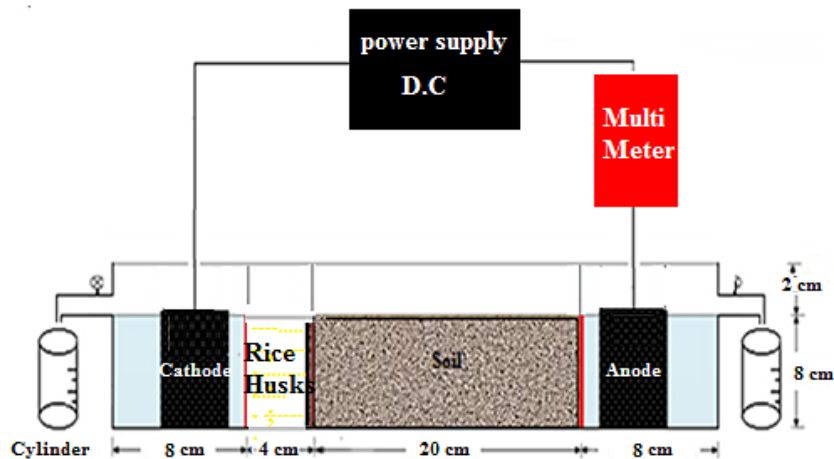


Figure 1. Schematic diagram of electro-kinetic cell

$\times 10$ cm (W)) for each part. Electrode has (6 cm (D) \times 8 cm (L)). A perforated plastic barrier has been placed to isolate the system compartments from each other and with dimensions (10 \times 10 cm). These pieces are perforated with holes of diameter 5 mm and a space of 1 cm from the hole to the other. The power source (LDESTAR, LP 3005D) was used to supply the cell with a constant voltage through the electrode. The electric current during the experiments passing through the soil was monitored by a multi-meter.

Laboratory work

In the beginning, filter paper was placed at the beginning and end of each compartment inside the cell. The polluted soil was placed in this cell to the permissible limit and was manually stacked with a tool and soil was left (24 hrs.) to obtain homogeneous shape. One constant level of the solution was maintained in electrode chambers during experiments to avoid hydraulic gradients in soil. Then the power supply was connected to the electrodes and the system was turned on. Many experiments have been done to study the influence of varying pH of the solution and the applied voltage. The solution used in all tests is household water.

The conditions used in the first experiment were at household water pH at 3, EC at 1298 μ s/cm in the chamber with electrodes and the applied voltage was 30 V. In the second experiment, the pH was 6 and EC at 1180 μ s/cm, while the concentration and voltages were the same value in the first test. The conditions of third experiment were pH at 9 and EC at 980 μ s/cm, while the

concentration and voltages were the same value in the first test. In the fourth experiment, the best conditions were chosen through the three experiments with changing the application voltage to 20 volts. The initial concentration of cadmium in all experiments was 400 mg per kg of soil. To maintain the stability of the pH of the solution during cell operation, dilute HCl was added to cathode compartment and Na OH to anode compartment.

After the end of each experiment, soil and rice husks were extracted from the system. The soil was isolated into five sections and a sample was taken from each section and placed in a container for 24 hours. To calculate the EC and pH for each section of the soil, a sample of 5 g was taken and placed in a glass container with water of 12.5 ml, then the sample was mixed with water and the glass container containing them was rubbed by the hand for a few minutes and then left for 60 minutes so that the soil particles settle to the bottom. Thus, the pH and EC of the sample were calculated. Table 2 shows the laboratory conditions for the removal process.

Digestion process

One gram of treated soil was taken and placed in a (250 ml) tube with addition 10 ml of (HNO₃). The mixture was heated for 45 minutes and at a temperature of 90 °C, which then increased to 150 °C for 8 hours so that a clear solution was obtained. Then, 5 ml of concentrated (HNO₃) was added at minimum three times to the sample and the digestion procedure continued until volume became (1 ml). The inner wall of the tube has been washed by a small amount of distilled water and during the digestion process the tube was shaken

Table 2. Operational conditions

EX. NO.	Duration of remediation (days)	Initial concentration of cadmium (mg/kg)	Voltage gradients (V/cm)	pH of purging solution	Goal of exp.
EX-1	6	400	1.5	3	Basis exp.
EX-2	6	400	1.5	6	pH impact
EX-3	6	400	1.5	9	pH impact
EX-4	6	400	1	3	voltage impact

softly to keep the inner wall clean and to prevent sample loss. Then, the mixture was cooled down, 5 ml of (1%) nitric acid was added to the mixture and the mixture was filtered by a Whatman (No. 42). The filtered mixture was then quantitatively transferred to glass beaker (25 ml) by adding de-ionized water (Zheljazkov and Nielson 1996)). Cadmium concentration was calculated by (AAP).

pH impact

In this process, it is observed that pH of the solution has an obvious impact on the removal process. In Figure 2, the remaining cadmium concentration along the soil section after removal is completed and for the first three experiments. The basic cadmium concentration in the soil after contamination and before operating the cell was 400 mg/kg. The concentration of cadmium remaining in the soil was between 128–194 mg/kg close the anode and between 168–230 mg/kg close the cathode. It was observed that when pH of the solution was reduced, the cadmium concentration increased close the cathode, because of absorbing most of the cadmium from soil and migrate to the cathode electrode. The top removal rate (68%) at pH

of 3. Immigration of cadmium ions was from the anode toward cathode. The amount of cadmium ions moving towards the cathode reduced with the gradual increased in the pH value of the solution, because of the low cation exchange capacity (CEC) for soil during high soil pH. Therefore, there will be an increased tendency for cadmium ions to be adsorbed by soil particles. There is a variation in the pH value along the section of the soil towards the cathode shown in Figure 3. The hydrogen and hydroxide ions move in opposite directions. In general, from experiments, the values of the soil pH are low nearby anode and high at cathode.

OH^- ions were bound adjacent the cathode, whereas H^+ ions were constantly moving. It is known that the increase OH^- ions means increase in precipitated metal pollutants; therefore, it opposes the movement of the pollutant to the cathode. Acid front movement is faster than the basal front movement because hydrogen ions have a greater ability to migrate than OH^- ions, (Acar and Alshawabkeh, 1993). The values of EC change along the soil section, where it was ranges between (2.3 and 3.3 ms/cm) adjacent anode and about (0.9 to 1.8 ms/cm) adjacent cathode as shown in Figure 4. It was noticed that with the progression in time

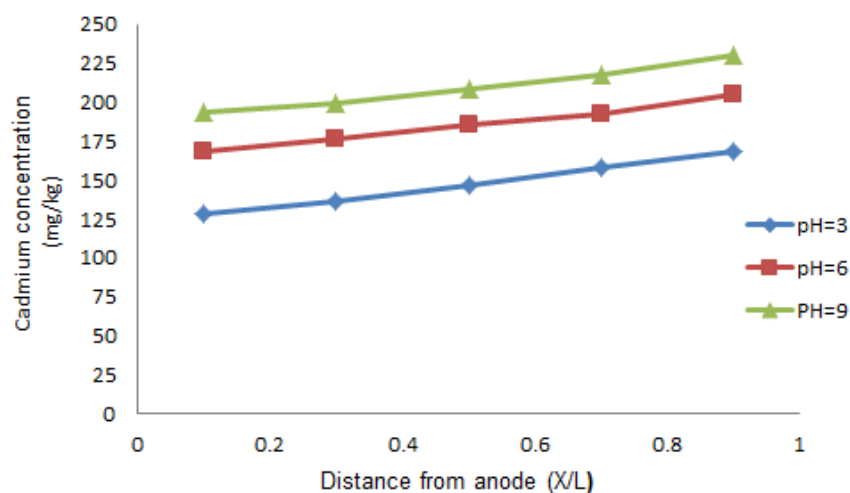


Figure 2. Cadmium concentrations (mg/kg) versus distance from the anode at different pH values of the purging solutions

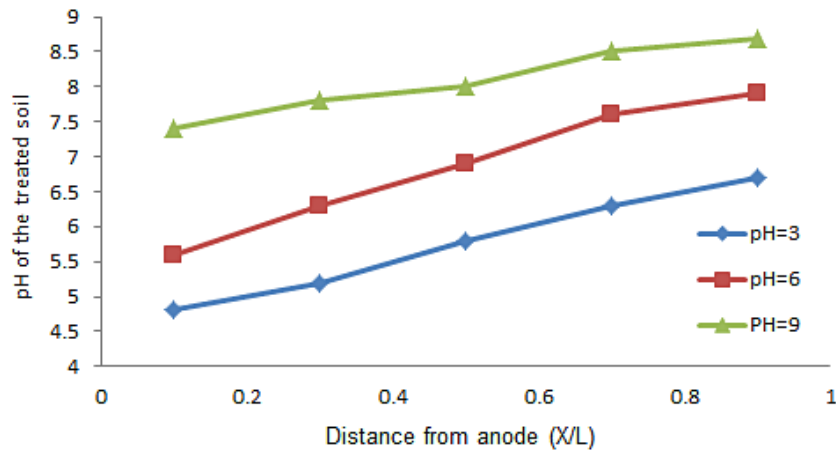


Figure 3. Soil pH versus distance from the anode at different pH values of the purging solutions

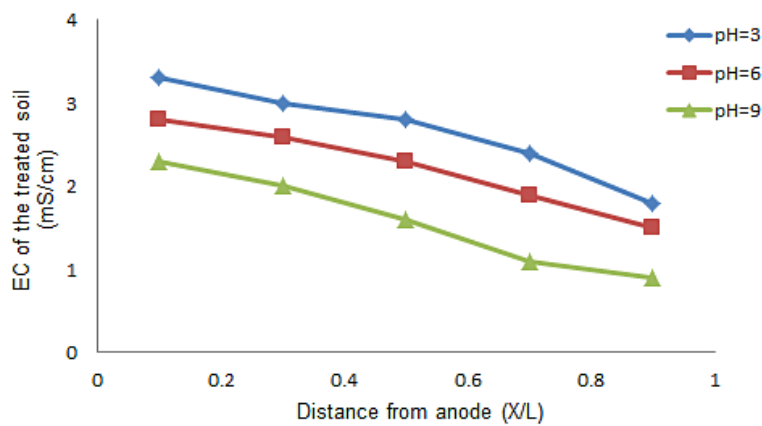


Figure 4. Soil EC versus distance from the anode at different pH values of the purging solutions

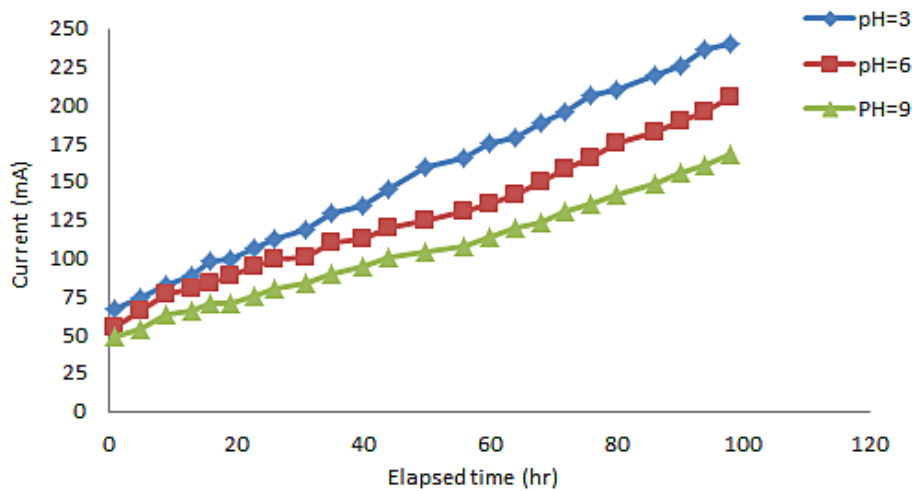


Figure 5. Current (mA) versus time (hrs.) at different pH values of the purging solutions

during the operation of the cell, the electric current passing through the soil increased as shown in Figure 5, and also the solution pH value had impact on the electric current with a variation in physical and chemical characters, as in the setting of dissolution and chemical precipitation of heavy

metals, etc. Therefore, when the pH began to decrease, the electric current took a trend towards the useful value of the process due to the migration and high solubility of heavy metals (Hamed and Bhadra, 1997). The rice husks showed their good ability to adsorb the contaminant (cadmium)

returned as a result of reverse osmosis, there is a quantity of cadmium on the surface of this medium (rice husks) because of the effectiveness of the salt ions with cadmium ions in the soil section. The amount of cadmium ions adsorbed by rice husks was about 30 to 39 mg/kg in all experiments.

Voltage impact

After this study and experiments, it was found that the effort in the removal process has an effect, although it is not great. Figure 6 demonstrates the gradual change in the residual cadmium concentration from the anode to the cathode after the remediation is finished. It was observed that the cadmium ions moving from the anode to the cathode began to increase along the voltage. Thus, it means an increase in the removal rate. It was concluded that when the voltage is increased, the current passing through the soil increases. Thus, the intensity of electrolysis reaction adjacent to the

anode and cathode increases. The electrolysis reaction in this process generate OH^- and H^+ which allows them to move faster than before this reaction in the soil (Reddy and Shirani, 1997). It was noticed that the rise in soil pH was to the cathode from the anode gradually and slightly, as the soil had a large amount of buffering capacities (Reddy and Shirani, 1997). The pH of the soil was between 4.8 at the anode to 8.7 at the cathode, as shown in the Figure 7. Figures 6 and 7 show a comparison between the first and the fourth experiments with the change of voltage (30 V and 20 V).

Removal rate

The cadmium removal rate was calculated mathematically for all experiment by applying the equation:

$$\eta \% = \frac{\text{Initial conc.} - \text{Residual conc.}}{\text{Initial conc.}} \quad (1)$$

where: η % – removal rate.

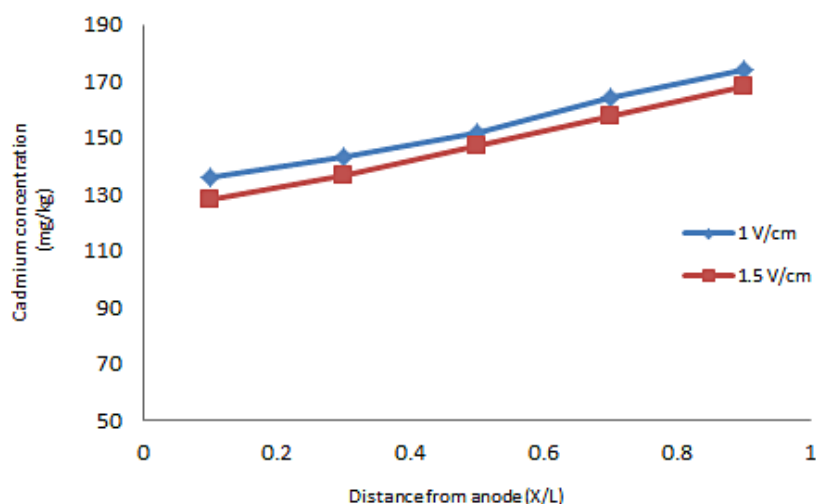


Figure 6. Cadmium concentrations (mgkg) versus distance from the anode at different voltages gradient

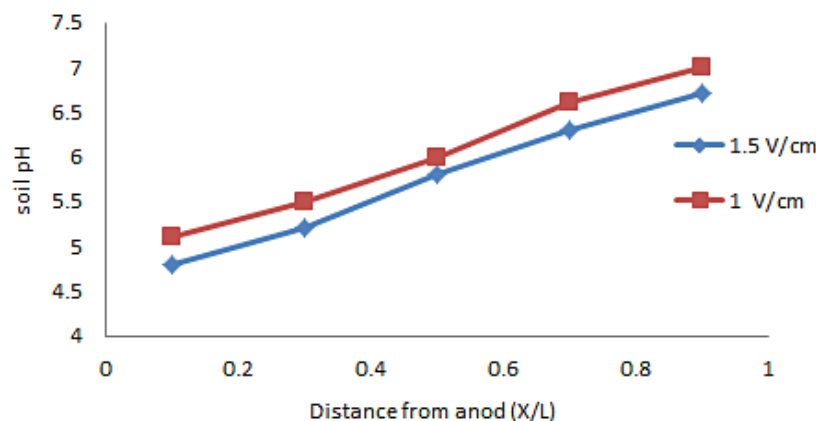


Figure 7. Soil pH versus distance from anode at different voltage gradient

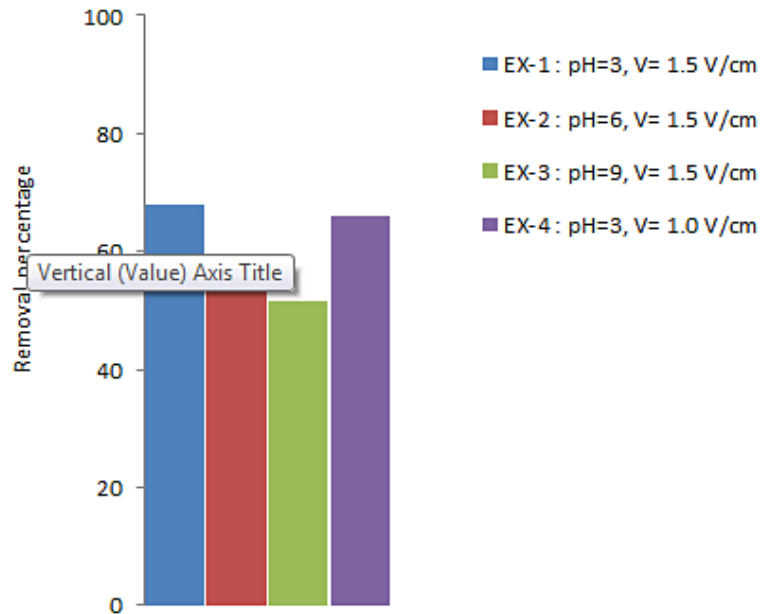


Figure 8. Removal rate of cadmium (%)

The highest rate of removal of cadmium in this study was 68% in the first experiment, as shown in Figure 8. The rest of the removal rate for the other trials in this study were 58%, 51.5%, and 66% in experiments 2, 3 and 4, respectively.

CONCLUSIONS

This research showed that the electro-kinetic method is successful in removing heavy metals (cadmium) from polluted soils. Various trials have been performed with different circumstances. The experiments proved that with pH increasing of the solution, the removal rate decreased. The removal rates were 68% at pH 3, 58% at pH 6, and 51.5% at pH 9. The increase in voltage also increased the removal rate, the removal rates were 68% at 30 V and 66% at 20 V. Rice husks showed that it is a useful adsorbent medium to counter reverse osmosis when compared to another group of commercial adsorbents, and that the adsorption technique using rice husks is environmentally and economically successful.

Acknowledgements

The researchers are grateful to the Environmental Engineering Department at Al-Mustansiriyah University and their laboratories for their cooperation.

REFERENCES

1. Acar, Y.B., Alshwabkeh, A.N. 1993. Principles of electro kinetic remediation). *Environmental Science & Technology*, 27, 2638–2647.
2. Alshwabkeh A.N., Yeung A.T., Bricka M.R. 1999. Practical aspects of in-situ electro-kinetic extraction. *Journal of Environmental Engineering*, 125, 270–35.
3. Hamed, J.T., Bhadra, A. 1997. Influence of current density and pH on electro kinetics. *Journal of Hazardous Materials*, 55(1–3), 279–294.
4. Hamdan, L.H., Al-Sulttani A.O., Nagam, O.K. 2021. (Adsorption of Lead Ions from Aqueous Solutions onto Rice Husks, Continuous System). *Journal of Ecological Engineering*, 22(10), 269–27.
5. Hamdan L.H., Al-Sulttani A.O., Nagam. O.K. 2021. (Electro-Kinetic Remediation of Nickel from Contaminated Soil Using Bio remedies Banana Peels and Surfactant-Enhance). *Journal of Ecological Engineering*, 22(5), 214–222.
6. Hamdan L.H., Al-Sulttani A.O., Nagam. O.K. 2021. (Chromium Elimination from Contaminated Soil by Electro-Kinetic Remediation, Using Garlic Peels Powder). *Journal of Ecological Engineering*, 22(7), 252–25.
7. Lindgren, E.R., Kozak M.W., Mattson E.D. 1992. Electro-kinetic Remediation of Unsaturated Soils. Conference: Industrial and Engineering Chemistry (I and EC) Special Symposium of the American Chemical Society (ASC), 21–23 Sep.
8. Hergren L. et al. 2005. Understanding heavy metal and suspended solids relationships in urban storm water using simulated rainfall. *Journal of Environmental Management*, 76(2), 149–158.

9. Reddy K.R., Shirani A.B. 1997. Electro-kinetic remediation of metal contaminated glacial tills. Department of Civil and Materials Engineering, University of Illinois at Chicago. Geotechnical and Geological Engineering, 15, 3–29.
10. Rosestolato, R.B., Ferro S. 2015. Electro kinetic remediation of soils polluted by heavy metals (mercury in particular). Chemical Engineering Journal, 264, 16–23.
11. Srivastava, R.K., Tiwari, R.P., Bala Ramudu, P. 2007. Electro-kinetic remediation study for cadmium contaminated soil. Civil Engineering Department, Iranian Journal of Environmental Health, Science and Engineering, 4(4), 207–214.
12. Rao, K.S., Mohapatra, M., Anand, S., Venkateswarlu, P. 2010 Review on cadmium removal from aqueous solutions. International Journal of Engineering, Science and Technology, 2(7), 81–103.
13. Tessier, P.C., Bisson, M. 1979. Sequential extraction procedure for the speciation of particulate trace metals. Environmental Science Analytical Chemistry, 51, 844–850.
14. Vocciante, M., Caretta, A., Bua, L., Bagatin, R., Ferro, S. 2016. Enhancements in electro kinetic remediation technology: Environmental assessment in comparison with other configurations and consolidated solution. Chemical Engineering Journal, 289, 123–134.
15. Yang, R., Luo, C., Zhang, G., Li, X., Shen, Z. 2012. Extraction of heavy metals from e-waste contaminated soils using EDDS. Journal of Environmental Sciences, 24, 1985–1994.
16. Zhao N., Yanshan C., Yu, F., Jianzhi, X. 2011. Leaching of Cd and Pb from a contaminated soil with EDTA and EDDS: Effectiveness and health risk assessment. Modern Agricultural Science And Technology, 30, 958–963.
17. Zheljazkov, V., Nielson, N.S. 1996. Effect of heavy metals on peppermint and cornmint. Plant and Soil, 178, (59–66).