

Improved electrokinetic process for capturing heavy metals in contaminated soil

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, ROMINA GHOBADI declare that this thesis, is submitted in fulfilment of the requirements for the award of *PhD*, in the *School of Civil and Environmental Engineering/Faculty of Engineering and Information Technology* at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

This research is supported by the Australian Government Research Training Program.

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CONTENTS

TABLE OF CONTENTS

IMPROVED ELECTROKINETIC PROCESS FOR CAPTURING HEAVY METALS IN CONTAMINATED SOIL	i
CONTENTS.....	4
LIST OF FIGURES	9
LIST OF TABLES	12
LIST OF PUBLICATIONS	13
CHAPTER ONE: INTRODUCTION.....	18
1.1. Background.....	18
<i>1.1.1. Soil pollution.....</i>	<i>18</i>
<i>1.1.2. Adverse effects of heavy metals on environment.....</i>	<i>19</i>
<i>1.1.3. Removal technologies of heavy metals from soil</i>	<i>20</i>
<i>1.1.4. Removal of heavy metals by EK process.....</i>	<i>21</i>
1.2. Research Hypothesis.....	22
1.3. Research Objectives.....	24
1.4. Thesis Outline	25
CHAPTER TWO: LITERATURE REVIEW	28
2.1. Conventional soil remediation techniques	28
<i>2.1.1. Phytoremediation.....</i>	<i>28</i>
<i>2.1.2. Bioremediation.....</i>	<i>29</i>

2.1.3. <i>Soil flushing</i>	29
2.1.4. <i>Thermal</i>	30
2.1.5. <i>Permeable reactive barrier (PRB)</i>	30
2.2. Overview of EK soil remediation	31
2.3. Transport mechanism of EK process	35
2.4. Factors affecting EK technology.....	36
2.4.1. <i>Soil properties</i>	36
2.4.2. <i>Contaminant type</i>	37
2.4.3. <i>Electrode type</i>	38
2.4.4. <i>Electric voltage</i>	41
2.5. Enhancement techniques and integration with EK	42
2.5.1. <i>EK using enhancement agents</i>	42
2.5.2. <i>EK coupled with bioremediation</i>	44
2.5.3. <i>EK coupled with phytoremediation</i>	44
2.5.4. <i>EK coupled with PRB</i>	45
2.6. Conclusion and research gaps	47
CHAPTER THREE: MATERIALS AND METHODS.....	51
3.1. Materials	51
3.2. Methods.....	53
3.2.1. <i>Preparation of heavy metal-spiked kaolinite soil</i>	53
3.2.2. <i>Preparation of multi-heavy metals contaminated real soil</i>	53
3.2.3. <i>Preparation of RFM</i>	54

3.2.4. <i>EK reactor setup</i>	55
3.2.5. <i>Regeneration and reuse of RFM</i>	56
3.2.6. <i>Removal efficiency</i>	57
3.2.7. <i>Power consumption</i>	58
3.2.8. <i>Analytical methods</i>	58
CHAPTER FOUR: COPPER REMOVAL FROM CONTAMINATED SOIL THROUGH EK PROCESS WITH RFM	61
4.1. Introduction.....	61
4.2. Material and Methods	65
4.2.1. <i>Materials and soil preparation</i>	65
4.2.2. <i>EK test design</i>	66
4.3. Results and discussion	67
4.3.1. <i>Electrical current</i>	67
4.3.2. <i>Soil pH</i>	68
4.3.3. <i>Electrical conductivity of soil</i>	69
4.3.4. <i>Removal of copper from soil</i>	71
4.3.5. <i>Characterisation of RFMs</i>	74
4.3.6. <i>Performance of EK-RFM under constant current</i>	76
4.3.7. <i>Regeneration of RFM</i>	79
4.4. Conclusions.....	79
CHAPTER FIVE: ENHANCED COPPER REMOVAL FROM CONTAMINATED KAOLINITE SOIL BY EK PROCESS USING COMPOST RFM	81

5.1. Introduction.....	82
5.2. Material and Methods	86
5.2.1. <i>Materials, soil preparation and analysis</i>	86
5.2.2. <i>Experimental design</i>	87
5.3. Results and discussion	88
5.3.1. <i>Performance of EK-C in copper removal</i>	88
5.3.2. <i>Performance of EK-(BC+C) in copper removal</i>	95
5.3.3. <i>Characterization of compost RFM</i>	97
5.3.4. <i>Performance of EK-RFM under a constant current</i>	100
5.3.5. <i>Regeneration and reuse of compost RFM</i>	105
5.4. Conclusions.....	106
CHAPTER SIX: EFFECTIVE REMEDIATION OF HEAVY METALS IN CONTAMINATED SOIL BY EK TECHNOLOGY INCORPORATING RFM	109
6.1. Introduction.....	109
6.2. Methodology	115
6.3. Results and discussion	116
6.3.1. <i>Electric current and voltage</i>	116
6.3.2. <i>Soil pH</i>	118
6.3.3. <i>Removal of heavy metals from soil</i>	120
6.3.4. <i>Remediation mechanism for heavy metals</i>	127
6.3.5. <i>Electricity consumption analysis</i>	131
6.4. Conclusions.....	135

CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH	
.....	137
7.1. Conclusions.....	137
7.2. Research Significance and Contributions to the Field.....	139
7.3. Recommendations for Further Research.....	140
REFERENCES	142

LIST OF FIGURES

Figure 2.1. Concept of in-situ EK remediation of contaminants (Alshawabkeh et al., 1999).	33
Figure 3.1. (a) Schematic diagram of the EK apparatus; (b) front view of the EK apparatus.	56
Figure 4.1. (a) Change of electric current during the EK treatments (with a constant applied voltage); (b) pH of different soil sections (normalized distance from anode to cathode) after the EK operations; (c) EC of different soil sections (normalized distance from anode to cathode) after the EK operations.	70
Figure 4.2. (a): Copper concentration through the soil sections (from anode to cathode) after EK Operation; (b): Efficiency of copper removal through the soil sections.	73
Figure 4.3. SEM images and EDS of (a, b) activated carbon and (c, d) biochar after EK treatment.	75
Figure 4.4. Zeta potential of BC and AC before and after EK experiments.....	75
Figure 4.5. Fourier transform infrared (FTIR) spectra of (a) BC before and after EK treatment (EK-BC); (b) AC before and after EK treatment (EK-AC).	76
Figure 4.6. Residual copper concentration and pH of the soil through the soil sections from anode to cathode after EK-BC under constant current operation.	78
Figure 4.7. Energy consumption for the per unit volume soil for EK experiments.....	78
Figure 5.1. (a) Variation of electric current during seven days of EK operations under a constant voltage; (b) profiles of pH and electric conductivity in soil sections (from anode to cathode) after the experiments.....	92
Figure 5.2. (a) Residual copper and (b) efficiency of copper removal in soil sections S1-S5 after EK and EK-C experiments.	94

Figure 5.3. (a) Copper concentration, (b) removal efficiency of copper, and (c) pH profile across the soil sections at the end of EK treatment.....	96
Figure 5.4. (a) EDS analysis and spectrum of compost, (b) SEM image showing EDS analysis area, and (c) EDS map showing detection of copper (red). Scale bars: 20 μm	99
Figure 5.5. (a) Zeta potential of compost before and after EK operations; (b) FTIR spectra of compost and biochar before and after EK operations.	100
Figure 5.6. (a) Variation of voltage over time for EK-100%C and EK-(10%BC+90%C) treatments under a constant current; Copper concentration, pH and electric conductivity in soil sections after (b) EK-100%C and (c) EK-(10%BC+90%C) treatment under a constant current.	103
Figure 5.7. Comparison of total copper removal and associated power consumption per unit volume of soil during different EK treatments.	104
Figure 5.8. (a) Cu concentration and (b) Cu removal efficiency across the soil sections after the EK experiments coupled with the recycled compost RFM.	106
Figure 6.1. Changes of (a) electric current, and (b) electric potential during different EK operations.	118
Figure 6.2. Soil pH profile after different EK treatment.....	120
Figure 6.3. Residual heavy metals along the soil profiles from anode to cathode after EK operations.	125
Figure 6.4. Heavy metals removal efficiency across the soil after EK treatments.	127
Figure 6.5. EDS analysis of RFM (a) before and (b) after EK treatment, showing detection of different heavy metals.....	130
Figure 6.6. FTIR spectra of soil before and after EK operations.....	131

Figure 6.7. Total heavy metals removal and specific energy consumption during EK-RFM treatment of soil.	133
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LIST OF TABLES

Table 2.1. Summary of the main application challenges of conventional soil remediation techniques (Lima et al., 2017; O'Brien et al., 2018; Ren et al., 2014; Sturges et al., 1991; Yeung et al., 2010; Yeung and Gu, 2011).	34
Table 3.1. Chemical and physical properties of kaolinite clay soil.	52
Table 3.2. Key characteristics and heavy metal content of the natural soil before and after spiking.	52
Table 3.3. Physicochemical characteristics of RFMs.	55
Table 4.1. Summary of the experimental conditions.	67
Table 4.2. Mass balance and removal efficiency of copper in the EK experiments.	73
Table 5.1. Experimental condition of different EK experiments.	88
Table 5.2. Mass balance and total copper removal in the EK tests.	104
Table 6.1. Summary of EK experimental conditions for heavy metal removal in soil.	116
Table 6.2. Mass balance (%) and RFM adsorption efficiency (%) of heavy metals during different EK-RFM tests.	134
Table 7.1. Soil quality guidelines for zinc (Zn) from international jurisdictions (NEPC, 2011)	Error! Bookmark not defined.

LIST OF PUBLICATIONS

As the 1st author, I have published three peer-reviewed articles derived from this thesis:

Romina Ghobadi, Ali Altaee, John L. Zhou, Peter McLean, Sudesh Yadav “*Copper removal from contaminated soil through electrokinetic process with reactive filter media*” **Chemosphere**, 252 (2020): 126607.

Romina Ghobadi, Ali Altaee, John L. Zhou, Peter McLean, Namuun Ganbat, Donghao Li “*Enhanced copper removal from contaminated kaolinite soil by electrokinetic process using compost reactive filter media*”, **Journal of Hazardous Materials**, 402 (2021) 123891.

Romina Ghobadi, Ali Altaee, John L. Zhou, Erika Karbassiyazdi, Namuun Ganbat “*Effective remediation of heavy metals in contaminated soil by electrokinetic technology incorporating reactive filter media*”, **Science of the Total Environment**, 794 (2021) 148668.

In addition, I co-authored 2 peer-reviewed publications during PhD Study:

Sudesh Yadav, Ibrar Ibrar, Ali Altaee, Akshaya Kumar Samal, **Romina Ghobadi**, John Zhou “*Feasibility of brackish water and landfill leachate treatment by GO/ MoS₂-PVA composite membranes*”, **Science of the Total Environment** 745 (2020) 141088.

Namuun Ganbat, Ali Altaee, Uttam Kumar, Andrew Hursthouse, Sudesh Yadav, John Zhou, **Romina Ghobadi** “*Soil remediation techniques from organic and inorganic pollutants: review*”, **Journal of Environmental Management**. Under review.

ABSTRACT

Soil contamination is a worldwide problem affecting human health. Electrokinetic (EK) remediation is a promising electrochemical remediation technology for soil decontamination using low-intensity direct current and resulting in the mobilization of chemical contaminants through electromigration and electroosmosis. EK application in the heavy metals contaminated soil faces with a few obstacles such as high pH distribution and contaminants extraction from the zone near the cathode region. Therefore, this study focused on integrating the EK technique with different reactive filter media (RFM) of activated carbon (AC) and biochar (BC), for the first time, without adding chemicals to facilitate the removal of copper ions from the contaminated kaolinite soil. This study initially selected copper as the heavy metal contaminant due to many reports on soil contamination by copper ions. RFM serves as an adsorbent during the electroosmosis and electromigration processes to facilitate contaminants removal. The performance of these RFMs in the EK system has been examined to select the best in terms of EK performance, regeneration, and contaminant removal. Tests based on EK (control test), EK coupled with AC (EK-AC), and EK combined with BC (EK-BC) were performed under an electric potential of 10 V, and the overall removal efficiency of copper ions decreased as EK-BC > EK-AC > EK. The results show that 27% of copper in the soil was captured by BC, compared with only 10% by AC. Additional EK-BC test performed under a constant current (20.00 mA) revealed that the acid front swept across the soil, resulting in 70.6%-95% copper removal from soil section 4 to section 1 close to the anode region, with more copper accumulation in section 5. Similar to the EK-BC test under a fixed voltage, BC captured 26% of copper in the soil during EK-BC treatment under a constant current, although with higher energy consumption. Moreover, RFM was regenerated by flushing with an acid solution,

achieving 99.3% of the copper recovery in BC and 78.4% in AC. Although the permeability of AC-RFM was higher than that of BC-RFM, the copper contaminant was more easily leached out from the BC-RFM.

Another recyclable RFM called compost (C) was proposed for the first time in this study to be applied in the EK system for copper removal from contaminated kaolinite soil. The feasibility of regeneration of compost was also studied for its reuse. Similar to other RFM, compost placed near the cathode served as an environmentally friendly adsorbent to bind copper ions while buffering the advancement of the alkaline front in the soil. The total copper removal rate increased from 1.03% in EK to 45.65% in EK-C under an electric potential of 10 V. Further experiments conducted by using compost/biochar (C+BC) mixture RFM at different ratios showed total Cu removal efficiency decreasing as $EK-100\%C > EK-(10\%BC+90\%C) > EK-(20\%BC+80\%C) > EK-(30\%BC+70\%C) > EK$. The application of a constant electric current of 20.00 mA further enhanced copper removal to 84.09% in EK-100%C, although it did not show significant enhancement in EK-(BC+C). The compost RFM was regenerated by acid extraction and then reused twice, achieving a total removal of 74.11%. The findings demonstrated compost as a promising and reusable RFM for the efficient removal of copper in contaminated soil.

In addition, compost RFM was incorporated in the EK process for simultaneously treating multi-heavy metals contaminated real soil. Six EK operations were performed to investigate the performance of EK-RFM under different operating conditions such as the electric current, processing time, and the amount of the RFM. The electric current and treatment time demonstrated a significant impact on removing Zn, Cd, and Mn ions, while changing the amount of the RFM had an insignificant impact on heavy metals removal efficiency. The results showed that 51.6% to 72.1% removal of Zn, Cd, and Mn was achieved at 30.00 mA electric current and 14 days of operation. The energy consumption of the EK process was 0.17 kWh

kg⁻¹. The organic matter in the natural soil had a detrimental effect on the mobilization and migration of heavy metals such as Cu and Pb in soil. The results reported in this study should be useful in optimizing the design of the EK-RFM system and extending it to the field-scale applications.