COMPATIBILITY OF THREE TROPICAL CLAYEY SOILS WITH MSW LANDFILL LEACHATE

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ABSTRACT

This paper reports compatibility studies involving three tropical clayey soils and municipal solid waste (MSW) landfill leachate using a constant-flow fixed wall permeameter. The soils were placed under a vertical confining stress of 160 kPa simulating the stress at the base of a landfill with an approximate waste height of 22 m. They were then sequentially permeated with 0.01N $CaSO_4$ and MSW landfill leachate and the effluent and hydraulic conductivity monitored. The effluent breakthrough curves for potassium and iron generally showed strong retardation while the sodium curve showed retardation with tailing. Apart from Pb and Mn all the trace metals were moderately to strongly retarded while Ca and Mg showed early arrival. The hydraulic conductivities of the soils essentially decreased after the passage of 6-12 pore volumes of the leachate probably, due to the high confining stresses imposed, chemical precipitation, pore-clogging and cationic exchange-dependent double layer expansion.

RÉSUMÉ

Cet article présente des études de compatibilité impliquant trois sols argileux tropicaux et le lixiviat des déchets municipals d’enfouissement par employer constant-coulent, perméamètre à paroi fixé. Les sols ont été placés sous une contrainte de confinement verticale qui simulant la pression à la base d'un site d’enfouissement avec une hauteur approximative des déchets de 22 mètres. Ils alors ont été séquentiellement infiltrés par le 0.01N sulfate de calcium et le lixiviat des déchets municipals d’enfouissement et les effluents et la conductivité hydraulique ont été surveillés. Les profiles d’effluents chiminiques obtenus pour le potassium et le fer ont généralement montré le retardement fort tandis que la courbe de sodium montrait le retardement avec l'équeutage. Indépendamment de le plomb et de manganèse tous les oligo-métaux étaient modérément fortement à retardé tandis que le calcium et le magnésium montraient l'arrivée tôt. Les conductivité hydraulique des sols essentiellement a diminué probablement après le passage de 6 à 12 fois le volume des vides interstitiels avec le lixiviat probablement en raison de, la contrainte de confinement élevés imposés, la précipitation chimique, la obstruction des vides, et la expansion de la double couche créé par les reactions d’ échanger des cations.

1. INTRODUCTION

Among the requirements for a good liner in a municipal solid waste (MSW) landfill is the expectation that the liner possesses a low hydraulic conductivity, typically not exceeding the regulatory value of 10^{-9} m/s. Minimum shrinkage potential to minimize cracking, adequate shear strength to ensure stability of the liner and compatibility with the intended leachate are also desirable qualities of a good liner. Due to their low hydraulic conductivity and high sorptive capacity several clayey soils have been considered for use either alone or, preferably, in conjunction with geosynthetic materials as chemical and hydraulic barriers to contaminating fluids in MSW disposal facilities. In order to reliably assess the performance of the clay liner, an evaluation of its compatibility with the intended leachate is necessary. This assessment should take into account the environmental conditions prevalent at the site. Despite the wealth of information available from clay-leachate compatibility studies that have been undertaken over the years, there is a paucity of data on tropical soils as most of the studies have involved the use of clays from temperate regions. The knowledge of the behaviour of tropical clayey soil liners and especially their compatibility with MSW landfill leachate is important, as significant differences exist between the temperate and tropical environments. Examples are differences in the properties of soils and environmental conditions. As engineered MSW landfills are being considered as a viable waste disposal option in some tropical developing countries, the need for tropical clay barrier-MSW leachate compatibility assessments cannot be overemphasized.

Diffusion and hydraulic conductivity studies together with the evaluation of the mineralogy and the physicochemical properties of potential clay liners have usually been used to assess clay liner- leachate compatibility. Compatibility studies involving hydraulic conductivity assessments, evaluation of effluent composition and the mineralogical and physicochemical properties of the soils, before and after permeation, have been undertaken. This paper reports on preliminary results of compatibility studies involving three tropical clayey soils and MSW landfill leachate using a constant-flow fixed wall permeameter.

2. MATERIALS AND METHODS

2.1 Materials

Three tropical soils from Ghana, West Africa, designated as Samples HW, AS and KWB were sampled for this study. Samples HW and AS are residual weathered products of Lower Birrimian (Middle Precambrian) phyllites. Sample HW is reddish brown while Sample AS is yellowish brown. Sample KWB however, is dark brown and derived from the weathering of massive quartzite of Middle to Late Precambrian age. During the study period the first batch of engineered landfills were then under initial stages of construction in Ghana. Leachate from an engineered landfill within this tropical environment was thus unavailable for sampling. Leachate was therefore sampled from W12A Landfill, London, Canada for the study. The choice of this leachate was primarily influenced by the similarities in some of its properties to those of some tropical leachates reported in the literature (Li et al. 1999, El-Fadel at al. 2002)

2.2 Test Procedures

2.2.1 Index geotechnical and physicochemical tests

The following index geotechnical and physicochemical tests were performed on the soils in accordance with American Society for Testing and Materials (ASTM) specifications (ASTM 2002): natural moisture content, Atterberg Limits, shrinkage characteristics, specific gravity of solids, particle size distribution and the standard Proctor compaction. The pH and electrical conductivity of samples were determined using miniprobes.

2.2.2 Soil and Leachate Composition

The specific surface of the soils was determined by the glycol retention method (Martin 1955). The cation exchange capacity (CEC) of the soils was determined using potassium chloride and silver thiourea exchange procedures. The concentrations of cations in the decanted supernatants were then determined by atomic absorption spectrophotometry using Philips Atomic Absorption Spectrometer PU9100X. The total organic matter content of each soil was determined using a titrimetric dichromate redox (the Walkley–Black) method (Walkley and Black 1934). With the use of the Chittick apparatus, a gasometric method based on the procedures described by Dremanis (1962) was used to determine the carbonate content of the soils. The composition of some elements and trace metals within the soil and liquid samples were also determined. The composition of cations in liquid samples was determined using Inductively Coupled Plasma– Atomic Emission Spectroscopy (ICP-AES).

The mineralogical compositions of the soils were determined using X-ray Diffraction (XRD) and X-ray Fluorescence (XRF) techniques. To obtain good dispersion of the samples prior to XRD testing, they were vigorously shaken in water and later with a sonic dismembrator. The mixture was then subsequently centrifuged. Another objective of the pre-test sample preparation was to remove soluble salts from the samples as their presence could result in clay particle flocculation. For instance, it has been known that iron oxides can cement particles together and thus inhibit dispersion of clay mineral particles (Moore and Reynolds, 1997). They can also increase the background noise on the x-ray diffractogram. The targeted removal of extractable Al, Fe and Si compounds were undertaken using acid hydroxylamine (0.25M hydroxylamine hydrochloride, $NH_2OH.HCl$ – 0.25M hydrochloride acid, HCl solution) and adopting the procedures of Ross et al (1985) and Wang et al (1987). The untreated soil and soil samples saturated with potassium and magnesium were x-rayed. The slides were also subjected to wetting with water, air-drying, ethylene glycol solvation and heating at 550ºC for 30 minutes prior to x-ray analysis. X-ray diffraction (XRD) analysis was performed using a Rigaku Rotating Anode X-ray diffractometer that employs cobalt $K\alpha$ radiation in a horizontal mount. The samples for powder pattern analysis were scanned at a rate of 10° 2θ per minute over an angular range of 2°- 82° with the filtered $CoK\alpha$ radiation.

2.2.3 Hydraulic conductivity testing

The soils were compacted at target moisture content of 2% above optimum, using a Harvard miniature compactor, in a cylindrical stainless steel mould. Approximately 2 cm of compacted soil was permeated with the permeant. A detailed description of the permeameter used has been provided by Fernadez and Quigley (1985). During the hydraulic conductivity tests the soils were placed under a vertical confining stress of 160 kPa simulating the stress at the base of a landfill with an approximate height of 22 m. They were then sequentially permeated with 0.01N $CaSO_4$ and MSW landfill leachate and the effluent and hydraulic conductivity monitored. The pH, electrical conductivity and compositions of selected elements within the effluents that were sampled, during the passage of several pore volumes of the permeant, were also monitored. The mineralogical composition, CEC, organic matter content and the glycol retention values of the clayey soils were also determined prior to and after permeation to assess any compositional changes as a result of the permeation.

3. RESULTS AND DISCUSSION

3.1 Soil and Leachate Properties

3.1.1 Index geotechnical and physicochemical properties of soils

Index geotechnical and some of the physicochemical properties of the soils are presented in Table 1. The natural moisture contents of the samples were between 27% and 29%. The minimum moisture contents of the air-dry powder were within the range 1.2 – 4.6%. The high air-dry moisture content of Sample KWB (4.6%) suggests that it could contain a clay mineral with interlayer water. Texturally, the soils can be considered as loamy clays. The specific gravities of the samples are high (2.72-2.78) and this is typical of tropical soils that contain iron minerals and concretionary gravels. Under the Unified Soil Classification System the soils classify as inorganic clays of high plasticity (CH).

Table 1: Index geotechnical and physicochemical properties of soils.

Property	Sample		
	HW	AS	KWB
Moisture Contents (%)			
Natural	*27*	*27*	*29*
Air-dry powder	*1.4*	*1.2*	*4.6*
Atterberg Limits, %			
Liquid Limit	47	53	87
Plastic Limit	26	26	27
Plasticity Index	21	27	60
Shrinkage Characteristics			
Shrinkage Limit, SL	*22*	*18*	*8*
Shrinkage Ratio, R	*1.70*	*1.80*	*2.80*
Volumetric Shrinkage, Vs at w = OMC + 2%	*1.0*	*9.3*	*36.7*
Linear Shrinkage, L_s	*20.9*	*43.9*	*64.5*
Specific Gravity	2.78	2.72	2.78
Particle Size Distribution, %			
Clay	39	35	39
Silt	28	33	49
Sand	33	32	12
Activity, A	0.55	0.77	1.54
Liquidity Index, LI	0.06	0.03	0.04
Standard Proctor Compaction			
MDD, kg/m^3	1592	1570	1632
OMC, %	20.8	21.1	19.0

Due to its high plasticity index of 60% (Table 1) Sample KWB would, in general, have a higher swelling potential than the others. All the soils would behave as plastic materials when sheared since they have liquidity indices exceeding zero but less than unity. Based on the classification scheme for soil activity (Head 1980) Sample HW is an inactive clay (A<0.75), Sample AS is a "normal" clay (0.75<A<1.25) while Sample KWB is an active clay (A>1.25). Indeed these activity values suggest the likely presence of montmorillonite (not the Na-type; A ≅ 1.5) in KWB and illites (A ≅ 0.9) and kaolinites (A ≅ 0.4) in the others (Head 1980; Yong and Warkentin 1975; Mitchell 1993). Although the soils contain relatively high percentages of clay-size particles (35-39%), the high linear shrinkage of Sample KWB suggests that the clay minerals have a more dominant influence on the shrinkage properties of Sample KWB than the others. The shrinkage ratio which is the ratio of the change in volume, expressed as a percentage of the final dry volume, to the change in moisture content, above the shrinkage limit was highest for Sample KWB (2.80) and least for Sample HW (1.70). The soils had high linear shrinkage (20.9 - 64.5). Their volumetric shrinkage values, calculated at 2% of OMC, were however, low for Sample HW (1), moderate for Sample AS but high for Sample KWB (36.7) (Table 1). Shrinkage parameters give an indication of the extent of volume changes and hence the potential for expansion, desiccation and cracking that could occur with moisture fluctuations. The shrinkage properties of the soils suggest that the hydraulic conductivities of Samples HW and AS could be only slightly affected by volumetric changes, as they do not show high shrinkage potential. Omidi et al (1995) have shown that the hydraulic conductivities of soils with volumetric shrinkage exceeding 11% are greatly affected by desiccation after compaction. Thus, it may be necessary to blend Sample KWB with a suitable amendment to reduce its volumetric shrinkage to less than the threshold value of 11% before it could be considered for liner construction. The soils appear to have adequate compacted strength with maximum Proctor dry densities of at least 1592 kg/m^3 at optimum moisture contents varying between 19% and 20.8%.

3.1.2 Leachate

The results of the chemical analysis of the leachate are presented in Table 2. With a near-neutral pH of 7.39 the leachate is potentially not aggressive suggesting that the acetogenic activity of the landfill has declined. With the non-acidic pH of the leachate, most of the heavy metals in the landfill would have probably precipitated out of solution leading to the low concentration of heavy metals in the leachate.

Using data from 13 municipal landfills in Hong Kong, Li et al (1999) reported that the leachates generated at domestic waste landfills have high NH^+_4-N (3000-6000 mg/L) while those at sites for a mixture of domestic and construction waste have a relatively less NH^+_4 –N composition (1000-2500 mg/L). Another reported characteristic feature of such Hong Kong leachates is a low BOD_5/COD ratio of 0.21-0.25 and COD/NH^4_+ - N ratio of 1 – 2.33. The leachate used in the present study has a low BOD_5/COD ratio of 0.07 and COD/NH^4_+ - N ratio of 1.55. The low BOD_5 values show that there is depletion of readily biodegradable matter within the landfill. In addition, with a moderate NH^+_4 –N concentration of 1164 mg/L, the leachate is typical of that generated from a landfill in a tropical climate that accepts a mixture of domestic and construction wastes. The ammonia concentrations and the high Kjeldahl-Nitrogen (ammonia and organic) and chloride concentrations show that the physico-chemical attenuation or biological processes within the landfill have had little or no effects on the concentrations of these compounds (El-Fadel et al, 2002).

Table 2: Chemical composition of leachates.

Parameter	Value*	Parameter	Value*
pH [ ]	7.39	Total Iron	5.89
Conductivity, µS/cm	16,140	Manganese	0.06
Suspended Solids	2330	Calcium	1006
BOD_5	131	Magnesium	401
COD	1802	Mercury, µg/L	<0.01
DOC as C	439	Arsenic	<0.002
COD/DOC Ratio	4.1	Barium	0.25
Ammonia as NH_4^+ - N	1164	Boron	6.94
BOD/COD Ratio	0.07	Strontium	1.84
COD/ NH_4^+ - N Ratio,	1.55	Nickel	0.22
Alkalinity as $CaCO_3$	5744	Zinc	0.14
TKN as N	1566	Lead	0.05
Nitrate as NO_3 - N	2.51	Cobalt	0.05
Nitrite as NO_3 -N	<0.01	Chromium	0.04
Sulphate as SO_4	870	Copper	0.03
Total Phosphorous as P	8.51	Cadmium	<0.01
Chloride as Cl^-	1781	Selenium	<0.002
Sodium	1415	Beryllium	<0.001
Potassium	1100		

* Unless otherwise stated all units are in mg/L

3.1.3 Chemical and mineralogical composition of soils

The results of the chemical tests have been summarized in Table 3. According to the classification of soil pH proposed by Young (1976), Samples HW and AS may be described as strongly acidic while Sample KWB is either weakly alkaline or neutral. The high losses on ignition of the soils at 105^{o}C suggest the presence of significant amounts of free or molecular water and also reflect the amounts of organic matter present in the soils. From Table 3, it is evident that the soils are essentially composed of oxides of silicon, aluminium and iron in decreasing order of concentration. Oxides of these three elements constitute at least 80% (81.9– 88.5%) of the oxides in each of these soils. Of the oxides that occur in trace amounts the significant ones are TiO_2, K_2O, MgO and CaO. Soils with silica: sesquioxide ratios of <1.33 and 1.33 – 2.00 are described as laterites or lateritic and non-lateritic respectively. Thus, Sample HW can be described as a laterite or lateritic soil while the others are non-lateritic.

Table 3: Summary of some chemical properties of the test soils

Property	Sample		
	HW	AS	KWB
Standard pH (air-dried soil: water; 1: 2)	4.82	4.87	7.25
Total Organic Matter, %	0.9	0.9	1.7
Glycol Retention, mg/g clay	33.7	22.1	83.8
Cation Exchange Capacity (CEC), meq/100g	2.8	3.2	22.6
Carbonates, %	2.6	3.7	4.5
Dolomite	1.63	2.32	1.56
Calcite	0.97	1.38	2.94
Major Oxides, %			
SiO_2	55.0	66.3	60.7
Al_2O_3	21.4	17.9	13.9
Fe_2O_3	8.1	4.3	7.3
TiO_2	1.3	0.9	1.3
K_2O	0.13	0.8	0.26
MnO	0.04	0.02	0.19
MgO	0.21	0.3	0.87
CaO	0.11	0.08	2.23
Na_2O	<0.01	.01	0.73
P_2O_5	0.07	0.03	0.04
Cr_2O_3	0.02	0.03	0.02
Silica: Sesquioxide Ratio [$SiO_2/(Al_2O_3 + Fe_2O_3)$]	1.86	3.00	2.90
Loss On Ignition (%)	12.9	8.7	12.0
Trace Metal Concentration, ppm			
Vanadium	152	145	174
Chromium	86	156	125
Zinc	47	56	62
Nickel	45	47	41
Copper	27	21	42
Lead	16	12	24
Arsenic	7	11	3
Cobalt	11	9	40

The mineralogical compositions of the soils were determined based on the random powder diffractograms, preferred orientation x-ray diffractograms, the chemical test results and the semi-quantitative analyses of the XRD data (not shown). The results suggest the following compositions:

Sample HW - 46% quartz, 35.7% kaolinite, 8.1% iron oxyhydroxides (goethite, ilmenite and magnetite), 5.4% bayerite, 2.1% Mg-Vermiculite and 1.8% potassium feldspar.

Sample AS –36% quartz, 21.4% kaolinite, 17.9% aluminum oxyhydroxides (gibbsite and bayerite), 13.8% dehydrated halloysite, 4.3% goethite, and 3.2% vermiculite, 2.8% interlayered smectite - illite and 0.1% potassium feldspar.

Sample KWB - 40% quartz, 36.6% Fe-chlorite - Al-interlayered smectite, 8.3% aluminum oxyhydroxides (gibbsite, bayerite and diaspore), 6% iron oxyhydroxides (goethite, haematite and magnetite), 2.8% dolomite, 1.6% iron and/or titanium oxides (ilmenite and anatase), 1.3% kaolinite and traces of potassium and plagioclase feldspars.

Essentially the glycol retention values and the CEC test results are consistent with the results of the mineralogical studies. The glycol retention values of 22.1 and 33.7 mg/g (whole soil) for Samples AS and HW respectively suggest the predominance of 1:1 layer silicate minerals in these soils. On the other hand, the value of 83.8 mg/g suggests that low charge clay minerals may be the dominant clay minerals in Sample KWB. Similarly, the low CEC values of Samples HW and AS do not suggest the occurrence of significant amounts of active clay minerals in these soils. The CEC of 22.6 meq/100g is indicative of the occurrence of active clay mineral(s) in Sample KWB while the low values preclude their occurrence from the other soils.

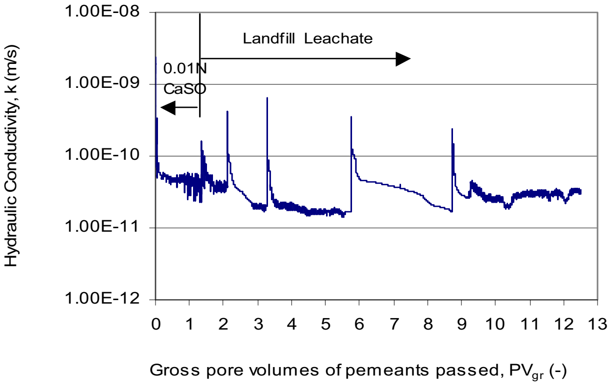
3.2 Clay-Leachate Compatibility

3.2.1 Hydraulic Conductivity Variation

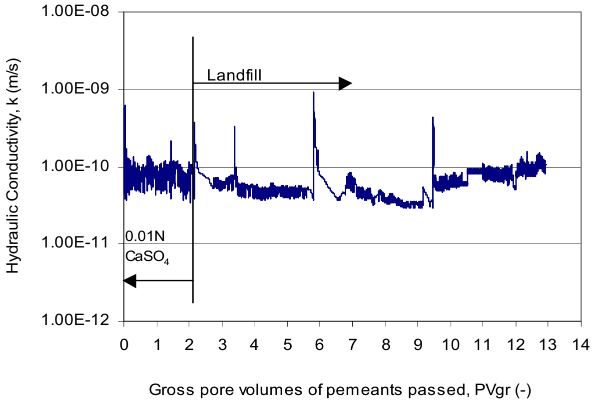
Figure 1 shows the hydraulic conductivities, K obtained as a result of the permeation. The K test for Sample KWB was terminated after 6 pore volumes of permeation, to prevent damage to the pressure transducer as its capacity of 700 kPa was on the verge of being exceeded.

The average final baseline hydraulic conductivities obtained with 0.01N $CaSO_4$ were 4.66 X 10^{-11} m/s, 7.84 X 10^{-11} m/s and 1.64 X 10^{-12} m/s for Samples HW, AS and KWB respectively.

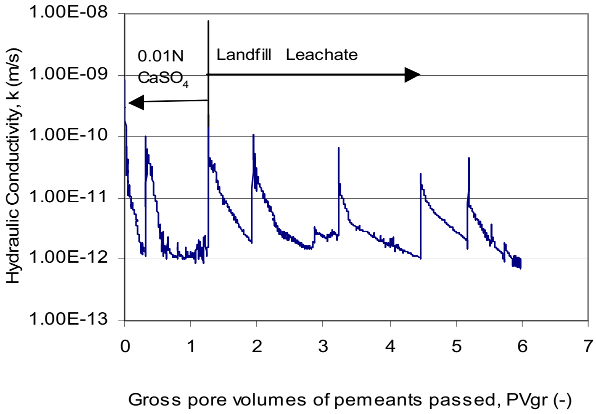
At the end of permeation with 5-12 pore volumes of the landfill leachate the K attained were 3.14 X 10^{-11} m/s, 9.01 X 10^{-11} m/s and 9.51 X 10^{-13} m/s for Samples HW, AS and KWB respectively. These results indicate a decrease in hydraulic conductivity upon leachate permeation of Samples HW and KWB. On the other hand, the final K of Sample AS slightly increased above the baseline value although the soil experienced an earlier decrease during permeation with landfill leachate. The observed decrease in K of the Samples HW and KWB, which are consistent with the results of Yong et al (1985), Quigley et al (1987) and Yanful et al (1990), can be attributed to several factors.



(a) Sample HW



(b) Sample AS



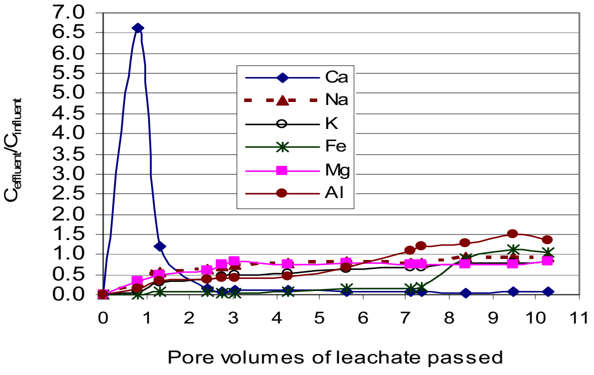
(c) Sample KWB

Figure 1: Variation of hydraulic conductivity of soils

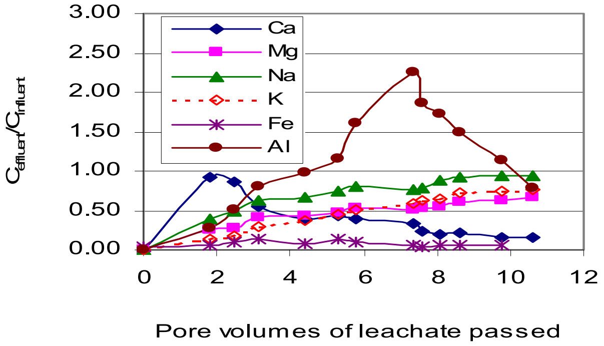
There were high concentrations of $NH4^+$, Na+ and K^+ in the leachate and these cations were involved in exchange with the Mg^{2+} and Ca^{2+} present in the soils. The exchange of these univalent cations with the divalent cations can result in double layer expansion and hence hydraulic conductivity decrease (Yong and Warkentin 1975, Rowe et al 1997, Yanful et al 1990 and Mitchell 1993). The decrease in K could also be due to pore plugging caused by either microbial growth or chemical precipitates. The high confining stresses used to simulate the field stresses could also have resulted in consolidation of the samples and hence the decrease in K. However, the observed slight increase in the hydraulic conductivity of Sample AS towards the end of permeation could not be explained by the above phenomena. Sample AS was difficult to compact probably due to the occurrence of halloysite in the soil. Figure 1b shows that Sample AS had an erratic hydraulic conductivity suggesting rapid clogging of compaction-induced micro fractures within the soil. Although the potential for self-healing of cracks has been acknowledged in the literature (Fickies et al 1979, Boyton and Daniel 1985, Mallwitz 1998) almost all these studies found an increase in hydraulic conductivity after crack-healing over the uncracked soil liner. These results show that when cracks are formed they become persistent planes of weakness and may serve as preferred conduits for flow thereby increasing hydraulic conductivity of the liner. It is probable that on prolonged permeation with landfill leachate some of the precipitates in the macropores were unplugged thereby resulting in the observed minor increase in K.

3.2.2 Effluent Composition

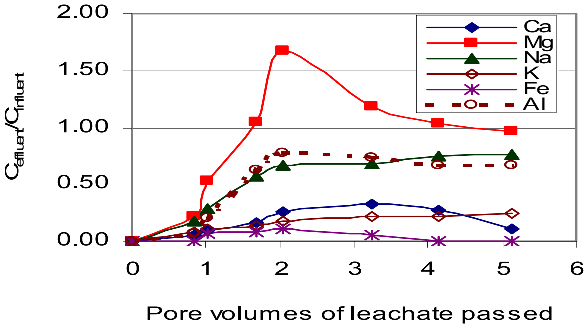
The effluent breakthrough curves for the cations are shown as Figure 2. The effluent breakthrough curves for potassium and iron generally showed strong retardation while the sodium curve showed retardation with tailing in all the soils (Figure 2). Calcium and magnesium arrived early and were desorbed indicating that they were major cations involved in exchange reactions with species like sodium and potassium, which were present in appreciably high concentrations in the leachate. The effluent/influent concentration ratio of magnesium did not return to unity in Sample KWB suggesting long-term dissolution of Mg-rich minerals (oxyhydroxides and carbonates) that occur within the soil. In all the soils the concentration of iron in the effluent did not exceed that present in the leachate. The breakthrough curve shows that aluminium concentration in the effluent exceeded the influent concentration in Samples HW and AS for a long period (Figure 2a and 2b). This may suggest the long-term dissolution in the leachate of aluminium oxyhydroxides present in the soils after prolonged permeation. On the contrary during permeation in Sample KWB, the ratio of the effluent/influent aluminium concentration was always less than unity (Figure 2c). It is probable that interaction of the leachate with the soil was not long enough for the solubilisation of aluminium oxyhydroxides in Sample KWB, due to the premature termination of the K test to prevent damage to the pressure transducers as a result of the generation of unacceptably high pressures.



(a) Sample HW



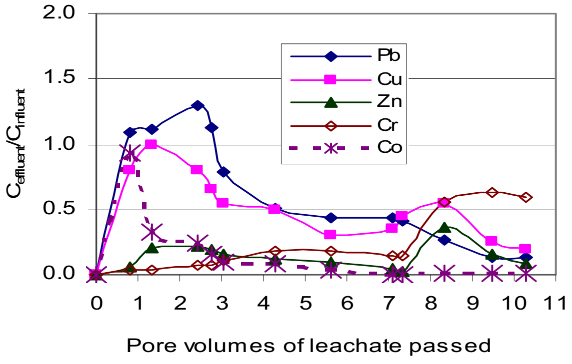
(b) Sample AS



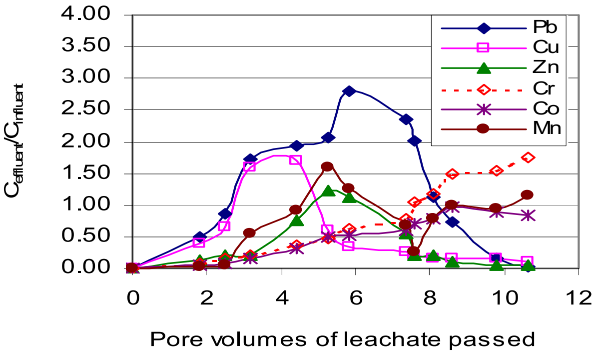
(c) Sample KWB

Figure 2: Variation of effluent cation composition

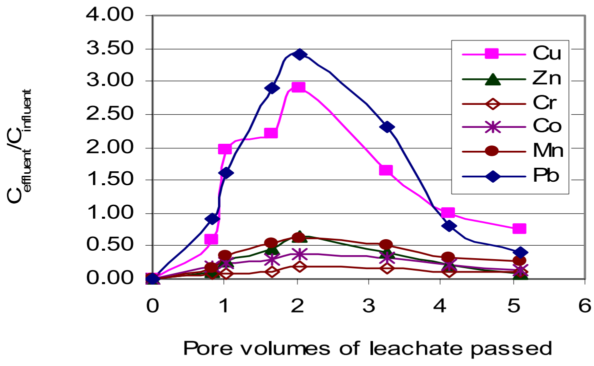
Figure 3 shows the effluent breakthrough curves for the trace metals. Apart from Pb, Cu and to some extent Co, which showed early arrival from Samples HW and KWB (Figures 3a and 3c), all the trace metals were moderately to strongly retarded suggesting that these soils could be effective hydraulic barriers against the release of some of the trace metals from the leachate.



(a) Sample HW



(b) Sample AS



(c) Sample KWB

Figure 3: Variation of effluent metal composition

With the test samples at moisture contents above optimum, oxygen diffusion through the samples during permeation would be minimised. Under these conditions, soil bacteria near the soil-influent interface use up oxygen present in the permeant and render the system practically devoid of molecular oxygen (Yanful et al 1990). This reducing environment results in the reduction of sulphate to sulphide and this has the tendency to form metal sulphides thereby reducing leachate metals to lower concentrations, as observed in the effluents (Figure 3). The pH of the influent leachate was 7.9 while the average effluent pH towards the end of the permeation was 9.0. The increase in the pH of the permeant during permeation would also create a conducive environment for precipitation of heavy metals thereby resulting in the reported low metal concentrations in the effluent.

3.2.3 Soil Compositional Changes

The total organic matter contents of the soils upon permeation with landfill leachate increased to 1.2%, 1.1% and 1.5% for Samples HW, AS and KWB respectively. These increases could be attributed to the formation within the soil of moderate to high molecular weight humic substances from the organic matter in landfill leachate. These humic substances tend to form strong complexes with heavy metals (Reinhart and Al-Yousfi 1996). The glycol retention values of the soils at the end of permeation were lower than those of the native soils.

Glycol retention values are related to the specific surface of the soils and this is a function of their mineralogical compositions. The lowering of the glycol retention values suggests mineral alterations within the soils and consequent impact on soil properties such as plasticity, water retention and cohesion. There were minor differences in the diffractograms (not presented) of the leachate-permeated soils from the natural soils, particularly with respect to the clay mineral peaks of Samples HW and AS. However, in all the soils the leachate had either enhanced most of the non-clay mineral peaks or resulted in the development of a few new peaks. Some of the new minerals that were likely to have been formed were strontianite ($SrCO_3$), pyrite (FeS_2), $FeCO_3$ and dickite.

4. CONCLUSIONS

The effluent breakthrough curves for potassium and iron generally showed strong retardation while the sodium curve showed retardation with tailing in all the soils. Ca and Mg arrived early suggesting desorption from soil as a result of ion exchange with Na and K originally present in high concentrations in the leachate. Some of the soils were effective in the retention of trace metals such as cobalt, zinc and chromium. The low metal concentration in the effluent would suggest precipitation of heavy metal hydroxides or carbonates due to an increase in the pH of the permeant during permeation. Some of the new minerals that were likely formed as a result of the prolonged landfill leachate permeation were strontianite ($SrCO_3$), pyrite (FeS_2), $FeCO_3$ and dickite. The hydraulic conductivities of two of the soils essentially decreased after the passage of 5-12 pore volumes of the leachate probably, due to the high confining stresses imposed, chemical precipitation, pore-clogging and cationic exchange-dependent double layer expansion. However, the third sample experienced a slight increase in the baseline hydraulic conductivity. This may be attributed to the unplugging of some of the precipitates in the compaction-induced soil macropores after prolonged permeation with landfill leachate. The results of the study have shown that the tropical soils were essentially compatible with the landfill leachate.

References

ASTM, 2002 Annual Book Of ASTM Standards. Section 4 Construction – Volume 04.08 Soil and Rock (I): D 420-D 5779. ASTM International, W. Conshohocken, PA: 1672pp.

Boyton, S. S. and Daniel, D. E. 1985 Hydraulic conductivity tests on compacted clay. ASCE Journal of Geotechnical Engineering, Vol. 111, No. 4, pp.: 465-478.

Chao, T. T. and Zhou, L. 1983. Extraction techniques for selective dissolution of amorphous iron oxides from soils and sediments. American Journal of Soil Science Society, Vol. 47, pp. 225-232.

Curtin, D. and Rostad, H. P. W. 1997. Cation exchange and buffer potential of Saskatchewan soils estimated from texture, organic matter and pH. Canadian Journal Of Soil Science, Vol. 77, pp. 621-626.

Dremanis, A. 1962. Quantitative gasometric determination of calcite and dolomite by using Chittick Apparatus. Journal of Sedimentary Petrology. Vol 32, No. 3 (Sept., 1962), pp 520-529.

El-Fadel M., Bou-Zeid E., Chahine W. and Alayli B., Temporal variation of leachate quality from pre-sorted and baled MSW with high organic and moisture content. Waste Management, Vol. 22, No. 3, pp. 269-282.

Fernandez, F. and Quigley, R. M. 1985 Hydraulic conductivity of natural clays permeated with simple liquid hydrocarbons. Canadian Geotechnical Journal, Vol. 22, pp. 205-214.

Fickies, R. H., Fakundiny, R. H. and Mosley, E. T. 1979 Geotechnical analysis of soil samples from test trench at Western New York Nuclear Service Center, Report to US Nuclear Regulatory Commission, West Valley, NY.

Head, K. H. 1980. Manual of soil laboratory testing Vol. 1 – Soil classification and compaction tests. John Wiley & Sons, Toronto.

Holtz, R. D. and Kovacs, W. D. 1989. An introduction to geotechnical engineering. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Li, X. Z., Zhao, Q. L. and Hao, X. D. 1999 Ammonium removal from landfill leachate by chemical precipitation. Waste Management, Vol. 19, pp. 409-415.

Mallwitz, K. 1998 Crack-healing in damaged compacted clayey liners in waste deposits. Proc. Of the Third International Congress on Environmental Geotechnics, Lisbon, Portugal (ed. P. S. Seco e Pinto), Environmental Geotechnics Vol. 1, pp.: 347-352.

Martin, R. T. 1955. Glycol retention analysis. Proc. Of Soil Science Society America, Vol. 19, No. 2, pp. 160-164.

Mitchell, J. K. 1993 Fundamentals of Soil Behaviour. John Wiley & Sons Inc., New York, NY.

Moore, D. M. and Reynolds, R. C. Jnr. 1997 X-Ray Diffraction and the Identification and Analysis of Minerals, Oxford University Press Inc., New York

Omidi, G. H., Thomas, J. C. and Brown, K. W. 1995 Effect of desiccation cracking on the hydraulic conductivity of a compacted clay liner. Water, Air and Soil Pollution, Vol. 89, pp. 91-103.

Quigley, R. M., Fernandez, F., Yanful, E. Helgason, T., Margaritis, A. and Whitby, J. L. 1987 Hydraulic conductivity of contaminated natural clay directly below the Confederation Road domestic waste landfill, Sarnia, Ontario. Canadian Geotechnical Journal, Vol 24, pp. 377-383.

Ross, G. J., Wang, C. and Schuppli, P. A. 1985 Hydroxylamine and ammonium oxalate solutions as extractants for Fe and Al from soil. American Journal of Soil Science Society, Vol. 49, pp. 783-785.

Rowe, R. K., Quigley, R. M. and Booker, J. R. 1997 Clay barrier systems for waste disposal facilities. E & FN Spon, London, UK.

Walkley, A. and Black, I. A. 1934 An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science, Vol. 34, pp. 29-38.

Wang, C., Schuppli, P. A. and Ross, G. J. 1987 A comparison of hydroxylamine and ammonium oxalate solutions as extractants for Al, Fe and Si from Spodosols and Spodosol-like soils in Canada. Geoderma, Vol.40, pp. 345-355.

Yanful, E. K., Haug, M. D. and Wong, L. C. 1990 The impact of synthetic leachate on the hydraulic conductivity of a smectitic till underlying a landfill near Saskatoon, Saskatchewan. Canadian Geotechnical Journal, Vol. 27, pp. 507-519.

Young, A. 1976 Tropical Soils and Soil Surveys. Cambridge University Press, London.

Yong, R. N. and Warkentin, B. P. 1975 Soil Properties and Behaviour. Developments in Geotechnical Engineering Vol. 5, Elsevier Sc. Pub. Cnyy, Amsterdam.

Yong, R. N., Elmonayaeri, D. S. and Chong, T. S. 1985 The effect of leaching on the integrity of a natural clay. Engineering Geology (Amsterdam), Vol. 21, pp. 279-299.