Potential Electrokinetic Remediation Technologies of Laboratory Scale into Field Application- Methodology Overview

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Abstract. Heavy metal in soil possesses high contribution towards soil contamination which causes to unbalance ecosystem. There are many ways and procedures to make the electrokinetic remediation (EKR) method to be efficient, effective, and potential as a low cost soil treatment. Electrode compartment for electrolyte is expected to treat the contaminated soil through electromigration and enhance metal ions movement. The electrokinetic is applicable for many approaches such as electrokinetic remediation (EKR), electrokinetic stabilization (EKS), electrokinetic bioremediation and many more. This paper presents a critical review on comparison of laboratory scale between EKR, EKS and EK bioremediation treatment by removing the heavy metal contaminants. It is expected to propose one framework of contaminated soil mapping. Electrical Resistivity Method (ERM) is one of famous indirect geophysical tools for surface mapping and subsurface profiling. Hence, ERM is used to mapping the migration of heavy metal ions by electrokinetic.

1. Introduction
Contaminated soil is a tremendously global issue along the rapidly industrialization. In Malaysia, contamination has risen due to ex-mining sites, industrial activities, urbanization activities, disposal of municipal solid waste (MSW) activities, petrol station, former railway yards, abandoned rubber factories, landfill, industrial sites, agriculture waste and sites with underground storage tanks [1,2]. Currently, government is cooperating with engineers and researchers to minimize the adverse impact of contaminated soil due to 80% of hazardous wastes from the industries which generally affect the physical and mental development of human even at lowest level of exposure [3, 4]. Therefore, contaminated soil needs urgent solution where there are several remediation methods that have been applied. The remediation process is defined as any actions taken to eliminate, reduce, control or mitigate the risk resulting from contamination of the soil and/or groundwater media [5]. Therefore, remediation actions can be taken to reduce or mitigate the human health and also ecological risk posed by subsurface contamination which include data collection for planning, remediate design, remediation implementation and post remediation evaluation. Heavy metal exists in soil has become a great concern in ecological cycle that has potential impact and may harm the environment and human health also high risk for safe groundwater and surface water supplies [6, 7]. Electrokinetic remediation (EKR) is a potential technology to fulfill cost beneficially soil remediation. There are so many EKR laboratory scales that have operated successfully and have used specific homogenous soils spiked with single contaminant converge strong experimentation, mechanism and theoretical aspect to commercialize EKR. The academician and government recognized development potential of EKR as field scale, effective, efficient, non-selective remediation technology [8, 9].

2. Electrokinetic remediation (EKR) laboratory scale
Generally, electrokinetic remediation (EKR) is a high demand treatment for heavy metal soil contaminated removal. The application of a direct electric current to soil results in several changes, such as moisture content, pH, redox potential and electrolyte concentration, in the soil medium [10, 11].
Unfortunately, these studies do not investigate in detailed chemical specification of the contaminants or how the contaminants are held [10]. Figure 1, 2, 3, and 4 illustrate electrokinetic remediation (EKR) laboratory set up it is discussed elaborately in Table 1. Bioremediation is one of electrokinetic fields that applies the current to remove the soil. Figure 5 illustrates the schematic diagram where pseudomonas putida (bacteria) rapidly remove contamination through electrokinetic process. Hence, electokinetic principles being extended as chemical stabilization for contaminated soil which is Electrokinetic Stabilization (EKS). Thus, comparison of methodologies of the EKR treatment, and the parameters of EKR are current, voltage drop, pH value, electrolyte concentration, ionic concentration, and time duration [4, 10, 11, 12, 13, 16] influence the migration of heavy metal toward anode and cathode based on its ionic charged.

Table 1. Comparison of electrokinetic process methodology.

| Methodology | Findings | Ref. |
|-------------|----------|-----|
| The reactor consists of electrokinetic cell, two compartments, two electrode reservoirs, power sources, and a multimeter. The process is controlled by valve and separated by graphite and porous stone (made with aluminum oxide bonded with glass). Figure 1 illustrates the electrokinetic set up which is made by plexiglass with dimension 19.1 cm in length, 6.2 cm of inner diameter, and 3.8 cm of inner diameter (reservoir). | • The electrokinetic treatment depends on conductivity of the soil across soil specimen. The higher concentration of ionic species presents in pore fluid, the higher current passing through the soil. In this study, the current may vary because the voltage difference was kept constant between the electrodes. • Overall, this study proved that parameter such as current, electroosmotic flow, pH, and contaminant migration enhance the electrokinetic process and the treatment duration. | [10] |
| Heavy metals used are copper, chromium, lead, and zinc. Total time for experiment being conducted from initial (0 hours) until 40 hours (8 hours per day for 5 consecutive days). The set-up of sewage treatment is illustrated in Figure 2. The electrochemical cell was constructed in acrylic with dimension (10 x 25.5 x 5.5 cm) where 100 g sample of sludge was maintained between the electrodes. The electrochemical cell was separated by anode (two graphite rods) and stainless steel as cathode (23 cm x 5.5 cm x 0.15 cm). The distance between anode and cathode was kept constant at 6 cm. | • The electrokinetic process successful in removing metal from the sewage treatment station. • After 40 hours, the experiment considered average an electrolyte flow rate of 1.34 L.h^{-1} at 20 V. • The resulted shows that percentage removal for all metals monitored was over 50%. From the observation shows that the highest removal efficiency is lead (72.49%) and the lowest is chromium (54.87%). | [12] |
| The electrokinetic stabilization (EKS) treatment was designed into test rig is shown in Figure 3. It was made by using transparent acrylic plate with dimension of 420 mm, 170 mm and 358 mm depth, width and length respectively. Hence, the EKS test rig had been comprised of three compartments. A constant voltage gradient (50 V/m) was applied to the soil sample (middle/main compartment with dimension of 278 mm depth, 165 mm width and 413 mm length). | • The experiment being conducted in 21 days where as first days (1, 2, 4, 6, 8 hours) then continued seconds days onward current value in every 24 hours. • The EKS was succeed under 14 V current applied may affected by the physicochemical characteristics of soil, and pH of soil yet important in assessing the electromigration and electroosmosis process. | [13] |
| Direct current 50 V was applied across bioremediation testing at anode and cathode for 5 days. The set-up of bioremediation is illustrated in Figure 4. This method testing was used XRF test and bacteria counting to verify the effectiveness. | • The result shows slight difference between before and after treatment with or without using bacteria since mobility of heavy metals increased with decreament in soil pH. • The results of zinc and bacteria count proved that electro-bioremediation can remediate over 89% contaminated soil. | [4] |
Electrokinetic process is most applicable for remediation of contaminated clayey soil which have low conductivity [13]. The efficiency of the principle enhances by electrolyte and stabilization agents that summarized in Table 2 below accordingly research in figure 1, 2, 3, 4.

**Figure 1.** Schematic of electro-kinetic reactor [10].

**Figure 2.** Schematic diagram of electro-remediation assay [12].
Table 2. Types of Electrolyte/Stabilized Agents.

| Type of Electrolyte/Stabilized Agents | References |
|--------------------------------------|------------|
| Deionized water (DI)                 | Figure 1 [10] |
| Nitric acid (HNO₃) – to control pH value |           |
| 0.025 mol.L⁻¹ 10L Sodium Chloride (NaCl) | Figure 2 [12] |
| 50 L Electro-Remediation Effluent    |            |
| 0.1 M calcium chloride (CaCl₂) – anode | Figure 3 [13] |
| 0.1 M sodium silicate (NaSiO₃)/distilled water - cathode |       |
| Pseudomonas putida – anode           | Figure 4 [4] |
| Distilled water - cathode            |            |
| 0.04 M of citric acid in local groundwater | Figure 5 [16] |
| 0.1 M of extractant as facilitating agent which is: |       |
| Sulfuric acid                        |            |
| Organic acid (such as EDTA, acetic and citric acid) |      |
| Deionized water (DI)                 | [11]       |

Electrokinetic remediation uses an electrical current to mineralize organic compounds, and to mobilize and remove metal contaminants from soils or sediments. The technique consists of the application of an electrical field gradient between electrodes for the extraction and migration of contaminants by electrokinetic transport mechanisms. This electric field generates transport processes of ions and pore fluids and electrically charged particles, promoting the extraction of contaminants [12,13]. Hence, electrokinetic can be simplified as a process that separates and extracts organic, inorganic, radioactive contaminants, and variety of metallic and organic contaminants under the influence of an applied electrical field [14] – [16].

Electrokinetic Stabilization (EKS) is one of enhancements by using non-toxic chemical stabilization by using lime or Calcium Chloride (CaCl₂). The EKS is the most appropriate method for soft clay since it is categorized as soft consistency soil. Based on Figure 3, it shows that schematic diagram of EKS is comprised into three compartments where soil specimen was placed into main compartment and other two compartments to supply chemical stabilizer into the sample [13].

Figure 3. Schematic diagram of EKS test rig [13].
3. **Field Application of electrokinetic remediation (EKR)**

According to Zhou et al. [17], the pilot-scale experiment was conducted in rectangle box in dimension of (1.2 x 0.8 x 1.0) meter length, width and height, respectively. The soil sample about 700 kg was spiked with 18 g CuSO$_4$.5H$_2$O per 5 kg soil in solution form and cultivated at room temperature for 2 weeks. Four electrode cylindrical stainless steels (75 cm length in diameter 6 cm) were used. Therefore, a constant of 80 V direct applied current across soil box successful removed the Cu-contaminated which is about 76% in 140 days of treatment. In conjunction, figure 5 illustrated field application of electrokinetic remediation (EKR) for lined treatment cell where filled by 2.4 m$^3$ contaminated soil being spiked. The treatment was successful in 60 days and every 10 until 14 days needs to maintain the soil moisture/hydration [18]. Therefore, 12 V of battery will be recharged every 4 days. Schematic diagram shows that 10 electrodes (70 cm length with 20 mm diameter) were arranged in five rows with spacing 1.5 m between anode and cathode. Hence, the field scale experiment needs analytical technique employed to trace element and actinide mobilization and redistribution by using portable X-ray Fluorescence to access elemental composition of soil samples, gamma spectroscopy, gross alpha beta analysis, and radiochemical analysis [19].
Electrode design is an important element in EKR to enhance the migration of subsurface contaminant under the influence of an electric field via important mechanisms which are electrolysis, electromigration, electrophoresis, and electro-osmosis [20] - [24]. Hence, transporting the migration of ionic species towards oppositely charged electrode. The electrode compartment aims to place the electrolyte based on the research objective as shown in Table 2. As shown in Figure 6 below the electrode compartment for electrolyte in dimension (34 x 40 x 40) cm with diameter of steel plate 0.3 cm was proposed for this research. Therefore, the electrode compartment is expected to become anode and cathode for the treatment across 400 cm contaminated soil which is illustrated as schematic diagram in Figure 7.

Figure 5. Lined treatment cell used for field scale [18].

Figure 6. Electrode compartment for electrolyte.

Figure 7. Schematic Diagram of propose field work EKR.

4. Electrical Resistivity Method (ERM) mapping the contaminated soil
Geophysical methods are spread widely in studying the earth such as electrical resistivity, seismic, gravity, magnetic, gravity, geology, and archeological studies. However, electrical resistivity method (ERM) non-destructive and green applied comply in maintaining the sustainable needs, cost effective, time and full data coverage [25]. Furthermore, electrical resistivity method (ERM) is one of alternative
geophysics tools that high in industry demands especially in subsurface mapping, leachate mapping [26], bedrock mapping [27], and groundwater monitoring [28].

Wenner array [25, 28, 29] and Schlumberger array [25, 30] are default protocols for horizontal and vertical resolution respectively as illustrated in schematic diagram of Figure 8. Preliminary studies were conducted in Research Centre for Soft Soil, RECESS to verify the small electrode in dimension 16.3 cm in length and diameter 0.3 cm as displayed in Figure 9 below which is successive to provide strata mapping with spacing 0.1 m (since the minimum default of Terrameter electrode spacing is 0.1 m) as shown in Figure 10 below. Moreover, this dimension evidently agreed with studies by Abidin et al. [29] were using small steel electrodes with 6 inches (15 cm) in length and diameter 2 mm to mapping the embankment with spacing 0.05 m (by calculation).

![Figure 8. Wenner (left side) and Schlumberger (right side) electrode array arrangement [25].](image)

![Figure 9. Electrode dimension for contaminated soil mapping.](image)

![Figure 10. Soil mapping RECESS clay with 0.1 m spacing.](image)

The preliminary study shows that future work is expected to be done by combining the electrokinetic remediation treatment as shown in Figure 7 with proposed electrode displayed in Figure 6. Hence, the
small electrode in Figure 9 is expected to mapping the heavy metal soil contaminant before and after EKR treatment with immolization approach while mapping the migration of heavy metal ionic species inside the contaminated soil.

5. Conclusion
Electrokinetic remediation (EKR) is a non-destructive method, cost effective, green application for post-treatment for EKR since this alternative geophysical tool is applicable for subsurface strata profiling which can be extended to provide data coverage for contaminated soil mapping. Future work for this study is expected to verify EKR treatment time by considering their parameters and variables for the research. To conclude, author expects to combine EKR and ERM as an alternative approach in solving the environment issues due to heavy metal contamination towards sustainable development. The critical review shows that heavy metal contaminated soil can be removed about at least 50% and above after treatment. Hence, electrical resistivity method (ERM) is applicable to verify the effectiveness of EKR also mapping the migration of heavy metal ions.

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