Buffering of TOC-Contaminant Using Natural Clay Mineral Liner

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

Abstract— A geo-composite liner under leachate leakage through circular puncture in a membrane was tested in a bespoke device. Soil liner-24mm thick, polythene plastic-2mm thick with centered 5mm hole simulated the circular puncture in the membrane and a 225mm thick buffering profile (BP) made up the experimental setup. The bespoke column hybrid model-160mm diameter coupled to a hydraulic pressure frame is capable of applying up to 1000kPa pressure to the liner. Leakages through liner-BP system were evaluated for tests under pressures up to 150kPa. The measured leakage rates for good membrane-soil interface contact conditions were found to be valid whereas that of a perfect contact condition was unachievable in this study. Outcomes of the test however, revealed notable reduction in leakage rates with increased pressure, p, on the membrane. This is plausibly due to reduced liner system transmissivity, θ, and densification of the liner. Concentrations of organic matter in the BP after compactibility tests confirmed leakage through the punctured membrane-soil liner and showed poor buffering tendencies of zeolitic natural soil investigated in this study to migrating organics.

Keywords—*Total organic carbon, Geo-composites, membrane, Leachate*

I. Introduction

MOST by-products of human activities are usually generated as solid wastes and it has become critical that these waste products are properly disposed in engineered containment systems considering the difficulties of handling via other means. Land disposal has come a long way as an approach to ridding off various generated waste and it will for a long time remain the most common form of disposal. Landfill waste containments produces gases and leachates whose infiltration into surrounding soil and ground water must be prevented or curtailed at worse in order to minimize environmental impacts [1]. Rain, runoffs, waste containing high moisture and bacterial activities triggers the generation of contaminants in landfills. Therefore, protection of important soil and ground water resources against pollution from landfill leachates is of great concern. Geo-composite liners are now been well employed in managing the transportation of contaminants from disposal sites to levels of consequential impacts. In rare cases membrane; as part of a geo-composite may be punctured from fabrication, installation or over time due to ultraviolet radiation. In some other cases, constructing disposal systems around vital water sources cannot be escaped but it is only ensured that the protection of important soil and ground water regimes from waste bodies are competently done [2]. This is achievable by utilizing compacted clay liners (CCL) as components of geo-composite lining systems to control any traveling contaminant from reaching vital ground resources in cases where the membrane fails i.e., failures of Geomembrane (GM) or Geosynthetic Clay Liner (GCL). Hence, membrane-soil liners are recommended globally and are at present actively used in the construction of waste containment systems which forms a significant component for many multiple systems in engineered landfills. As recorded by [3] the use of geosynthetic materials are recognized in designs and are quickly expanding as manufacturers source, develop new and improved materials and engineers/designers develop new analysis routines for better services. However as already stated, in-situ defects in membranes cannot be completely avoided [4].

Emmanuel Emem-Obong Agbenyeku is a research student at the University of Johannesburg, South Africa (phone: +27 11 559 6396; e-mail: emmaa@uj.ac.za).

Edison Muzenda is Head of Environmental and Process Systems Engineering Research Unit, Department of Chemical Engineering, University of Johannesburg, South Africa (phone: +27 11 559 6817; e-mail: emuzenda@uj.ac.za).

Innocent Mandla Msibi is Executive Director of the Research and Innovation Division, University of Johannesburg, South Africa (phone: +27 11 559 6280; e-mail: mimsibi@uj.ac.za).

The daily disposal of more than 41 thousand tonnes of solid waste in South Africa with Gauteng province and Johannesburg city dumping more than 17 and 4 thousand tonnes respectively is a thing of concern [5]. This waste disposal has health, environmental and aesthetic impacts. Pollution of vital subsurface and groundwater resources is one of the many impacts which needs to be addressed thus, creates the impetus for the study. Applied pressure on leakage rate through punctured membrane, organics transport mechanism through geo-composite liner with natural zeolitic soil as CCL and its buffering capabilities have not been sufficiently documented. However, about 75% of Municipal Solid Waste (MSW) in South Africa is dumped in landfills. The liners bound to be under pressure from the mountain of disposed waste over time. From filed reconnaissance, pressure on the lining systems was estimated to be around 200kPa for waste heights and thicknesses of 8-10m. This study therefore investigated on leachate leakage through a punctured membrane as part of a geo-composite lining system underlain by zeolitic soil liner as CCL and BP. The pressure influence on leakage rate, organic contaminant transport and the buffering capability of the natural zeolitic soil were reported.

II. Materials And Experimental Approach

Zeolitic soil was collected and used as CCL and BP in this study. The natural soil was sampled close to landfill site in Johannesburg, South Africa, at points remotely far from the

http://dx.doi.org/10.15242/IICBE.C1214093

actual dump in order to prevent impurities as seen in Fig. 1. The zeolitic soil was mechanically and chemically tested and Fig. 2 shows its grain size distribution curve while the relationship between optimum water content (OWC) and the maximum dry unit weight (MDUW) of the soil was determined by the compaction test in conformance with [6].

Fig. 1 Soil sampling area

The standard proctor compaction test was done with a light rammer having self-weight of about 0.0244kN and striking effort of about 595kN-m/m^3. The compaction curve is shown in Fig. 3.

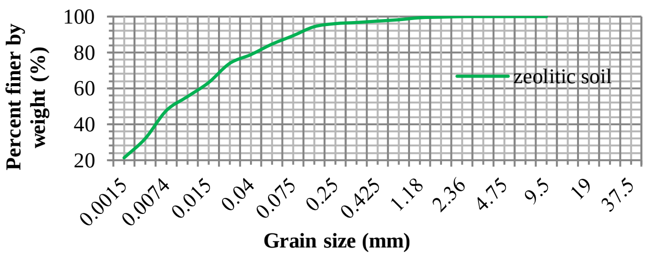


Fig. 2 Grain size distribution curve for zeolitic soil

The tests yielded OWC of 15.5% and MDUW of 17.1kN/m^3 for the natural zeolitic soil. Values for permeability coefficient were measured by falling head test in consonance with [7]. The relationship between the permeability and dry unit weight of the natural soil is seen in Fig. 4. Through the testing periods, the BP prepared had relatively low water content and was lightly compacted to simulate in-situ conditions of natural soils. The permeant used was collected from the leachate pond at the disposal site (see Fig. 5) designed to hold leachate generated at the landfill (from infiltrated storm water and/or intercepted subsurface water with the waste body).

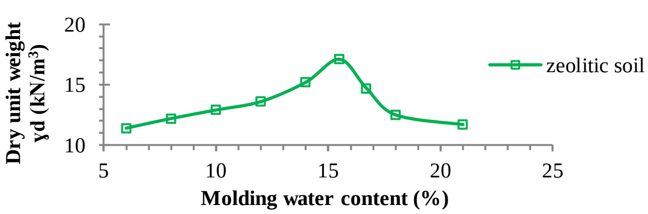


Fig. 3 Compaction curve for zeolitic soil

The leachate sample was fetched from a number of points within the pond and thoroughly mixed together to get a proper leachate composition. Table I shows the initial concentrations (mg/l) of the targeted contaminant specie from the chemical analyses of leachate. The organic chemical matter was measured by full spectral analysis method on the influent and effluent and was compared to the South African standard of drinking water as per [8] and [9].

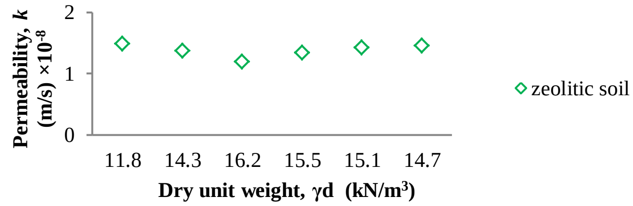


Fig. 4 Zeolitic soil permeability variation

In the tests under pressure, densification of the soil liner occurred due to changes in the applied loads. After unloading the system at the end of the test, the soil layers showed negligible changes. The 2mm thick polythene plastic as membrane with 5mm diameter centered puncture was improvised due to material constraints. As such, other varieties of lining designs could not be tested. However, it should be noted that the study was not to investigate different membrane liner designs.

Fig. 5 Permeate fetched from leachate basin

Considering the complexity and nature of the contaminant species capable of being generated from the decomposition of solid waste in landfills, the insufficient spectral testing materials however, made it impossible to detail all compositional features and characteristics of such products. Thus, only organic matter was tested for intrusion and retention in form of Total Organic Carbon (TOC) in the cores of the BP from the countless chemical species present in the leachate sample.

TABLE I

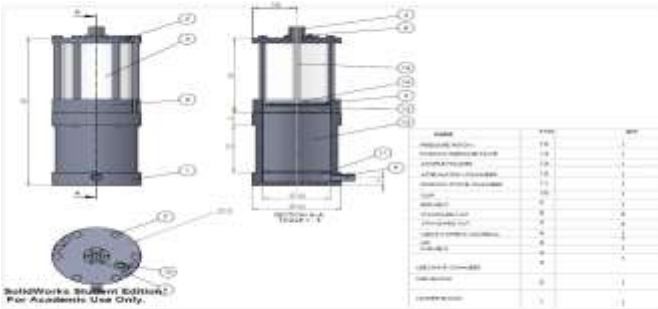
ANALYSIS OF LEACHATE USED FOR SOIL COMPACTIBILITY TEST

Parameter	ASTM Test	Conc. (mg/l)	Drinking water standard (mg/l)*
TOC	D 2579	170	-

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

The selection of TOC contaminant specie was dependant on: (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 chemical carbon present in the leachate solution generated at the landfill site.

a) Pictorial view



b) Schematic view

Fig. 6 Bespoke column hybrid device

The parameter analyzed for the organic matter was as, TOC. The leachate chamber was marked to hold a constant head of 250mm through the duration of the test. A view of the bespoke device is shown in Fig. 6. The device composed of three parts: (1) the bottom part called the buffering/attenuation chamber; which contained the natural soil layer acting as the natural earth and BP below the geo-composite system (as shown in Fig. 7) (2) the mid-block called the sample holder; contained the designed geo-composite barrier system (natural soil as CCL and punctured membrane) which overlies the buffering chamber (see Fig. 8) and (3) the upper portion above the geo-composite liner; functioned as the leachate reservoir/chamber (as per Fig. 9).

(a) (b)

Fig. 7 (a) Moist geotextile on porous stone to prevent outlet clogging (b) Lightly rammered BS to simulate loosed subsoil

Soil layers were prepared inside the bottom chamber, the mid-block/sample holder and the punctured membrane 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 pressure), the leachate was then added and the desired pressure was applied. The vertical hydraulic conductivity, k_z value, in stratified soil (hydraulic conductivity of a liner-BP) was calculated and used to determine the leakage rate, *Q*.

(a) (b)

Fig. 8 (a) Soil compacted in layers (as CCL) in liner holder (b) Failed polyethylene with 5mm centred puncture overlain the CCL

In the first test conducted no pressure was applied. Consequently, samples collected from six sectioned cores of the BP were tested and measured for concentration of target source TOC 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 as per [10].

(a) (b)

Fig. 8 (a) Leachate in reservoir (b) Liner under hydraulic pressure

III. Result And Discussion Of Findings

A. Column Hybrid Leachate Leakage Test

Outside the confirmatory tests carried out in this study, one main compactibility test was conducted. Table II summarizes the test features; durations and materials under which the test was carried out.

TABLE II
TEST FEATURES

Parameters	Properties
MDUW (kN/m^3) of mineral liner (CCL)	17.1
MDUW (kN/m^3) of Buffering profile (BP)	12.8
Geosynthetics	2mm thick polythene
Puncture size, type and position	5mm circular centred puncture
Pressure (kPa)	0→25→50→100→150
Test duration	About 100days

Test to determine the TOC concentrations and migration through the BP was measured to investigate the mechanism of contaminant travel through the liner and the buffering power of the zeolitic soil to organics. This was done at the end of every test and result for the leakage rate through the lining system is seen in Fig. 9a - e. Wetted geotextile on a porous stone was used as filter to prevent fines from clogging the outlet of the chamber. The concentration and conductivity of the effluents from the test revealed a steady increase over the test periods. Steady or quasi steady state was reached in roughly 20days into the test and the leakage rate was observed and measured over a period of 30days. The leakage rate, *Q*, was seen to gradually increase to a steady value. However in Fig. 9a - e, changes in the flow rate were observed as pressure was introduced.

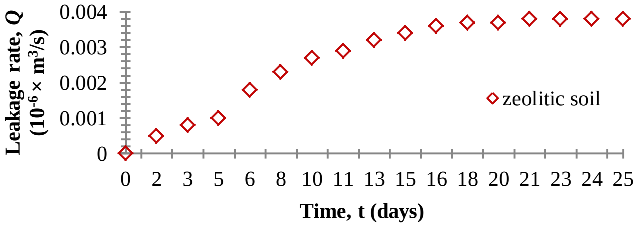


Fig. 9a Leachate seepage rate against time for p = 0kPa

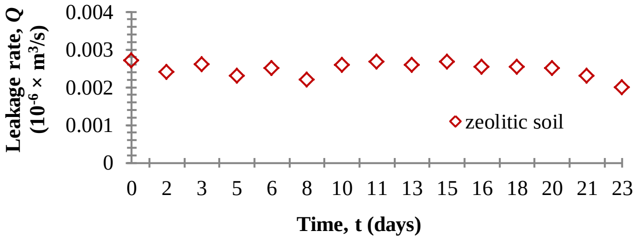


Fig. 9b Leachate seepage rate against time for p = 25kPa

The first pressure, p, of 25kPa was applied to the system of the zeolitic soil. Steady state was reached after about 18-20days as shown in Fig. 9b and the leakage rate was monitored and measured for a duration up to 30days. To further investigate the effect of pressure on the systems leakage rate, the pressure was increased from 25 to 50, 100 and 150kPa. This was done to simulate the waste load imposing the barrier liners of a typical landfill.

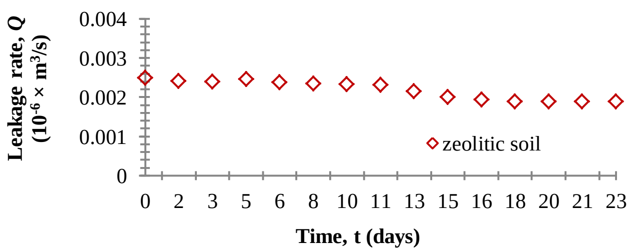


Fig. 9c Leachate seepage rate against time for p = 50kPa

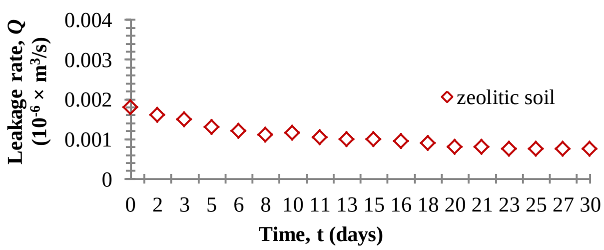


Fig. 9d Leachate seepage rate against time for p = 100kPa

The leakage rate was measured for each pressure and Fig. c - e shows the measured relationship between leakage rates, *Q*, versus time, t, for pressure values of 50-150kPa. An increasing pressure on the membrane showed the leakage rates to gradually reduce to a steady value. Fig. 10 shows the relationship between the measured leakage rates, *Q*, against pressure, *p*.

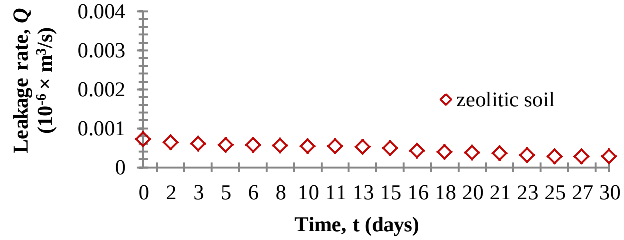


Fig. 9e Leachate seepage rate against time for p = 150kPa

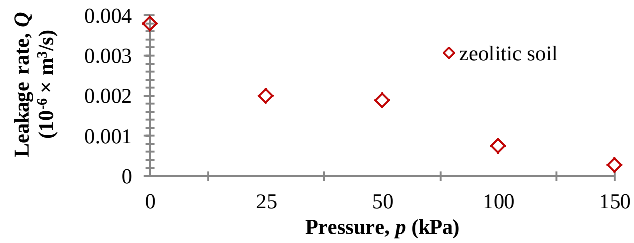


Fig. 10 Leachate leakage rate against pressure values

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 membrane and the soil liner thereby reducing the interface transmissivity; reducing the interface thickness and transmissivity, θ, which could explain the gradual decrease to a steady state of the leakage rates, *Q*.

B. Buffering of Transported TOC Contaminant Specie

Leachate solution generated from the dissolution of buried solid waste at sanitary landfills is usually characterized by the presence of high concentration of organic compounds. The organic content in most cases accounts for about 40 to 60% of the total constituents. However in the case at hand (the sampling landfill site), the organic fraction was relatively low, constituting only about 10 to 15%. These organic compounds usually consist of the remains of biologically-produced compounds of low molecular weight, principally fulvic acid, in addition to a variety of synthetic organic contaminants. Such organic substances were found to be mobile in mineral/clay-water system and presented an absolute threat to ground water quality even in minute concentrations. Results from the permeation compactibility test confirmed that these mobile substances do not migrate in any peculiar manner through the cores of the natural zeolitic soil. The effluent relative concentration for TOC with respect to the pore volume for the permeated zeolitic soil after reaching steady state is shown in Fig. 11. Hence, the buffer observed in the organic load contained in the leachate solution as it seeped through the column hybrid containing the zeolitic soil was vital to the study.

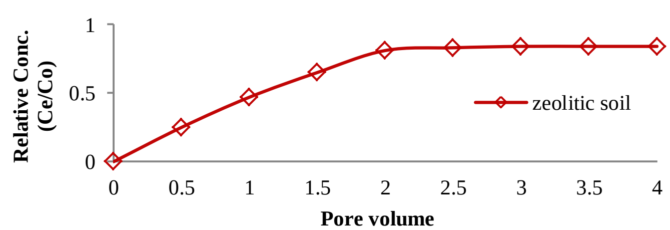


Fig. 11 Relative conc. of TOC (Co and Ce = initial and final conc.)

It was seen that little buffer was found for the organic load measured as TOC. The breakthrough point for TOC was recorded at an early pore volume passage and this was in agreement with the results reported by [11], who recorded a poor removal of chemical oxygen demand (COD) when leachate was passed through soils. In the permeation compactibility tests, the collected landfill leachate with initial TOC value of 170mg/l with other ionic contaminant species percolated the zeolitic soil cores with and without the effect of applied pressures. Generally, the natural zeolitic soil exhibited poor buffering tendencies toward the transportation of organic loads through the BP. The percolation profile depth for the natural zeolitic soil is shown in Fig. 12.

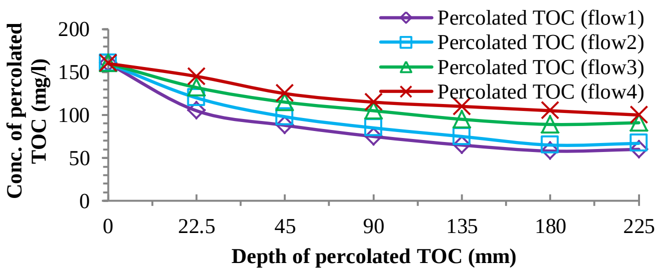


Fig. 12 Transport profiles of TOC through the BP

An average of 15 to 20% TOC removal was observed in the course of the experimental study and to a great extent could be as a result of the chemo-characteristic of the zeolitic soil. These data indicated that the exchange capacity and the chemical characteristics of the zeolitic soil are the dominant features controlling its buffering ability. Results obtained from the chemical analysis of the pore fluid extracted from six core sections of the BP were found to be consistent with the soil column effluent concentrations. Results showed that significant removal of TOC could be attributed to the complex formation of organic metallic ions, since organic matter adsorbs metal ions better than clays.

IV. Conclusions

Test on geo-composite systems under leachate leakage from punctured membrane was conducted in a bespoke column hybrid laboratory device. Pressure effects, imposing the leakage rate, transportation and buffering of contaminants (TOC) were investigated. From analysis of findings, the following conclusions were drawn:

- The increase in pressure on the lining system was observed to significantly reduce the leakage rates; with clear indication that the reduction was as a result of reduced membrane-soil interface transmissivity, θ, and the soil liner densification.
- The tests with punctured membrane showed interface flow between the membrane and soil liner; that a perfect membrane-soil barrier contact was not achieved with results from the permeation compactibility test and pore fluid concentration of the transported TOC confirming the flow through the geomembrane-soil interface.
- The concentration of TOC in the six sectioned cores of the BP after the permeation test showed the natural zeolitic soil to have poor buffering capacity towards the organic matter-TOC; the results showed that significant amounts of TOC migrated the BP and only little buffer occurred across the cores of the zeolitic sample. However, further study is recommended on the influence of pressure on interface contact behaviour for other lining designs as well as the buffering of other contaminant species not addressed herein.

In a nutshell, the buffering of the organic compounds observed can be linked mainly to the adsorption of organic molecules on the soil surfaces. The forces involved are those acting in all directions where atoms and molecules are in close proximity. Hence, the high mobility of organic compounds has two main consequential effects: (i) the deterioration of the groundwater quality and (b) the alteration of the soil characteristics behaviour (index properties, strength, hydraulic conductivity etc). This study has therefore demonstrated that the tested soil type used in the experimental works to contain the generated leachate from solid waste disposal should be cautiously used as a buffer towards the investigated selected contaminant specie (TOC).

Acknowledgment

The Authors appreciate the University of Johannesburg where the study was done.

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