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Leachate Percolation through Failed Geomembrane of a Geo-Composite Soil Barrier

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Abstract Sequence of laboratory tests on geo-composite barriers under the influence of leachate transport through failed geomembrane were conducted in a small-scale model device. A 24mm thick soil barrier liner, 2mm thick polyethylene plastic with 5mm hole to simulate failed geomembrane and a 225mm thick Attenuation profile (AP) constituted the model setup. Leachate transport through the barrier-AP system was measured for tests under pressure of up to 150kPa. Measured flow rates for good geomembrane/soil interface contact conditions were considered in this study. Results and analysis however, shows significant reduction in leachate flow rates with increased pressure, p, on the defected geomembrane. The reduction in flow rates are accounted for by the reduced barrier system transmissivity, θ, and the soil barrier densification. The measured concentration of selected contaminant species/ions in the AP after every test confirmed the flow through the failed geomembrane/mineral barrier layer and showed the three natural soils investigated in this study to have good buffering capabilities towards the selected chemical species/ions.

Keywords: *contaminant; leachate, geo-composite, geomembrane, attenuation*

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1. Introduction

SOLID wastes generation have been documented as the result of by-product of human activities [1,2]. It is essential that these waste products are hauled off in engineered facilities if they cannot be properly handled by other processes. In South Africa, However, land disposal has always been and would remain the most common form of disposing various types of waste in ages to come. Waste disposal by landfill as stated by [1] produces gases and leachates, whose break away from disposal facilities must be restricted. This must be done to curtail or better still, eliminate impact on the environment. Rain, runoffs, waste containing high moisture and bacterial activities triggers the generation of leachate in landfills. Hence, to ensure the protection of important soil and ground water regimes against impacts from landfill leachates, geo-composite barriers are usually utilized. In some instances, geomembrane; forming part of a geo-composite may fail due to defects from fabrication, installation or aging. In some other cases, siting landfills near important water sources is unavoidable and in such scenarios, the separation of waste body and ground water need be efficiently executed [2]. This can be achieved by considering the use of compacted clay liners (CCL) as part of the composite lining system to control any leachate that may infiltrate the failed liner i.e. Geomembrane (GM) or Geosynthetic Clay Liner (GCL). As such, Geomembrane/soil composite liners are widely and actively used in waste containment facilities and will continue to form significant components for many of the multiple systems in engineered landfill facilities.

The application of geosynthetic components is firmly recognized in designs and is gradually expanding as manufacturers source, develop new and improved materials and engineers/designers develop new analysis routines [3]. Nonetheless, in-situ defects in geomembrane cannot be completely avoided [4]. The daily disposal of more than 41 thousand tonnes of solid waste in South Africa with Gauteng province and Johannesburg city dumping off more than 17 and 4 thousand tonnes respectively is gradually attracting major concerns [5]. This waste disposal in turn often leads to serious health, environmental and aesthetic problems. Among these is the pollution of vital subsurface and groundwater resources thus, the need for the study. The influence of applied pressure on leachate transport rate through failed geomembrane and contaminant migration mechanism through geo-composite barrier with natural soils as CCL and the buffering capabilities of natural soils have not been well documented. However, about 75% of Municipal Solid Waste (MSW) in South Africa is disposed in landfills, the barrier systems are under pressure, p, from the heap of waste. Pressure on the lining systems is estimated to be about 150kPa considering the height of the heaped waste/landfill thicknesses of about 8-10m.

Therefore in this study, a small-scale model test on leachate transport through a defected geomembrane liner system underlain by a layer of soil as CCL and AP was conducted. The effect of the applied pressure on the flow rate, the mechanism of contaminant seepage and the buffering capacity of the natural soils were investigated.

2. Materials and Method

Three soils were collected and used as CCLs and APs in this investigation. The soils were obtained close to three different landfill sites at points sufficiently distant from the actual dump as shown in Figure 1. This was done to prevent impurities as much as possible and the samples were labeled A, B and C for the three sites respectively. In the first test conducted, soil-A was mixed with 50% coarse sand (equal proportion of particles passing 4.75mm, 3.35mm, 2.36mm and 2.00mm sieves). Inclusion of coarse sand was primarily to increase permeability of the barrier layer and shorten the test duration. Gravelly back-fill material mixed with coarse sand (equal proportion of particles passing 4.75mm and 3.35mm) was used as AP.

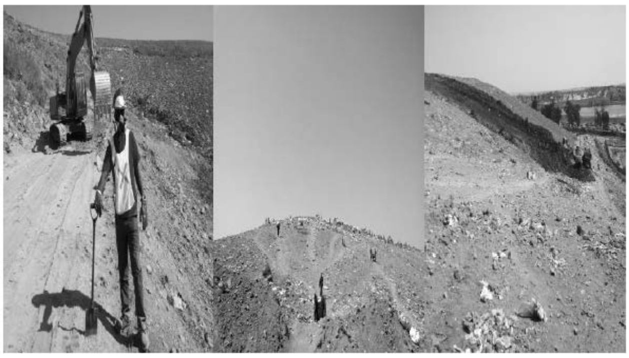

Figure 1. Pictorial view of soil sampling areas

The soils were passed through mechanical and chemical tests. Figure 2 shows the grain size distribution curves of the soils, while the relationship between water content and the dry unit weight of the soils were determined by the compaction test in accordance with [6]. The standard proctor compaction test was done using a light rammer with self-weight of about 0.0244kN and striking effort of about 595kN-m/m^3. The respective compaction curves are shown in Figure 3.

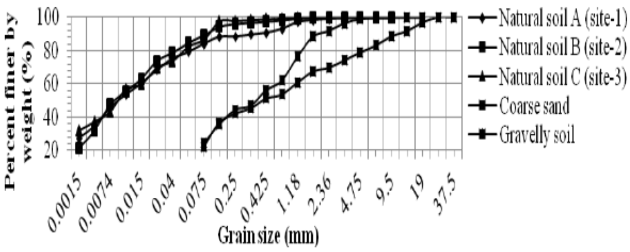

Figure 2. Grain size distribution curves for the different soils

The tests yielded optimum water contents of 8.7, 14.7% and maximum dry unit weights of 17.3, 16.2kN/m^3 for soil-A+coarse sand and the gravelly soil respectively. While optimum water contents of 16.2, 15.4 and 15.7% and maximum dry unit weights of 15.2, 16.4 and 17.4kN/m^3 were gotten for the respective natural soils. Values for permeability coefficient were measured by falling head test in accordance with [7]. The relationship between the permeability and dry unit weight of the natural soils is shown in Figure 4. Through the entire testing sessions, APs were prepared at relatively low water content and lightly compacted to simulate in-situ conditions of natural soils. Saline water prepared from mixing 10g of salt per 1L of de-ionized water was used as leachate in the first test. Other permeant used were gotten from leachate ponds (as in Figure 5) designed to collect leachate generated at the various landfill sites (due to infiltration of storm water and/or interception of the subsurface water with the buried waste).

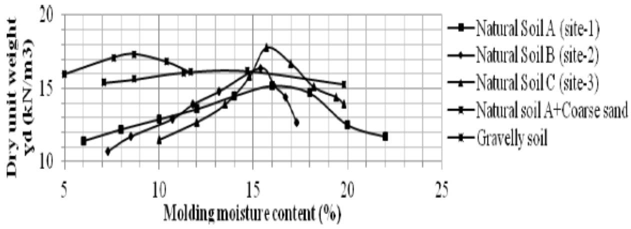

Figure 3. Compaction curve for the various natural soils

The leachate samples were labeled X, Y and Z to differentiate respective ponds of collection. Each sample was taken from a number of points within a leachate pond and pooled together to ensure a proper leachate mixture. Table 1 shows the initial concentrations (mg/l) of the targeted chemical parameters from chemical analyses for the different leachates. The chemical ions were measured by full spectral analysis method on the influent and effluent and compared to standard drinking water in consonance with [8,9].

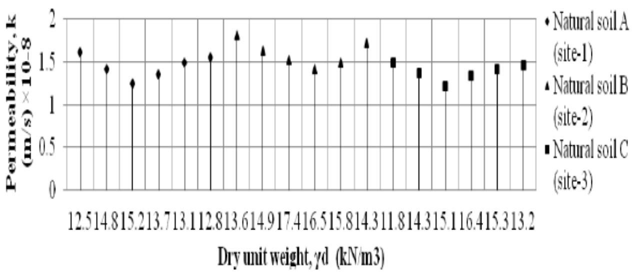

Figure 4. Permeability variation of the various soil samples

Figure 5. Permeate collected from different leachate ponds

In the tests under pressure, densification of the soil barrier occurred due to changes in the applied loads. Nonetheless, after the system was unloaded at the end of the test, the soil layers showed negligible changes. A 2mm thick polyethylene plastic as geomembrane liner with a 5mm diameter hole at the center to simulate defect was improvised due to material constraints. Other varieties of barrier lining designs could not be tested. Although this work was not to investigate different geomembrane liners. However, the complexity and nature of the different contaminant species capable of being generated from the decomposition of solid waste in landfills and the insufficient spectral testing materials, made it impossible to detail all compositional features and characteristics of such products. As such herein, only one main category of the different chemical species was investigated namely; Heavy Metals. Due to the countless chemical species present in the various leachate samples, only two selected individual contaminants were tested for intrusion and retention in the AP.

Table 1. ANALYSIS OF LEACHATE SAMPLES USED FOR LEACHING TESTS

Parameter	ASTM Test No.	Concentration (mg/l) of Sample X Sample Y Sample Z			Standard for Drinking Water (mg/l)*
		Sample X	Sample Y	Sample Z	
Fe	D 1068	5.0	4.0	6.0	15
Pb	D 3551	1.0	0.09	1.2	0.05

(Water services authorities South Africa, 1997).

The selection of these contaminants was made based on the following criteria: (a) the potential hazardous effect expected in the case of the contaminant breakthrough to the subsurface environment based on; (b) the availability and concentration of these chemical species present in the different leachate solutions generated at the landfill sites. The parameters analyzed included the following: Fe ions and Pb ions. The leachate chamber was marked to hold a constant head of 250mm through the series of tests. A view of the model device is shown in Figure 6.

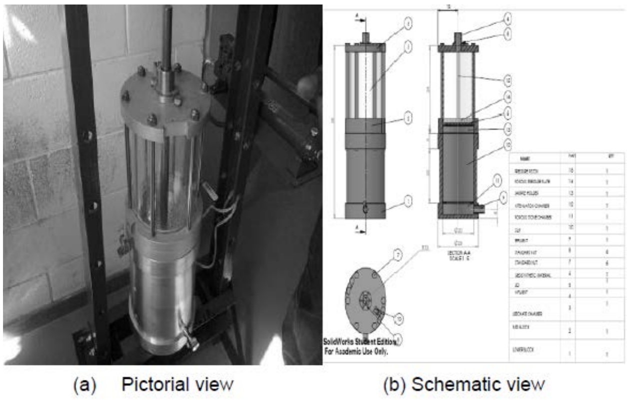

Figure 6. Modular consolidometer-percolation column hybrid device

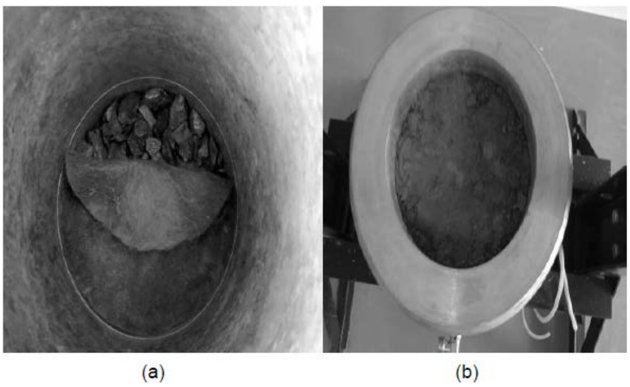

Figure 7. (a) Wetted geotextile on porous stone to prevent outlet clogging (b) Lightly rammered AP to simulate loosed subsoil in the chamber

The device comprised of three parts: (1) the bottom part called the buffering/attenuation chamber; which contained the natural soil layer acting as the natural earth and AP below the geo-composite system (as shown in Figure 7) (2) the mid-block called the sample holder; contained the designed geo-composite barrier system (natural soil as CCL and failed geomembrane) which seats on the buffering chamber (see Figure 8) and (3) the upper portion above the geo-composite barrier; functioned as the leachate reservoir/chamber (as per Figure 9).

Soil layers were prepared inside the bottom chamber, the mid-block/sample holder and the failed geomembrane was placed on top of the soil layer. After the components were assembled, O-rings, gasket corks and silicon sealants were used to prevent leakages and maintain tight seals between the top, mid and bottom sections of the device. The loading frame was set up (for tests which required applied pressure), the leachate added and the desired pressure, p, was applied. The vertical hydraulic conductivity, k_z value, in stratified soil (hydraulic conductivity of a barrier layer-attenuation profile) was calculated and used to determine the flow rate, Q.

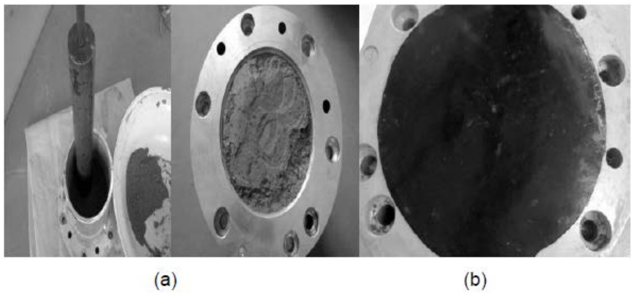

Figure 8. (a) Compacting the soil in layers (as CCL) in the barrier holder (b) Defected geomembrane with 5mm hole placed over CCL

In the first test conducted with saline water, no pressure was applied. Consequently, samples collected from six sectioned cores of the AP were tested and measured for concentration of target source parameters/ions in the pore water using pulverized pore fluid extraction method and silver thiourea method. The analyses were conducted using the 902 Double Beam Atomic Absorption Spectrophotometry in line with [10].

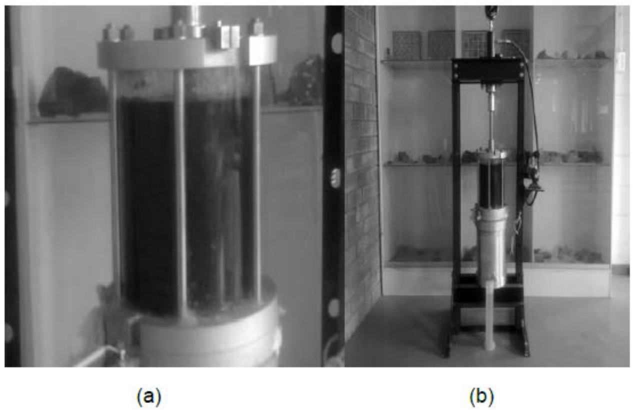

Figure 9. (a) Leachate in reservoir (b) Set-up under load from the hydraulic pressure system

3. Discussion of Findings

3.1. Column-Hybrid Permeation Tests

Regardless of other confirmatory tests carried out in this study, four main permeation tests were conducted.

The first test was done with samples D (a mixture of soil A+coarse sand) to form the soil barrier and sample E (a mixture of gravelly soil+coarse sand) served as AP with saline water as the leachate and no pressure applied to the system. Successive tests were for the respective samples collected at the different landfills.

Table 2 summarizes the test features; durations and materials under which each test was carried out. In the first test with saline water (done with and without geomembrane) flow rates were measured, ions concentration and conductivity values from effluent were taken using an ion meter. The results are shown in Figure 10a and b.

Table 2. TEST FEATURES

Test No.	Barrier Lining System (Natural soil as CCL)		Geosynthetic material	Defect Size, Type and Position
	Soil	Dry Unit Weight (kN/m^3)		
1	D	16.2	2mm thick polyethylene plastic as Geomembrane	5mm circular hole in the centre
2	A	15.2	"	"
3	B	16.4	"	"
4	C	17.4	"	"
Test No.	Attenuation Profile (Natural soil as CCL)		Pressure, p (kPa)	Test duration
	Soil	Dry Unit Weight (kN/m^3)		
1	E	13.6	0	7days
2	A	11.9	0→25→50→100→150	100days
3	B	12.7	0→25→50→100→150	93days
4	C	12.3	0→25→50→100→150	95days

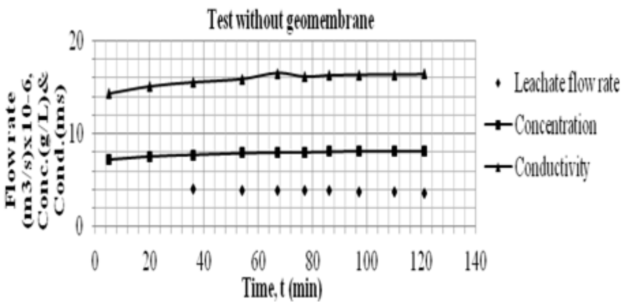

Figure 10a. Flow rate, conc. and cond. values for test without geomembrane at p = 0kPa

Test to determine the heavy metals concentration and migration through the AP was measured to investigate the mechanism of contaminant transport in the composite liner and the buffering capabilities of the soils. This was done at the end of every test and results for the leachate flow rate through the composite liners are shown in Figure 11a to e. From Figure 10a, the flow rate for test without geomembrane was noticed not to reach steady state due to suspected clogging by moving fines.

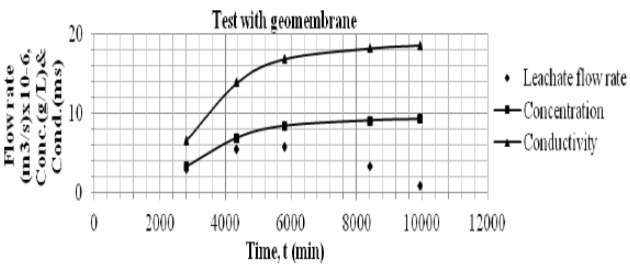

Figure 10b. Flow rate, conc. and cond. values for test with geomembrane at p = 0kPa

However, in subsequent tests this was controlled by using moistened geotextile on a porous stone which served as filter to prevent moving fines from clogging the outlet of the system. The concentration and conductivity of the effluents from tests with and without geomembrane revealed a steady increase over the test periods as seen in Figs. 10a and b.

For subsequent samples, steady or quasi steady state was reached in about 20days into the test and the flow rate was monitored and measured for a period of up to 30days. The flow rate, Q, was seen to gradually increase to a steady value. However in Figs. 11a to e, changes in the flow rate were observed as pressure was applied.

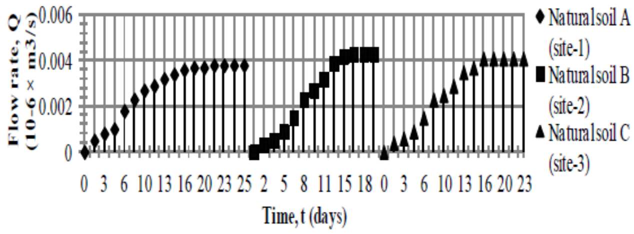

Figure 11a. Leachate flow rate against time for p = 0kPa

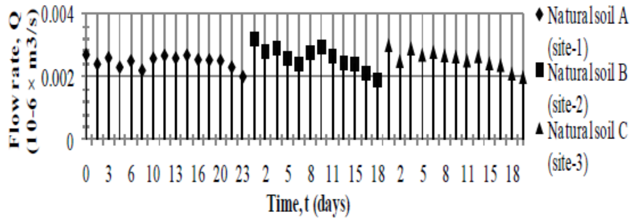

Figure 11b. Leachate flow rate against time for p = 25kPa

The first pressure, p, of 25kPa was applied to the systems of the three samples. Steady state was reached after about 18-20days as shown in Fig. 11b and the flow rate was monitored and measured for a period of 30days.

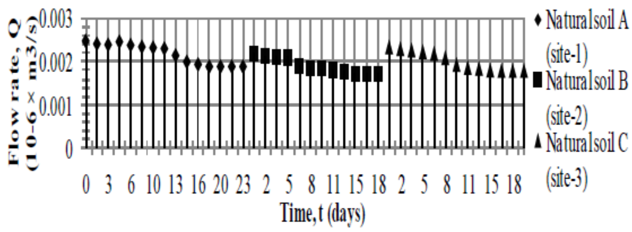

Figure 11c. Leachate flow rate against time for p = 50kPa

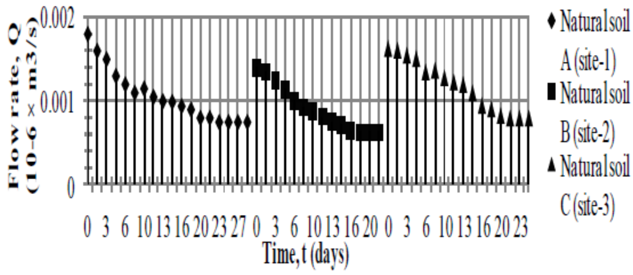

Figure 11d. Leachate flow rate against time for p = 100kPa

The flow rates, Q, were measured for each pressure and Figure 11c to e shows the measured relationship between flow rates, Q, versus time, t, for pressure values of 50-150kPa.

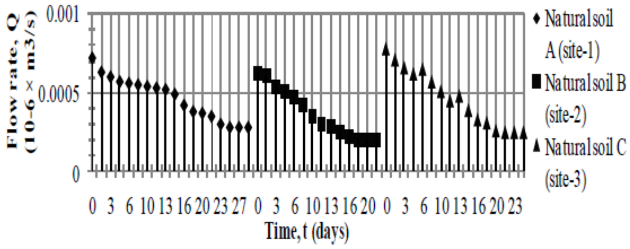

Figure 11e. Leachate flow rate against time for p = 150kPa

An increasing pressure on the geomembrane showed the flow rates to gradually reduce to a steady value. Figure 12 shows the relationship between the measured flow rates, Q, against pressure, p.

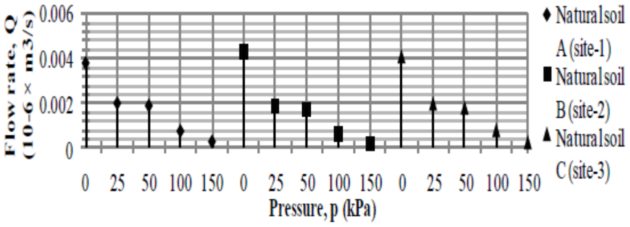

Figure 12. Leachate flow rate against p values for the different samples

The increase in pressure caused a change in density which led to a decrease in the permeability of the soil barrier. Furthermore, the applied pressure to the system may have created a fair contact between the geomembrane and the soil layer thereby reducing the interface transmissivity; reducing the interface thickness and transmissivity, θ. This accounts for the gradual decrease to a steady state of the flow rates, Q.

3.2. Soil Buffering Capacity and Ions Transport

It was recorded during the leachate analyses and characterizations that the landfill leachates had relatively low trace elements including heavy metals.

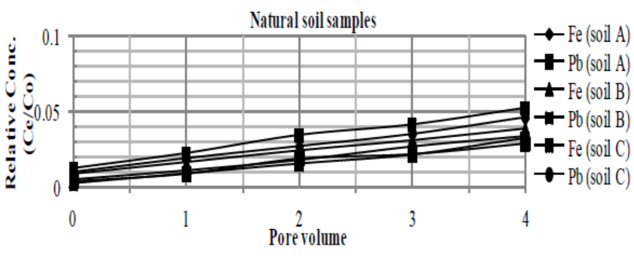

Figure 13. Relative conc. of heavy metals in effluent (Co and Ce = initial and final conc.)

Results from the percolation tests then confirmed that these small amounts of trace elements do not migrate in any peculiar or significant manner through the respective soils. The effluent relative concentration for the heavy metals; Fe and Pb with respect to the pore volume for the three soils after reaching steady state is shown in Figure 13. There was no recognized significant difference in the transportation of the heavy metals through the soils.

Results from the APs were compared for the different soils, the heavy metals in soil C were found to be more mobile than soils A and B. These data indicate that the exchange capacity and the chemical characteristics of the soils are the dominant features controlling the buffering of heavy metals. Results obtained from the chemical analysis of the pore fluid extracted from six core sections of the AP were consistent with the soil column effluent concentrations.

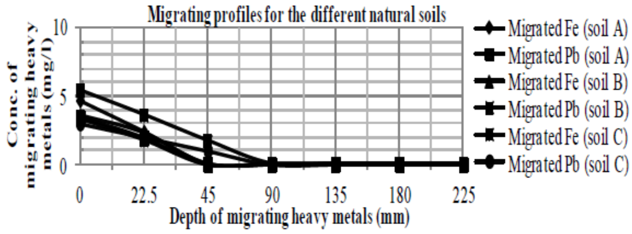

Figure 14. Migration profiles of heavy metals through the AP

The results showed that significant amounts of heavy metals were retained in the top portions of the soil as revealed in the concentration depth profiles in Figure 14. The Fe ions appeared to be more mobile than Pb ions found in the leachate, especially in the case where a more acidic environment prevailed. Therefore, in general, the natural soil exhibited good buffering tendencies to the migration of heavy metals through the AP.

4. Conclusion

The tests on geo-composite liners under the influence of leachate flow from geomembrane defects were conducted in a small-scale model device called a Modular Consolidometer-Percolation Column Hybrid. Influence of the pressure, imposing the leachate transport rate together with the transport mechanism and attenuation of contaminants (heavy metals) were investigated. From tests and analysis of results, the following conclusions were arrived at;

The increase in pressure, on the barrier systems was observed to significantly reduce the leachate transport rates; and from analysis, there was clear indication that the reduction was as a result of the reduction in geomembrane/soil interface transmissivity, θ, and the expected soil liner densification.

The tests with geomembrane showed interface flow between the geomembrane and soil barrier; that a perfect geomembrane/soil barrier contact was not achieved with results from the percolation tests and pore fluid concentration of the transported ions confirming the flow through the geomembrane-soil interface.

The measured concentration of selected contaminant species in the six sectioned cores of the AP after the termination of each test revealed the natural soils to have good buffering capabilities towards the selected chemical species; the results showed that significant amounts of heavy metals were retained in the top portions of the soil samples. However, further study needs to be conducted on the influence of pressure on the interface contact behaviour.

Acknowledgment

The authors appreciate the University of Johannesburg where this study was successfully carried out.

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