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Natural sorption capability of heavy metals: Granitic residual soil from Broga and marine clay from Sg. Besar Selangor

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Abstract: The study aims to investigate sorption capability of heavy metals (HMs), i.e. lead (Pb), copper (Cu), nickel (Ni) and zinc (Zn) by two soil types; granite residual soils from Broga (BRG) and marine clay soils from Sg. Besar (SBMC). All samples were subjected to physico-chemical properties and batch equilibrium tests (BET). The physico-chemical test results show that SBMC soils have high pH, high clay content, high CEC and SSA values and montmorillonite. In contrast, BRG soils have low pH, low clay content, low CEC and SSA values and contain mainly kaolinite and illite. Sorption tests (BET) show that SBMC soils have higher sorption for HMs compared to BRG soils. The sorption capability of these soils is greatly controlled by their physico-chemical properties.

Abstrak: Kajian bertujuan untuk menentukan kapasiti penjerapan terhadap logam berat plumbum (Pb), kuprum (Cu), nikel (Ni) dan zink (Zn) oleh dua jenis tanah iaitu tanah baki granit dari Broga (BRG) dan lempung marin dari Sg. Besar (SBMC). Ujian sifat fiziko-kimia tanah dan ujian penjerapan berkelompok (BET) dijalankan ke atas semua sampel. Hasil ujian fiziko-kimia menunjukkan tanah SBMC mempunyai nilai pH yang tinggi, kandungan lempung dan nilai CEC-SSA yang tinggi dan kehadiran mineral lempung montmorilonit. Manakala tanah BRG mempunyai pH, kandungan lempung dan nilai CEC-SSA yang lebih rendah, serta mineral lempung koalinit dan ilit. Hasil ujian penjerapan (BET) menunjukkan tanah SBMC mempunyai keupayaan penjerapan yang lebih baik berbanding dengan tanah BRG. Keupayaan penjerapan tanih ini sangat dipengaruhi oleh sifat fiziko-kimia.

INTRODUCTION

Landfills are regarded as the best place to dispose of waste. The main problems related to landfill are biogases and leachate. Leachate that is produced inside the landfill from water infiltration can contaminate the environment. Heavy metals (HMs) are one of the main constituents of leachate and can pose very serious problems to human health and the environment. Most landfills today utilise various types of liner materials, i.e. geomembrane (plastic liner), geosysnthetic clay liner, compacted clay liner and natural clay (soil). There are about 11 active landfill sites in Selangor alone and only two of them have complied with the basic liner requirement as required by the DOE (1995). Others still depend on natural soil as their liner material. Therefore, detailed study of the ability of the soil materials to function as landfill liner is vital.

Soils have the capability to sorb different types of organic and inorganic pollutants, and their sorption capabilities are very much controlled by physico-chemical properties (Wan Zuhairi, 2000, 2001; Yong, 2001). The study was designed to compare two types of soils to function as natural liner material; to evaluate the sorption capability of these soils and to investigate the importance of physico-chemical properties on soil sorption capability.

MATERIALS AND METHODS

Two types of soil samples were collected in the study. The first adjacent to an active landfill site in Selangor, i.e. marine clay from Sg. Besar landfill in Sabak Bernam (SBMC) and the other from residual soil in Broga Semenyih (BRG) (Figure 1). Soil from Broga was chosen because the area has been identified for the biggest incinerator plant in Selangor and will be operated by Selangor State Government. BRG soil is residual soil, which is a product of extensive weathering on granitic rock in this area.

All soil samples were subjected to two main tests; i.e. (i) physical and chemical tests; and (ii) soil sorption tests via batch equilibrium tests (BET). Physical tests followed the British Standard, BS1377 (BSI, 1975). Physical tests that have been conducted were particle size distribution and falling head permeability tests. Chemical properties were tested using the standard manual produced by the Geotechnical Research Centre of McGill University (unpublished). Among the chemical tests that have been performed were clay mineralogy via XRD, cation exchange capacity (CEC) using ammonium acetate, specific surface area (SSA) using EGME method, and pH measurement using the pH probe meter.

Batch equilibrium tests were carried out using the standard by USEPA (1992). The same procedure was also reported by Yong *et al.* (1992), Yong (2001) and Wan Zuhairi (2000, 2003a, 2003b). According to Jessberger *et al.* (1997), batch tests provide a quick method of estimating the sorption capacity of soils. In BET, 4 g of soil was mixed with 40 ml of a known concentration of tested solution, i.e. HMs. After 24 hours of agitation, soil and solution (supernatant) was then separated by centrifuging. The solution was then analysed using AAS to determine the concentration of HMs left in the solution. The concentration of HMs adsorbed by the soils was then

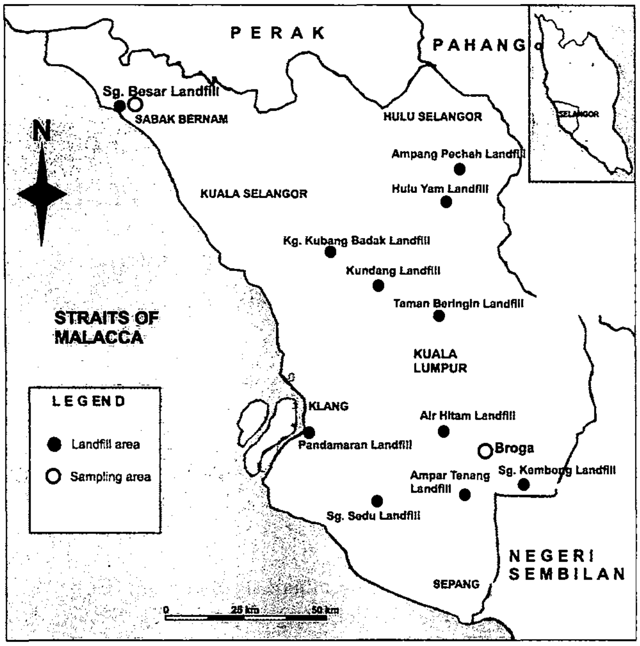

Figure 1. The sampling location map.

calculated. In this test, the soils were exposed to different concentration of nitrate HMs ranging from 100-400 mg/l.

RESULTS AND DISCUSSIONS

Wan Zuhairi (2000 & 2001) studied the material suitability of natural soils from the United Kingdom for engineering clay liner based on their physical and chemical properties. He established that physical and chemical properties greatly control the sorption capability of the soils. In the current study, two different types (genetically) of soils were used. The two types of soil possess very different soil properties, as shown in Table 1. Marine clay soils (SBMC) possess a high percentage of clay and silt, and lesser sand fraction compared to residual soil (BRG). This is due to the presence of the primary mineral quartz in granite, which is highly resistant to weathering. The permeability values after compaction using the standard Proctor test showed very close values for both soils, i.e. in the order of 10^{-9} m/sec. These values are sufficient to comply with the minimum permeability criteria for compacted clay liner as recommended by DOE (1995) and Murray *et al.* (1992).

The SBMC and BRG soils have contrasting chemical properties. SBMC soils have higher pH values compared to BRG soils (only 2 readings are shown for BRG). Soil with high pH values have an ability to adsorb more HMs. This is due to the fact that HMs tend to precipitate with hydroxides/oxides and carbonate materials at higher pH. Soils with high pH values also possess high buffering capacity, i.e. the resistance to change when they are exposed to an acidic solution.

It is interesting to note the contrast in CEC and SSA values for both groups of soils. SBMC soils have higher CEC and SSA values compared to BRG soils. The sorption capability of the soils increases with the increasing values of CEC and SSA (Wan Zuhairi, 2003a, 2003b; Yong, 2001). The discrepancy in SSA and CEC values is due mainly to different types of mineralogy in these soils. SBMC soils contain montmorillonite, which is an active clay mineral that increases the CEC and SSA values. However, in BRG soils, montmorillonite is absent and the content is mainly kaolinite and illite, resulting in small values of SSA and CEC. According to William (1997), montmorillonite has higher SSA (600-800 m^2/g) and CEC (80-100meq/100g) values compared to kaolinite and illite (SSA 5-20 m^2/g and CEC 3-15 meq/100g).

With respect to the physical and chemical values of these soils as presented in Table 1, it is obvious that SBMC soils have higher sorption capacity compared to BRG soils. The results from BET would be very useful to support this information. Figure 2 shows the amount of HMs removed (i.e. adsorbed) by soils from the metal nitrate solution against the concentration of HMs left in the solution after 24 hours of agitation. The figure clearly shows two sets of adsorption curves; (i) almost vertical curves for SBMC soils and (ii) horizontal curves for BRG soils.

The sorption curves for SBMC soils show that all HMs in solution were largely adsorbed, as indicated by small concentration of HMs remaining in the solution after agitation, i.e the small concentration of HMs at the horizontal axes. For instance, in the case of Pb, almost 100% of Pb in solution was adsorbed by SBMC soil at the lowest initial concentration (i.e. 100 mg/l). Similarly at the highest initial concentration of Pb (400 mg/l) almost 100% of Pb was also adsorbed (i.e. ~4 mg/g of Pb was adsorbed as shown in Figure 2). The sorption capability of SBMC soils is excellent, the sorption capacity increased with increasing concentration of initial HMs in solution. This is however not the case for BRG soil. The sorption capacity of BRG soil increased onlt slightly with increasing concentration of HMs in the initial solution (i.e. horizontal-shaped curves as depicted in Figure 2). Taking Pb as an example, at an initial concentration of 100 mg/l, only 0.5 mg/g (50 mg/l or 50%) of Pb was adsorbed by BRG soil. At the highest initial concentration (400 mg/l) only 1.2 mg/g (120 mg/l or 30%) of Pb was adsorbed by BRG soil.

The sorption phenomena in these two soils was contributed by their differences in physical and chemical properties as shown on Table 1. SBMC soils have high pH, high CEC - SSA values, and high clay content with the presence of montmorillonite. These values have contributed to maximum sorption capacity for SBMC soils, as depicted on Figure 2. In contrast, BRG soils, which have very low pH, small SSA-CEC values, and low clay content with only kaolinite and illite present (no montmorillonite); have produced minimum sorption capability (Table 2). According to Frost and Griffin (1977), montmorillonite sorbs approximately five times more of HMs in solution than kaolinite. Yong (2001) stated that montmorillonite can

Table 1. Physical and chemical properties that affect the sorption capability of soils. (SBMC =Sungai Besar marine clay; BRG = Broga residual granite; %S = sand; %M = silt; %C = clay; K = permeability; CEC = cation exchange capacity; SSA = specific surface area; M = montmorilonite; K = koalinite; I = illite; na- = data not available)

	Physical Properties				Chemical properties			
	% S	% M	% C	K x 10^{-9} (m/sec)	pH	CEC Meq/100g	SSA m^2/g	Mineralogy
SBMC1	0	85	15	1.49	7.43	92.48	187	M>K>I
SBMC2	0	84	16	1.18	7.38	101.20	187	M>I
SBMC3	0	78	22	-na-	7.43	118.50	194	M>A>I
SBMC4	0	76	24	-na-	7.45	102.85	201	I>M
SBMC5	3	83	14	-na-	7.62	139.19	88	I>M
BRG1	60	37	2	4.0	4.94	1.85	17	K
BRG2	62	30	7	-na-	4.90	1.66	20	K>>I
BRG3	64	31	3	-na-	- na-	- na-	- na-	K>>I
BRG4	66	27	5	-na-	- na-	- na-	- na-	K
BRG5	59	34	7	-na-	- na-	- na-	- na-	K

Table 2. Comparison of sorption capability between SBMC and BRG soils which are greatly influenced by their basic soil properties.

Soil types	Soil properties	Sorption capacity
Marine clay from Sungai Besar (SBMC)	High pH, high values of CEC and SSA, high amount of montmorillonite, and high clay content	High
Residual soil from Broga (BRG)	Low pH, small values of SSA and CEC, only kaolinite and illite are present (no montmorillonite), and low clay content	Low

sorb metals more rapidly because the absence of restrictions on its mineral structure permits expansion of interlayer space and allow for entry of metals.

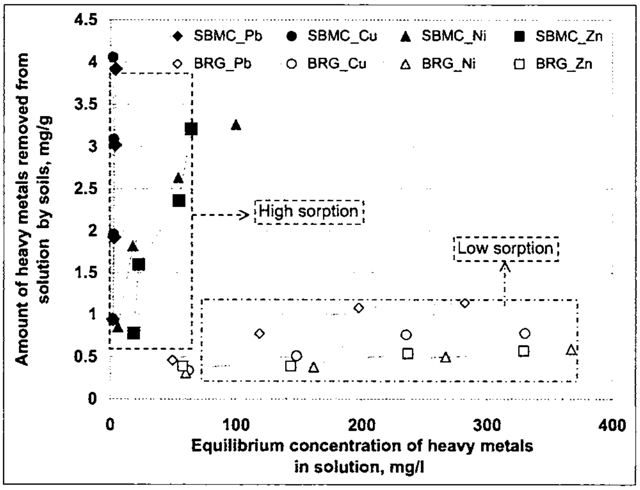

Figure 2. Marine clay soil (SBMC) has better sorption capacity for HMs compared to residual granitic soil (BRG).

CONCLUSIONS

The study clearly shows that the capability of soils to adsorb HMs are greatly controlled by their basic soil properties. Marine clay soils from Sungai Besar in Sabak Bernam (SBMC soils) possess higher sorption capacity compared to residual granitic soil from Broga Semenyih. The study also revealed that soil pH, CEC and SSA values, clay mineralogy, and clay contents are important parameters that affect and control the sorption capability of the soils.

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