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FEASIBILITY OF SOIL-EFB MIXTURES AS A FILLED BARRIER MATERIAL FOR WASTE DISPOSAL SITE

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ABSTRACT

This paper present the results of laboratory experiment that is involved the characterization and removal efficiency test of soil-EFB (Empty Fruit Bunch) of oil palm mixture. In this study, soil samples were mixed with EFB at 10% (EFB10), 30% (EFB30), and 50% (EFB50). The characterization included the physical and chemical properties of the soil-EFB mixture such as compaction behaviour, cation exchange capacity, permeability and its surface physical morphology. Batch Equilibrium Test was performed in order to determine the adsorption capability of the soil-EFB mixture with the heavy metals solution. Five solutions with different concentrations (2.5 mg/l, 5.0 mg/l, 7.5 mg/l, 10.0 mg/l and 12.5 mg/l) were used in this experiment. Base on the compaction test, the value of optimum water content was influence by the EFB introduced into the soil. This is due to the presence of hydroxyl group, which was probably attributed to absorb water. The permeability of the soil-EFB mixtures ranges from 2.4×10^{-7} to 6.5×10^{-7} cm/s meanwhile the Cation Exchange Capacity (CEC) result ranges from 11.6 to 31.9 meq/100g. The study has revealed that different percentages of soil-EFB mixture possess different capabilities to remove heavy metals. From the removal efficiency test, it is shown that the removal percentages of heavy metals for soil-EFB mixtures were relatively high as compared to soil alone. Based on the characterization and removal data, the soil-EFB mixture has a good potential to be used as filled barrier material.

Keywords: Soil-EFB mixture, permeability, compaction, cation exchange capacity, batch equilibrium test

INTRODUCTION

Natural barriers or engineered barriers are generally used for the control of migration of leachate. In selecting the candidate barrier materials for potential use in engineered barrier, characterization of materials need to be conducted and must meet the requirement of the standard agreements. Engineered barrier implemented in the surrounding landfill site must have two main criteria i.e. low permeability and high adsorption capability (DOE, 1995, Rowe et al., 1995, CIRIA, 1996). For landfill sites where there is a potential hazard to groundwater system, the sites must have engineered barrier, which must have a layer that satisfied the permeability and thickness requirements (Scottish Environmental Protection Agency SEPA. 2002). The permeability and the adsorption capability of the barrier are dependent on the characteristics and physico-chemical properties of the barrier materials such as particle size distribution, degree of compaction, particle shape, surface area, cation exchange capacity and mineralogy.

Another characteristic that should be taken into account for a filled barrier for landfill is the compressive strength of the materials (Len Schwer, 2001). The material used must be relied upon to satisfy particular engineering purposes. The material must have sufficient shear strength to resist shear stresses that develop during loading and also must have adequate stiffness so that deformations resulting from loading do not cause problems. Therefore, geotechnical engineers test material to determine such engineering properties as the drained or undrained shear strength and the stress-strain behaviour.

In addition, special tests such as the batch equilibrium test that can provide an insight into the behaviour of the barrier materials with respect to adsorption and removal efficiency of various contaminant species from the waste disposal site would be more useful. Up to now, very few studies had been performed to disclose the feasibility of soil admixtures materials applied on landfill barrier. This study emphasize on the laboratory experiments that is involved the characterization of soil-EFB mixture and to determine the possible usage of EFB as adsorbent for pollutants removal, especially heavy metals. Metal adsorption to soil after the application of organic wastes has been studied in single metal systems by several researchers (Illera et al., 2000; Zhou and Wong, 2001, Vaca-Paulin et al., 2006).

MATERIALS AND METHODS

Preparation of Soil-EFB mixtures

The soil sample was collected adjacent to landfill sites in Taiping, Perak and characterized as sandy clay (Engoebumi, 2003). The soil was air dried and pulverized to pass through 1mm sieve. Empty Fruit Bunches (EFB) of oil palm was obtained from a local mill situated in Bangi, Selangor. The raw material EFB was washed several times with distilled water, dried at 100 °C for 24 hours in an oven to remove moisture until constant weight. The dried EFB was then ground and sieved to a particle size of < 1 mm and preserved at room temperature.

The soil samples were mixed with the EFB with percentages of 10%, 30%, and 50% in weight respectively. These soil-EFB mixtures were designated as EFB10, EFB30 and EFB50 based on the percentage of the EFB in the soil. The samples were then put in the rotary blender in order to obtain get a homogeneous mixture. After mixing, all the samples were put in sealed bags for further analysis.

Physical and chemical properties of soil-EFB mixtures

The basic properties soil and EFB such as Atterberg limits, grain-size distribution and heavy metals content were measured following (American Society of Testing Materials ASTM, 1984), Standard D2216-17. Several Soil-EFB mixtures were investigated their physical and chemical properties. The physical properties tested include compaction (standard proctor) and permeability (falling head), which is accordance with British standards. (BS1377, 1975). The surface physical morphology of the Soil-EFB mixtures was observed by a scanning electron microscopy (SEM). Chemical properties tested include cation exchange capacity. The test methods adopted are contained in the laboratory manual, geotechnical Research Centre, McGill University, Montreal Canada. While CEC was determined the batch test incorporating ammonim acetate exchanges (ASTM D4319, 2001). Pore fluids were obtained by the Saturation Extract method involving vacuum suction. Ammonium acetate solution was used as a buffer solution in this experiment. The qualitative estimation of the surface functional groups was performed by Fourier Transform Infra-Red spectroscopy (FTIR, Perkin-Elmer Spectrum GX).

The soil-EFB mixture (10 gram) was transferred to a centrifuge tube, and then 30 ml of 1.0 M NH_4 Ac (Ammonium acetate) was added. The tube was then sealed and centrifuged for 10 min. (10 min at 3500 r/min). There after, the supernatant liquid was filtered into a 100 ml volumetric vessel. The procedure was repeated twice and the collected extracts were filled up with 1.0 M NH_4 Acetate to 100 ml. Finally, the concentrations of Ca, K, Mg, Mn and Na were determined using an inductively coupled plasma technique (ICP, Perkin–Elmer Optima 3000). The amount of exchangeable cations was then calculated as meq/100g.

Batch Equilibrium Test

The effectiveness of natural soil-EFB mixture as adsorbent for heavy metals was studied using batch equilibrium tests. Batch equilibrium test is a useful and quick method to assess the adsorption capability of material for heavy metals (Jessberger et al., 1997). In this experiment, several heavy metal species were chosen as synthetic waste leachates. Stock solutions of heavy metals viz. Pb, Cu, Cd, and Zn (1000 mg/l) in the nitrate form were used in this study. All the heavy metal solutions were prepared by diluting the stock solution with de-ionized water. The concentration of stock solutions used depends on the various factors for experimental setup. In order to reduce the precipitation process of metals ion, the synthetic waste leachate had a pH <3.

The removal efficiency and effectiveness of natural soil and soil-EFB mixtures as adsorbent for heavy metals i.e. Pb, Cu, Cd and Zn was studied using batch equilibrium tests. Several solutions with various concentrations ranges from 2.5 mg/L to 12.5 mg/l were used in this experiment. Each solution was mixed with the soil-EFB mixtures at a ratio of 10:1 (10ml solution + 1 g soil-EFB mixture) and shaken in a tube for 24 hours (EPA, 1987 & USEPA, 1992). After reaching equilibrium, the tubes were then centrifuged at 5,000 rpm for 25 minutes. The supernatant was filtered with Whatman filter paper (No. 42) and then analyzed using ICP-MS. From these analyses, the concentration of heavy metals left in the solution is used to calculate the amounts of heavy metals removed by the sample materials.

Percentage removal of heavy metals from initial solution concentration C_o, calculated from the following Equation:

$$\%R = \frac{(C_0 - C)}{C} \times 100\%$$

Where,

$\%R$ = Percentage of heavy metal removed from the solution
C_o = Initial concentration of the solution before mixing with soil (mg/l)
C = the equilibrium concentration left in the solution after the mixing (mg/l)

RESULTS AND DISCUSSION

General characteristics

Basic properties of the soil and EFB are shown in Table 1. The result of grain-size analysis shows that the soil contains 19.7% clay, 23.9% silt, and 56.4% sand. This clearly illustrates that the grain size of soil is sandy clay. The results of Atterberg limits reveal the liquid limit LL.46%, the plasticity limit PL.24%, and the plasticity index PI.22%. Obviously, the soil is classified as a low plasticity liquid limit less than 50% according to the US unified soil classification system. Benson et al. (1994) stressed that basic soil properties normally monitored during construction quality control of soil liners. The fiber of EFB consist mainly of cellulose, hemicelluloses, lignin and having a lots of hydroxyl group in their structures. According to Gurmit et.al (1989), the EFB is composed of 45-50% of cellulose, 25-35% of hemicelluloses and 25-35% of lignin.

Table 1: Basic properties of soil and EFB

SOIL		**EFB**	
Particle size (%)		Property	
Sand (>0.063 mm)	56.4	Cellulose (%)	45-50*
Silt (0.063-0.002 mm	23.9	Hemicellulose (%)	25-35*
Clay (<0.002 mm)	19.7	Lignin (%)	25-35*
		Moisture content	14*
Atterberg Limit			
Liquid limit (%)	46	Heavy metal content (Background):	
Plastic limit (%)	24	Lead, Pb (mg/l)	0.002
Plasticity index (%)	22	Manganese, Mn (mg/l)	0.017
		Chromium, Cr (mg/l)	0.013
Heavy metal content (background):		Copper, Cu (mg/l)	0.032
Lead, Pb (mg/l)	ND	Zinc, Zn (mg/l)	ND
Manganese, Mn (mg/l)	0.003	Cadmium, Cd (mg/l)	0.007
Chromium, Cr (mg/l)	0.005	Nickel, Ni (mg/l)	0.011
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Nickel, Ni (mg/l)	ND		

*Gurmit et.al (1989)

Physical and Chemical Properties

The physical and chemical properties results involve compaction test, permeability (falling head), surface physical morphology, cation exchange capacity and the qualitative estimation of the surface functional groups. Figure 1 shows the graph compaction test of the soil-EFB mixture. From the graph, it was found that the optimum water content was increased with the increased percentage of EFB added into the soil. This is due to the presence of the hydroxyl group in EFB, which was capable to absorb water.

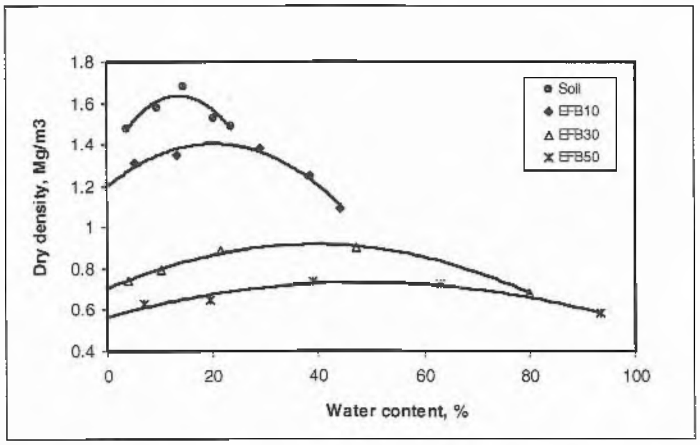

Figure 1: Graph of compaction test soil alone and soil-EFB mixture

Table 2 The average permeability values of soil, EFB10, EFB30, and EFB50 were 1.5 X 10^{-6} cm/s, 6.5 x 10^{-7} cm/s, 4.5 x 10^{-7} cm/s, 2.4 x 10^{-7} cm/s respectively. There were no significant differences observed for the Soil-EFB mixtures. The permeability of the soil alone is seen relatively high compared to the soil-EFB mixtures. This agrees with the results of other material on compacted mixtures (Al-Tabbaa et al.. 1997). The decrease is significant indicating good bonding or interaction between the soil particles and EFB fiber, hence the development of large pores and cracks was minimal. Based on the permeability test results, EFB30 and EFB50 seem to be more appropriate use as barrier or lining material, where the permeability, k value should below than 10^{-9} m/s (DOE. 1995, CIRIA, 1996 and SEPA 2002).

Table 3 shows the results of cation exchange capacity (CEC) for the soil-EFB mixtures. The CEC of soil samples ranges from 1.78 meq/100g to 2.22 meq/100g, whereas the CEC value for EFB10, EFB30, and EFB50 was 26.78 - 31.92 meq/100g, 23.38 - 30.26 meq/100g and 11.62 - 20.60meq/100g respectively. It was found that the CEC of the soil-EFB mixtures (EFB10, EFB30 and EFB50) was 10 times higher than CEC of the soil alone. This is due to the combination ion exchange reaction on the silica surface and the various functional groups in the soil-EFB mixture. This reaction occurs when positively charged ion such contaminant ions are attracted to the negative charge on the silica surface (Yong, 2001). The presence of carboxyl groups in soil-EFB mixtures is believed to be primarily responsible for the sorption of metal ions. It can be concluded that the addition of EFB into soil will improve capability of the material to absorb the heavy metals through CEC process.

Table 2: Results of permeability test

Materials	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
Soil (x 10^{-6} cm/sec)	1.6	1.3	1.5	1.5	1.5	1.5
EFB10(x 10^{-7} cm/sec)	6.5	6.1	6.2	6.2	6.2	6.2
EFB30(x 10^{-7} cm/sec)	4.4	4.6	4.5	4.5	4.5	4.5
EFB50(x 10^{-7} cm/sec)	2.4	2.6	2.3	2.4	2.4	2.4

Table 3: Results of CEC

Samples	**Cation Exchange Capacity (meq/100g)**
Soil	1.78 – 2.22
EFB10	26.78 - 31.92
EFB30	23.38 - 30.26
EFB50	11.62 - 20.60

Percentage removal of heavy metals from initial solution concentration C_0, calculated from the following Equation:

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Where,

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Figure 2 shows the surface physical morphology of the EFB in 3000 times magnification. Pores of different size and different shapes could be observed. Some particles were trapped into the pores and could possibly block the entry of pores to some extent. Figure 3 shows the particles of soil clay layer in 5000 times magnification. The negative charges of the clay layer have a tendency to attract the positive charge as a physical-sorption.

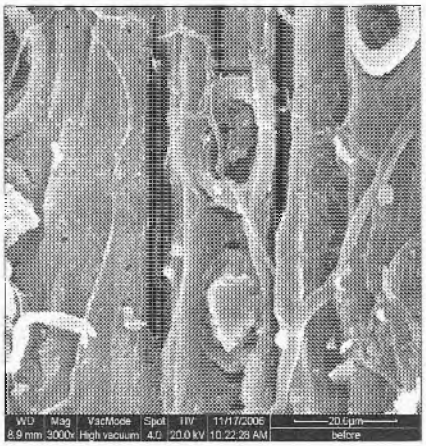

Figure 2: The surface physical morphology of EFB

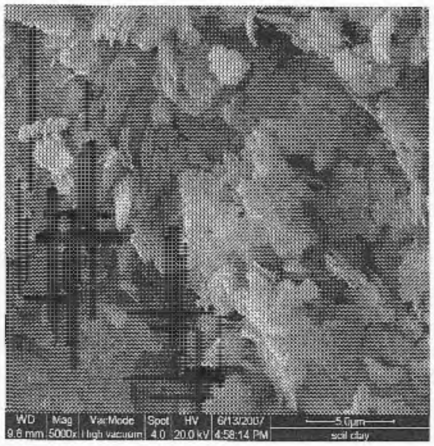

Figure 3: The surface physical morphology of soil

Figure 4 gives the FTIR spectrum of the Soil-EFB mixtures. Although the information obtained from FTIR scanning was limited as the concentration of the functional groups on the products surface were in fact very low, the absorption bands and peaks provide the evidence of the presence of some surface functional groups such as carboxyl, hydroxyl, etc. that are capable of adsorbing metal ions. The broad and flat band at 3400 cm^{-1} could be assigned to hydroxyl group, which was probably attributed to adsorbed water. The broad and strong band observed at 1040 cm^{-1} was assigned to either Si–O–C or Si–O–Si structures (Duggan and Allen, 1997), which was associated with the pronounced concentration of silicon in the materials. Wave number of 3334.686 for EFB indicates the presence of OH groups on the EFB fibre surface. The trough that is observed at 2912.891 cm^{-1} indicates the presence of C-H groups. The 1725.956 cm^{-1} band is a result of CO stretching mode, conjugated to a NH deformation mode and is indicative of amide 1 band. The trough at 1242.939 cm^{-1} is due to CO or CN groups. This reveals the presence of several functional groups for binding heavy metals ions on soil-EFB mixtures surface.

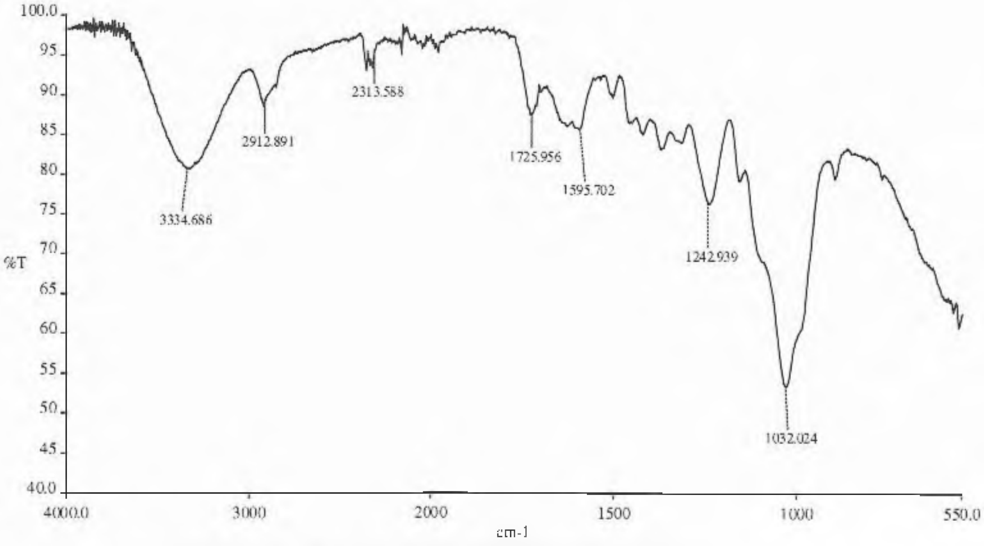

Figure 4: The FTIR spectrums of soil-EFB mixtures

Batch Equilibrium Test

Removal Efficiency Tests

In this study several heavy metals viz. Pb Cu, Cd and Zn with the initial concentration (10 mg/l) were used to obtain the adsorption efficiency of EFB10, EFB30. EFB50 and the soil sample alone. Figure 5 shows the result of removal efficiency test done with the samples. The removal of Pb for soil-EFB mixtures i.e. EFB10. EFB30, and EFB50 were detected more than 90% whiles the soil capable to remove Pb only 40% from the solution. The percentage removal of the Cu for soil sample was 47.1%. However, the percentage was increased with the soil-EFB mixtures, where the heavy metals removal was obtained more than 80%.

The percentage removal of Cd and Zn for soil alone was 25.4% and 52.1% respectively. Meanwhile, the percentage removal of Cd and Zn for soil-EFB mixtures ranges from 65.4% to 70.8% and 65.3 to 77.8% respectively. Based on the data, the soil-EFB mixtures seem to be more effective to remove most of the heavy metals from the solution and have a good potential to be utilized as filled barrier material.

Figure 5: Removal percentage of heavy metals from the solution

Initial concentration effect to the removal efficiency

The effect of initial heavy metals concentration on the removal efficiency by soil, EFB10, EFB30, and EFB50 was systematically investigated by varying the initial concentration between 2.5 and 12.5 mg/l. Figure 6 (a-d) shows the percent removal of Pb, Cu, Cd and Zn as a function of initial concentration. It was observed that the percent removal of heavy metals from the solution by the soil and soil-EFB mixtures sample decreased with an increased of initial concentration. This indicated that the removal efficiency of the samples was influenced by the heavy metals concentration and a positive correlation between the sorption capacity and basic properties of soils and soil-EFB mixtures. Most of the soil-EFB mixtures removed Pb and Cu from the solution more than 90%. In the case of soil, the removal of Pb and Cu were 99% and 96.5% at the initial concentration 2.5 mg/l and dramatically reduced to 28.5% and 33% at 12.5 mg/l respectively (Figure 6a and Figure 6b).

Figure 6c shows that the percentage of Cd removed from the solution by the soil-EFB mixture was seen more than 70% and the removal was level off although the initial concentration of the solution was increased. The removal of Cd by soil as a media was 67.29% at the initial concentration 2.5 mg/l and reduced to 43.34% at the initial concentration 12.5 mg/l. In the case of Zn, the removals by the soil-EFB mixtures were ranges 98.5%-98.9% at an initial concentration 2.5 mg/l and 59.4%-71.9% at 12.5 mg/l. Meanwhile, the removal Zn by the soil was found 80.2% at the initial concentration 2.5 mg/l and decreased to 43.5% at the initial concentration 12.5mg/l (Figure 6d). Previous studies (Christensen et al., 1992; Revans et al., 1999; Flyhammar and Hakansson, 1999) reported that one of the possible mechanisms that control heavy metal removal in a solute environment was sorption activity. In this study, the surface charge of clay mineral and EFB material are expected to be a contributing factor for the high levels of heavy metals adsorption. Metal ions (i.e., Pb, Cu, Cd and Zn) that are positively charged will be attracted to the negatively charged fine soil and EFB surfaces.

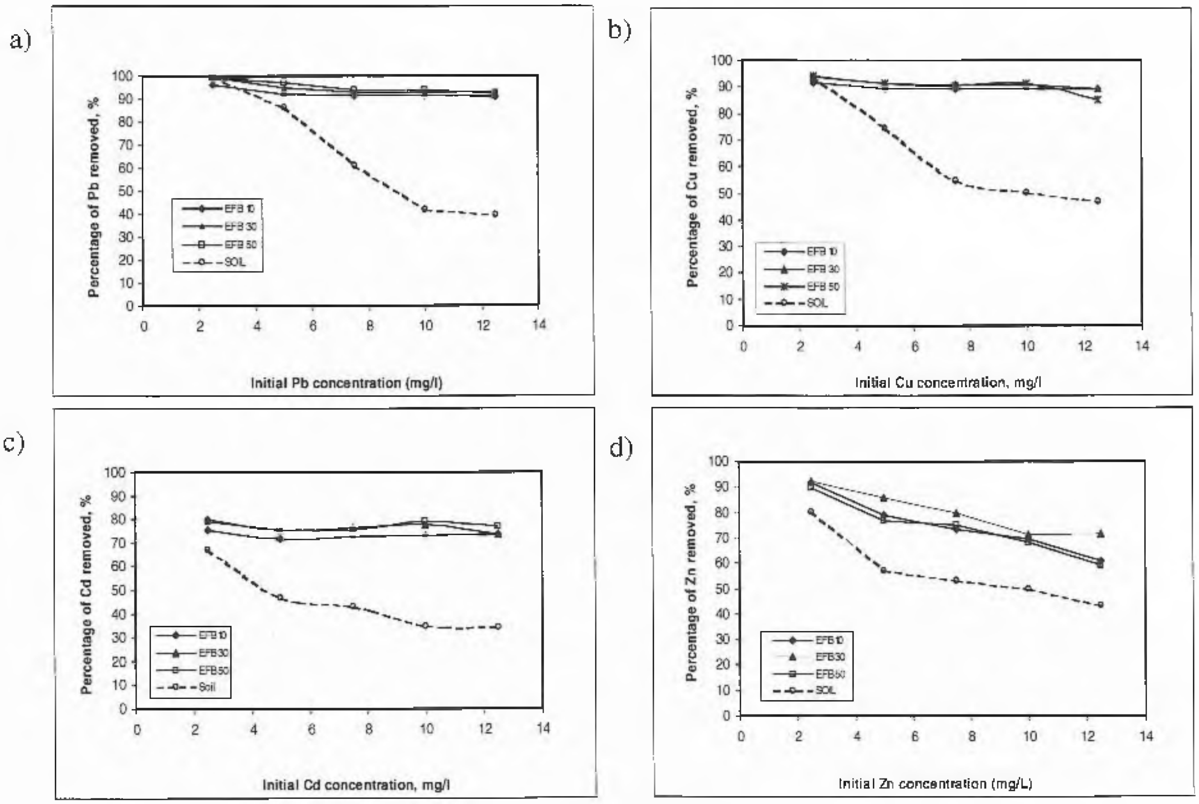

Figure 6: Effect of initial concentration on the removal of a) Pb. b) Cu. c) Cd and d) Zn

Table 4: Summary of heavy metals removal by the soil, EFB10, EFB30 and EFB50

Sample	**Heavy Metals**	**Percentage of heavy metals removed (%)**	
		Initial concentration of solution (2.5 mg/l)	**Initial concentration of solution (12.5 mg/l)**
Soil	Pb	99.7	39.4
	Cu	93.7	47.1
	Cd	67.3	34.4
	Zn	80.2	43.5
EFB 10	Pb	96.1	91.0
	Cu	91.9	89.2
	Cd	75.3	73.8
	Zn	92.0	60.8
EFB 30	Pb	99.6	92.8
	Cu	93.8	89.3
	Cd	79.9	73.7
	Zn	92.3	71.9
EFB 50	Pb	99.3	92.6
	Cu	94.4	85.4
	Cd	79.1	76.7
	Zn	89.9	59.4

CONCLUSION

In conclusion, results of physical and chemical characterization of soil-EFB mixtures were obtained. These data were useful to evaluate the potential of the soil-EFB mixtures to be used as a filled barrier material. Based on the removal efficiency data, the soil-EFB mixtures seem to be more effective to adsorb heavy metals and have a good potential to be utilized as filled barrier material. This is due to the interaction between surface charge of soil mineralogy and organic constituents of EFB as well as cation exchange process.

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