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Geochemical Evaluation of Contaminated Soil for Stabilisation with Lime

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Abstract

Stabilisation of heavy metals by addition of lime is proposed to protect water and soil from contamination. Two contaminated soil samples namely clayey soil and waste sediment from Ranau, Sabah, were treated with hydrated lime ($Ca(OH)_2$) in this study. According to the physico-chemical properties, the clayey soil sample is more capable of being stabilised with the addition of lime, thus reducing the amount of leachate to the environment whereas the waste sediments may need more lime to arrest the heavy metals.

Penilaian Geokimia Tanah Tercemar untuk Distabilkan oleh Kapur

Abstrak

Kestabilan logam berat yang ditambah dengan kapur telah dicadangkan untuk melindungi air dan tanah daripada tercemar. Dua sampel tanah tercemar iaitu tanah berlumpur dan sedimen buangan daripada Ranau, Sabah telah dikaji dengan menambahkan kapur terhidrat ($Ca(OH)_2$). Daripada sifat fisiko-kimia, sampel tanah berlumpur adalah lebih cenderung untuk distabilkan dengan penambahan kapur, yang boleh mengurangkan jumlah larut-resap kepada persekitaran sementara sedimen buangan memerlukan lebih banyak kapur dalam menghalang logam berat.

INTRODUCTION

Humans are presently generating wastes of all kinds at an unprecedented rate. This creates problems because the generation of wastes, effluents and emissions, may create severe negative environmental impacts. Industrial waste and mining activities are among the contributors of environmental degradation due to the leaching of contaminants and heavy metals. To prevent the contamination of groundwater, surface water and soil, stabilization with lime has been proposed. The term stabilization in the chemical aspect is altering the hazardous wastes to produce less toxic or mobile forms (Anderson, 1994). Lime stabilisation has so far been used to stabilised soft clay. The application of lime stabilisation has now been extended to stabilise heavy metals in clay soils. The principal advantages of stabilisation are economy, versatility and speed. The mixing of lime with soil could also improve the strength, stress-strain properties, and permeability (Bell, 1996). According to Greaves (1996) the stabilising effect depends on the reaction between lime and the clay minerals. The reaction of lime-clay soil would produce calcium aluminate hydrates mineral, whereas with quartz it would produce calcium silicate hydrates (Bell, 1996). The exchange capacity of calcium aluminate hydrates (ettringite) with regard to environmental contaminants such as heavy metals makes it of particular interest to workers dealing with environmental contamination and waste stabilisation in cementitious materials (Perkins and Palmer, 1999). The study by Davis *et al.* (1999) demonstrated that lime amendment represents a viable long-term method to mitigate acid generation in waste sediment. Application of lime in stabilising heavy metals however, has not been implemented in Malaysia. Thus, the aim of this research is to establish the design and procedure for heavy metal stabilisation using lime. The leaching test is used as a tool to assess the effectiveness of the cementitious compound produced by lime-clay reaction to arrest heavy metals in soil.

GEOLOGICAL BACKGROUND

The study area is underlain by ultrabasic rocks, intermediate rocks, sedimentary rocks of the Crocker Formation, and Quaternary alluvium. The intrusion of ultrabasic rocks during the Triassic period has formed the highland topography in the western and northern parts of the area. The ultrabasic rocks have contributed to the high concentration of heavy metals in the overlying soil. Quaternary deposits such as the Pinousuk Gravel, is distributed along the lowlands at Lohan Valley and towards Kg. Poring (Figure 1).

MATERIAL AND METHODS

Contaminated Soil Samples

Soil samples consisting of clayey soil from Kampung Bongkud (KgB) and waste sediment from Lohan Dam (LDA) were collected for this study (Fig. 1). The clayey soil was taken from the weathering profile of sedimentary rocks at depths of 100 cm from the surface. Based on visual inspection, the soil is dark yellowish in color with black mottle of organic matter. The sedimentary rock is underlain by igneous rocks. LDA samples were collected from the effluent of mining activity. The Mamut Copper Mine has been operating since 1972 and the tailings have been dumped in the Lohan Valley near Kg. Bongkud, Ranau. The waste sediment samples were taken from the tailings profile at depths of 50 cm from the surface. The samples are light yellow, highly porous, with high content of sand.

Lime as Additive

Hydrated lime [$Ca(OH)_2$] is used as an additive to stabilise heavy metals. Hydrated lime was obtained from a lime factory in Pasir Gudang, Johor. The composition of major elements and trace elements in the lime are shown in Table 1.

The mechanism of lime clay reaction in the stabilisation process is called pozzolanic reaction. The reaction would produce new minerals. The minerals are in the form of gel disseminated within the soil particles, creating bridges between the soil particles, and filling into the pore spaces. As a result it will reduce the pore spaces and would retain the mobility of the heavy metals. The formation of calcium aluminate hydrate gel during the pozzolanic reaction is believed to be able to control the movement of the heavy metals via the adsorption and sorption processes.

PHYSICO-CHEMICAL TEST AND PROCEDURE

Dry sieving method was used to analysed the particle size distribution of the coarse soils. Further particle size analysis of clay and silt were conducted using the settling velocity method. The organic matter content was measured by heating 20 g soil samples in 400°C for 8 hours, whereas pH was measured by pH meter. The specific gravity test (SG) and index test were measured according to British Standard. The permeability test and unconfined compression test were adapted from ASTM method. The physico-chemical characteristic of both samples were summarized in Table 1.

The soil samples were air dried and made into powder before further chemical analyses. X-ray fluorescence was used to analyses the concentration of heavy metals and major elements for both samples. The samples were made into pressure pellets and fuse discs (Norrish and Hutton, 1969) and analysed using the 'Philips PW 1480 X-ray Digital' instrument and controlled by Digital Software X 44' microcomputer software. The composition of major elements and heavy metals in the soils samples are shown in Table 2.

Soil mineralogy was identified using the X-ray diffraction method. The KgB sample consists of quartz, kaolinite and muscovite, whereas the LDA sample consists of quartz, microcline and chalcopyrite.

Design of Leaching Test

Leaching tests have been used in a number of disciplines to assess the interaction between fluids and solids. Leaching tests are frequently used to predict the long-term behavior of materials because they allow a much greater degree of contact between the solid and the leachate compared to what really occurs in nature. Hence, they can be used to simulate in a relatively short period of time, the field conditions. In this study, leaching cells, which comprised 150 mm and 100 mm diameter cylindrical plexiglass with pressure gauges attached to measure induced pressure was designed (Figure 2). The setting up of the leaching cell was modified from Tan (1993) and Reid and Brookes (1999). The top and base plates of the cell were made from teflon PTE. The inner side of the leaching cell consists of

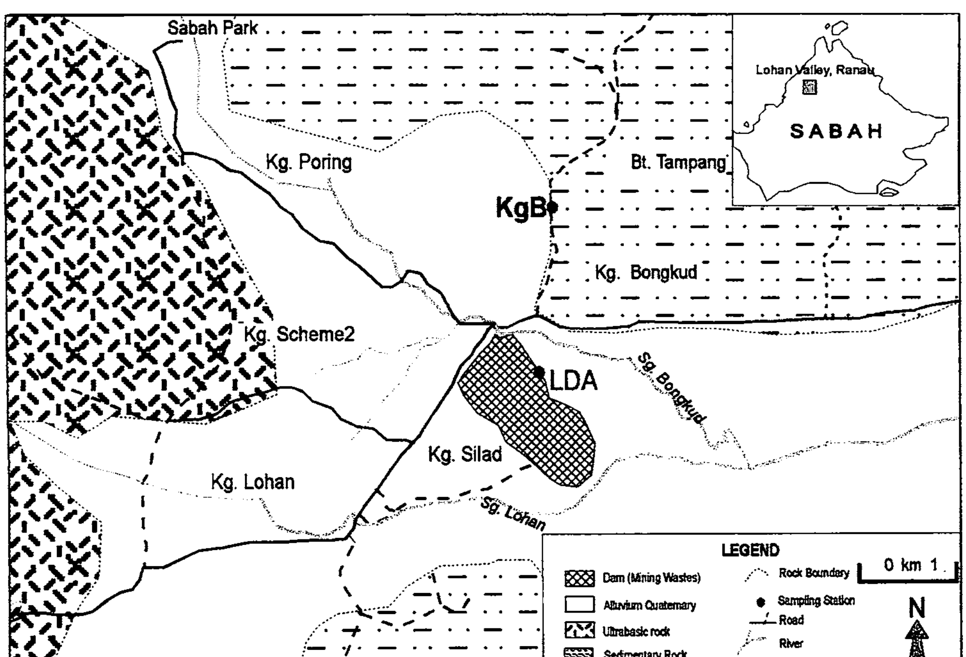

Figure 1: Map of the Lohan Valley, Ranau, Sabah showing the geology and the location of the sampling station.

Table 1: Physico-chemical properties of clayey soil (KgB) and waste sediment of tailing effluent (LDA) from Ranau, Sabah.

Physico-chemical	Samples	
	KgB	**LDA**
Moisture Content (%)	7.31	7.48
Liquid Limit (%)	51	28.5
Plastic Limit (%)	23	-
Plasticity Index (%)	28	-
Specific Gravity	2.57	2.71
Grain Size (%)		
Clay	29.46	4.84
Silt	36.82	12.11
Sand	33.73	83.05
Shrinkage Limit		
S.L (%)	45.39	-
S.R	1.60	-
Permeability (cm/s)	3.62×10^{-8}	7.64×10^{-7}
Dry Density (Mg/m^3)	1.5	3.9
W_{opt}(%)	20	13
Organic Matter (%)	0.73	0.22
pH	3.83	6.84

Table 2: Composition of major elements and heavy metals in clayey soil (KgB), waste sediment of tailing effluent (LDA) from Ranau, Sabah and lime. Note: bdl: below detection limit; KgB: soil samples from Kg. Bongkud, Ranau; LDA: soil sample from tailing effluent in Lohan Dam, Ranau.

Major Elements (%)	Samples		
	KgB	LDA	LIME
SiO_2	64.78	74.85	0.00
TiO_2	0.80	0.22	0.00
Al_2O_3	19.41	7.25	0.10
Fe_2O_3(T)	3.79	6.04	0.10
MnO	0.01	0.07	0.02
MgO	bdl	2.63	2.04
CaO	0.11	1.74	65.82
Na_2O	bdl	0.06	0.00
K_2O	2.24	3.22	0.02
P_2O_5	0.12	0.13	0.02
L.O.I	8.74	3.77	31.88
TOTAL	100.00	100.00	100.00
Heavy Metals (ppm)			
As	38	61	5
Cr	165	383	bdl
Cu	25	1077	bdl
Ni	11	212	36
Pb	395	49	7
Zn	64	100	22

perforated plates and porous stone placing at both ends of the soil samples. The top component of the leaching cell features a leachant inlet and bleed valves.

Among the variables measured in the leaching tests are pH, thickness of soil, time of leaching, curing time of soil and applied loading. Stabilised soil with optimum lime content was used in all leaching samples.

GEOCHEMICAL EVALUATION

The concentration of heavy metals and major elements in clayey soil and waste sediment from the area studied is shown in Table 2. According to the results obtained, LDA samples contained higher heavy metal (As, Cr, Cu, Ni, Zn) concentrations compared to the KgB sample, except for Pb, which is higher in the KgB soil. The highest concentration of Cu is in the LDA sample. The high concentration of heavy metals in both the soil samples is governed by the presence of major minerals. The abundance of SiO_2 and Al_2O_3 in the KgB sample is due to the abundance of kaolinite (clay mineral). However, the abundance of Fe_2O_3 in LDA is due to the abundance of chalcopyrite ($CuFeS_2$). The occurrence of kaolinite in the KgB sample indicates a high degree of weathering which resulted in a thick soil profile, whereas the mineralogy of the LDA samples reflect that the source of the waste sediment are primary minerals.

The acidic environment of the clayey soil (KgB sample) is due to the low pH value of the soil. Whereas, the low pH value in the waste sediments (LDA sample) is cause by acid drainage. Organic matters are higher in the KgB sample compared to the LDA sample, due to its location in the root zone. The waste sediment however, originates from bedrock.

The physical data obtained indicate that the KgB sample is more capable of being stabilized with hydrated lime due to its high plasticity. The sample also shows a low value of permeability (3.62×10^{-8} cm/s), high plasticity index (28) and high content of clay sized particles (29.46%). These are among the criteria of acceptance for lime stabilisation. Soil with lower plasticity and clay fraction, however, can still be stabilised with lime with the addition of artificial pozzolan from the ashes of waste products, for example rice husk ash (RHA). RHA is known to be high in silicate, which is one of the major components for the pozzolanic reaction to take place.

The laboratory leaching tests and treatment with lime is still in progress. The formation of new silicate minerals due to the lime-silicate mineral reaction particularly from clay may be able to stabilise the heavy metals in the contaminated soils thus reduce its mobility.

CONCLUSION

According to the physical properties obtained, the KgB soil is more capable being stabilised with the addition of lime. This has the potential to decrease the amount of heavy metals realeased into the environment. On the other hand, waste sediments (LDA sample) may need more lime or assistance from artificial pozzolan to arrest the heavy metals.

By adding lime to the clayey soil, it will reduce the pore spaces due to formation of calcium silicate hydrate gel and would retain the mobility of the heavy metals through to the water and soil. The adsorption and sorption processes of clay mineral and calcium aluminate hydrate were believed would control the movement of the heavy metals.

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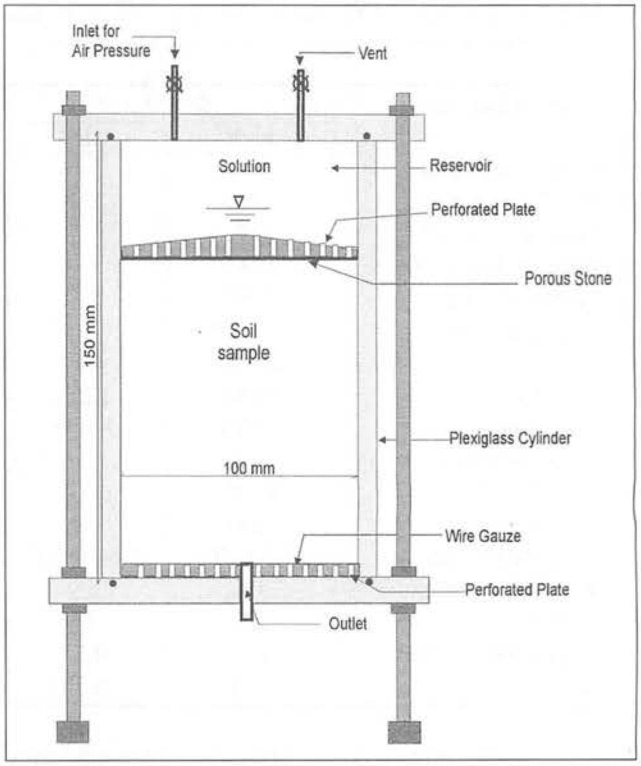

Figure 2: The laboratory leaching cell (modified from Tan, 1993 and Reid and Brookes, 1999).