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Characteristics Study of Daily Soil Cover in Pulau Burung Landfill, Penang

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Abstract. Municipal solid waste landfills are major sources of environmental pollution. This study evaluated heavy metal concentrations in soils around Pulau Burung Landfill, Penang, Malaysia, to determine the pollution potential of a landfill. Soil samples were collected at depths of 0–20 cm (top), 20–40 cm (center) and 40–60 cm (bottom) around the landfill and at a control site and characterized for various properties and concentrations of Lead (Pb) and Zinc (Zn). Samples of daily soil cover, collected from the same sites where soil samples were collected, were also analyzed for several of heavy metals analysis. The soils were silty sand, mostly acidic (4.45) with low organic matter content (0.41%) and cation exchange capacity (3.15-3.19 meq/100 g). Other basic physico-chemical and adsorption properties were conducted on soil indicated that soil alone is not effective to be used in the landfill to support the pollutant for a long time. Heavy metals concentrations (as background data) in the soils followed the order Iron (Fe) > Zinc (Zn) > Manganese (Mn) > Lead (Pb) > Arsenic (As) > Chromium (Cr) > Cadmium (Cd) > Copper (Cu) > Nickle (Ni) with samples from around the landfill having higher concentrations especially Iron, (Fe) and Zinc, (Zn). For soil profile contribution, heavy metal enrichment was highest at a depth of 40–60 cm. In short, soil alone cannot retain and minimize the migration of heavy metals in landfill based on the results of this study including removal efficiency test. Monitoring of environments around active landfills needs to be ongoing to mitigate negative impacts on humans and the environment.

Introduction

In sanitary landfills, waste is covered by a cover system. There are three types of cover used in a landfill which is daily cover, intermediate cover and final cover. Daily cover is associated with the layer of compressed soil or earth which is laid on top of a day's deposition of waste on an operational landfill site. Daily cover serves many functions that are considered essential for municipal solid waste landfills. For most of the municipal solid waste landfills, 15 cm of daily cover is used to cover the waste. Daily cover improves access, improves aesthetic, reduces windblown debris (such as paper, plastics), reduces risk of disease transmittal through vectors (such as birds, insects and rats), odors, fire risk and provides a media for partial attenuation of leachate [1]. Incidents of groundwater contamination caused by landfill leachate have been extensively reported since the early 1970s. This lead to authorities to investigate the mechanisms that control leachate formation, quality, quantity, and most importantly migration characteristics with associated spatial and temporal variations during landfill operations and after closure [2].

Most of the landfills in Malaysia used laterite soil as a daily cover in their operation. Soil alone may not be an ideal landfill daily soil cover material as it cannot reduce the major problems in the landfill [3]. The selection of the cover type is a big challenge when designing the landfills. Owing that there is no universal landfill cover applicable for all landfills, different types of landfill covers were proposed and executed all over the world. Using daily cover on landfills helps to control odours, reduce windblown litter and inhibit fires, as well as minimizing the percolation of water through the waste which results in the generation of leachate. Cover also helps to prevent the breeding of insects which spread disease and eliminates sources of food for rodents and birds as they can cause considerable annoyance and impact both on the environment and the amenities in proximity to disposal sites [4, 5].

Laterite soil also known as red earth is found in the tropic and subtropics and generally comprises substantial amount of iron and aluminum oxides [6, 7, 8]. Laterite is a red tropical soil in which the oxides are derived from rock weathering under strongly oxidizing and leaching conditions [9]. It is a residual product of a wide variety of intensive chemical weathering processes that affects rocks under strong oxidizing and leaching conditions [10]. In addition, laterite soil is enriched with aluminum silicates, aluminum hydrosilicates, iron oxides and iron hydroxides because the water leaches out the bases and the silic acid [7]. Such phenomenon can be proved by the iron compound, which leads to the typical red color of the soil. Consequently, in this study, Pulau Burung Landfill has been chosen as a model to evaluate the municipal solid wastes' impact on certain physicochemical and adsorption properties of the landfill's daily soil cover.

Methodology

Sampling

Local soil that is used as daily soil cover in landfill was sampled at Pulau Burung Landfill in Penang. Figure 1a shows the location of soil sampling point and Figure 1b shows a typical soil covers sampling in Pulau Burung Landfill by using soil corer. 5 of sampling points were chosen randomly at the landfill cover area in order to study the distribution of heavy metals in the profile of top soil cover.

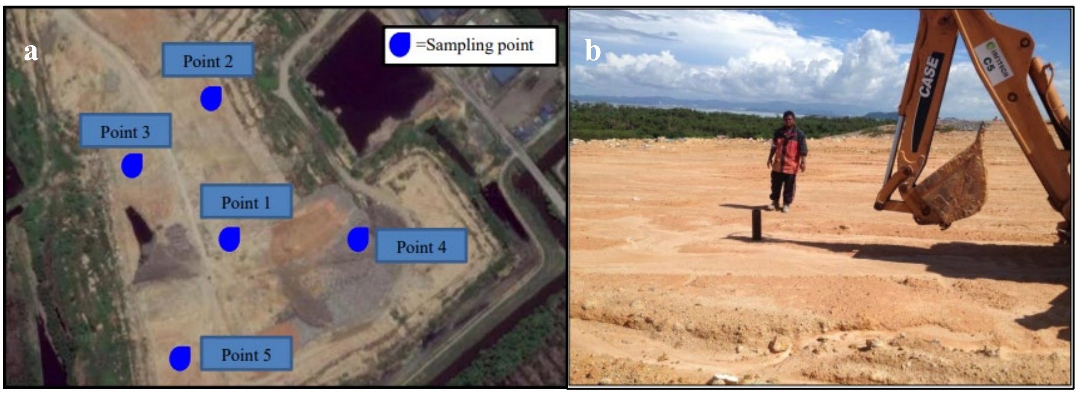

Fig. 1a and 1b. Location of collected of soil profile in the study area

Laboratory Test

1) Preparation of Sample

The laboratory tests that had been conducted were preparation of laterite soil, characterization of laterite soil (for heavy metals analysis), batch equilibrium test onto laterite soil and finally soil column test. Characterization of soil samples included the determination of several basic properties, physicochemical properties and geotechnical properties of samples.

The local laterite soils collected were air-dried and sieved using 1000 µm sieve to remove large and coarse pebbles. The soil samples were then dried and analyzed for their characteristics that involved physicochemical and adsorption properties. Figure 2 present the soil sample that has been used in this study. The relevant standards used were British Standard (BS 1377) [11], ASTM Standard (ASTM, D2216-17) and Standard Proctor Compaction, ASTM D698 [12].

Fig. 2. Soil samples

2) Physico-chemical Properties

Physico-chemical properties of the laterite soil were determined. The physical properties were analyzed by natural moisture content test, pH test, organic content test, determination of Atterberg limits test, determination of carbon content and specific gravity, compaction test, unconfined compression test, shear strength test, specific surface area determination and particles size distribution analysis. The chemical properties analysis involved the determination of cation exchange capacity (CEC), surface functional groups analysis and heavy metal content (background data). Mineralogy content of the soil was also determined by using X-Ray Diffraction (XRD), Model X'Port Pro. The relevant standards used were British Standard (BS1377) [11], ASTM Standard (ASTM, D2216-17) and Standard Proctor Compaction, ASTM D698 [12].

3) Adsorption Properties

Batch equilibrium test was performed in order to evaluate the removal efficiency of heavy metals by using laterite soil 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 3 [13, 14].

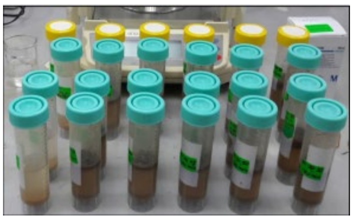

Fig. 3. Centrifuge tubes

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 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 soil. 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:

$$\% \ Removal = \frac{C_o - C_e}{C_o} \ x \ 100\% \quad (1)$$

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

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

Results & Discussion

Heavy Metals Distribution in Soil Profile of Top Soil Cover

The Pulau Burung Landfill represents a large source of different contaminants, including common organic and inorganic constituents of MSW leachate, toxic metals and organic chemical. Since the waste was disposed of directly onto the alluvial sediments, a number of contaminants were shown to penetrate efficiently through the soil strata and eventually reach the groundwater system. Figure 4 shows the concentration of Lead (Pb) content in soil profile of top soil cover in Pulau Burung landfill.

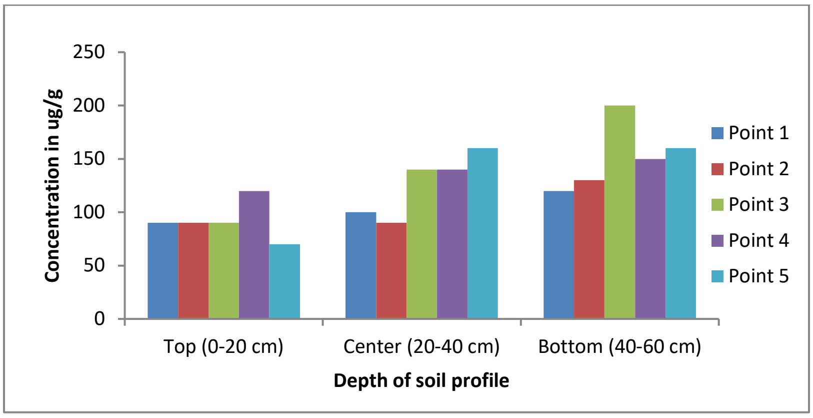

Fig. 4. Pb concentration in soil profile of top soil cover

5 sampling points were selected to determine soil profile information. This is the baseline information on heavy metals uplift in landfill capping. The depth of sample taken was of 60 cm. The soil profile was divided by three levels starting from surface which were 20 cm top, 20 cm center and 20 cm bottom. The concentrations of Pb in top soil cover were increasing from the soil surface (0-20 cm) until the bottom of core sample (40-60 cm) for the overall sampling points. The highest concentration of Pb in the top soil cover was 200 ug/g which was detected at the bottom of core sample within the range of 40-60 cm depth at point 3. Though waste materials disposed in the landfill are the main sources of heavy metals in landfill leachate and soils around the landfill environment, the covering and capping material could also contribute significant amounts of heavy metals [15]. Figure 5 shows the concentration of Zinc (Zn) content in soil profile for top soil cover in Pulau Burung landfill.

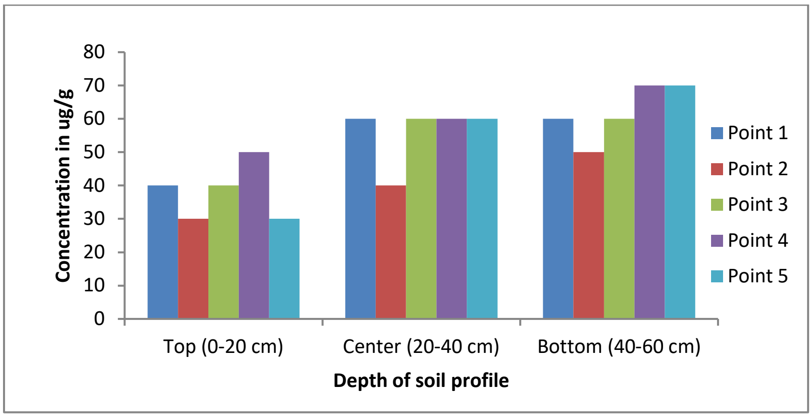

Fig. 5. Zn concentration in soil profile of top soil cover

For the whole sampling points, the concentrations of Zn in the soil profile were also seen quite high and increasing from the soil surface (0-20 cm) until the bottom of core sample (40-60 cm). The highest concentration of Zn was 70 ug/g at point 4 and 5 (bottom 40-60 cm). The result indicated that the deeper the depth of soil profile, the higher the concentration of heavy metals content in the top cover of landfill for these elements namely Pb and Zn. From the result, concentration of heavy metals in soil cover in contact to the waste was higher. Migration of heavy metals occurred from below to the upper part of the soil cover or in other words, there is an upward contaminant movement through evaporation process via soil capillary action from the waste beneath the landfill cell. However, the elements of Cd, Cr, Cu, Fe, Mn and Ni were shown to be below detection limit (BDL). The remediation activities have to take into account that the waste contains significant contribution of domestic waste and the soil below the landfill is heavily contaminated [16]. The pollutants were presented in the contaminated soil as a consequence of enhanced groundwater levels and therefore their replacement before constructing an impermeable daily cover is highly recommended.

Physico-chemical Properties

Characterization tests are very important in ensuring the suitability of materials considered for each of the landfill cover components. The characteristics studies were conducted on soil samples. Basic properties of the soil samples as according to the British Standard BS 1377 Method [11] are shown in Table 1. Referring to Table 1, moisture content for soil showed a reading of only 18.7% which similarly by the previous study from Sujeeth, [17] with his data of natural moisture content in range between 18-34% and the pH value of soil showed to be 4.45 which was in acidic condition. The slightly acidic nature of the soils around the landfill may have limited impact on metal mobility in soils around the landfill environment [15]. From previous study, most of laterite soil in Malaysia considered as strongly acidic at pH 4.58 [18]. Soil organic content and its percentage of carbon content were found to be 0.41% and 0.14%, respectively.

The Atterberg limits is the original tests for the determination of these consistency limits originate from the investigations of Atterberg [19], and their subsequent standardization for use in civil engineering applications. In the other words, Atterberg limits are important to describe the consistency of fine-grained soils or help to identify the state of soil [20]. The results of Atterberg limits showed that the liquid limit (LL) was 67.5%, the plasticity limit (PL) was 16.9% and plasticity index (PI) to be 50.6%. Generally, the soil is classified to have high plasticity as the liquid limit is more than 50% according to the US unified soil classification system (USCS). According to USCS, soil with high plasticity is able to carry more water content. From this behavior, soil with high plasticity will be categorized as clay while soil with low plasticity will be categorized as silt. From here, it can be concluded empirically, high plasticity will affect the strength of soil [21].

Specific gravity of soil (G_s) was measured to be 2.33 (N/m^3).This value of specific gravity of soil was quite similar with the previous study done by Borude and Patil, [22] that found the changes in properties of soil due to disposal of waste had resulted in its specific gravity to be 2.57. Cation exchange capacity (CEC) of the soil sample was ranging from 3.15 to 3.19 meq/100 g which was indicated to be quite low. Sorption processes are complex and are influenced by media properties such as cation exchange capacity in any particular adsorbents [23]. A lower CEC value signifies less media capability in adsorption efficiency. The decrease in CEC is due to the removal of surface functional groups and the formation of aromatic carbon [24]. The result of grain-size analysis showed that the soil consisted of 47.71% sand, 31.3% silt and 6.13% clay with the rest to be classified as gravel of 14.87%. From the analysis, it clearly illustrated that the grain size of the local soil was silty sand which was closely with the result from previous study [25]. This paper indicated the particle size distribution analysis for laterite soil from sources near Nibong Tebal, Penang were found to consist on the average, 10.96% gravel, 45.94% sand, and 43.10% fines. The heavy metals concentrations in the soil samples were very low, excluding Fe and Zn, which indicated high concentrations of 14.7 mg/L and 2.56 mg/L respectively. Benson and Daniel [26] mentioned that the basic soil properties normally monitored as a part of quality control during construction of soil in landfill. From XRD analysis, the soil contained kaolinite, muscovite, microline, quartz, montmorillonite and magnetite but dominantly kaolinite. The study on the mineralogy and microstructure showed that kaolinite and quartz are two major minerals present in the Malaysian soil [27, 28, 29].

Table 1. Basic properties of local soil at landfill

Properties	**Results**
Moisture content	18.7
pH	4.45
Organic content (%)	0.41
Carbon content (%)	0.14
Atterberg limits (%)	
- Liquid limit	67.5
- Plastic limit	16.93
- Plasticity index	50.57
Specific gravity (N/m^3)	2.33
Specific surface area (m^2/g)	22.8
Cation exchange capacity (meq/100g)	3.15-3.19
Particle size distribution (%)	
- Sand (> 0.063 mm)	47.7
- Silt (0.063 – 0.002 mm)	31.3
- Clay (< 0.002 mm)	6.13
Heavy metal content mg/L (Background data)	
- As	0.43
- Cd	0.08
- Cr	0.23
- Cu	0.05
- Fe	14.7
- Mn	0.66
- Ni	0.03
- Pb	0.57
- Zn	2.56

Figure 6 present the percentage transmission (%T) in y-axis for various wave numbers in x-axis, cm^{-1} given by the FTIR spectrum of the soil. 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 3700-3600 cm^{-1} could be assigned as hydroxyl group which was probably attributed in adsorbing water. The 1870-1650 cm^{-1} is stretching vibration of C=O. The broad and strong band observed at 1110-1050 cm^{-1} was assigned as Si-O-C or Si-O-Si a structure that was associated with the pronounced concentration of silicon in the materials [30, 31].

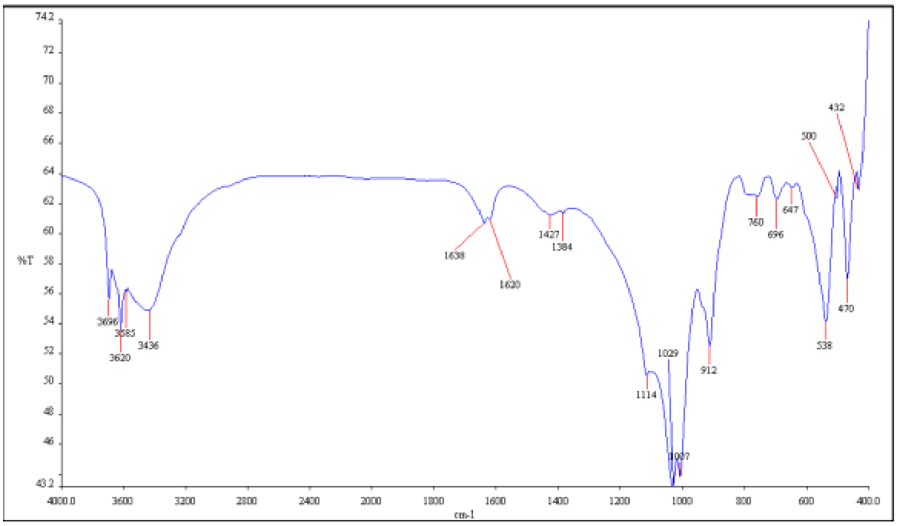

Fig. 6. FTIR spectrums of soil

Geotechnical Properties

Compaction is a process of increasing soil density and removing air, usually by mechanical means. Compaction of wastes at a landfill is the main factor that controls short-term density and resulting placement efficiency of wastes in the landfills. Maximizing waste density allows to reduce landfill space requirements or to prolong the life of a facility [32]. Compaction is an important part in obtaining the optimum maximum dry density and water content. Figure 7 shows the compaction behavior of soil was investigated in terms of dry density and moisture content. Allowable range for the optimum water content for compaction was 11.5% - 20.5%. This range results in 95% or greater maximum dry unit weight. There was an increment in dry density of soil. From this overview, soil 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 [33].

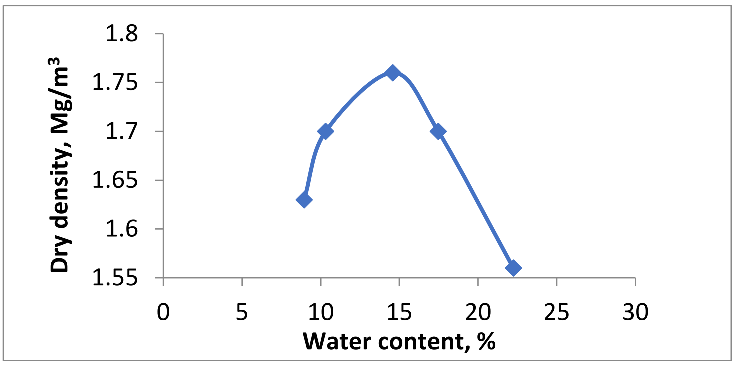

Fig. 7. Compaction test graph

Determination of the unconfined compressive strength was done to evaluate and to develop an alternative daily cover with high strength for the landfills. The stress-strain behavior was investigated during the unconfined compression tests for the samples of soil. From this test, it can be concluded soil revealed lower compressive strength. Table 2 shows the summary of strain-stress data for soil.

Table 2. Summary of unconfined compressive strength

Sample	Bulk density (Mg/m3)	Moisture content (%)	Strain at failure (%)	Compressive strength (kPa)	Shear strength (kPa)
Soil	1.97	8.7	1.97	96	48

According to Cross (1997), 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 soil, the more difficult it is to fail when pressure or loading is applied [28]. 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 [34]. Addition of fibers has been found to improve toughness, reduce cracking from plastic shrinkage and decrease crack width and transfer stress across cracks [28].

The average permeability value of soil was 4.19 x 10^{-5} cm/s. Although the permeability of the soil is not as low as possible, it is sufficient to support surface water runoff as the permeability value of soil is considered as low permeability. Low permeability value is good for landfill daily cover requirement. There is no specification of permeability (hydraulic conductivity) for daily cover, as its main purpose is not to reduce the rain invasion [35]. However, low permeability behavior helps to lengthen water retention time through the garbage and reduce production of leachate release.

Batch Equilibrium Test (BET)

Batch equilibrium test was performed in order to evaluate the removal efficiency of heavy metals by using EPA, [12] and USEPA standard, [13] methods. In this study several heavy metals viz. Cd, Cr, Cu, Fe, Mn, Ni and Zn with the initial concentration of 10 mg/L were used to obtain the adsorption efficiency of the soil sample. Figures 8 show the result of removal efficiency test done with the soil samples. From the figure, it was clearly shown that soil could only remove 2.07% of Cd and 19.6% of Cr. Next for Cu, soil only removed 1.6% and for Fe, soil was capable of removing 33.3% of Fe from the solution. Soil showed the least removal of just 9.9% for Mn compared to Ni could only remove 32.8%. Finally, soil showed the least Zn removal of only 5.2%. From ANOVA analysis, there was no significant improvement where $p>0.05$ for all of the heavy metals removal from the solution. This indicates that the laterite soil alone could not significantly improve the sorption capacity where desorption of most of the heavy metals seems to be occur. Laterite soil alone is less appropriate to be used as a medium for the reduction or elimination of certain constituents in landfill leachate.

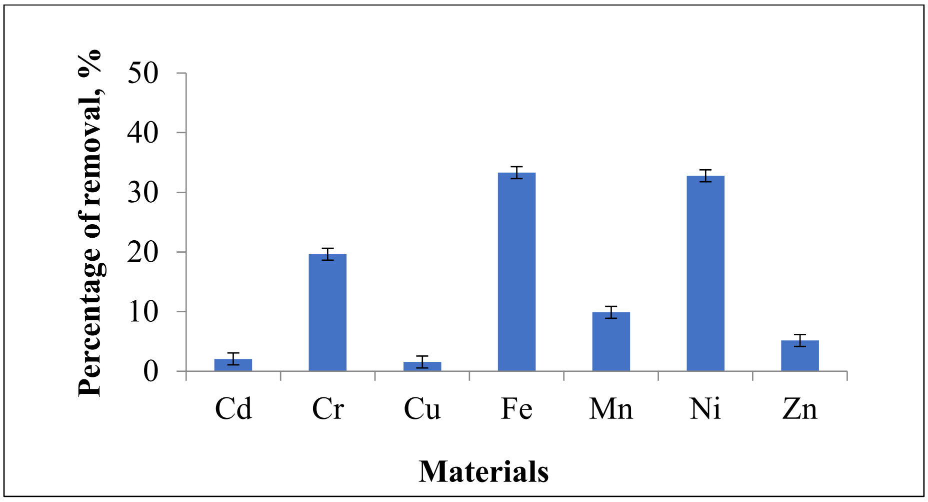

Fig. 8. Removal percentage of heavy metals from the solution

Conclusions

Based on the characteristics study of daily soil cover in Pulau Burung Landfill, soil alone had poor sorption capability as the desorption process occurred where most of the heavy metals were flushed out from the removal efficiency test. This indicated that the soil alone could not significantly improve the sorption capacity where desorption of most of the heavy metals seemed to occur. Soil alone was less appropriate to be used as a medium for the reduction or elimination of certain constituents in landfill leachate migration. Furthermore, study on addition of fiber plus organic material in soil is proposed to improve geotechnical properties so that it will be suitable as landfill daily soil cover. Therefore, an investigation is strongly recommended for landfill soil cover before using them in waste containment applications because they might not provide the required engineering characteristics.

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