IOP Conf. Series: Materials Science and Engineering **226** (2017) 012062 doi:10.1088/1757-899X/226/1/012062

The Use of Electrical Resistivity Method to Mapping The Migration of Heavy Metals by Electrokinetic

A T S Azhar[1*], S A Ayuni[1], A M Ezree[1], Z M Nizam[1], M Aziman[1], Z A M Hazreek[1], M S Norshuhaila[2] and E Zaidi[3]

[1]Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat Johor, MALAYSIA
[2]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat Johor, MALAYSIA
[3]Faculty of Science, Technology and Human Development, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat Johor, MALAYSIA

Corresponding author: saifulazhar870@gmail.com

Abstract. The presence of heavy metals contamination in soil environment highly needs innovative remediation. Basically, this contamination was resulted from ex-mining sites, motor workshop, petrol station, landfill and industrial sites. Therefore, soil treatment is very important due to metal ions are characterized as non-biodegradable material that may be harmful to ecological system, food chain, human health and groundwater sources. There are various techniques that have been proposed to eliminate the heavy metal contamination from the soil such as bioremediation, phytoremediation, electrokinetic remediation, solidification and stabilization. The selection of treatment needs to fulfill some criteria such as cost-effective, easy to apply, green approach and high remediation efficiency. Electrokinetic remediation technique (EKR) offers those solutions in certain area where other methods are impractical. While, electrical resistivity method offers an alternative geophysical technique for soil subsurface profiling to mapping the heavy metals migration by the influece of electrical gradient. Consequently, this paper presents an overview of the use of EKR to treat contaminated soil by using ERM method to verify their effectiveness to remove heavy metals.

1. Introduction

Generally, our environment consists of various medium such as air, water and land that needs urgent conservation due to the continuous contamination from urban development. In fact, this medium is considered as highly potential exposed easily to the contamination process [1]. Environmental pollution can be defined as release of any contaminated substances to the environment freely without treatment which is very harmful to the people and any other living organisms on this planet [2, 3]. Environmental contamination in soil, groundwater resources and air pollution are serious issues and need urgent mitigation. In order to achieve a sustainable ecosystem, the effort to reduce the soil contamination nowadays attracts serious attention by worldwide researchers since soil is an important element that contains minerals for plants and other living things. In Malaysia, contaminated lands were found at ex-mining sites, motor workshop, petrol station, oil depots, former railway yards, bus depots, abandoned rubber factories, landfill, industrial sites and the sites attached with underground storage tanks [4]. Heavy metal contaminated soil is tremendously an important problem to be solved properly by concerning the sustainability ecosystem in this world. In facts, heavy metal is also considered as an external substance that has potential to give negative impact to the human brain. The presence of heavy metal in soils shows a very significant environmental hazard, and quite difficult to remediate [5]. This may due to metals occur naturally and known as toxic to humans and animals if presence in abundance [6]. For instance, the most common non-biodegradable heavy metal found at contaminated sites are lead (Pb), Chromium (Cr), Arsenic (As), Zinc (Zn), Cadmium (Cd), Copper (Cu), Mercury (Hg) and Nickel (Ni) [7-8]. Therefore, this paper aims to discuss on the electrical resistivity method to mapping remediation of heavy metal contaminated soil and simultaneously, verify the electrokinetic remediation efficiency.

2. Electrokinetic Remediation (EKR)

Electrokinetic is one of the typical developed methods for removal of contaminated soils in geoenvironmental engineering. The Electrokinetic Remediation (EKR) is a technique which are cost effective, easy to install, operates less noise-pollution, shorter treatment duration and applicables for both in-situ and ex-situ [9]. In fact, this EKR is using immobilization approach compared with extraction approach identified advantage in term of cost effective and environmental friendly [10]. However, EKR is comparatively a new method that most of researchers are still working to improve it to be more sustainable and cost-effective. This method has successfully reduced more than 90% of mobile and weakly bond fraction of heavy metal under sequential attraction [11]. In order to achieve high efficiency of EKR method in contaminated soils, the soil samples must achieve certain high amount of heavy metal ions. This is to ensure that the entire process successfully dissolved and separated the heavy metal from the soil. By contrast, EKR is less effective if the concentration of heavy metal is lower. Currently, EKR is limited to the artificially remediation contaminated soil in the laboratory [12]. However, this method can be expanded and integrated with various fields such as highway structure and slope stabilization. Beside that electrokinetic remediation (EKR) is new remediation mainly applying voltage at the two sides of the soil to form electric gradient [1] Basically, EKR is a process of involving in the movement of electron through chemical reaction of electrolysis, electroosmosis, electrophoresis, and electromigration.

2.1 Electrolysis

Electrolysis is defined as applying a direct current at the electrodes to promote electron transfer of ionic species towards the electrodes of opposite charge through the electrolysis of water. During application of electricity to soil, water at the electrode sites as well as in the soil pores undergoes electrolysis, dissociating into its components, H^+ and OH^-. Electrolytic migration is the migration of ionic species present in the pore fluid as well as the migration of H^+ (produced at anode) and OH^- (produced at cathode) toward opposite electrode [13].

2.2 Electroosmosis

Electroosmosis is defined as the movement of liquid relative to some stationary charged surfaces of electrode [14]. This process refers to the movement of water molecule in the electric field condition [15]. This process produces a rapid flow of water in low permeability of soils and probably contributes significantly to the decontamination process in soil especially clay soils [13]. In fine grained soils, these charged surfaces are provided mainly by the clay mineral with diffuse double layers around their negatively charged surfaces. If an electrical field applied tangentially along the charged surface, it will exert a force on the charges of the diffuse layer. If the force of the applied electrical field exceeds the electrostatic attraction of the ions to the surface, the ions move along to the field and drags the water by viscous interaction through the pores towards the electrodes under electroosmotic velocities of several centimeters per day have been achieved by applying electric gradients of 100 V/m [13].

2.3 Electrophoresis

Electrophoresis is a movement of charged particles relative to a stationary fluid under the influence of an electrical field. This process produces migration of charged colloids in a soil liquid mixture. Electrophoresis may less important for the compact system since the solid phase restrained from the movement unless if the migration colloids have chemical species of interest that adsorb on them [13]. The process involves charged particles are in distinct size, electrophoresis can only take part if the pore sizes are large enough for the particle which compared to fine grained soils. Therefore, electrophoresis can be neglected in the fine-grained characterize soils [14].

2.4 Electromigration

Electromigration is defined as the mass transfer of charge ions and molecules which are dissolve in the pore fluid of a soil when an electrical field applied to the soil. The process involves anions are to move toward the anode, and cations are moved towards the cathode. The migration velocity is proportional to the ionic charge, the local electrical field, and the ion mobility. In fine grained soils, transportion of velocities by electro-migration are 5-40 times much higher than those transportion of velocities by electro-osmosis. Meanwhile, coarse-grained characterized soils, the electromigration dominates clearly over lower content of charged surfaces, and electroosmosis [14].

3. Electrical Resistivity Method

Soil resistivity is an electrical resistance (in ohm per unit length) of a column of the soil (unit area of cross section) [16]. The purpose of electrical surveys in soils is to determine the specific resistance of the soil and subsurface resistivity distribution through measurements on the ground surface for physical mapping [17,18]. Soil resistivity is determined largely by the content of its electrolyte which consists of moisture content, minerals, temperature and the dissolved salt which have a great influence on the soil resistivity [19,20]. High composition of fine-grained soil such as clay and silt may produce low permeable soil which cause water retention and high in moisture content [21]. It is necessary to identify the resistivity value at the planning stage as it may give an indication for required electrode should be. When selecting the test technique for soil resistivity, a few factors such as maximum probe depths, length of cables requires, efficiency of the measuring technique, cost and ease of interpretation of the data need to be considered wisely. The resistivity value shows in Table 1 below indicates the soil type by referring to resistivity values in term of minimum, mean and maximum. Meanwhile, Resistivity Imaging (RI) uses electrical resistivity method to provide useful information such as degree of saturation, clay content, pore water and mineralogical contents [22]. For instance, RI is used on a municipal solid waste (MSW) landfill liner in which reported that the degree saturation of soil varies to the soil resistivity.

Table 1. Soil types and Resistivity Values [19].

Soil Type	**Resistivity (Ohm-meter)**		
	Minimum	**Mean**	**Maximum**
Clay	5	27.2	60
Sand/Clay	6.28	215.0	346.83
Limestone	36.4	50.2	95.8
Sand	50	270	476.58
Laterite	961.3	1200	1528.7
Rock	1557	2500	19,012.92

Resistivity measurements are also the indicator to the relative ability of a medium to carry the electrical currents. When a metallic structure immersed in a conductive medium, the ability of the medium to carry the current may be influenced by the magnitude of galvanic currents and cathodic protection currents. The degree of electrode polarization will also affect the size of such currents. The operational process of electrical resistivity method involves of field measurement, data processing, interpretation, and conclusion always championed by the physicist and expertise [23]. In addition, the application of electrical resistivity method also gives high confidence level to engineers who often bemused by the lack of clarity of result and justification produced by geophysicist. This approach was discussed by Abidin et. al. [23]. Table 2 presents the summarization of comparison between conventional method and electrical resistivity method in soil contamination.

There are few studies on the field measurement for resistivity value using specific method and the findings are summarized as in Table 3. Based on Table 3, ABEM Terrameter SAS 4000 provide data logger in which analyzed using software RES2Dinv. This method widely used in industry and still need improvement. The procedure for field measurement depends on the area and depth of the location site. The examples of electrodes protocol that are commonly used are Wenner array (horizontal resolution) and Schlumberger array (vertical resolution). On the other hands, Table 3 also shows the summarization of using electrical resistivity method for soil identification and verification of Electrical Resistivity Value (ERV). Meanwhile, default method for Wenner array and Schlumberger array using 41 of electrode connected by 42 of jumper cables [21&23].

Table 2. Comparison between conventional method and electrical resistivity method.

Conventional Method	**Electrical Resistivity Method**
• Provides information at particular drilling (ID information) point. • Destructive method (Boreholes or soil samplings) • Needs more manpower. • Lacks of application for difficult accessibility situation.	• Provides large data coverage (2D image). • Non destructive method • Provides a continuous image of the subsurface profile. • Requires less manpower. • Data processing and result have become quite easy. • Suitable as alternative tool for subsurface site investigation.

Table 3. Summarization of methods from previous researchers.

Methods (Equipment)	Findings	References
This study used ABEM SAS 4000 by using Schlumberger array which equipped by 2 land cable, 41 num. of electrode and 42 num. of jumper cable. The measurement applicable at spacing 0.05meter (50mm) which located in Kuala Kangsar and Lenggong, Perak.	ERV of gravelly SAND (278Ωm & 285Ωm) was slightly higher than silty SAND (223 Ωm & 199 Ωm) due to uncertainties nature of soil. The result in range of 10-800 Ωm for sand and 100 – 250 Ωm for wet silty sand. The findings from this paper proved that this method was able to map different type of soils thus contributed in assisting geotechnical engineer for field soil identification.	[21]
Performed via fieldwork laboratory work and data processing. Construction of embankment model using lateric soil in loose condition by using ABEM SAS 4000. Dimension is as follows; 3m(L) x 1m(W) x 0.3048 m(H), slope = <45^0. The fieldwork setting used Wenner array protocol with the spacing, 0.05m along the line for 41 of electrode which connected by 42 jumper cables	Soil Basic Physical Properties is very important to verify ERV which are: density(ρ), moisture content, (*w*), and particle size distribution (d).	[23]
Groundwater monitoring using equipment EC300 YSI and sample collected using bailer. ABEM Terrameter, SAS4000 combined the ES10-64 electrode selector was used. The Wenner array was chosen for the resistivity transverse for a dense near-surface cover of resistivity data. This method also provides (as horizontal structures) good vertical resolution and clear image of groundwater, saltwater intrusion and sand clay boundaries.	Resistivity Survey involved finding of correlation between sub-surface earth resistivity and geochemical data from monitoring well. The groundwater samples, the anion analysis was chloride (Cl-), sulphate (SO42-), nitrate (NO3-) and bromide(Br-), on Dionex ion chromatography model ICS2000. While, the cation analysis were sodium (Na), calcium (Ca), magnesium (Mg), potassium (K) and iron (Fe), on Perkin Elmer inductive coupled plasma optical emission spectrometer model Optima 3300RL	[24]
This study was performed using ABEM Terrameter LS with configuration based on Schlumberger array and Wenner array. The survey used four resistivity land cables, 61 electrodes and 64 jumper cables with 5.0 m spacing along 200 m length.	Schlumberger array produced higher electrical resistivity value (ERV) compared to the Wenner array. The electrical resistivity imaging (ERI) shows that residual soil zone (10-600 Ωm) and shale zone (20-2000 Ωm) effectively applied for acidic barren slope assessment.	[25]

4. Conclusion

The application of electrical resistivity method is a well-known instrument that applicable to measure the electrical resistivity values with the help of computer software. This brief review found that the minimum distance for this instrument to work properly is about 0.1 meter. Therefore, an extensive laboratory scale for this works need to consider the length and the size of tank while the small field testing is proposed to be conducted on the ground for the next step of study. Interestingly, the electrical resistivity method is very useful and acts as an effective tool to mapping out the distribution of heavy metals which are migrated due to the application of EKR . In fact, this alternative technique is cost-effective technology, non-destructive method, easy monitoring and less time consumption as compared to other conventional methods in order to achieve the sustainable ecosystem towards urban development in the future.

Acknowledgement

This paper is fully supported by Universiti Tun Hussein Onn Fundametal Research Grant Scheme FRGS VOT1455. The author would like to thank the reviewers for their kindly comments and suggestions in this research.

References

[1] Tajudin S A A, Marto A, Azmi M A M, Madun A & Abidin M H Z, 2015 Utilization of sugarcane BagAsse ash for stabilization/solidification of lead-contaminated soils, Jurnal Teknologi 77(11) 119- 125

[2] Peter Attewell 1993 Ground Pollution: Environment, Geology, Engineering and Law. E&FN SPON. Pg. 5.

[3] Azhar, A.T.S., Nabila, A.T.A., Nurshuhaila, M.S., Zaidi, E., Azim, M.A.M., Farhana, S.M.S. (2016) Assessment and Comparison of Electrokinetic and Electrokinetic-bioremediation Techniques for Mercury Contaminated Soil *IOP Conference Series: Materials Science and Engineering*, 160 (1)

[4] Yang, Y C and Suhaimi 2016 Overview of Brownfields in Malaysia. *Jurutera Magazine*. Retrieved from dspace.unimap.edu.my (16-23)

[5] Dube A, Zbytniewski R, Kowalkowski T, Cukrowska E, Buszewski B. 2001 Adsorption and Migration of Heavy Metals in Soil. Polish Journal of Environmental Studies. Vol. 10, No. 1 1-10

[6] Auburn 2000 Heavy Metal Soils Contamination. United State Department of Agriculture. *Soil Quality Urban Technical Note*. 3(1-7).

[7] Raymond A W and Okiemen F E 2001 Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risk and Best Available Strategies for Remediation. *International Scholarly Research Network. ISRN Ecology.*

[8] Sruthy and Jayalekshmi 2014 Electrokinetic Remediation of Heavy Metal Contaminated Soil. International Journal of Structural and Civil Engineering Research.

[9] Mosavat N, Oh E and Chai G 2012 A Review of Electrokinetic Treatment Technique for Improving the Engineering Characteristics of Low Permeable Problematic Soil. Int. Journal of GEOMATE. Vol, 2. No. 2 (266-272).

[10] Tajudin S A A, Azmi M A M & Nabila A T A, 2016 Stabilization/Solidification Remediation Method for Contaminated Soil: A Review, IOP Conference Series: Materials Science and Engineering 136 1-6.

[11] Kim W S, Kim S O, Kim K W 2005 Enhanced Electrokinetic Extraction of Heavy Metals from Soils Assisted by ion Exchange Membrane Journal of Hazardous Materials B118 (Pg.93-102)

[12] Chaudhary N, Singh B, and Srivastava R K 2015 Electrokinetic Remediation of heavy metal contaminated soil: a short review. International Daily Journal. Discovery Publication. (Pg.6-11)

[13] Pamukcu S, and Wittle J K 1992 Electrokinetic Removal of Selected Heavy Metals from Soil. Environment Progress. Vol. 11, No. 3 (241-250)

[14] Bradl H A 2005 Heavy Metal in the Environment: Origin, Interaction and Remediation. Elsevier Academic Press. Interface Science and Technology. Vol6
[15] Cindy L and Leonard L P L 2014 Application of electro-kinetic in controlling heavy metals migration in sand: A feasibility study. UNIMAS e-Journal of Civil Engineering.
[16] British Standard Institution. Method of Test for soils for civil engineering purpose: Classification Tests. BS1377-2:1990.
[17] Loke 1999 Electrical Imaging Surveys for Environmental and Engineering Studies: A Practical guide to 2-D and 3-D surveys.
[18] Z A M Hazreek, M Aziman, A T S Azhar, W D Chitral, A Fauziah and S Rosli (2015) The Behaviour of Laboratory Soil Electrical Resistivity Value under Basic Soil Properties Influences, IOP Conference Series: Earth and Environmental Science, Vol 23, pp. 1-9.
[19] Adegboyega G 2011 Assessment of Soil Resistivity on Grounding of Electrical System: A Case study of North-East Zone, Nigeria. Journal of Academic and Applied Studies. (Pg. 28-38)
[20] Prabhakar C and Deshpande R A 2014 Evaluation of Soil Resistivity and Design of Grounding System for Hydroelectric Generating Station in a Hilly Terrain – A Case Study. International Conference on Advances in Energy Conversion Technology.
[21] Abidin M H Z, Saad R, Wijeyesekera D C, Ahmad F, Tajudin S A A, Madun A, Bakar I, 2015 Soil Identification using Field Electrical Resistivity Method. Journal of Physics: Conference Series 495. IOP Publishing.
[22] Kibria G and Hossain M S 2015 Investigation of degree of saturation in landfill liners using electrical resistivity imaging. Waste Management 39. Elsevier. (Pg.197-204)
[23] Abidin M H Z, Ahmad F, Wijeyesekera D C Saad R, 2014 The Influence of Basic Physical Properties of Soil on its Electrical Resistivity Value under Loose and Dense Condition. Journal of Physics: Conference Series 495. ScieTech. IOP Publishing.
[24] Baharuddin M F T, Taib S, Hashim R, Abidin M H Z, Rahman N I 2013 Assessment of seawater intrusion to the agricultural sustainability at the coastal area of Carey Island, Selangor, Malaysia. Arab Journal Geosciences. 6 (3909-3928)
[25] Hamzah U, Yaacup R, Samsudin A R, Ayub M S, 2006 Electrical imaging of the groundwater aquifer at Banting Selangor, Malaysia. Environmental Geology (1156-1162)
[26] Azhar A T S, Hazreek Z A M, Aziman M, Haimi D S, and Hafiz Z M, 2016 Acidic Barren Slope Profiling using Electrical Resistivity Imaging (ERI) at Ayer Hitam area Johor, Malaysia. Journal of Physics: Conference Series 710. IOP Publishing.