Electrokinetic remediation of arsenic contamination from alluvial and red clay soil

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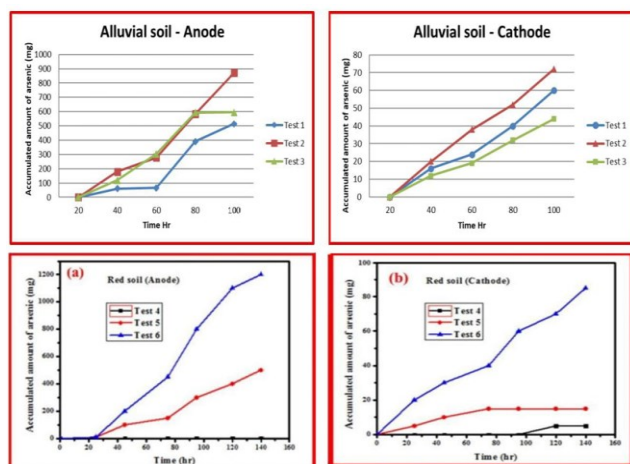
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Graphical abstract

Abstract

In this research the arsenic contaminations issues are exposed and suitable measures are recommended through electrokinetic remediation. The arsenic expulsion was assessed using the electro kinetic remediation from two different soil tests; alluvial clay soil and red clay soil taken from the Tamilnadu zone. Three distinct cathodic electrolytes—deionized water (DIW), potassium phosphate (KH_2PO_4), and sodium hydroxide—were used to test the viability of upgrading experts (NaOH).The consequences of the examinations on the alluvial mud soil shows that the potassium phosphate (0.1N) was the best in extricating arsenic (79.5% removal efficiency), likely because of anion trade of arsenic species by phosphate. Then again, the sodium hydroxide (0.1N) appeared to be the most proficient in with eliminating arsenic (63%) from the red soil. The sodium hydroxide's ability to increase soil pH and hasten the ionic migration of arsenic species through the desorption of arsenic species as well as the disintegration of arsenic-bearing minerals may help to explain and suggest this result.In order to forecast the effectiveness of removing arsenic from polluted soil, studies using response surface technique are also designed using the Box Behnken Method.

Keywords: Electrokinetic remediation, alluvial soil, red soil, arsenic, response surface analysis

1. Introduction

Environmental deterioration has grown to be a significant social problem. Along with natural elements, unchecked human activity is to blame. Heavy metal soil contamination is a well-known threat to the environment worldwide. A class of metals and metalloids known as heavy metals has an atomic density greater than five times that of water (Banerjee *et al.*, 2011). They are also regarded as important sources of heavy metals, roads, dumpsite areas, and automobiles. Surface waters including runoff and releases from storage and transport, soil, and air including combustion, extraction and processing are only a few of the different ways that heavy metals are released into the environment. The major ways that toxic heavy metals and minerals enter the human body are through tainted food and water. Heavy metals are toxic or poisonous even at low concentration. Exposure to them during production, usage and their uncontrolled discharge into the environment causes lot of hazards to man, other organisms and the environment. It leads to overt and insidious health problems to human (Chang *et al.*, 2019). Although, adverse health effects of heavy metals have been known for a long time, exposure to heavy metals continues and is even increasing in the world. Improper and inadequate waste management practices cumulate the risk of exposure to the communities within contaminated areas as well as in surrounding and downstream of that.

Among the various types of heavy metals ions, the arsenic contamination is considered to be the major issue in recent days with its specific areas and number of people getting affected indirectly or directly. Arsenic poisoning in groundwater measures is acquainted globally, however the soil contamination consequences are still unknown to the community of contaminated regions.Arsenic is a crucial spontaneous concern for the people and other life forms related with the vegetables and crops poisoning. Several remediation technologies majorly include biological,

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physical and chemical methods which have evolved with the time to check the impacts. However certain remedial measures were mostly ineffective and highly expensive (Dalal *et al*., 2002). They are restricted to specific applications in aqueous models and gives toxic sludge which is considered as major concern. In order to mobilize pollutants in the form of charged species, electrokinetic remediation uses low-density direct current between electrodes buried in the soil. From both saturated and unsaturated soils, electro kinetics can be utilized to remove radio nuclides, metals, and organics. It provides the elimination of organic and inorganic impurities at a comparatively low cost compared to other technologies as an in-situ treatment approach (Figueroa *et al*., 2016). It is thought that this method's use in clayey soil represents a breakthrough in soil decontamination. Figure 1 shows the experimental setup of electrokinetic remediation process.
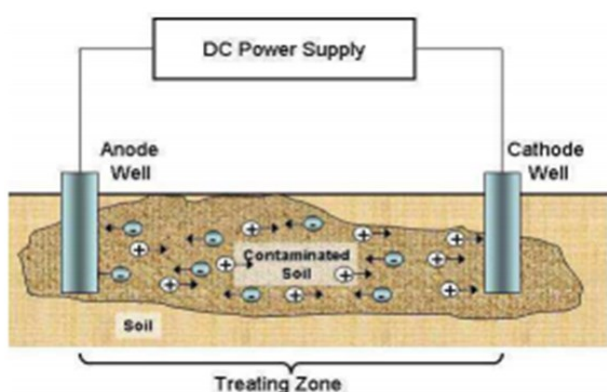

Figure 1 Process of electro kinetic remediation

The extraction rate and efficiency of heavy metals in electrokinetic remediation are dependent on the physical and chemical characteristics of the soil, and the influence of various factors that may limit the application of electrokinetic remediation is difficult to understand. It is necessary to develop a simple and dependable solution that makes use of easily measurable, less complex but still influential common soil characteristics (Fox and Doner, 2002). The main objective of this experimental study is to analyze the extent of removal on two soils (alluvial and red clay soils) by varying individual factors known to influence remediation like different types of electrolytes within practically possible limits of occurrence in field when other factors remain constant. Also, to validate a model using Response Surface Methodology to predict the remediation and can take decision for the optimization of process parameters, necessity for enhancement etc. This model shall be validated with the experimental data on contaminated soils.

2. Materials and methods

2.1. Study area

Figure 2 shows Ramanathapuram taluk which is located in Ramanathapuram district in Tamilnadu southern part on India east coast. The climate succeeds with 36 °C max in summer and 25° C of min temperature in winter, 500 mm average rainfall is recorded. The Ramanathapuram taluk soil can be mixed into significant types like sand and alluvial, clay, sandy clay, sandy loam. Vaigai is considered to be the important river of the taluk, which is stream and channel in mandapam and tirupullani blocks. Ramanathapuram taluk total population is 1,66,232 as per 2011 census.

Figure 2 Study area geographical map

2.2. Characterization of soil samples

The clay materials of two different types, alluvial and red clay which is having low hydraulic conductivity and high plasticity, used in this research have collected from Ramanathapuram district, Tamilnadu, India. These raw materials were appropriate to two sedimentary formations like two clays from alluvial deposits in Ramanathapuram district. For wider industrial applications range, the geological specifications of materials were continuity, accessibility and reserves facilitate the robustness usage of materials. The proposed study area is shown in Figure 2. It focuses on the major clay deposits of geological information in Tamilnadu. Sufficient quantity of soil samples was collected and analyzed for physical and chemical properties which is shown in Table 1. Initially using the agate mortar, the samples have dried for 24 hours at 8°C for further evaluation.

Table 1 Properties of soil samples

Properties	Alluvial	Red soil
pH	7.88	6.53
EC (dS m^{-1})	0.53	0.67
OC (%)	2.8	3.4
Specific gravity	2.51	2.79
CEC meq/100gms	12.8	11.9

2.3. Preparation of soil and purging samples

Arsenic trioxide was used to prepare contaminated soil samples. The final concentration of contaminated soil was 1000mg/kg. It was planned to conduct one controlled test with deionized water as purging solution and two enhanced tests with 0.1 N of sodium carbonate as anolyte and 0.1 N potassium phosphate, 0.1 N sodium hydroxide as catholyte solution for both soil samples. Platinum and titanium were used as anode and cathode. Other electrodes like graphite can also be used as anode and cathode. Figure 3 shows the schematic view of electrokinetic remediation process used for these experimental studies.
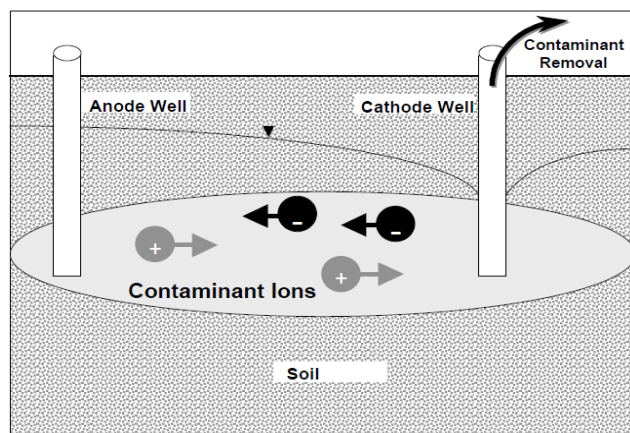
Figure 3 Electrokinetic remediation process

2.4. Experimental analysis

The experimental dimension and apparatus are shown in Figure 4. The apparatus comprised with four major parts like power supply, soil cell, reservoirs of electrolyte solutions and electrode compartments. In order to avoid sudden pH variations in electrolyte solutions, every electrode compartment comprised with electrolyte solution with sufficient volume (Giannis et al., 2007). The electrolyte solution has been measured again in both electrode compartments using peristaltic pumps and a BIORAD DC 96 power source (model Power Pac 200, 5-200 V, 0.01-2 A, 200 W) (Masterflex, 1–100 rpm, 3 heads).
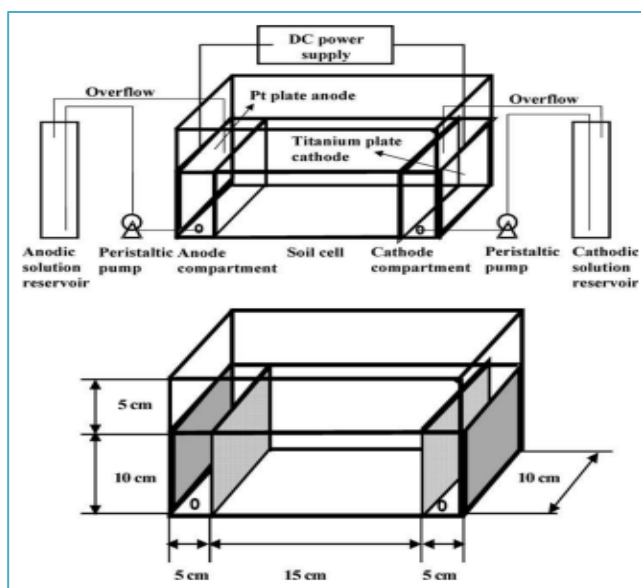

Figure 4 Experimental setup of electrokinetic remediation process for arsenic removal

Every 4 hours, a number of physical chemical parameters have measured during the experiment performed. The total voltage drops from electrode compartments and soil cell. Both electrolyte solutions show pH differentiations. By electro-osmotic flow, transported pore water volume and soil pH variation is observed. From soil bed, samples obtained directly using stainless steel sampler with 1.2 cm diameter after treatment in order to determine the final soil pH and arsenic residual concentration. Using aqua regia, arsenic from soil samples was removed, which has an HCL: HNO3 ratio of 3:1. Each dry soil sample was first

treated with aqua regia and then further agitation (100 rpm, 70°C, and 1 hour) after wet soil samples were dried at 105°C. Through hydride generator atomic absorption spectrometry (HG-AAS, Perkin–Elmer ZL 5100), arsenic concentrations have evaluated (Helena et al., 2012).

Six tests from test 1 to test 6 were developed and performed for arsenic removal from soils through electrokinetic remediation process.Two enhanced tests as well as one control test were carried out on two types of samples, including alluvial and red soil. Using the DIW-deionized water as neutral electrolyte solution, control tests have performed. 0.1 M sodium hydroxide (NaOH) and 0.1 M potassium phosphate (KH_2PO_4) solutions have used in enhanced tests as catholytes for alkaline and acidic conditions simulation. Specifically, because of the anion exchange capacity with arsenic species, phosphate solution has chosen in between different kind of acid solutions (Han et al., 2010). As anolytes, sodium carbonate ($Na2CO3$) solutions have used in tests 2 and test 5 for hydrogen ions neutralization which are generated through electrolysis of anodic water and which prevents developing acidic conditions within soil bed. The experimental program is explained in the Table 2.

Table 2 Arsenic electrokinetic removal- experimental program and evaluated parameters

Anode	Platinum plate
Cathode	Titanium plate
Reactor dimensions	Width – 10 cm
	Height – 10 cm
	Length – 15 cm (C/S)
Current	0.1 A (current density 1mA/cm^2)
Initial arsenic concentration	1500 mg/kg
Duration	100 hours

For 24 hours, every electrolyte solution has refreshed for diminishing the water electrolysis impact which presented in both the electrode compartments. Constant-current mode has used except in test 4 for maintains the net rates of constant electrolytic reactions and difficult current boundary conditions minimized. In test 4, due to the electric resistance which has increased continuously the applied current has controlled from 0.1 to 0.05 A in stepwise manner after 28 hr, after 64 hr, again 0.05 to 0.03 A.

3. Results and discussion

3.1. Effect of pH variations in alluvial and red soil

The pH variation in the soil bed has been represented in Figure 5 a & b. The electrolytic process of H_2O leads to the generation of –OH ions at the cathode and H^+ ions at the anode region. With no conditioning of the electrolytic solutions, the alkaline and acid fronts will move towards the anode and cathode causing increase and decrease in the pH of the soil in both cathode and anode region (Isosaari and Sillanpää, 2010). As represented in the Figure 5a, the pH of the soil possesses a characteristic pattern in the test. These tests revealed that there is no conditioning of the electrolytes. The rate of soil pH change was observed

to be insignificant in between the red soil and the alluvial soil because of their various and differing initial and buffering capacity of the pH. Meanwhile in the test 2 and 5, the generation of OH- ions at the cathode region has been found to be contracted by the inclusion of the phosphatase solution. Due to this process, the soil bed's overall pH level has been kept as low as possible. Accordingly, the pH of the soil was found to be increases in the overall soil bed in the test 3 and 6 and it leads to the inclusion of alkaline solutions to both catholyte and anolyte (Jez and Lestan, 2016). This study discovered that, despite identical conditions, the soil pH in test 6's final stage is lower than it was in test 3's, and that the starting pH of the red soil in test 6's is lower than the alluvial soil in test 3's. The cause was found to be due to the investigated tests' various processing times. Additionally, test 3's processing time was shorter than test 6's, and less -OH was dispersed across the soil bed once test 3 was finished, which resulted in test 3's low pH.

3.2. Effect of voltage variations in alluvial and red soil

The electrical conductivity differential and the anticipated voltage drop during processing represented the movement of species inside the soil bed. Every experiment's total voltage drop throughout the soil bed is depicted in the figure. Because of the steadily rising voltage from across bed region, the applied current is adjusted progressively in test 4 rather than remaining constant, as was initially planned, in the other experiments (Kaur *et al.*, 2019). Figure 6 (a & b) represented the variation of voltage drops during the experiments.
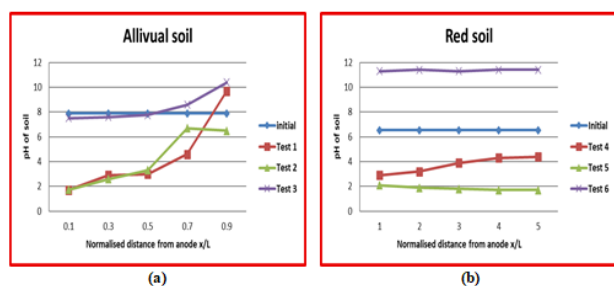

Figure 5 (a) & (b) Variation of pH in the soil bed for alluvial and red soil

For test 1 and 4, the voltage drops increases constantly, suggesting that the EC reduced in a gradual manner in soil bed. Using the water electrolysis process the hydroxide ions and hydrogen gas was produced in both electrode compartments, there were no other sufficient species present to flow across the soil bed throughout this experimental method. In contrast, the other 4 conductivity test increased in a gradual manner during the experiment. Such increase in the conductivity attributes to migrate three types of species in which the H^+ and OH^- ions were produced by electrolysis of water, the ions were produced in the system by adding improved agents like phosphatase ions in in cathode in second and fifth test (Kawa, 2019). Further OH^- ions H^+ ions in catholyte and anolyte respectively were found in test 3 and 6.

Accordingly, the species extracted from the original soil specimen because of mobilizing process like ion exchange, dissolution and desorption etc. The impact of produced ions by water electrolysis either through enhancing chemicals was disregarded in the test when the test conditions are applied equally when the study evaluate to contribute every species to a significant increase in the conductivity inside the soil bed (Kim, 2014). Because of this, it is possible to match the voltage profile to the movement and transport of species found in soil samples. Particularly the voltage signified the importance of migration and mobilization of the arsenic species in both the red soil and alluvial soil due to the contamination with only arsenic concentration and other contaminants of the red soil (Kishi). Further, within the soil bed, the reduction of voltage in these four tests (2,3,5, and 6) represented the transport and mobilization of As species.
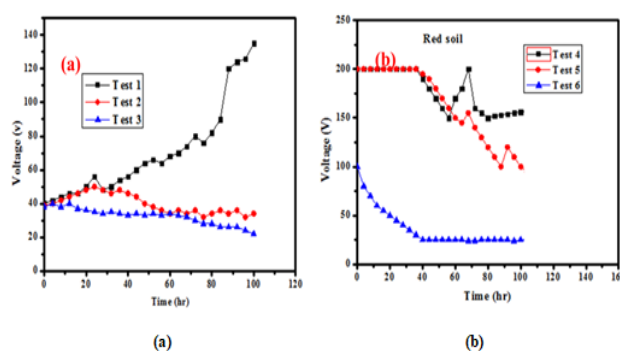

Figure 6 (a) & (b) – Voltage profile of Alluvial and Red soil

3.3. Effect of arsenic concentration and its distribution

The concentration of arsenic in anode and cathode compartment is explained graphically in Figure 7 (a) & (b). During the experiment, the total amount of arsenic in the electrolyte was estimated. The As amount has been increased in both catholyte and anolyte in the entire experiment. But the elevated arsenic rate in the entire electrolyte was more in the anolyte which represented that the species predominantly shifted towards the anode and are accumulate to anolyte (Liu *et al.*, 2020). Additionally, the arsenic amount estimated in the electrolytes were constrained in the test 4 representing that more arsenic has been removed from the river bed.

In every electrolyte the arsenic accumulative amount has calculated. In both catholyte and anolyte, arsenic amount has increased gradually. Compared with catholyte, the arsenic increasing rate has importantly higher in anolyte. It shows that arsenic species mainly accumulated to anolyte through moving towards anode. Moreover, among the tests experiments, arsenic increasing rate observation was different in every electrolyte (Liu *et al.*, 2018). In particular, the amount of arsenic found in both electrolytes, which indicates that it was severely limited in test 4, indicates that more or a faster rate of arsenic removal from the soil bed. Figure 8 (a) & (b) represents the accumulation of arsenic in electrode compartment for red soil.
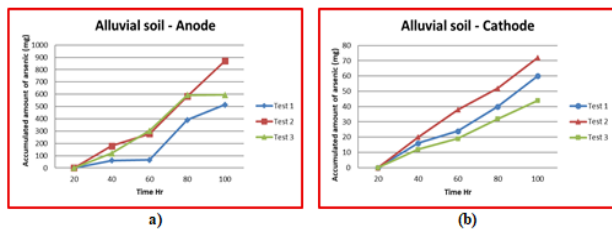
Figure 7 (a) & (b) Accumulation of arsenic metals in Alluvial soil with electrolytes
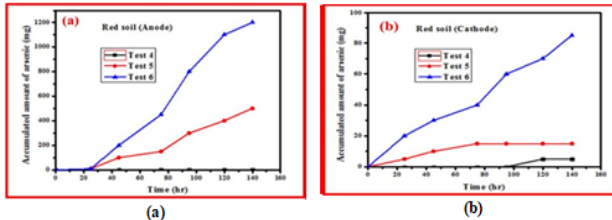

Figure 8 (a) & (b) Red soil experimental analysis for the accumulation of arsenic in anode and cathode electrolytes

Figure 9 (a) & (b) Distribution of the residual arsenic concentration in the alluvial and red soil beds

Figure 10 (a) & (b) Efficiency of arsenic removal with respect to distance for Alluvial and red soil beds

Figure 9 (a&b) gives the distribution of arsenic concentration in the soil bed for alluvial and red soil. In all the studies, the arsenic concentrations generally decreased compared to initial concentrations. Compared with other four tests, the residual arsenic concentrations distribution trends for tests 1 & 3 shows different. Towards the anode, residual arsenic concentrations show decrease in rate seen in tests 1 & 3, but in other tests it shows increase in rate towards the anode. During the process, it can be recognized to difference in magnitude and direction of electro-osmotic flow tests 1 & 3, predominantly build towards cathode (Ma *et al*., 2020). The electro-osmotic flow blocked the arsenic electro migration towards anode leads to arsenic removal retardation in soil bed of cathodic part. It has observed that the EK removal of heavy metals major mechanism from soil has said to be electro-migration (Mao *et al*., 2016). But during EK processing, electro-osmosis also plays major role in heavy metals removal. In the instance of the alluvial experiment, it is asserted that the phosphate solution is a highly efficient improvising agent between the studied electrolytes. In all types of tests based on alluvial soil experiments, the majority of the arsenic species were present mostly as absorbed forms. Arsenic species that were absorbed were successfully mobilized by anion exchange by hydroxide as well as phosphate ions.

The pH is higher when there is anion exchange by hydroxide ions, described as higher hydroxide ions activity, refer generally as desorption. Arsenic desorption is essentially described as an anion to hydroxide ion exchange in terms of the process for arsenic mobilization (Muñoz *et al*., 2016). The outstanding arsenic concentrations between the three tests differ significantly with test 1 and test 3 having greater residual arsenic concentrations than test 2 even though the electrolysis of cathodic water in tests 1 and 3 continuously produced hydroxide ions. The removal efficiency of arsenic in red and alluvial soil is explained in the Figure 10 (a&b).
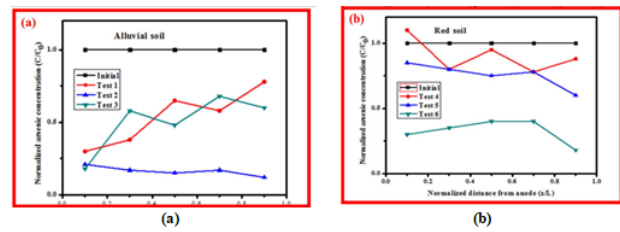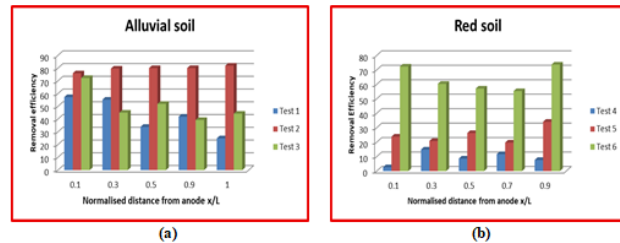
To increase the amount of hydroxide ions produced by water electrolysis in the cathode compartment in test 3, sodium hydroxide solution is specifically employed as the cathode electrolyte solution. However, test 3's residual arsenic concentration seemed to be larger than test 2's. In test 1, water was formed as a result of the interaction between the hydrogen ions produced by the anodic electrolysis of water and the hydroxide ions created by the cathodic water electrolysis. Their anion interchange for arsenic species was thus decreased. As a result, after test 1, there was a reduction in arsenic removal and a high residual arsenic content (Niroum *et al*., 2012).Additionally, the rapid electromigration of arsenic towards the anode was significantly slowed down by the intense electro-osmotic flow more toward the cathode. For these reasons, test 3's attempt to remove the arsenic was unsuccessful. In test 3, the addition of sodium carbonate (Na_2CO_3) neutralized the hydrogen ions in the anode compartment whereas the addition of sodium hydroxide solution to the cathode compartment raised the hydroxide ion level and produced a high pH in the soil bed.

3.4. Response surface analysis

When two or more quantitative elements are present, the Response Surface Methodology (RSM) or Response Surface Modeling approach is used to maximize the response(s). In response surface methods, the independent variables or factors are commonly referred to as the predictor variables, while the dependent variables are known as responses. The Box Behnken Method is used to design experiments that use response surface methodology (Ryu *et al*., 2017). To investigate the removal of arsenic from the soil environment, three independent variables were used: time (hr), distance (x/L), and current (A). For all three factors, three levels (-1, 0, +1) were used. The levels are chosen based on the batch study, and they range from 20 to 100 hours for time, 0.1 to 0.9 for distance, and 0.05 to

0.1 for current. The response will be predicted by the model using the quadratic equation shown in equation1.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1} \sum_{j=i+1} \left(\beta_{ij} x_i x_{ij} + \in \right) \quad (1)$$

where, Y response (% removal efficiency), β0, βi, βii and βij - intercept, quadratic, linear, and interaction effects, xi,

xj- independent variables and ε is the error. The batch

experiments were carried out using the experimental trails created by BBM. Table 2 summarizes the removal efficiency of arsenic for each batch trail. At distance of 0.5 (x/L), current of 0.1 A, and time of 100 hours, the maximum removal efficiency of 80.07 % was obtained. The lowest removal efficiency of 5.99% was observed at 20 hours of operation, 0.5 (x/L) distance, and 0.05 A current (Table 3).

Table 3 Removal efficiency of arsenic for each batch trail

S.No	Time	Distance	Current	Removal Efficiency- Experimental	Removal Efficiency- Predicted	Residual Error
1	20	0.5	0.05	5.99	3.07	2.92
2	20	0.1	0.075	6.45	6.23	0.22
3	20	0.9	0.075	8.61	12.25	-3.64
4	20	0.5	0.1	15.75	15.25	0.50
5	60	0.1	0.05	26.51	29.65	-3.14
6	60	0.9	0.05	40.65	39.93	0.72
7	60	0.5	0.075	47.38	47.38	0.00
8	60	0.5	0.075	47.38	47.38	0.00
9	60	0.5	0.075	47.38	47.38	0.00
10	100	0.5	0.05	48.10	48.60	-0.50
11	60	0.1	0.1	51.25	51.97	-0.72
12	100	0.1	0.075	61.28	57.64	3.64
13	60	0.9	0.1	67.31	64.17	3.14
14	100	0.9	0.075	73.90	74.12	-0.22
15	100	0.5	0.1	80.07	82.99	-2.92

Table 4 ANOVA for Removal efficiency of Arsenic

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Remarks
Regression	9	8229.9	8229.9	914.44	70.52	<0.001	-
Linear	3	7752.66	7752.66	2584.22	199.28	<0.001	-
Time	1	6415.61	6415.61	6415.61	494.74	<0.001	Significant
Distance	1	252.90	252.90	252.90	19.50	0.007	Significant
Current	1	1084.15	1084.15	1084.15	83.60	<0.001	Significant
Square	3	325.74	325.74	108.58	8.37	0.021	-
Time*Time	1	325.30	325.30	325.30	253.09	0.004	Significant
Distance*Distance	1	0.58	0.69	0.69	0.05	0.826	Insignificant
Current*Current	1	0.98	0.98	0.98	0.08	0.794	Insignificant
Interaction	3	151.60	151.60	50.53	3.90	0.089	Insignificant
Time*Distance	1	27.35	27.35	27.35	2.11	0.206	Insignificant
Time*Current	1	123.32	123.32	123.32	9.51	0.027	Significant
Distance*Current	1	0.92	0.92	0.92	0.07	0.80	Insignificant
Residual Error	5	64.84	64.84	12.97	*	-	-
Lack-of-Fit	3	64.84	64.84	21.61	*	-	-
Pure Error	2	0.00	0.00	0.00	*	-	-
Total	14	8294.83	*	*	*	-	-

3.5. Analysis of variance (ANOVA)

Table 4 summarizes the analysis of variance for arsenic removal. The Fishers test (F Value) predicted for the model was 70.52, confirming that the developed model was significant. The F Test is calculated using the model variance and the residual variance. Values close to one indicate that the models are more significant, while values greater than one indicate that the models are more significant (Smedley and Kinniburgh, 2002). Similarly, the ANOVA P value is used to validate the developed model. The model was predicted with a 95% confidence level. This

means that P values greater than or equal to 0.05 indicate that the test results are insignificant, whereas P values less than 0.05 indicate that the test results are significant. According to Table 4, the model was overall significant because the P value was less than 0.001. According to the results, all of the parameters in the linear interaction P vales are less than 0.001, indicating that the model was significant in linear interaction (Wan *et al.*, 2017). The P value for the square interaction of time and the two-way interaction of time and current is less than 0.005, indicating the model's significance. The correlation coefficient R^2 was determined to be 0.9922. The R^2 value was nearly one,

indicating the best fit between the experimental and predicted values. The adjusted R^2 value was determined to be 0.9781, and the difference between R^2 and adj R^2 was determined to be 0.014. This indicates that the adj R^2 was very close to the predicted R^2, confirming the developed model's significance (Zhao *et al.*, 2019). The variation of the mean value in the data set is calculated by adjusted R^2, and a value close to unity indicates that the model's predicted mean value is accurate, and no residual error was associated with the independent terms used in the model or the experimental date used for model development. The quadratic equation created by the model to forecast the effectiveness of removing arsenic from soil is shown in Equation 2.

The normal probability plot of the data sets used for prediction was depicted in Figure 11. The normal probability plot confirms that the predicted value is very close to the experimental data, with residual errors ranging from +4 to -4. For observations 3 and 2, the maximum residual error was +3.64 and -3.64, respectively. Observation 1, 7 and 11 showed nil residual error indicates the perfect match of the experimental and the predicted values. So totally three observations were performed with zero residual errors.

$$\%Removal = -31.80 + 0.91A + 3.36B + 232.4C - 0.005A^2 - 2.71B^2$$
$$-826C^2 + 0.16AB + 0.55AC + 48BC \tag{2}$$

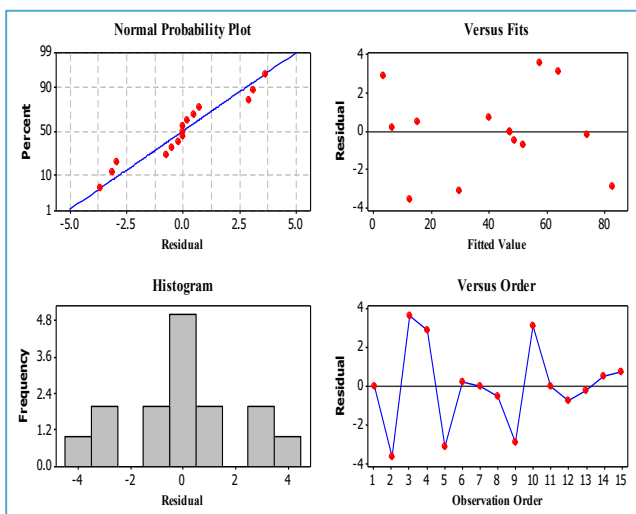were, A Time (hours); B – Distance (x/L); C- Current (A).

Figure 11 Normal probability plot

3.6. Main effect plot and interaction plot

Figures 12 (a) & (b) depicted the main effect and interaction plots for various variables. Figure 12 a show that increasing time, distance, and current increased mean removal efficiency. A mean removal efficiency of 9.02% was obtained after 20 hours, and a mean removal efficiency of 65.83% was obtained after 100 hours. Similarly, at a distance of 0.1, a mean removal efficiency of 36% was observed, and when distance was increased to 0.9, the mean removal efficiency increased to 47%. Furthermore, when the current was increased from 0.050

to 0.1 A, the mean removal efficiency increased from 30 to 53% respectively. Figure 12 b depicted the interaction plot of various variables. According to the interaction plot, a mean removal efficiency of 73.9% wasobtained after 100 hours and at a distance of 0.9 (x/L). Similarly, at a time interval of 100 hours and a current of 0.1 A, a maximum removal efficiency of 80.07% was obtained. The interaction plot confirmed that removal efficiency was always highest for the longest time interval, distance, and current.
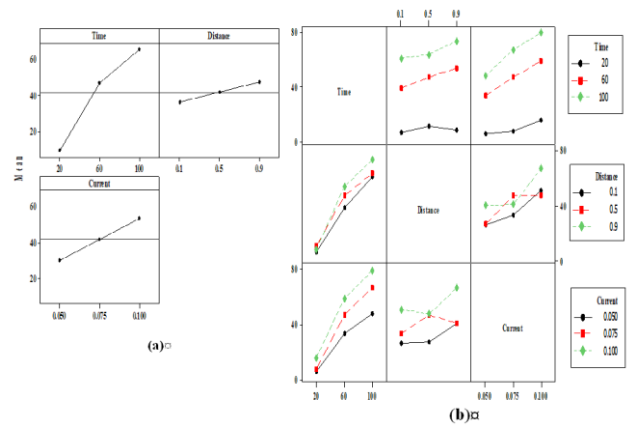

Figure 12 (a) & (b) Main Effect Plot &Interaction plot for the removal efficiency

3.7. Surface and contour plots

Figures 13 (a), (b) & (c) depicts the contour plots. The contour plot, which is based on two-dimensional interactions, is used to determine the same removal efficiency obtained among two different variables. The contour plot clearly demonstrated that the maximum mean removal efficiency was obtained when time was kept constant at 100, current was kept constant at 0.1 A, and distance was kept constant at 0.9 (x/L). 13 a show that a maximum removal efficiency of more than 80% was obtained when the current density was around 1 A and the distance was 0.9 (x/L). When the current density was kept between 0.09 and 0.05 A and the distance between 0.1 and 0.9, the removal efficiency was 60-80%. Figure 13 b also showed that the maximum removal efficiency was obtained at various combinations of current and distance. Higher current and lower distance resulted in removal efficiency of 60-80, while intermediate current and distance resulted in removal efficiency of 60-80%. Surface plot is a three-dimensional interaction between two independent variable (x and y) and one response (Removal Efficiency). The surface plot of Removal Efficiency vs. Distance and Time is shown in Figure 13. According to the results, increased distance and time resulted in the best removal efficiency. Initially, removal efficiency was very low at lower time for all distances (Ryu *et al.*, 2017). The removal efficiency is highly dependent on time. However, the removal efficiency, which is related to distance, has little impact. The results showed that even when the distance was kept constant at 0.1 (x/L), the removal efficiency was close to 78% over a 100-hour period. When the distances were increased from 0.1 to 0.9 (x/L), the removal efficiency was close to 80% over a 100-hour

period. So, based on the surface plot, it is clear that time is one of the most important influencing parameters when compared to all other parameters.

3.8. Response optimizer

Response optimizer is used to maximize the target (Removal of Arsenic). The desirability is maintained as 1. Response optimizer plot predicted that the maximum removal efficiency of 91.27% can be attained at an operating conditions of Time 100 hours, distance of 0.9 (x/L) and current of 0.1 A. To validate the response plot batch experiments were conducted at these operating conditions for three maximum sets. The batch results obtained a maximum removal efficiency of 85.12 %. The maximum removal efficiency of arsenic in actual experimental trails was obtained as 80.07%. Response plot has enhanced the removal efficiency by 5.05%. Figure 14 illustrated the response probability plot for the removal of arsenic.
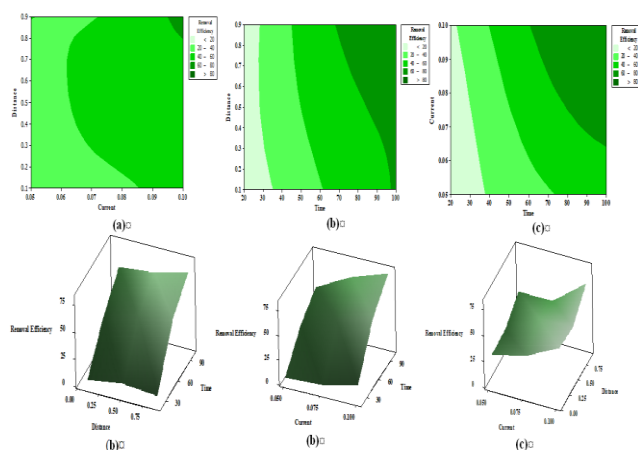

Figure 13 (a), (b) & (c) Contour and Surface plots of removal efficiency vs distance and time
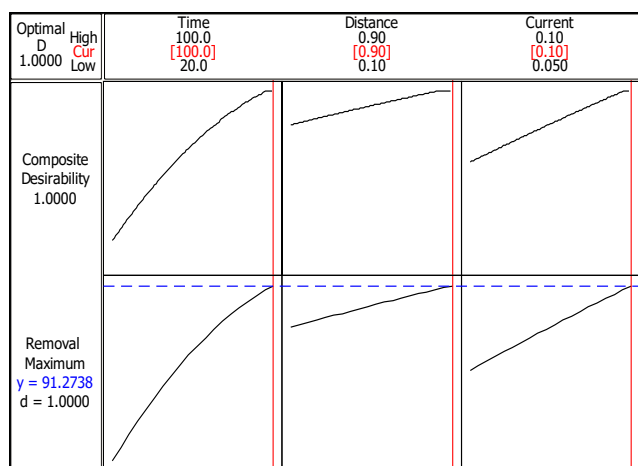

Figure 14 Response optimizer for maximizing the target

4.   Conclusion

The electro kinetic process was evaluated by six tests to determine the removal efficiency of arsenic. For the two different kinds of soils used, namely the alluvial and red soil one control trial and two enhanced trials were conducted by varying electrolytes in each test. The sodium hydroxide

solution (0.1N) as catholyte is most effective in the extraction of arsenic species out of the red soil. The trends in the distribution of residual arsenic concentrations were found significantly distinct in red soil compared with alluvial soil. In the case of alluvial soil, potassium phosphate plays a significant role in arsenic removal efficiency. The anion exchange of arsenic with phosphate ions initiates the extraction. Accordingly, test 2 for alluvial soil and test 6 for red soil had the lowest residual quantities of arsenic pollutants.Response surface method was used to predict the removal efficiency of arsenic from contaminated soil. The electrodes produce hydrogen and hydroxyl ions, which change the pH of the system and cause the soil's cations and anions to move about. The key benefits of electrokinetic remediation were its adaptability to all soil types with only minor modifications to the electrodes and their placement, enhancing agents, and the ability to remediate toxins on-site.

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