Zeolitic Mineral Liner as Hydraulic and Buffering Material

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

Abstract—Laboratory tests were done using a bespoke device to investigate landfill leachate seepage through a circular failed geo-composite liner. Pressures simulating actual landfill waste loads were applied to the lining system. The buffering capacity of a natural zeolitic mineral layer was investigated by measuring the leachate seepage rate and anionic (Cl and HCO_3) contaminant transport through the geo-composite liner-buffering strata (BS). Simulated landfill waste loads from 25-150kPa were introduced to the system at intervals. The findings showed considerable reduction in seepage rate over the increased pressure. The seepage reduction is ascribed to the reduced liner transmissivity, θ and compressed soil layer. The natural zeolitic soil exhibited poor buffering of Cl ions but showed a fair outcome in the case of HCO_3 ions. Data for seepage rates were compared with predicted values from existing equations by Forchheimer and Giroud. The comparisons showed inapplicability to this study and to real life scenarios, if conditions of perfect contact at the polyethylene/soil interface were assumed. Nonetheless, Giroud's equation for good contact condition gave considerable seepage rate prediction through a failed geo-composite liner.

Keywords—Anions, Geo-composites, Polyethylene, Leachate

I. INTRODUCTION

WASTE disposal involves the use of land and this trend has been the case from decades past. 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 surrounding environs. As such, to guarantee that soil and ground water resources be protected from landfill leachates, geo-composite barrier systems are mostly employed. Polyethylene (PE)/mineral composite barriers are often utilized in engineered contaminant restriction facilities and for the time being, will continually gain grounds as significant components of landfill lining systems. It is well known however, that in-situ and ex-situ PE failures can at best be minimized but cannot be prevented. In this light, PE as part of a geo-composite liner may fail due to defects on or out of site from fabrication, installation or aging [2]. Therefore, ascertaining leachate seepage through a failed polyethylene above a zeolitic mineral soil liner 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 from ground water need be executed [3]. This can be made possible when compacted clay liners (CCLs) are utilized as part of the lining system to control traveling leachate that may infiltrate the defected liner i.e. PE or Geosynthetic Clay Liner (GCL). In a fast growing and developing country like South Africa, Gauteng province and Johannesburg City alone generates approximately half of the Nations daily waste with decreasing available deposition sites (landfills) with time. As recorded by [4] the vast and increasing tonnes of disposed waste each day are attracting concern, with improper waste dumping leading to health, environmental and aesthetic problems. Pollution of vital subsurface and groundwater resources is often something to worry over, thus, the need for the study. There are several predictive equations proposed for similar problems of seepages through failed landfill systems however, [5] and [2] stated that predicted values differ by wide margins for different scenarios and operating conditions. The influence of waste loads on leachate seepage through a failed PE of a zeolitic mineral geo-composite, the transportation pattern through the geo-composite of the natural zeolitic material as CCL and its buffering capability to anionic contaminant influx have not been well reported. Hence, test using a bespoke device to investigate the leachate seepage through circular failed PE with underlying natural zeolitic mineral layer as CCL and BS was done. Effects of pressure applied to the system on the seepage rate, mechanism of seepage and the buffering capability of the natural soil to anions; HCO_3 and Cl were determined.

II. MATERIALS AND METHODS

A soil liner layer-24mm thick and a 5mm diameter puncture in the center of a 2mm thick PE plastic simulated a failed system having a 225mm thick BS which made up the bespoke test setup. The bespoke device- a Column Hybrid of 160mm diameter is joined to a steel loading frame capable of applying over 500kPa pressure to the geo-composite system. Fig. 1 shows a view of the device consisting of three sections: (i) the bottom part called the buffering bucket; which contained the natural zeolitic soil serving as the natural earth/subsoil and BS below the geo-composite liner (as in Fig. 2) (ii) the mid-section called the sample holder; which contained the designed geo-composite liner (natural zeolitic soil as CCL and the failed PE) placed over the buffering bucket (see Fig. 3) and (iii) the upper section above the geo-composite system; which served as the leachate basin/pond (as in Fig. 4).

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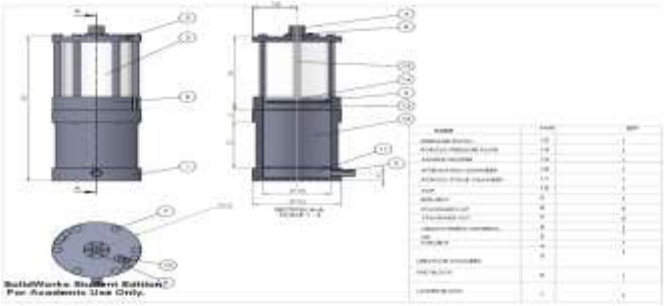
a) Pictorial view



b) Schematic view

Fig. 1 Bespoke column hybrid device

The leachate basin held a constant head of 250mm through the span of the tests. Layers of soil were compacted in the bottom and mid sections of the device. The failed PE with a centred puncture overlaid the prepared soil liner. A moistened geotextile on a porous stone served as filter to prevent moving fine soil particles from clogging the outlet of the device. 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) (b)

Fig. 2 (a) Moist geotextile on porous stone to prevent outlet clogging (b) Lightly rammered BS to simulate loosed subsoil

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

(a) (b)

Fig. 3 (a) Soil compacted in layers (as CCL) in liner holder (b) Failed polyethylene with 5mm centred puncture overlain the CCL

The natural zeolitic soil used as CCL and BS was collected around a landfill in the city of Johannesburg, South Africa (see Fig. 5) and was mechanically and chemically tested. Fig. 6 shows the soil grain size distribution curve, while optimum water content (OWC)-maximum dry unit weight (MDUW) relationship was determined by compaction test in accordance with [7].

(a) (b)

Fig. 4 (a) Simulated leachate pond (b) Liner under hydraulic pressure

Fig. 5 Soil sampling vicinity

The test yielded OWC and MDUW of about 15.5% and 17.1kN/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 0.0244kN and striking effort of about 595kN-m/m^3. Permeability coefficients were measured by falling head test in accordance with [8] and the lowest permeability, k value obtained at MDUW and OWC was 1.19×10^{-8} m/s (see Fig. 8).

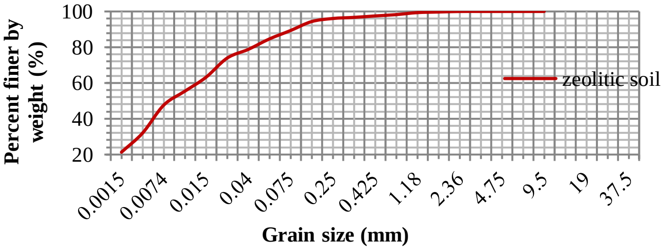


Fig. 6 Grain size distribution curve for the soil

The BS was prepared at relatively low water content and lightly compacted to simulate in-situ conditions of natural soils. Leachate used as permeant for the test program was manually scooped from a landfill leachate pond (see Fig. 9) designed to retain generated leachate (due to infiltration of storm water and/or interception of the subsurface water with the buried waste).

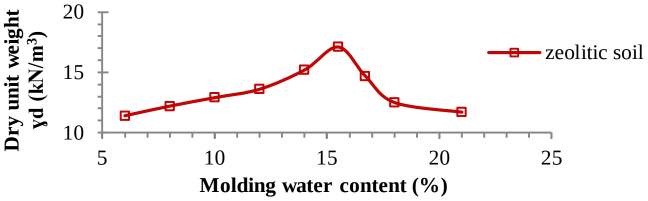


Fig. 7 Compaction curve for the soil

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

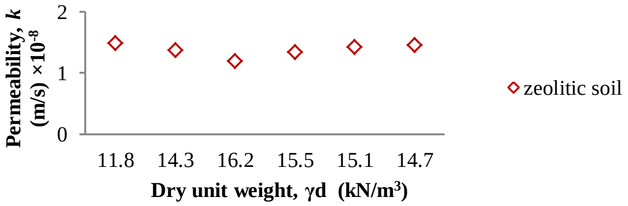


Fig. 8 Zeolitic soil permeability variation

Initial concentrations (mg/l) of the targeted contaminant ions from chemical analyses of the leachate are given in Table I. The 2mm thick failed PE liner was used due to material constraints and the duration of the percolation test lasted for roughly 100days.

Fig. 9 Permeate scooped from leachate pond

TABLE I

ANALYSIS OF LEACHATE USED FOR SOIL PERMEATION TEST

Parameter	ASTM Test	Conc. (mg/l)	Drinking water standard (mg/l)*
HCO_3	D 1253	273	-
Cl	D 513	140	230

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

III. DISCUSSION OF RESULTS AND FINDINGS

A. Seepage rate through circular Failed Polyethylene

Summaries of the test features, test duration and materials under which the percolation test was conducted are given in Table II. The seepage test was for the sample collected around the landfill site. The seepage rate was determined and the concentration of transported anions through the BS was determined to investigate the mechanism of contaminant travel through the geo-composite liner as well as the buffering capability of the natural zeolitic soil which 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 20days into the test for 0kPa pressure and the seepage rate was monitored and measured for up to 25days before the first pressure of 25kPa was introduced to the system. The seepage rate, *Q*, was seen to gradually increase to a steady value. However, changes in seepage rates were noticed as the applied pressure changed.

Table II

TEST FEATURES

Parameters	Properties
MDUW (kN/m³) of mineral liner (CCL)	17.1
MDUW (kN/m³) of Buffering strata (AS)	12.8
Geosynthetics	2mm thick PE
Puncture size, type and position	5mm circular hole in the centre
Pressure (kPa)	0→25→50→100→150
Test duration	About 100days

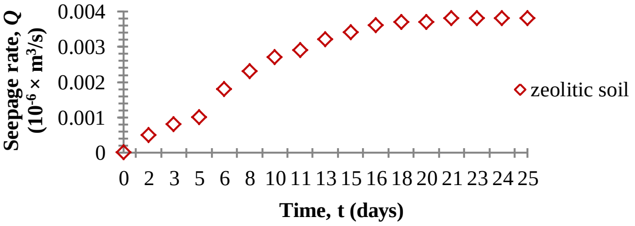


Fig. 10 Leachate seepage rate against time for p = 0kPa

The first pressure, p, of 25kPa was applied to the system and steady state was reached in roughly 20days and the seepage rate was then monitored and measured over duration of 30days. To further investigate the influence of pressure on the systems seepage rate, pressure was increased from 25 to 50, 100 and 150kPa to simulate waste loads imposing typical landfill liners. The seepage rates, *Q*, were measured for each applied pressure and the duration of the entire test lasted about 100days. An increasing pressure on the PE showed the seepage rates to gradually reduce considerably to a steady state. In Fig. 11, the relationship between the measured seepage rates against applied pressure for the natural zeolitic soil is shown. The increase in pressure caused a change in density which led to a decrease in the permeability of the soil liner. Furthermore, the pressure to the system may have created a fair contact between the PE and the mineral soil liner thereby, lessening the interface transmissivity thus, reducing the interface thickness and transmissivity, θ. This may therefore, have accounted for the gradual decrease to a steady state of the seepage rate.

B. Predicting Seepage rate from an Empirical Perspective

The leachate seepage rates through failed PE have several proposed predictive equations. These equations were divided into two groups by [2] and [5] based on assumed PE-underlain soil contact conditions namely; perfect contact and imperfect contact. The former assumes that there is no seepage at the PE-soil interface, while the latter assumes that there is seepage at the interface between the PE 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 liner. The representative equations for perfect contact conditions are given as follows;

$$Q = 4r_0 k_L h_w \quad (1)$$

$$Q = 2\pi r_0 k_L h_w \quad (2)$$

Where r_0 = radius of circular puncture
k_L = hydraulic conductivity of the underlying soil liner and
h_w = leachate head on the geo-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 seepage at PE-soil interface for a given head distribution and it is expressed as follows;

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

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

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 from (1) - (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 bespoke 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.

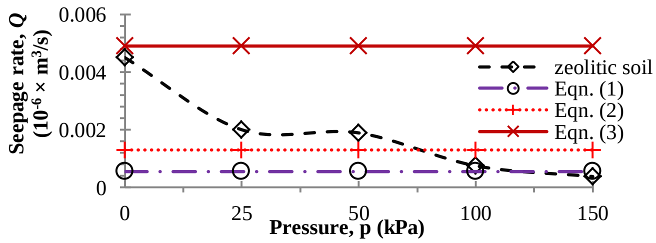


Fig. 11 Leachate seepage rate against various applied pressure, p

C. Buffering of Transported Anionic Contaminants

The analyses and characterization of the leachate sample generally 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 travel in a considerable manner through the natural BS examined. Effluent and relative concentration profiles for the Cl ions with respect to the pore volume of the natural zeolitic soil after reaching steady state is shown in Fig. 12. The observed buffer is generally not a function of the type or amount of clay minerals present in the zeolitic material. Hence, there was no recognizable difference in the transportation of anions through the soil. Results from the BS showed low accumulation and retention of the Cl ion, as revealed in distribution profile depths. Minute HCO_3 was however, detected in the extracted pore fluid after the leachate seepage (see Figs. 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 due to other chemical reactions.

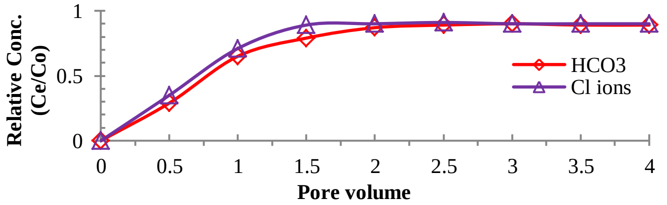


Fig. 12 Relative conc. of anions (Co and Ce = initial and final conc.)

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.

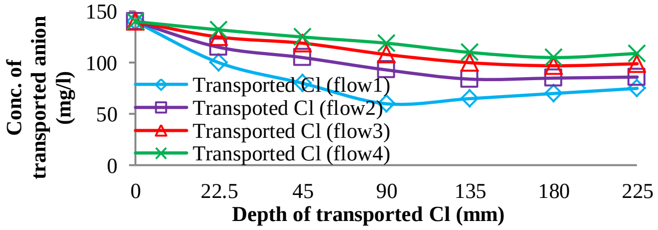


Fig. 13a Transport profiles of Cl ions through the BS

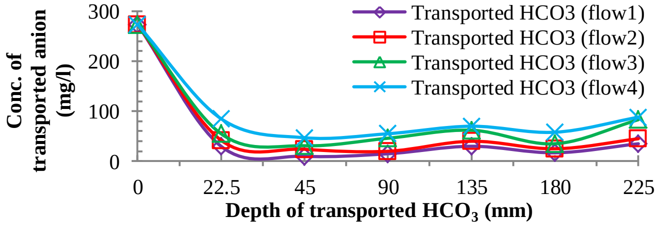


Fig. 13b Transport profiles of HCO_3 ions through the BS

The buffering of chloride ion 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 zeolitic soil exhibited poor buffering characteristics towards Cl ions but had a reasonably fair outcome in the case of HCO_3 ions.

IV. CONCLUSIONS

Tests on geo-composites with failed PE under the influence of seeping leachate were conducted in a bespoke Column Hybrid device. Pressure effects on the leachate seepage rate, seepage mechanism and buffering of anionic contaminant species were investigated. From the analysis of results the following conclusions were reached:

- The increase in applied pressure on the liner considerably reduced the leachate seepage rate; and from analysis, there was clear indication that the reduction was as a result of the reduction in PE-soil interface transmissivity, θ, and the soil liner densification.
- The assumption of perfect PE-soil interface contact condition is not applicable to leachate seepage through a failed system with underlying mineral layer. Giroud's empirical equations for good contact condition provided a rational prediction for this problem under pressure = 0kPa. 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 transported ions, confirmed there was flow through the PE-soil interface; the concentration of the selected anion in the sectioned cores of the BS after the compactibility test revealed the natural zeolitic soil to have poor buffering tendencies towards Cl ions but had fairly buffered the HCO_3. Nevertheless, further study is recommended for other trace contaminants/ions to be investigated.

In summary, the chloride transport curves through the zeolitic soil showed the characteristics of the non-reactive ions, which were not readily altered by chemical and biological processes. This revealed that Cl ions travelled faster through the BS than in the HCO_3 ions. This study has demonstrated that the tested soil type used in the experimental works to contain the generated leachate from solid waste disposal can be sparingly used to contain the different selected contaminant species investigated herein. The results collated in this study further suggested that under favourable soil conditions, landfill leachates containing low anionic trace levels will not pose a substantial threat to the subsurface environment. Hence, it is noted that the buffering capability of the zeolitic tested soil is not infinite. Therefore from observations and analysis of results, care must be taken not to dispose heavy concentrated organic waste in the landfill site where the soil samples were harvested.

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