An Experiential Perspective of Leachate Seepage through Defected Geomembrane of Geo-composite Barrier

Emmanuel Emem-Obong Agbenyeku, Edison Muzenda and Innocent Mandla Msibi

Abstract—Laboratory tests using a small-scale model device were carried out on leachate seepage in geo-composite barriers due to circular geomembrane defects. Various pressures simulating actual landfill waste loads were applied to the barrier systems. Seepage rate, anion migration and the attenuation tendency of a natural mineral layer were investigated. Seepage through the geo-composite barrier-attenuation strata (AS) system was determined under waste loads of up to 150 kPa impacting the defected geomembrane liner. The findings revealed appreciable reduction in seepage rate with increased pressure on the system. The reduction is ascribed to the reduced barrier transmissivity, θ and compressed soil layer. Data for seepage rates were compared with predicted values from Forchheimer's (1930) and Giroud's et al (1986) equations. The comparisons displayed inapplicability to this study and to real practice, if conditions of perfect contact at the geomembrane/soil interface are assumed. Nonetheless, Giraud's (1997) equation for good contact condition gave reasonable prediction of seepage rate through geo-composite liners with defected geomembrane.

Index Terms—*Geo-composite, Geomembrane, Ions, Leachate, Pressure*

I. INTRODUCTION

Waste disposal involves the use of land and this trend has been the case from decades ago. Disposal of waste in landfills as reported by [1] generates gases and leachates/contaminants whose break away from engineered contaminant restriction facilities must be constantly monitored and controlled to prevent or eliminate severe impact on the surrounding environment. As such, to guarantee that soil and ground water resources be protected from landfill leachates, geo-composite barrier systems are mostly employed. Geomembrane/mineral composite barriers are often utilized in engineered contaminant restriction facilities and will continually gain grounds as significant components of landfills lining systems. It is well known however, that in-situ and ex-situ geomembrane failures can at best be minimized but cannot be prevented. In this light, geomembrane forming part of a geo-composite liner may fail due to defects on or out of site from fabrication, installation or aging [2]. Therefore, to ascertain leachate seepage through defective geomembrane above a mineral/soil barrier is crucial to designs of containment facilities. The construction of such facilities around valuable water sources are in some cases inevitable. In such cases, the proper and effective separation of waste body and ground water need be executed [3]. This can be made possible when compacted clay liners (CCLs) are utilized as part of the composite barrier system to control migrating leachate that may infiltrate the defected liner i.e. geomembrane (GM) or geosynthetic clay liner (GCL).

In a fast growing and developing country like South Africa, Gauteng province and the City of Johannesburg (CoJ) alone generates approximately half of the nation's daily waste with deposition areas (landfills) drastically decreasing for reasons of land shortages with time. As recorded by [4] the vast and increasing tonnes of disposed waste each day are attracting concern and waste dumping often leads to health, environmental and aesthetic issues. Pollution of vital subsurface and groundwater resources is often times of major concern thus, the need for the study. There are several predictive equations proposed for similar problems of seepages through defected landfill barriers however, [2], [5] stated that predicted values differ by wide margins for different scenarios and applied conditions. The influence of pressure (simulating waste load) on leachate seepage through defected geomembrane of a mineral geo-composite, the migration pattern through the geo-composite of natural soil as compacted clay liner (CCL) and the attenuation capacities of the natural soil have not been well documented. Hence, small-scale model tests on leachate seepage through circular defected geomembrane with underlying natural kaolinitic soil as CCL and AS was executed. Effects of pressure applied to the system on leachate seepage rate, mechanism of seepage and the attenuation ability of the natural soil to anions; HCO_3 and Cl were investigated.

II. METHODOLOGY

A soil barrier layer-24 mm thick, 5 mm diameter hole placed at the center of a 2 mm thick polyethylene plastic simulated the defected geomembrane with a 225 mm thick AS made up the test model setup. The modeled device, a Modular Consolidometer-Percolation Column Hybrid of 160mm

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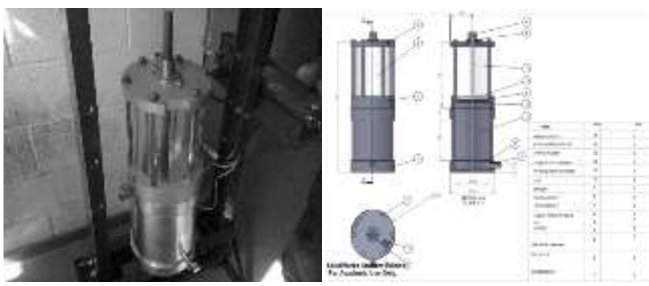
diameter is joined to a steel loading frame capable of applying well over 500 kPa pressure to the geo-composite system. Fig. 1 shows a view of the model device consisting of three parts: (i) the bottom part called the attenuation bucket; which contained the natural soil serving as the natural earth/subsoil and AS below the geo-composite barrier as shown in Fig. 2 (ii) the mid-section called the sample holder; contained the designed geo-composite liner (natural soil as CCL and defected geomembrane) seating on the attenuation bucket as shown in Fig. 3 and (iii) the upper portion above the geo-composite system; served as the leachate basin/pond shown in Fig. 4. The leachate basin held a constant head of 250 mm through the span of the tests. Layers of soil were compacted in the bottom chamber/bucket, the mid-section/sample holder and the defected geomembrane was placed on top of the prepared soil barrier. Wetted geotextile on a porous stone served as filter to prevent the outlet from clogging my moving fines. 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, the leachate added and the desired pressure was applied.



a) Pictorial view b) Schematic view

Fig. 1. Modular consolidometer-percolation column hybrid device.

(a) (b)

Fig. 2. (a) Wetted geotextile on porous stone to prevent outlet clogging (b) Lightly rammered AS to simulate loosed subsoil in the bucket

Vertical hydraulic conductivity, k_z value, in stratified soil (hydraulic conductivity of a barrier layer-AS) was calculated and used to determine the flow rate, Q. Thereafter, samples collected from six sectioned cores of the AS were tested by pulverized pore fluid extraction and silver thiourea methods. Concentrations of target source parameters/ions in the pore water were measured. The analyses were conducted using the 902 Double Beam Atomic Absorption Spectrophotometry in line with [6].

(a) (b)

Fig. 3. (a) Compacting the soil in layers (as CCL) in the barrier holder (b) Defected geomembrane with 5mm hole placed over CCL

The natural kaolinitic soil used as CCL and AS was collected around a landfill in CoJ as shown in Fig. 5 and was mechanically and chemically tested. Fig. 6 shows the soil grain size distribution curve, while water content-dry unit weight relationship was determined by compaction test in accordance with [7].

(a) (b)

Fig. 4. (a) Leachate in reservoir (b) Set-up loaded by the hydraulic pressure system

Fig. 5. Vicinity of soil sample collection

The test yielded optimum water content and maximum dry unit weight of about 15.7% and 17.4 kN/m^3 respectively and Fig. 7 shows the compaction curve. The standard proctor compaction test was done by a light rammer with self-weight of about 0.0244 kN and striking effort of about 595 kN-m/m^3. Permeability coefficients were measured by falling head test in accordance with [8] and the lowest permeability, k value obtained at MDD and OMC was 1.21×10^{-8} m/s as shown in Fig. 8. The AS was prepared at relatively low water content and lightly compacted to simulate in-situ conditions of natural soils.

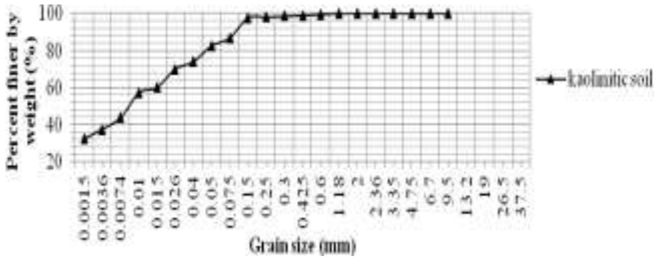


Fig. 6. Grain size distribution curve for the soil

Leachate used as permeant for the program was manually fetched from the landfill leachate basin shown in Fig. 9 designed to collect generated leachate (due to infiltration of storm water and/or interception of the subsurface water with the buried waste).

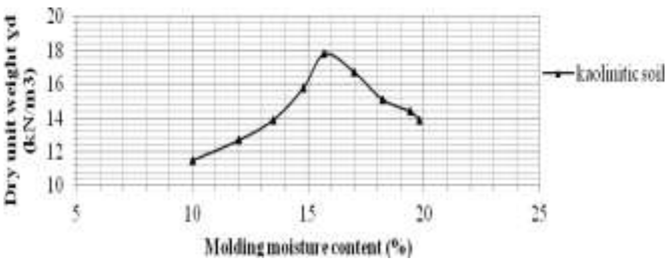


Fig. 7. Compaction curve for the soil

The permeant was taken from a number of points within the leachate basin and stirred together to ensure proper leachate mixture. The chemical ions were measured by full spectral analysis method on influent and effluent and were compared to standard drinking water. HCO_3 and Cl ions were analyzed in conformance to [9], [10].

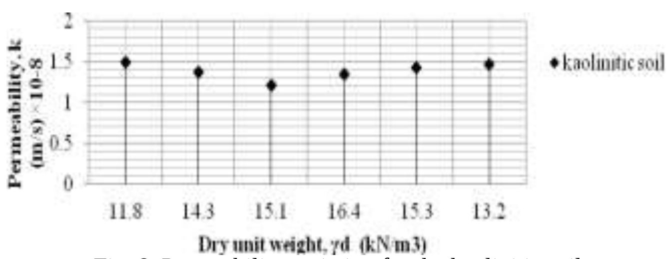


Fig. 8. Permeability variation for the kaolinitic soil

Initial concentrations (mg/l) of the targeted chemical ions from chemical analyses of the leachate are given in Table 1. The 2 mm thick polyethylene plastic as defected geomembrane was used due to material constraints and the duration of the leaching test lasted for a period of up to 90 days.

Fig. 9. Permeate collected from leachate pool

TABLE I
ANALYSIS OF LEACHATE SAMPLE USED FOR LEACHING TEST

Parameter	ASTM Test No.	Concentration of sample (mg/l)	Standard for Drinking Water (mg/l)*
HCO_3	D 1253	273	-
Cl	D 513	140	230

Source: *(Water services authorities South Africa, 1997)

III. RESULTS AND DISCUSSION

A. Seepage Rate Determination through a Circular Defect

Summaries of the test features, test duration and materials under which the leaching test was conducted are given in Table 2. The seepage test was for the sample collected around the landfill site. The seepage rate was determined and the concentration of migrated anions through the AS was determined to investigate the mechanism of contaminant transport through the geo-composite barrier as well as the attenuation capacity of the natural kaolinitic soil. This was done at the end of the seepage test. Fig. 10 shows the results of leachate seepage rate through the geo-composite liner. Steady to quasi steady state was reached in about 20 days into the test for a pressure value of 0 kPa and the flow rate was monitored and measured for a period of up to 30 days before the first pressure of 25 kPa was applied to the system. The flow rate, Q, was seen to gradually increase to a steady value. However, changes in seepage rates were noticed as pressure was applied.

TABLE II
TEST FEATURES

Test No.	Barrier Lining System (Natural soil as CCL) / Dry Unit Weight (kN/m^3)	Geosynthetic material	Defect Size, Type and Position
1	17.4	2 mm thick polyethylene plastic as Geomembrane	5 mm circular hole in the centre
Test No.	**Attenuation Profile (Natural soil as CCL) / Dry Unit Weight (kN/m^3)**	**Pressure, p (kPa)**	**Test duration**
1	12.3	0→25→50→100 →150	90 days

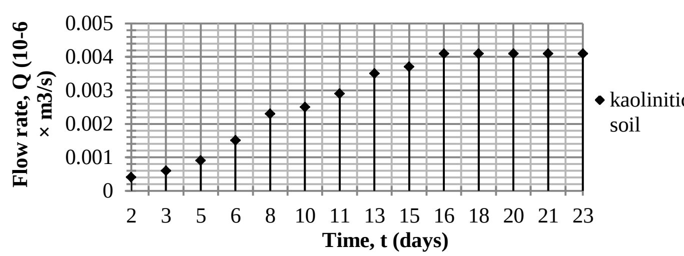


Fig. 10. Leachate flow rate against time for p = 0 kPa

The first pressure, p, of 25 kPa was applied to the system and steady state was reached after about 18-20 days with the seepage rate monitored and measured for another period of 30 days. To further investigate the influence of pressure on the systems seepage rate, pressure was increased from 25 to 50, 100 and 150 kPa to simulate waste loads imposing typical landfill barriers. The seepage rates, Q, were measured for each applied pressure and the duration of the entire test lasted over 90 days. An increasing pressure on the geomembrane, showed the flow rates to gradually reduce significantly to a steady state. From Fig. 11, the relationship between the measured flow rates, Q, against applied pressure for the natural soil can be seen. The increase in pressure caused a change in density which led to a decrease in the permeability of the soil barrier. Furthermore, the pressure to the system may have created a fair contact between the geomembrane and the soil layer thereby lessening the interface transmissivity; reducing the interface thickness and transmissivity, θ. This explains the gradual decrease to a steady state of the seepage rate.

B. *Experiential Prediction of Leachate Seepage*

The leachate seepage rates through defected geomembrane have several proposed predictive equations. These equations were divided into two groups by [2], [5] based on assumed geomembrane/underlain soil contact conditions namely; perfect contact and imperfect contact. The former assumes that there is no flow at the geomembrane/soil interface, while the latter assumes that there is flow at the interface between the geomembrane and the soil barrier. As stated previously, the variation of seepage rate can be caused by the change of the interface transmissivity, θ, and the permeability, k, of the soil barrier.

The representative equations for perfect contact conditions are given as follows;

$$Q = 4r_0k_Lh_w \qquad (1)$$

$$Q = \pi r_0k_Lh_w \qquad (2)$$

Where r_0 = radius of circular defect
k_L = hydraulic conductivity of the underlying soil barrier and
h_w = leachate head on the composite liner.

Equation (1) is a proposition by [11] while (2) was proposed by [12].

As for imperfect interface contact condition, [13] further divided it into good and poor contacts. The proposed empirical equation by [14] is under the assumption that there is flow at geomembrane/soil interface for a given head distribution and it is expressed as follows;

$$Q=1.12C_{qo}[1+0.1(h_w/H_L)^{0.95}]r_0^{0.2}k_L^{0.74}h_w^{0.9} \qquad (3)$$

Where C_{qo} = constant of 0.21 for good contact and 1.15 for poor contact, and H_L = thickness of the underlying soil barrier.

Other parameters are taken as already defined. The units from (3) are; m in the case of h_w, H_L, r_0 and m/s in the case of k_L and should be used as such.

The predicted values by (1) to (3) are expressed in Fig. 11. The observations made thereof from the comparisons between the predicted values and the measured/test data can simply be interpreted as follows; that (i) using (1) and (2) in the case of a perfect contact condition shows inapplicability in practice and to the small-scale test conditions due to the wide variations experienced and that (ii) for a case of a good contact condition, (3) fairly predicts the measured/test data. It must be noted however, that the influence of applied pressure, p, was not taken into account in the predictive equations as compared to the test results in this study.

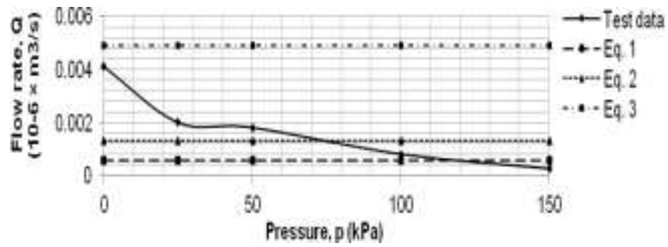


Fig. 11. Leachate flow rate against applied pressure, p

C. *Attenuation of Migrated Anionic Ionsy*

The leachate sample analyses and characterization showed relatively low trace elements including anions. The behaviour of chloride ions was studied mainly to separate the effects of dispersion and chemical processes operating in the soil system. Results from the percolation tests confirmed that these small amounts of trace elements do not migrate in any significant manner through the natural soil cores examined. Effluent and relative concentration profiles for the Cl ions with respect to the pore volume for the natural soil after reaching steady state is shown in Fig.12. The observed attenuation is generally not a function of the type or amount of clay minerals present in the soil system. Hence, there was no recognized significant difference in the migration of cations through the soil. Results from the AS showed low accumulation and retention of the Cl ion, as revealed in migrating profiles depth and little HCO_3 was detected in the extracted pore fluid after the leachate seepage as shown in Fig. 13a and b. This can be attributed mainly to physical dispersion in the soil column system, with perhaps a small amount of interaction at the anions exchange sites on the respective soil edges or to other chemical reactions.

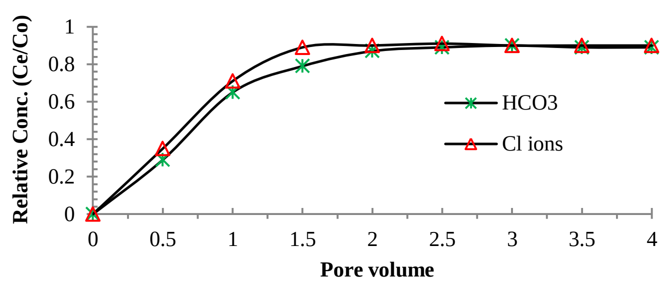


Fig. 12. Relative conc. of anions in effluent (Co and Ce = initial and final conc.)

The exchange between chloride ions and other ions with negative charges, which are part of the lattice is not feasible because the chloride ion is about two and half times the size of the oxygen ion, i.e., it is too large to replace or co-ordinate with oxygen and hydroxyl ions.

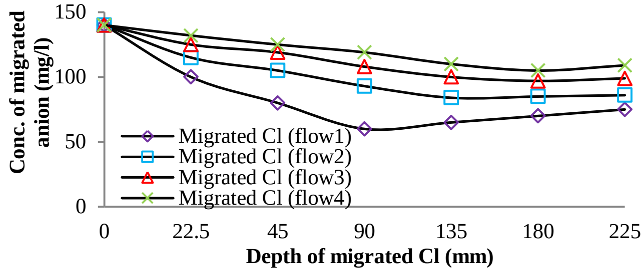


Fig. 13a. Migration profiles of Cl ions through the AS

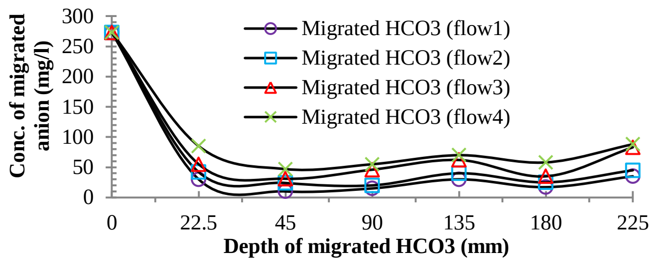


Fig. 13b. Migration profiles of CHO_3 ions through the AS

The chloride ion attenuation that was observed was relatively low and it is not surprising because: (a) Cl is considered to be a mobile and non-interacting anion (conservative contaminant) and (b) chloride ions are generally considered to be non-specific ions, (i.e. existing only in the outer coating of the double layer [15]. Therefore, the natural soil exhibited poor attenuation to Cl ions but a fair outcome in the case of HCO_3 ions.

IV Conclusions

Tests on geo-composites with defected geomembrane under the influence of seeping leachate were conducted in a laboratory small-scale model device called a Modular Consolidometer-Percolation Column Hybrid. Pressure effects on the leachate seepage rate, flow mechanism and attenuation of anionic parameters were investigated. The analysis of results arrived at the following conclusions;

The increase in applied pressure on the liner systems was observed to significantly reduce the leachate seepage rate; 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 soil barrier densification.

The assumption of perfect geomembrane/soil interface contact condition is not applicable to leachate seepage through a defected geomembrane with underlying mineral layer. Giroud's (1997) empirical equations for good contact condition provided a reasonable prediction for this problem under very low pressure (close to 0 kPa). However, the influence of pressure was not catered by the equation as in the case of this study.

The measured pore fluid concentration of the migrated ions, confirmed there was flow through the geomembrane-soil interface; the concentration of selected anionic ions in sectioned cores of the AS after leaching test revealed the natural soil to have poor attenuation capacities towards Cl ions but fairly attenuated HCO_3. Nevertheless, further study needs to be conducted on the influence of pressure on the interface contact behaviour, modification to Giroud's (1997) empirical equations such that the effect of pressure be considered and other trace contaminants/ions be investigated.

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