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Potentiality of Pressmud as an Additional Material in Soil Amendments to Enhance Soil Fertility & Strength Ability

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Abstract. In Malaysia, there are some accumulation of sugar refinery byproducts with a lot of this material not being utilized in a productive manner, while, these byproducts had the great potential when mixed into agricultural soils as organic fertilizer with many of benefits that can improve soil health, and sustainable agronomic productivity. Pressmud or known as filter cake is a by-product of sugar industry and for every 100 tons of sugarcane crushed about 3 tons of pressmud cake is left behind as by-product. This studies carried out on this material have not properly summarized their characteristics properties that they can be used as aid for future works. Data from tests involving pressmud samples from Malayan Sugar Manufacturing (MSM) Prai Berhad, Penang which was part of a larger collection was analyzed. The physicochemical properties of pressmud characterization as well as leaching test were carried out. The physicochemical and engineering properties involved compaction behavior, permeability, cation exchange capacity (CEC), compressive stress test and its surface functional groups. The leaching test method included batch equilibrium test and column test. The optimum value of water content in pressmud was determined in the compaction test. It was found out that pressmud has higher optimum water content value was observed. The permeability test of pressmud gave value in ranges of 1.84×10^{-5} cm/s. The Cation Exchange Capacity (CEC) of pressmud indicated value in the range of 99 to 101 meq/100 g. The high cation exchange capacity indicated that pressmud was believed to be primarily responsible for sorption of metal ions. It can be concluded that pressmud having the capability to remove heavy metals through CEC process. Pressmud also showed higher compressive strength value. Batch equilibrium test glaringly showed that pressmud have the capability to remove from 53.6%-93.8% metal removed from metal solutions for Chromium (Cr), Copper (Cu), Manganese (Mn), Nickle (Ni), Lead (Pb) and Zinc (Zn). From the result of column test, pressmud alone was able to retain efficiently all the heavy metals as these metals did not reach 1 (relative concentration) until 10 pore volume (PV.) indicating that pressmud was a good mixture material as it can assist in adsorption of heavy metals. Based on the

characterization study, removal efficiency and column test, pressmud has great potentiality to be used as an additional material in soil amendments to enhance soil fertility and strength ability.

Introduction

Today, soil metal pollution has become a significant environmental issue of great public concern. This is because soil is both a major sink for heavy metals released into the environment, by both pedogenic and anthropogenic activities; and also a major source of food chain contamination mainly through plant uptake and animal transfer. In addition, heavy metals contamination of soil leads to negative impacts on soil characteristics and function by disturbing both soil biological and physiochemical properties (e.g. extreme soil pH, poor soil structure and soil fertility and lack of soil microbial activity). This eventually leads to decreased crop production. Various soil remediation techniques have been successfully employed to reduce the risks associated with heavy metals efflux into soil. Among these, the use of low-cost and environmentally safe inorganic and organic amendments for the in-situ immobilization of heavy metals has become increasingly popular. Immobilization agents have successfully reduced the availability of metal ions through a variety of adsorption, complexation, precipitation, and redox reactions. Soil amendments can also be a source of nutrients and thus can also act as a soil conditioner, improving the soil's physiochemical properties and fertility, resulting in enhanced plant establishment in metal contaminated soils [1, 2].

Most of the soils have poor volume stability in the presence of water. The damage to structures built on soils is well documented [3, 4, 5, 6, 7]. Such soils should generally be avoided for the purpose of construction. Due to rapid urbanization and development, however, it is sometimes required to choose sites for projects with problematic soils such as laterite soils. Highway infrastructure projects hosted on soils are most susceptible to damage due to the existence of such problematic soils. One commonly used technique to mitigate soil damage is to stabilize them with the addition of external agents, such as lime or cement, to improve their engineering behaviors. In fact, adoption of soil stabilization in road construction projects can make them more cost-effective and sustainable [8]. Reuse of solid or organic wastes in soil stabilization can result in better management of wastes [9]. Use of industrial solid wastes in soil modification is also well documented [11, 12, 13, 14, 15].

One source of organic material that can be used to improve coastal sandy soil's physical properties is sugarcane pressmud, which are waste processing sugarcane stalks into sugar. This organic waste has a high nutrient and carbon content so that it has the potential to increase soil humus. According to Kumar et al. [15], sugarcane pressmud, a form of bio-product, has great potential to be used as an organic fertilizer, improving soil health and sustainable agronomic productivity. The composition of the nutrient content in this material varies from one sugar factory to another. The difference in nutrient content is influenced by the sugarcane variety and the soil type. According to Supari and Gunawan [16], sugarcane factory waste in the form of bagasse contains a complete element as an organic fertilizer. The nutrient content is organic-C (9.93%), total -N (1.13%), N-NH_4 (0.50%), N-NO_3 (0.11%), C/N ratio (8.76), P_2O_5 (1.05%), K_2O (0.16 ppm), Fe (10,308.67 ppm), Mn (758,597 ppm), Cu (50.75 ppm) and Zn (90.68 ppm). The nutrient content of sugarcane pressmud in vegetable cultivation has been shown to increase yield. The experimental results of Halifah et al. [17] proved that giving composted sugarcane bagasse can increase the weight of plant biomass and tuber weight [18]. Pressmud is considered as an addendum for testing its efficacy in soil stabilization. Though pressmud has several applications, for example, fertilizers, bio-sorbents, animal feed and extraction source for chemicals, pressmud application to soil stabilization is rare [19]. Available researches indicate that pressmud is utilized in the manufacturing of cement clinkers [20, 21] as well as preparation of sugarcane mulch for protection of erosive zones of dune sand [22].

Pressmud or sugarcane filter cake is waste from the sugar refinery industry [23]. This material is in the form of a blackish-brown solid with a high enough fiber content. This material can be used as a source of organic matter to increase the productivity of soils [18]. This study is aimed to examine the potentiality of pressmud as an organic material in order to evaluate its potentiality as an additional material in soil amendments to enhance soil fertility and as well as their strength ability. This article also aims to address the potentiality of pressmud on the characteristics study in term of physico-chemical properties and its strength ability.

Materials and Methods

The materials investigated are virgin sugarcane pressmud. Pressmud was collected from Malayan Sugar Manufacturing (MSM), Prai, Penang. The pressmud sample was subjected to basic characteristics, geotechnical, X-ray fluorescence (XRF), X-ray diffraction (XRD) and field emission scanning electron microscopy (FESEM) investigations. The geotechnical properties of the pressmud determined in accordance with British Standard 1377, [24], as a part of an earlier investigation. The various properties evaluated include pH, specific gravity, moisture content, standard proctor compaction, permeability test and cation exchange capacity (CEC).

Pressmud is the residue left behind after filtration of cane juice extracted from sugarcane in sugar industries. The total worldwide production of sugarcane amounted to 1841 million tonnes in 2017 [25]. The manufacture of sugar from sugarcane generates byproduct wastes like sugarcane trash, bagasse waste, bagasse ash, pressmud and spent wash [26] with bagasse and pressmud having more economic value than the rest [27]. With a conservative estimate of 2% generation of pressmud [28], the total pressmud generation in the world is estimated to be 36.8 million tonnes. Pressmud used in the study was obtained from MSM, Prai, Penang, Malaysia. Pressmud was subjected to the same set of characterization tests along with indirect determination of its properties.

The investigation commenced with the preparation and characterization of pressmud. Pressmud sample was prepared according to BS 1377 guidelines [24]. Pressmud was air-dried for a few days within the laboratory premises followed by removal of other foreign matter. The large clods were then broken by means of a hammer and the pressmud was further pulverized to achieve smaller particle sizes as shown in Figure 1.

Fig. 1. Sample of pressmud

The pulverized sample was then stored in closed trays for safe storage. As per the test requirements, the pressmud was sieved through the sieves (1000μm). Pressmud was dumped outside the sugar mill in huge quantities from which samples were collected and transported to the laboratory, where it was air-dried for a few days until it was visibly dry. It was then sieved through 1000μm sieve to remove the coarse fibrous materials, as there were not enough fines obtained when sieved through 1000 μm sieve. The sieving through 1000 μm sieve enabled removal of fibers to a good extent and the residual dust like material was used in the study. However, finer microscopic fibers smaller than 1000 μm still remained in the sample. Pressmud was dried at 105°C for 24 hours in oven to remove moisture until constant weight was achieved. The dried pressmud was stored at room temperature of 28±2ºC. Basic characterizations, physicochemical and geotechnical properties of this sample were then analyzed.

Laboratory Test

The laboratory tests that had been conducted were preparation of pressmud, characterization of pressmud (for heavy metals analysis), batch equilibrium test pressmud and finally column test. Characterization of pressmud samples included the determination of several basic properties (such as pH, specific gravity and moisture content), physicochemical properties, and geotechnical properties of the samples. Further explanations are discussed details in the following paragraph. The relevant standards used were BS 1377 [24], ASTM Standard (ASTM, D2216-17) [29] and Standard Proctor Compaction, ASTM D698 [30].

Physico-chemical properties of the pressmud were determined. The physical properties were analyzed by natural moisture content test, pH test, specific gravity, compaction test, unconfined compression test and permeability test. The chemical properties analysis involved the determination of cation exchange capacity (CEC), surface functional groups analysis and heavy metal content (background data) of pressmud. Batch equilibrium test was performed in order to evaluate the removal efficiency of heavy metals by using pressmud samples. Besides that, the adsorption capability of the materials tested was also determined. In this experiment, solution with the initial concentrations of 10 mg/L were mixed with the sample materials at a ratio of 20:2 (20 mL solution and 2 g of sample) and shaken in a centrifuge tube for 24 hours as shown in Figure 2 [31, 32].

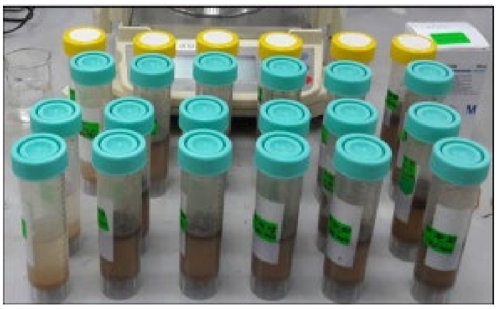

Fig. 2. Centrifuge tubes

After reaching equilibrium, the tubes were centrifuged at 5,000 rpm for 25 minutes to separate the liquid and solid forms. The supernatant was filtered with No. 42 What-man filter paper and then analyzed by using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) Model Varian 715-ES. From these analyses, the concentration of heavy metals left in the solution was used to calculate the amounts of heavy metals sorbed by the pressmud. Percentage removal of heavy metals from initial solution concentration C_o was calculated from the following equation (Eq. 1). Adsorption capacity and percent removal were used to optimize the material conditions:

Eq. 1

$$\% Removal = \frac{C_o - C_e}{C_o} \quad (1)$$

Where:
C_o = initial concentration of the solution (mg/L)

C_e = the equilibrium concentration left in the solution (mg/L)

The column cell used consisted of a Perspex glass cylinder with diameter 10 cm and height 30 cm. The column samples were compacted at maximum dry density and optimum moisture content using static compaction machine (Denison type T42 B4 Universal Testing Machine). These were utilized as triplicate columns with pressmud series as in Figure 3. There were two stages of leaching which were saturation stage using deionized distilled water and leaching stage using a test metal solution. The leaching experiments were conducted under constant air pressure at 10 psi (68 kPa) to reduce the time factor for solutions transport through the columns. The test solutions were Cr, Cu, Mn, Ni, Pb and Zn. The pH of the test solution was reduced to 2 as to avoid metal precipitation at onset of solutions penetration into the column and also to promote the increases of heavy metals mobility in the columns. The concentration of the metal solutions was 10 mg/L used in the column tests. The effluents were collected and analyzed at every 1 PV by using ICP-OES.

Fig. 3. Column experiments

Results & Discussion

Basic Characterizations

Basic properties of the pressmud as according to the British Standard BS 1377 Method (BS 1377, 1990) are shown in Table 1. Referring to Table 1, the pH value of pressmud showed 8.06, which was slightly alkaline but previous study in India from Rawat et al. [32] showed slightly acidic with the value of 6.8 may be due to difference of sugar refinery process between Malaysia and India. Specific gravity of pressmud was 1.76 N/m^3 whereas moisture content for pressmud showed a reading of 31.4%. The heavy metals concentrations in the pressmud were revealed to be low except for Fe and Zn concentrations which were 8.68 mg/L and 0.49 mg/L respectively. For Cu, Ni and Pb showed below the detection limits by ICP-OES.

Table 1. Basic properties of pressmud

Properties	Value
pH	8.06
Specific gravity (N/m^3)	1.76
Moisture content (%)	31.4
Heavy metal content (mg/L)	
- Arsenic, As	0.12
- Cadmium, Cd	0.02
- Chromium, Cr	0.04
- Copper, Cu	ND
- Iron, Fe	8.68
- Manganese, Mn	0.03
- Nickle, Ni	ND
- Lead, Pb	ND
- Zinc, Zn	0.49

*ND-Non detectable

Physico-chemical Properties

Compaction is a process of increasing soil or sample density and removing air, usually by mechanical means. Compaction of samples at a site is the main factor that controls short-term density and resulting placement efficiency of the material at the sites. Maximizing soil or sample density allows to reduce space requirements or to prolong the life of a facility [33]. Compaction is an important part in obtaining the optimum maximum dry density and water content. Figure 4 shows the compaction behavior of pressmud was investigated in terms of dry density and moisture content. There was an increment in dry density of pressmud. From this overview, pressmud gave a better result. However, one of the stabilization techniques is by adding material into the soil to enhance the strength and durability through compaction test. This is due to the formation of flocculation of these mixtures which requires more water to coat particles [34].

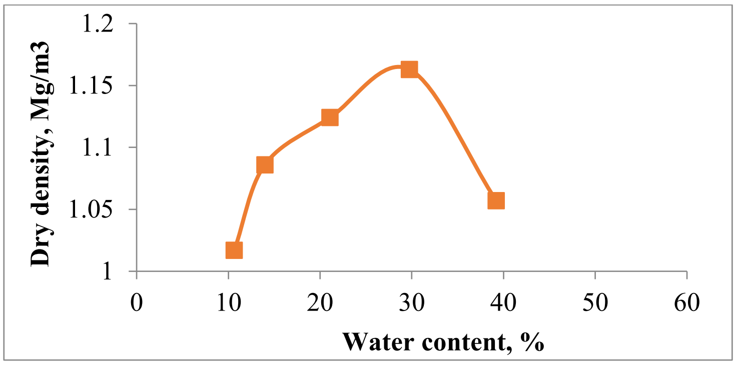

Fig. 4. Compaction test graph for pressmud

The optimum dry density and water content of pressmud was 1.17 Mg/m^3. From the graph, it was found that the optimum water content increased until 29.50% as shown in Table 2. This was due to the presence of the hydroxyl group in pressmud which was capable to absorb water. Decrease in the dry density was due to the lighter weight of pressmud [35, 36].

Table 2. Summary of maximum dry density and optimum water content of the tested sample

Maximum dry density (Mg/m^3)	Optimum water content (%)
1.17	29.50

The results of the permeability test using distilled water as medium are shown in Table 3. The average permeability value of pressmud was 1.84×10^{-5} cm/s. Although the permeability of the pressmud is not as low as possible, it is sufficient to support surface water runoff as the permeability value of pressmud is considered as low permeability. Low permeability value is good for compaction of soil cover requirement. There is no specification of permeability (hydraulic conductivity) for surface cover, as its main purpose is not to reduce the rain invasion [37]. However, low permeability behavior helps to lengthen water retention time and reduce production of water release.

Table 3. Results of permeability test

Materials	Permeability, cm/s
Pressmud	1.84×10^{-5}

Cation exchange capacity (CEC) of the soil sample was ranging from 99 to 101 meq/100 g which was indicated to be very high. Sorption processes are complex and are influenced by media properties such as cation exchange capacity in any particular adsorbents [38]. A higher CEC value signifies the increases of media capability in adsorption efficiency. The decrease in CEC is due to the removal of surface functional groups and the formation of aromatic carbon [39].

Determination of the unconfined compressive strength was done to evaluate and to develop an alternative material ability with the strength. The stress-strain behavior was investigated during the unconfined compression tests for the samples of pressmud. From this test, it can be concluded pressmud revealed lower compressive strength with the value of 68.5 kPa. Table 4 shows the summary of strain-stress data for pressmud.

Table 4. Summary of unconfined compressive strength for pressmud

Sample	**Bulk density (Mg/m^3)**	**Moisture content (%)**	**Strain at failure (%)**	**Compressive strength (kPa)**
Pressmud	1.36	27.36	3.25	68.5

According to Cross [40], slurry wall material must have the stress strength of more than 100 kPa and the strain at failure more than 5%. The increase in compressive and shear strength means that the stronger the sample, the more difficult it is to fail when pressure or loading is applied [41]. Generally, soil cover alone has the risk of cracking, thereby diminishing the strength of the containment system and increasing the potential for leakage. Cracks pose a special problem when the soil cover or barrier is exposed to repeat wet-dry cycles [42]. Addition of fibers or organic materials such as pressmud has been found to improve toughness, reduce cracking from plastic shrinkage and decrease crack width and transfer stress across cracks [41].

Figure 5 present the percentage transmission for various wave numbers given by the FTIR spectrum of the pressmud. The absorption bands and peaks provides evidence for the present of some surface functional groups such as carbonyl, hydroxyl and silica that are capable of adsorbing metal ions. The broad and flat band at 3692-3416 cm^{-1} could be assigned as hydroxyl group which was probably attributed in adsorbing water. The 2959-2515 cm^{-1} is stretching vibration of C=H. The broad and strong band observed at 1084-1141 cm^{-1} was assigned as Si-O-C or Si-O-Si (silica group) a structure that was associated with the pronounced concentration of silicon in the materials. [43, 44]. Meanwhile, 1796 cm^{-1} indicates the presence of carbonyl group on the pressmud surface and 713 cm^{-1} reveals the presence of C-H groups.

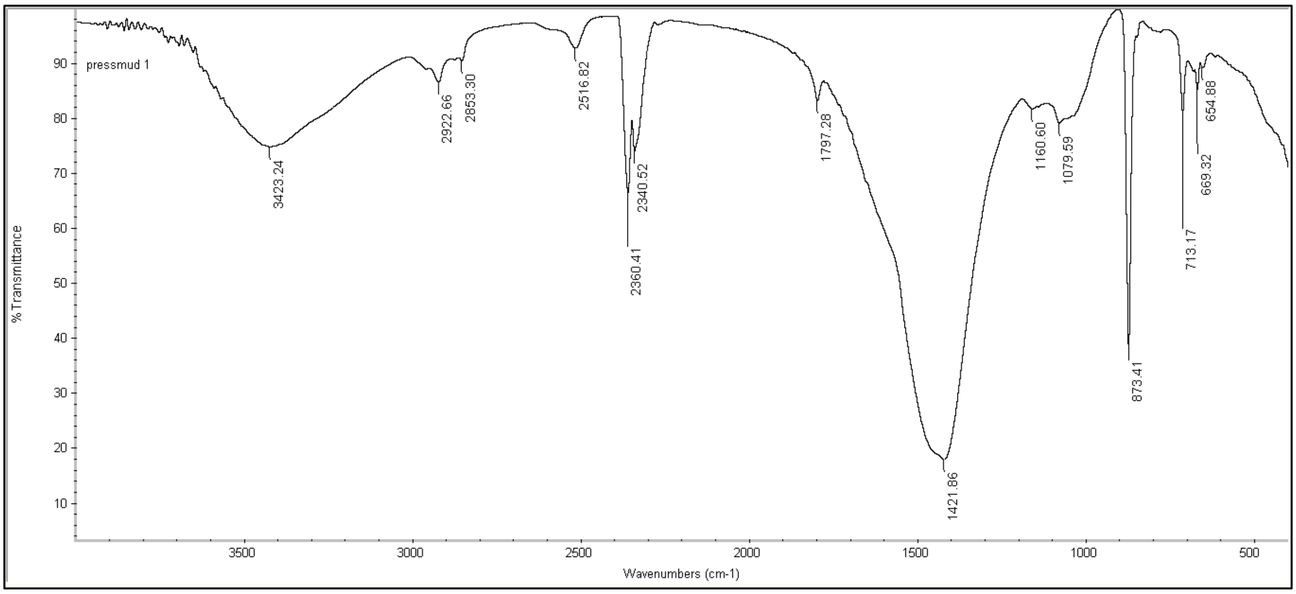

Fig. 5. FTIR spectrums of pressmud

Batch Equilibrium Test (BET)

Batch equilibrium test was performed in order to evaluate the removal efficiency of heavy metals by using EPA, [30] and USEPA standard, [31] methods. In this study several heavy metals viz. Cr, Cu, Mn, Ni, Pb and Zn with the initial concentration of 10 mg/L were used to obtain the adsorption efficiency of the pressmud. Figures 6 showed the result of removal efficiency test done with pressmud. From the figure, it was clearly shown that pressmud could remove 72.5% of Cr and 69% of Cu. Next for Mn, pressmud removed 53.6% and for Ni, pressmud was capable of removing 56.9% from the solution. Pressmud showed the highest removal of 93.8% for Pb and Zn could remove 77% of the removal from the solution. From ANOVA analysis, there was a significant improvement where $p<0.05$ for all of heavy metals removal from solution. This indicates that pressmud alone could significantly improve the sorption capacity in this test. Pressmud is appropriate to be used as a medium for the reduction or elimination of certain constituents in soil.

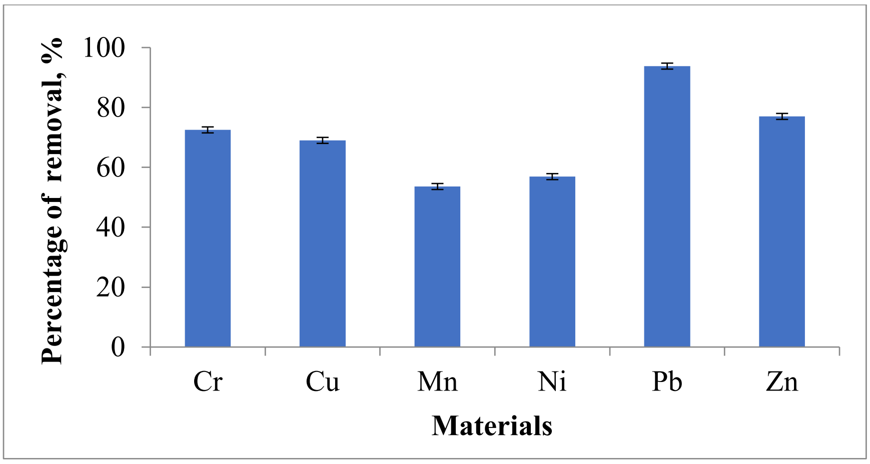

Fig. 6. Removal percentage of heavy metals from the solution for pressmud

Column Tests

Figure 7 shows variation of ratio of effluent (C_e) to the initial concentration (C_o) over pore volume of the solution for pressmud as a media. Pressmud alone was able to retain efficiently all the heavy metals as they did not reach the unity line ($C_e/C_o = 1$) until ten pore volumes indicating that pressmud was a good mixture material as it can assist in adsorption of heavy metals. The migrations of all the heavy metals exclude Cr, Mn and Ni still below 0.5 which indicates that pressmud has a capability to adsorb the heavy metals. Breakthrough curves for Mn and Ni approached near to one at six pore volume which indicates that pressmud has good attenuation and retention capability with respect to the heavy metals mobility. From this result, pressmud alone can stand by itself as all the heavy metals did not achieve the saturation point. Due to its natural characteristics, pressmud is very high in sugar content, so pressmud will be in sticky condition when it gets wet based on the laboratory observation. From this condition, it can enhance the capability to retain the heavy metals when the solution flows into the medium.

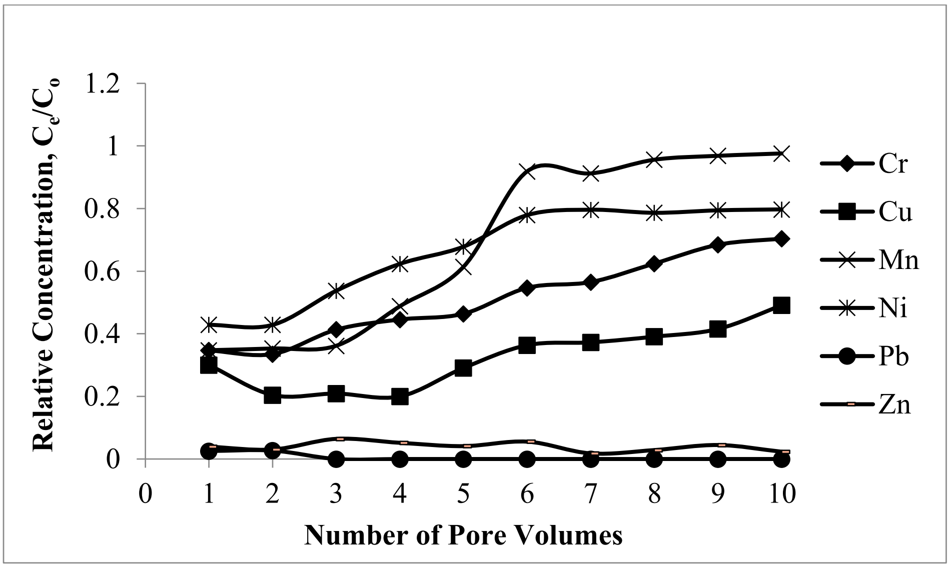

Fig. 7. Breakthrough curve of heavy metals for pressmud

Conclusions

Based on the characteristics study, pressmud had excellent characteristics and sorption capability. This indicated that pressmud could significantly improve the sorption capacity where most of the heavy metals can be removed in the range of 53.6%-93.8%. Pressmud was appropriate to be used as a medium for the reduction or elimination of certain constituents in soil composition. Furthermore, study on addition of fiber plus organic material in soil is proposed to improve geotechnical properties and other engineering characteristics. Therefore, an investigation is strongly recommended for soil solidification or remediation before using them in real applications because they might not provide the required agriculture properties. The use of pressmud in agriculture will also help in reuse of this industrial waste. However, more studies are needed with other cropping systems in different geographical conditions to have a concrete statement.

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