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Hydraulic conductivity of consolidated slimes from sand mining pits

Conductivité hydraulique de boues consolidées provenant des carrières de sable

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ABSTRACT

The generation of massive volume of slimes from sand mining industry ascertains the need for effective waste treatment. The application of slimes in landfill barrier/liner construction works has been identified as one of the processes that can be used to reduce their volume, enabling in this way the rehabilitation of dangerous sites. This paper presents results on the characterization of slimes from two sites located in South-East Melbourne. The hydraulic conductivity test show that values lower than 10^{-9} m/s can be achieved to meet local guidelines. However, the presence of high level of heavy metals, exceeding the local authority threshold concentrations, needs to be overcome before the slimes can be considered as a potential liner material.

RÉSUMÉ

La production de volume massif de boues visqueuses provenant des carrières de sable établit le besoin de traitement efficace de ces déchets. Leurs utilisations dans la construction des étanchéités minérales des centres de stockage des déchets a été identifiées comme l'un des moyens qui peuvent être employés pour réduire leur volume et faciliter de ce fait la réhabilitation de sites dangereux. Cet article présente des résultats sur la caractérisation des boues provenant de deux sites situés du côté sud-est de Melbourne. Les essais de conductivité hydraulique montrent que des valeurs inférieures à 10^{-9} m/s peuvent être réalisées satisfaisant ainsi les directives locales. Cependant, la présence d'un niveau élevé de métaux lourds, excédant de loin les concentrations de seuil autorisées par les autorités locales, doit être surmontée avant que ces boues puissent être considérées comme un matériau utilisable dans la construction d'étanchéité minérale.

1 INTRODUCTION

Sand mining has long been practiced in the south-east sand belt of Melbourne to obtain clean sand for use in construction. The mining operation is traditionally carried out by using a high pressure water jet to erode the sand and convert it into a slurry. The slurry is then pumped to a sand washing plant. The material remaining after the sand extraction, which generally exists in a sludge or slurry form, is commonly referred to as "slimes" by the local sand mining industry and consists mainly of clay which has been washed from the extracted sand and fine sand particles. The slimes are generated in large volume and are usually retained in a dam or mined out area as dewatering is difficult.

Since the late 1960's most of the abandoned sand mining pits located in the southeast Melbourne have been used for waste landfilling with a goal of obtaining the double benefit of waste disposal and land rehabilitation of marginal areas. Due to the increasing recognition of the impact of landfill leachate on groundwater resources, and also due to the unique hydrogeology of this region, where most landfills are buried below natural groundwater level in permeable sand formations, the use of properly engineered hydraulic barriers has become an essential consideration in the design process (Bouazza et al., 2000). A solution that has been identified is the use of the slimes as part of the lining system and/or as cut-off walls (slimes curtain wall). This not only can create further void space for the landfill but it can also provide an effective means of reducing the impacts of landfill leachate on groundwater.

Previous studies have shown that slimes have a low hydraulic conductivity to water (Soilmech, 1991; Yuen, 1993), which make their use as a hydraulic barrier highly desirable. However, limitations in liner application still exist, e.g. poor stability (Yuen and Style 1995) and difficulty in dewatering (Sparrow and Ihle 1978). More importantly, their interaction with typical contaminants encountered on site is still not known.

This paper presents the results of the laboratory characterization of the slimes, which include their physical properties and chemical properties. Discussion of the hydraulic conductivity test results obtained with acidic pore water (typical in the region where the slimes are used) is also included.

Table 1: Physical property of the slimes (from Wang and Bouazza, 2001)

	Fraser rd. slime	Ryan rd. slime
Water content (%)	127-295	122-272
Initial Void ratio (as sampled)	3.3-7.6	3.2-7.1
Particle size (%) (< 2 μm)	90.9	53.9
Particle density	2.580	2.600
Surface area (m^2/g)	33.9	18.7
Liquid limit (%)	48	37
Plastic limit (%)	69	63
Plasticity index (%)	21	26
Liner shrinkage (%)	16.5	16
Depth of sample (m)	1-6	>8

2 . PHYSICAL PROPERTIES

The physical properties of the slimes are summarized in Table 1. They are characterized by high water contents (120 to 295%), high void ratios (3 to 7) and high fine fractions. The shrinkage of the slimes is relative high, which means that substantial desiccation cracking of the slimes would result upon drying. Desiccation cracking is highly undesirable in liner application because preferential pathways are created in the lining system thus increasing the hydraulic conductivity. These physical attributes make the slime problematical to work with, and thus necessitate the use of various dewatering, stabilization, or treatment if it is to be used as landfill barrier/liner material.

3 MINERALOGY

The mineralogical compositions of the slimes were determined by the X-ray diffraction (XRD) method. The relative mineral fractions were estimated by comparing the peak heights of each mineral in the diffractogram. Attention has been given to the presence of clay minerals since there are the major constituents of the slime, and their surface activity would directly affect the behaviour and dispersion stability of the suspensions. The results of XRD are shown in Table 2.

Table 2: Slimes mineralogy

Location	Fraser rd.	Ryan rd.
Minerals in the slimes	Kaolin Quartz Hematite	Kaolin Quartz Hematite
Colour	Dark grey	Dark brown

The XRD results show that besides the clay minerals (mainly kaolin), non-clay minerals also occur, and consist predominantly of quartz and hematite. The positive surface charge of hematite can adsorb anions in the landfill leachate. This is an advantage in landfill liner material selection.

4 CHEMICAL PROPERTIES

The chemical properties of the slimes determined included the following: Cation Exchange Capacity (CEC), pore fluid electrical conductivity, salinity and pH, and heavy metal contents.

The Cation Exchange Capacity (CEC) of the soil solids was determined using the methylene blue adsorption test (MBAT) method. The results of the chemical analyses are given in Table 3. The high salinity and conductivity means the total amount of soluble cations must be high. The organic content measurements revealed that their contents in the slimes used in the present study are lower than the ones reported by Yuen (1993) for the Clayton Road slime (10%) and Soilmech (1981) for the Dunlop Road (8%), which are considered close to natural organic matter content. The specific surface areas of the slimes, as measured by Wang (2004), were 33.9 m^2/g for the Fraser road slime and 18.7 m^2/g for the Ryan road slime, respectively. Both values are in the high range for kaolin type of material. The high surface area of the slimes means that more chances are offered for the elements in the solution to be exchanged. The CEC of the slimes was thus expected to be in the high range of values experienced by kaolin (i.e 3-15 meq/100g). The results presented in table 3 indicate that the CEC of the slimes is lower than expected. The major reason for the lower CEC is because kaolinite is the only clay mineral in the slimes; in kaolin, the hydrogen ion can be exchanged for other cations. The ease with which the hydrogen can be exchanged (the negative of its bonding energy) increases as the pH of the pore water increases, i.e. as the hydrogen ion concentration of the pore water decreases. Therefore, the charge due to broken bonds increases as the pH increases. However, the pH of both slimes and their pore waters was found to be very low (around 2.9 and 3.1 respectively), indicating that hydrogen ion concentration must be higher at such low pH. Furthermore, the presence of fine sand (10% to 40%) tends also to lower the CEC. In addition, the slimes contain hematite. The positive charge of hematite will repel the cations from the surface of the slimes to reduce the frequency of cation exchange, and contribute to lower further the CEC. The low CEC means that the slimes cannot retard heavy metals efficiently.

Low pH for both the slimes and their filtrate provide acidic environment which is in agreement with the description provided by AGC (1987) regarding the properties of the slimes from South Clayton.

Table 3: Chemical properties (from Wang and Bouazza, 2001)

	Fraser rd. slime	Ryan rd. slime
CEC (meq/100 g)	3.67	1.53
pH (slime)	2.95	2.34
pH (filtrate)	3.85	3.28
Salinity (filtrate, ppm)	2770	2040
Fluid conductivity (filtrate, mS)	5.35	4.00
TOC (slime, %)	4.9	2.9

Table 4 shows the predominant presence of heavy metal based on the results of the quantitative XRF (X-ray fluorescent spectrometry) analysis conducted on the Fraser Road slime and Ryans Road slime and maximum heavy metal limits for the quality of waste discharges guideline from EPAV (1988). In view of the relatively high level of heavy metals contents in the slimes, the mobility of heavy metal and the factors that affect such mobilisation are of great significance if the slimes are to be used as landfill barrier/liner material.

Table 4: Chemical contents in the slimes

Element	Fraser Rd. slime (mg/L)	Ryan Rd. slime (mg/L)	Maximum heavy metal limits for the quality of waste discharges (EPAV, 1988) (mg/L)
Chromium	147	149	0.30
Copper	11	16	0.30
Iron	5.67	5.14	2.00
Lead	13	37	0.10
Ni	68	74	0.50
Zn	79	79	0.50

5 HYDRAULIC CONDUCTIVITY TESTS, RESULTS & DISCUSSION

For the slimes to be used as an effective low permeable material to line landfills, it is necessary to assess their hydraulic conductivity. The slimes slurries are not a solid material and there is no standard test available to determine their hydraulic conductivity. Their compressible and fragile gel structure makes hydraulic conductivity testing even more difficult. A hydraulic conductivity test system was specifically developed to measure the flow characteristics of these materials, combining consolidation and hydraulic conductivity tests using the same cell. The tests were performed in a rigid wall standard consolidation-cell permeameter, which was especially made for slurry materials. The permeameter consisted of a 100-mm-diameter stainless steel piston and two pieces of Grade 304 stainless steel consolidation molds as shown in Figure 1. Two GDS pressure/volume controllers were connected to the permeameters via interface chambers to accurately monitor the pressure and volume of the permeant flowing through the specimen. The purpose of the interface chambers was to protect the controllers from acidic slime and its pore water. The controllers used in the test accurately read pressure up to 1 kPa and volume up to three decimals of a millilitre. The cell pressure was applied by connecting a valve on the top cap of the cell to an air pressure gauge via a rubber tube. A volumetric cylinder recorded the drainage from the slurry during the consolidation process. The tests were conducted under room temperature (18 ^{0}C ± 2^o); different axial pressures were applied for the purpose of obtaining a range of void ratios.

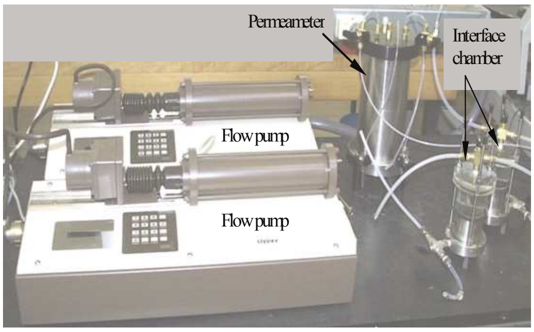

Figure 1. Hydraulic conductivity test set up.

Acidic permeants such as the ones encountered in the Clayton area could increase hydraulic conductivity by flocculation of the clay, dissolution of the clay minerals such as aluminosilicates, and dissolution of other minerals such as $CaCO_3$ (Shackelford, 1994). In order to investigate their potential effect, hydraulic conductivity tests were conducted with two permeants: tap water and pore water. The tap water used at Monash University is supplied by Yarra Valley Water. The pore water was recovered from Fraser Road and Ryans Road slime ponds. Their chemical parameters are summarized in Table5.

Table 5: Permeants characteristics

Parameter	Pore water	Tap water
EC µS/cm	9193	59
TDS (mg/L)	7243	45
Salinity (ppm)	6.37	0.03
DO (mg/L)	6.41	6.40
pH	3.8	6.7

Shackelford (1994) suggested that the primary criterion for termination of compatibility tests should be the establishment of chemical equilibrium between the liquid effluent and the influent used in the test. In this respect, the establishment of hydraulic conductivity equilibrium should be considered only after the chemical equilibrium criterion has been achieved. Two parameters were suggested to be measured: pH and electrical conductance (EC). Based on these considerations, the termination point in the tests conducted in this study initially monitored pH and electrical conductivity. It was found that chemical equilibrium was achieved at about 2 to 3 pore volumes depending on the initial void ratio. However, it was also observed that chemical equilibrium was not an accurate indicator of a hydraulic conductivity termination point for the slimes considered in the current investigation. Although chemical equilibrium was reached after 2 to 3 pore volumes, the flow rate needed 5 pore volumes to reach a stable state (Figure 2). This may have been caused by the chemicals already present in the slimes and the acidic nature of the slimes. Based on the above observations, the termination point for the tests conducted in this study was selected on the basis of the following criteria: 1) establishment of chemical equilibrium; 2) achievement of a stabilized flow. In general terms, the termination point was always slightly higher than 5 pore volumes.

Figure 3 indicates that hydraulic conductivity with pore water (PW) as a permeant is slightly higher than the hydraulic conductivity with tap water (TW) as a permeant. The variations are not larger than one order of magnitude.

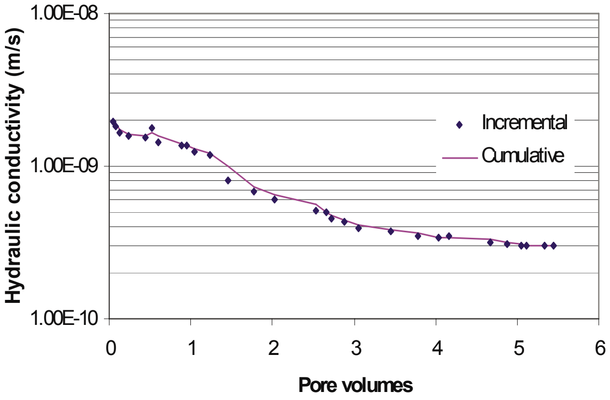

Figure 2. Typical plot of hydraulic conductivity variation versus pore volumes.

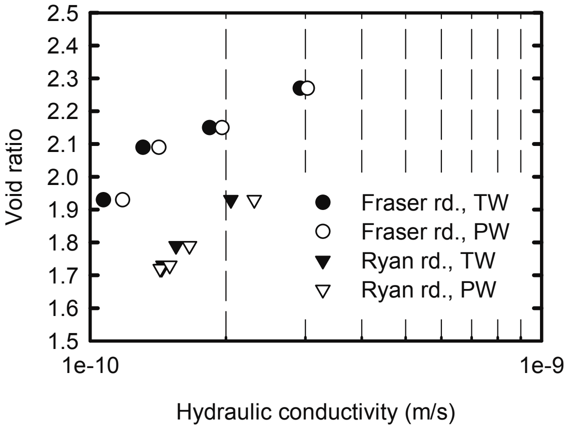

Figure 3. Void ratio versus hydraulic conductivity using different permeant

The possible explanations for these differences are (1) some heavy metals, which were originally adsorbed on the surface of the slimes, may have been desorbed by the acidic permeant. With driving force (hydraulic gradients), the dissolved chemicals might have been flushed out or produced an uneven pore size. As a result the pore size increases. There was an evidence of change in particles as shown in Figure 4. The flow rate (hydraulic conductivity) increases as the pore size of the soil increases; (2) the total dissolved solid (TDS) in the pore water is much higher than in the tap water (Table 5) in certain environments, the dissolved solid may precipitate. The precipitated solid can cause flocculation of the slimes to increase the hydraulic conductivity (Shackelford, 1994); (3) The low pH can dissolve the clay minerals (Shackelford, 1994) and increase the pore size, and hence lift the hydraulic conductivity; (4) Also the acidic permeant can dissolve other minerals, such as $CaCO_3$ and thus increase the hydraulic conductivity (Shackelford, 1994). Regardless of other factors, the hydraulic conductivity of the slimes seems to meet the EPA Victoria (2001) hydraulic conductivity liner requirement of 1×10^{-9} m/s. However, the presence of high level of heavy metals needs to be overcome before the slimes can be considered as a potential liner material.

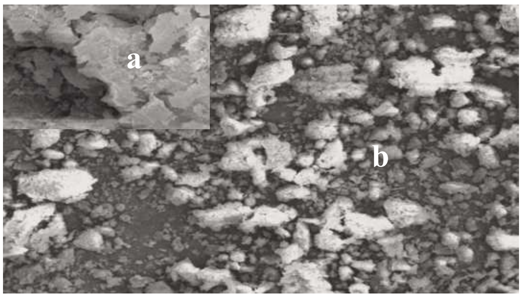

Figure 4. SEM (Scan Electronic Microscopy) image of the slime: a) original slime; b) slime after completion of hydraulic conductivity test with pore water as permeant

6 CONCLUSIONS

The slimes investigated in the present study are highly plastic. The predominant clay mineral component is kaolinite with quartz and hematite being the main non-clay contents. The slimes are very acidic and have very high salinities. The low hydraulic conductivity achieved is a fundamental desirable property of the slime in a landfill liner application. However, in view of the relatively high level of heavy metals contents present in the slimes, the mobility of heavy metal and the factors that affect such mobilisation are of great significance if the slimes are to be used as landfill barrier/liner material.

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