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ADSORPTION, LEACHING AND BIOAVAILABILITY OF CADIMUM AND LEAD IN AQUEOUS SOLUTION AND CONTAMINATED SOILS AMENDED WITH MODIFIED BIOCHAR

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By

ALAA HASAN FAHMI

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DEDICATION

I dedicate this work to those who taught, motivated, and helped me throughout my study; to my parents;

Hasan Fhmi and Nahyia Salman, brothers& sisters.

It is also dedicated to my dearest wife; Hiba Abbas and my kids; Ban, Bashar, Mayar, & Baneen for their encouragements and patience toward achieving this goal.

Also, finally to my country Iraq

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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Faculty : Agriculture

Cadmium (Cd) and lead (Pb) are among the global priority pollutants and contaminations of these heavy metals cover a wide range of soils. Biochar has been proven to be a very good adsorbent of heavy metals. Reduction of its particle size may increase the sorption and removal of heavy metals from soils or aqueous solution. The present study investigated the effects of crushing oil palm empty fruit bunch biochar (EFBB) to different particle sizes on the adsorptive removal of Cd and Pb from aqueous solution, extractable, leaching and phytoavailability of Cd and Pb in contaminated soil. Three different particle sizes of EFBB were used in this study; coarse (C-EFBB) (>2 mm), medium (M-EFBB) – (0.25 – 0.5 mm) and fine (F-EFBB) (< 0.05 mm). The F-EFBB was also coated with Fe to produce an iron coated F-EFBB (ICF-EFBB). A commercially available activated carbon (AC) was also included in the study as a benchmark for the sorption properties of the modified biochars. All the adsorbents were characterized for their physico-chemical and morphological properties using standard methods. A batch equilibrium study was performed using 0.1 g of each adsorbent with 40 mL of solution containing 0 – 500 mg L^{-1} Cd and/or Pb. The isotherm data was fitted to Freundlich and Langmuir's sorption isotherm models. The C-EFBB and F-EFBB at three different rates (0%, 0.5% and 1%) were added to soils contaminated with Cd and/or Pb and the extractable, leaching and phytoavailability of these two metals were studied.

The results indicated that F-EFBB had the highest CEC, pH, and acidic functional groups among the adsorbents but the AC had the highest BET surface area. The scanning electron micrographs suggested that crushing the biochar exposed the micropores which were otherwise hidden in the inner structure of the larger particle size biochar. There was no evidence of macropores presence in the AC. Sorption

isotherm data of the all adsorbents for Cd in the single system were better fitted to the Langmuir than the Freundlich model, except for AC. However, the bisorbate system were better fitted to the Freundlich than the Langmuir model, except for ICF-EFBB. The sorption isotherms of all the adsorbents for Pb in the single and bisorbate system were better fitted to the Langmuir than the Freundlich model, except for AC in the bisorbate system. The Q_{max} values for Cd and Pb adsorption follow the order of ICF-EFBB > F-EFBB > M-EFBB > C-EFBB> AC in the single systems (55.87, 40.32, 19.34, 17.79 and 14.31 mg g^{-1} for Cd and 142.86, 103.09, 58.14, 54.95 and 50.51 mg g^{-1} for Pb, respectively). The same order was observed for Pb adsorption in bisorbate systems (126.58, 98.04, 51.02, 45.25 and 43.86 mg g^{-1}, respectively). The order of Q_{max} values for Cd adsorption in bisorbate systems exhibited the following order: F-EFBB > ICF-EFBB > M-EFBB > AC > C-EFBB (20.79, 17.86, 12.87, 6.25 and 5.59 mg g^{-1}, respectively). The adsorption of Pb was more preferable than Cd by all the adsorbents.

Application of EFBB to the soils contaminated with Cd and/or Pb significantly reduced the synthetic rainwater (SRW) extractable Cd and Pb. The lowest SRW extractable Cd and Pb was recorded by the contaminated soils applied with 1% F-EFBB. The lowest extractable values of Cd from Cd-soil and Cd+Pb-soil were 0 and 10.786 µg kg^{-1} in week 8, respectively. The lowest extractable values of Pb from Pb-soil and Cd+Pb-soil were 4.180 and 9.770 µg kg^{-1} in week 8, respectively. Similar results were obtained from the leaching study, which showed the effectiveness of the F-EFBB in reducing the leaching of Cd and Pb from the soils compared to the other adsorbents. The growth parameters of mustard plants grown in Cd- and Cd+Pb-soil treated with EFBBs were significantly better compared to the untreated soil (control). However, there was no significant difference in the growth parameters of mustard plants grown in Pb-soil treated with EFBBs compared to the control soil. There was also no significant effect of EFBB particle size on the growth parameters of the mustard plants grown on the contaminated soils. However, the application of 1% F-EFBB to the contaminated soils showed significantly lower Cd and Pb concentrations in the roots and shoots of the mustard plants as compared to the mustard plants grown on the untreated contaminated soil. The lower values of Cd in roots were 448.6 and 346 mg kg^{-1}, while, the lower values in shoots were 115.200 and 99 $mgkg^{-1}$ in contaminated soils Cd-soil and Cd+Pb-soil, respectively. For the lower Pb values in roots were 4196 and 1529.5 mg kg^{-1}, while, in shoots were 78.467 and 35.733 mg kg^{-1}, in contaminated soils Pb-soil and Cd+Pb-soil, respectively. This may be attributed to the reduction in bioavailable Cd and Pb in soils treated with F-EFBB. It can be concluded from this study that all the EFBBs, regardless of their particle size adsorbed Cd and Pb better than the commercial AC. Reducing the EFBB particle size improved its adsorption capacity as well as reduce the extractable and leaching of Cd and Pb from contaminated soils. Therefore, the EFBB can be an alternative to the much costlier AC as an adsorbent for Cd and Pb.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

JERAPAN, LARUTLESAP DAN KEDAPATANBIO Cd DAN Pb DALAM LARUTAN AKUEUS DAN TANAH TERCEMAR MENGGUNAKAN BIOCHAR YANG DIUBAH MENGGUNAKAN KAEDAH FIZIK DAN KIMIA

Oleh

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Kadmium (Cd) dan plumbum (Pb) adalah antara bahan cemar utama dunia dan pencemaran logam berat ini merangkumi pelbagai jenis tanah. Biochar telah dibuktikan sebagai penjerap logam berat yang sangat baik. Pengurangan saiz zarah biochar meningkatkan penjerapan dan penyingkiran logam berat dari tanah atau larutan berair. Kajian ini menyiasat kesan saiz zarah yang berbeza terhadap biochar dari tandan kosong kelapa sawit (EFBB) hancur dalam menyingkirkan Cd dan Pb dari larutan berair, boleh diekstrak, larutlesap dan kedapatan fito Cd dan Pb dalam tanah yang tercemar. Tiga saiz zarah EFBB digunakan dalam kajian ini; kasar (C-EFBB) (> 2 mm), sederhana (M-EFBB) - (0.25 - 0.5 mm) dan halus (F-EFBB) (<50 µm). EFBB juga disalut dengan Fe untuk menghasilkan F-EFBB bersalut ferum (ICF-EFBB). Karbon aktif komersial (AC) juga dimasukkan dalam kajian ini sebagai penanda aras bagi sifat-sifat penyerapan biochar yang telah diubahsuai. Sifat fizik-kimia dan morfologi semua penjerap dianalisis menggunakan kaedah piawai. Kajian keseimbangan berkumpulan dijalankan menggunakan 0.1 g setiap penjerap dengan larutan 40 mL yang mengandungi 0 - 500 mg L-1 Cd dan/atau Pb. Data isoterma dipadankan pada model isoterma jerapan Freundlich dan Langmuir. C-EFBB dan F-EFBB pada tiga kadar berbeza (0%, 0.5% dan 1%) telah ditambahkan pada tanah yang tercemar dengan Cd dan/atau Pb dan keboleh ekstrak, larutlesap dan kedapatan fito kedua-dua logam ini juga dikaji.

Keputusan menunjukkan bahawa F-EFBB mempunyai KPK, pH, dan kumpulan keasidan tertinggi di kalangan penjerap tetapi AC mempunyai keluasan permukaan BET tertinggi. Imbasan mikroskop elektron menunjukkan bahawa biochar yang dihancurkan membuka banyak liang-liang mikro yang tersembunyi di dalam struktur

dalaman biochar. Tiada bukti kehadiran liang makro pada AC ditemui. Data penjerapan isotermik semua penjerap untuk Cd dalam sistem logam tunggal lebih padan kepada model Langmuir berbanding model Freundlich, kecuali untuk AC. Walau bagaimanapun, sistem dwilogam lebih sepadan dengan model Freundlich daripada model Langmuir, kecuali untuk ICF-EFBB. Jerapan isoterma semua penjerap untuk Pb dalam sistem logam tunggal dan dwilogam lebih padan dengan model Langmuir daripada Freundlich, kecuali AC dalam dwilogam. Nilai Qmax untuk penjerapan Cd dan Pb mengikuti turutan ICF-EFBB > F-EFBB > M-EFBB > C-EFBB > AC (masing-masing sebanyak 55.87, 40.32, 19.34, 17.79 dan 14.31 mg g-1 bagi Cd dan 142.86, 103.09, 58.14, 54.95 dan 50.51 mg g-1 bagi Pb) dalam satu logam tunggal dan turutan yang yang sama diperhatikan untuk penjerapan Pb dalam sistem dwilogam. Turutan nilai Qmax untuk penjerapan Cd dalam sistem dwilogam menunjukkan urutan berikut: F-EFBB > ICF-EFBB > M-EFBB > AC > C-EFBB, iaitu masing-masing dijerap sebanyak 20.79, 17.86, 12.87, 6.25, dan 5.59 mg g-1. Penjerapan Pb lebih tinggi daripada penjerapan Cd.

Penambahan EFBB kepada tanah yang tercemar dengan Cd dan/atau Pb membantu mengurangkan Cd dan Pb yang boleh diekstrak oleh air hujan sintetik (AHS). Cadmium dan Pb yang diekstrak adalah terendah dalam tanah yang tercemar yang ditambah dengan 1% F-EFBB. Nilai Cd terendah bagi tanah Cd dan tanah Cd+Pb, masing-masing adalah 0 dan 10.786 µg kg-1 dalam minggu kelapan. Keputusan yang sama diperoleh daripada kajian larutlesap, yang menunjukkan keberkesanan F-EFBB dalam mengurangkan larutlesap Cd dan Pb dalam tanah berbanding dengan penjerap yang lain. Parameter tumbuhan sawi yang ditanam di tanah yang dicemari Cd- dan Cd+ Pb yang dirawat dengan EFBBs adalah jauh lebih baik berbanding dengan tanah kawalan yang tidak dirawat. Walau bagaimanapun, tidak perbezaan ketara yang ditemui pada tumbuhan sawi yang ditanam pada tanah yang dicemari Pb yang telah dirawat menggunakan EFBBs berbanding dengan tanah kawalan. Tidak ada kesan yang signifikan terhadap saiz zarah EFBBs pada parameter pertumbuhan pokok sawi yang ditanam di tanah yang tercemar. Walau bagaimanapun, penambahan 1% F-EFBB pada tanah yang tercemar menunjukkan kepekatan Cd dan Pb yang lebih rendah dalam akar, pucuk dan keseluruhan tumbuhan sawi berbanding tumbuhan sawi yang ditanam di atas tanah tercemar yang tidak dirawat. Nilai Cd dalam akar adalah 448.6 dan 346 mg kg-1 manakala terdapat 115.200 dan 99 mg kg-1 Cd dalam pucuk tumbuhan yang ditanam pada tanah tercemar dengan Cd dan Cd+Pb. Jumlah nilai Pb yang terendah dikenalpasti pada paras 4196 dan 1629.5 mg kg-1 dalam akar serta 78.467 dan 35.733 mg kg-1 dalam pucuk yang ditanam pada tanah tercemar dengan Pb dan Cd+Pb. Ini mungkin disebabkan pengurangan kedapatan bio Cd dan Pb dalam tanah yang dirawat dengan F-EFBB. Dapat disimpulkan daripada kajian ini bahawa semua EFBB, tanpa mengira saiz zarah boleh menjerap Cd dan Pb lebih baik daripada AC komersil. Pengurangan saiz zarah EFBB meningkatkan kapasiti penjerapan serta mengurangkan keboleh ekstrak dan larutlesap Cd dan Pb dari tanah yang tercemar. Oleh itu, EFBB boleh menjadi alternatif kepada AC yang jauh lebih mahal sebagai penjerap untuk Cd dan Pb.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
SE	Standard Error
rpm	Round Per Minute
ASTM	American Society for Testing and Materials
EFB	Empty Fruit Bunch
EFBB	Empty Fruit Bunch Biochar
F-EFBB	Fine Empty Fruit Bunch Biochar
M-EFBB	Medium Empty Fruit Bunch Biochar
C-EFBB	Coarse Empty Fruit Bunch Biochar
ICF-EFBB	Iron Coated Fine Empty Fruit Bunch Biochar
AC	Activated Carbon
EC	Electrical Conductivity
CEC	Cation Exchange Capacity
FTIR	Fourier Transform Infrared Spectroscopy
BET	Brunauer-Emmett-Teller
FESEM	Field Emission Scanning Electron Microscope
EDS	Electron Dispersive Spectroscopy
SRW	Synthetic Rainwater
TC	Total Carbon
EDTA	Ethylenediaminetetraacetic acid
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
AAS	Atomic Adsorption Spectrometer

b	Langmuir constant
Q_{max}	Langmuir maximum adsorption
K_F	Freundlich constant
1/n	The affinity of sorbate to the sorbent
Cd-soil	Contaminated soil with Cd 12 mg kg^{-1}
Pb-soil	Contaminated soil with Pb 500 mg kg^{-1}
Cd+Pb-soil	Contaminated soil with Cd (12 mg kg^{-1}) + Pb (500 mg kg^{-1})
PZC	Point of Zero Charge
WHO	World Health Organization
MPOB	Malaysian Palm Oil Board
USEPA	United States Environmental Protection Agency

CHAPTER 1

INTRODUCTION

1.1 General Background

Cadmium (Cd) and lead (Pb) are significant pollutants found globally, causing contamination in many urban cities and related industrial sites (Mohan and Singh, 2002; Mohan et al., 2006; Thinakaran et al., 2017). Cadmium is toxic and can accumulate in bones and cause kidney damage in humans (Mohan and Singh, 2002; Yamkate et al., 2017). It is also a major cause of *itai-itai* disease (Mohan and Singh, 2002; Sharma et al., 2017). The major sources of Cd in the soils are by emission from alloy, pigments, battery, and from plastic manufacturing industries (Mohan and Singh, 2002; Peng et al., 2016) as well as from the application of phosphate fertilizers (Tianlik et al., 2016). Similarly, lead is released into the atmosphere or deposited in the soils or sediments through incomplete combustion of petroleum hydrocarbons and sulfide ore smelting (Mohan et al., 2014; Jiang and Zhou, 2018). In the case of water bodies, Pb is deposited on surface water resources via acid mine drainage (Mohan et al., 2014). Moreover, both Cd and Pb cannot be biodegraded (Inyang et al., 2012).

Heavy metals such as Cd and Pb can be removed from wastewater and soil using different technologies (Bolan et al., 2014). Some of the technologies used for wastewater heavy metals removal include precipitation, membrane filtration, electrocoagulation, ion exchange and packed-bed filtration (Inyang et al., 2012; Kim et al., 2013). Unfortunately, these technologies are costly and the pose disposal problems arising from the cumulation of sludge (Sud et al., 2008). Recently, the use of biosorbents has been reported to be a better alternative to the previously mentioned methods (Demirbas, 2009). Activated carbon (AC) is widely used in the decontamination of Cd and Pb from soils. However, as a result of biochar discovery, studies have indicated that AC is becoming less important in decontamination of heavy metals in soils because it is expensive to produce while biochar is cheaper and more environmentally friendly (Cornelissen et al., 2005; Kołtowski et al., 2017). Several investigators have proposed the use of biochar to replace AC as a biosorbent for large-scale soil remediation of heavy metals (Babel and Kurniawan, 2003; Liang et al., 2010; Fu and Wang, 2011). Moreover, Cao et al. (2009) revealed that using different sorbents for heavy metals removal in wastewater only result in the binding of only one metal ion contaminant and the method is expensive.

Biochar is defined as an organic material produced by heating biomass residues in the absence of oxygen (Sohi, 2012). Biochar has a capacity to sorb contaminants and heavy metals in soils (Beesley et al., 2011). Not only that, the addition of biochar to soil does serve various other functions such as increasing soil fertility and sequester carbon by storing carbon biomass which is more resistant to biodegradation (Sohi, 2012). Shen et al. (2015) showed that prior to a large-scale field application of biochar, there is a need to rely on commercially available and renewable feedstock that proved to have the potential for soil decontamination. Oil palm empty fruit bunch (EFB) is abundantly produced in Malaysia and about 23 million tons are generated yearly (Vijaya et al., 2008). The EFB is usually disposed off in landfills and this can result in gas emission leading to pollution problems (Kong et al., 2014a). The Malaysian Palm Oil Board (MPOB), which is under the Ministry of Plantation Industry and Commodities, commercially produces biochar from EFB at its factory located in Bangi Lama, Selangor. The EFB biochar is produced at a temperature of 250 ºC using a horizontal rotary kiln. The rotating motion of the kiln moves the EFB biomass along the kiln and the speed is controlled based on the period of the heating required.

The biochar produced at low temperature (<500 ºC) has advantages and disadvantages. The advantages of biochar produced at low temperature include greater CEC (Kołodyńska et al., 2012) high nitrogen content (Chan and Xu, 2009) high exchangeable bases (Anyika et al., 2015) higher amounts of functional groups (Rutherford et al., 2008; Xie et al., 2015) high yield (Kong et al., 2014a) and the process consumes less energy (Cao et al., 2009). However, the biochar produced at low temperature has low pH, low surface area, and unexposed functional groups (Chen and Chen, 2009) which will result in low adsorption capacity of heavy metals and organic pollutants (Goswami et al., 2016). The resulting low surface area and unexposed functional groups of biochar produced at low temperature are due to pore closing and/or blockage by volatile material (Uchimiya et al., 2011a) or as a result of bottleneck phenomena (Dieguez-Alonso, 2015). The micropores are of considerable importance in adsorption process and the pore size can be widened with high-temperature pyrolysis due to the destruction of walls between the pores (Downie et al., 2009). On the other hand, high-temperature pyrolysis may lead to the loss of functional groups, which are also important in adsorption (Ding et al., 2014; Jindo et al., 2014). Biochar produced at low temperature can be a potential biosorbent to be used for soil amendment and environmental remediation purposes especially if its surface area can be increased and its inner pores and functional groups can be exposed by physical methods such as crushing.

1.2 Problem Statement

Previous studies have established that physical enhancing biochar properties may result in greater sorption of metals (Yargicoglu et al., 2015; Lu et al., 2017). The important the physical properties of biochar affecting sorption of metals include particle size, surface area (Shen et al., 2015; Shen et al., 2016; Lu et al., 2017) and pore volume (Kołodyńska et al., 2012). According to the terminology used by the International Union of Pure and Applied Chemistry (IUPAC), pores can be divided into three sizes: micropores (< 2 nm), mesopores (2 – 50 nm), and macropores (> 50 nm) (Thommes et al., 2015). The micropores and mesopores are the most important pore size in the adsorption of heavy metals (Mohan and Pittman, 2006; Ishak and Abdullah, 2014; Kunhikrishnan et al., 2015). Blockage of the inner pores either by ash content or volatile materials such as tars and bio-oil will cause the inner pores to become inaccessible surfaces for adsorption (Downie et al., 2009; Lee et al., 2010;

Gupta et al., 2013; Ahmad et al., 2014; Jindo et al., 2014). Therefore, exposing these inner pores will increase the effective adsorption capacity of biochar for heavy metals. According to Dieguez-Alonso (2015), to avoid bottlenecks phenomenon and pore blockage the biochar should be crushed to smaller particle size. However, for production pore of sizes up to 100 nm, the particle size should not be crushed less than 10 µm. Therefore, in order to obtain biochar with pores up to 100 nm, the biochar has to be crushed to particle size near to 10 µm. Previous studies have attempted to exploit the inner pores of biochar via particle size reduction (Mohanty and Boehm, 2014; Jaafar et al., 2015). However, the particle size that researchers used was much larger than 0.05 mm, which was not capable of exposing the occluded inner pores.

Shen et al. (2015) have reported the effect of particle size on metal sorption. They compared the sorption of Pb by Salisbury wood biochar of < 0.15 mm and 2 mm particles sizes and they found that the < 0.15 mm biochar adsorbed greater Pb relative to those of the 2 mm biochar. They attributed the higher sorption capacity of the fine particle size biochar for Pb to the CEC and a functional group, not the surface area. This because the sorption capacity of the Salisbury wood biochar was higher than that of sugarcane biochar reported by Inyang et al. (2011) even though the surface area of the former was higher. Shen et al. (2015) also concluded that the adsorption of Pb on the Salisbury wood biochar was not controlled by physical sorption but rather by chemisorption.

Meanwhile, the use of biochars with small particle sizes will require more specific and expensive filter paper to separate the biochar particles from the treated wastewater (Wang et al., 2014; Han et al., 2015). Consequently, it is assumed that magnetizing the biochar will ease its separation from the wastewater by using a magnet (Baig et al., 2014; Wang et al., 2015a; Tan et al., 2016). The smaller the size of the magnetic biochar, the better the separation from aqueous solution because of the higher adsorptive area. However, if the size of the magnetic biochar is too small, the magnetic tractive force will not be strong enough to overcome the Brownian motion, and therefore, the separation from the aqueous solution will be difficult (Cotten and Eldredge, 2002; Yavuz et al., 2006).

Studies have reported that impregnation of biochar with iron oxide increased the surface area and oxygen-containing functional groups of the biochar, hence increasing its adsorption capacity for heavy metals (Song et al., 2014; Wang et al., 2015b; Tan et al., 2016). However, other studies revealed that iron oxide could block the pores and reduce the pore volume and surface area of biochar (Wang et al., 2011; Hu et al., 2015).

According to Kołodyńska et al. (2012), 3 mechanisms exists for metal adsorption on biochar surfaces: (1) migration of the metal ions from the bulk solution to the external surfaces of the biochar (film diffusion), (2) migration of the metal ions into the biochar interior surfaces by either pore diffusion or surface diffusion, and (3) adsorption of metal ions on biochar surfaces. It is important to note that most of the reported mechanisms involved the surface functional groups of the biochar. However, metal retention by the surface functional groups of the biochars inner pores has not been completely verified. Amonette and Joseph, (2009) and Mohan et al. (2015) reported that both acidic and basic functional groups do exist in the inner pores of the biochar and in biochars matrix.

As far as I know, very rare literature can be found on the influence of the inner pores functional groups to increase the sorption capacity of metals by exposing the inner pores via particle size reduction. In this study, the inner pores of biochar were exposed by crushing the biochar to a particle size of < 0.05 mm. It is hypothesized that this will expose the inner pores of the biochar, which may increase its adsorption capacity for heavy metals. It is also hypothesized that magnetizing the biochar with Fe oxide will increase its adsorption capacity for heavy metals and ease the biochar separation from aqueous solution. Apart from studying the effect of particle sizes on the sorption characteristics, extractable, leaching and phytoavailability characteristics of Cd and Pb were also investigated.

1.3 Research Objectives

The general objective of this research was to study the effects of biochar particle size in increasing its adsorption capacity for Cd and Pb. Consequently, reducing the leaching and phytoavailability of the metals. The specific objectives are listed below:

1. To determine the physico-chemical, mineralogical and morphological characteristics of different sizes of biochar (C-EFBB, M-EFBB, and F-EFBB), magnetic biochar (ICF-EFBB) and activated carbon (AC).
2. To study the sorption capacity of Cd and Pb in the single and bisorbate system by different sizes biochars (C-EFBB, M-EFBB, F-EFBB, ICF-EFBB, and AC).
3. To investigate extractable and leaching of Cd and Pb in contaminated soil (Cd, Pb, Cd+Pb) amended with different particle sizes (C-EFBB and F-EFBB) and rates of biochar (0%, 0.5%, 1%).
4. To determine phytovailability of Cd and Pb in contaminated soil (Cd, Pb, Cd+Cd) amended with different particle sizes (C-EFBB and F-EFBB) and rates of biochar (0%, 0.5%, 1%) by the mustard plant.

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BIODATA OF STUDENT

Alaa Hasan Fahmi was born on 1 September 1977 in Baqubah city located in Diyala Province - Iraq. He finished his primary and secondary school in (Al-Wa'am and Al-Adalah school, respectively) located in Hdmixer village, Baqubah city and finished his high school in Al-Markazia school located in Baqubah city. He obtained B.Sc. degree in soil and water science (honor study) from the College of Agriculture, Baghdad University in 1999. Then, he assigned to College of Agriculture, Diyala University. He obtained M.Sc. degree in soil chemistry and organic matter from the College of Agriculture, Tikrit University in 2011. After that, he worked as an assistant lecturer and decider of the Soil and Water Science Department in College of Agriculture, Diyala University, where he was offered a scholarship award from Diyala University- Ministry of Higher Education and Scientific Research-Iraq to study his Ph.D. at University Putra Malaysia in 2014.

LIST OF PUBLICATIONS

Fahmi, A. H., Samsuri A. W., Hamdan J. and Daljit S. 2018. “Physical Modification of Biochar to Expose the Inner pores and Their Functional Groups” has been accepted by the Royal Society of Chemistry, (RSC Advances).

Fahmi, A. H., Samsuri A. W., Hamdan J. and Daljit S. 2018. “Bioavailability and Leaching of Cd and Pb from Contaminated Soil Amended With Different Sizes of Biochar” has been accepted by the Royal Society Open Science journal.

Fahmi, A. H., Samsuri A. W., Hamdan J. and Daljit S. 2018. “Magnetization Improved Lead Adsorption of Fine Particle Biochar” has been submitted to Journal.

Fahmi, A. H., Samsuri A. W., Hamdan J. and Daljit S. 2018. “Effects of Particle Size and Rate of Biochar on the Phytoavailability of Cd and Pb by Mustard Plants Grown in Contaminated Soils” has been submitted journal.