# HYDRAULIC CONDUCTIVITY CHARACTERISTICS OF LEACHATE - CONTAMINATED LATERITIC SOIL

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**Abstract**

*Lateritic soil contamination due to the Leachate from Municipal Solid Waste is a major environmental problem. Landfill leachate is generated from liquids existing in the waste as it enters a landfill or from rainwater that passes through the waste within the facility. The properties and structure of a compacted liner can change with time due to changes in moisture content, capillary forces, and physico-chemical interactions with the liquid waste resulting in a reduction of the effectiveness of the liner as a barrier to contain solid and liquid waste. The changes in chemical characteristics of soils due to leachate contamination may be detrimental to the compacted soils/liner. To protect the groundwater from landfill contaminants, soil liners are widely used to impede the flow of leachate from municipal solid waste. A comprehensive laboratory analysis was carried out to determine the index properties, compaction characteristics and hydraulic conductivity of natural and contaminated lateritic soil. Contaminated samples were prepared by mixing the lateritic soil with varying percentage of leachate at step concentration of 0%, 25%, 50%, 75% and 100% to vary the degree of contamination. The effects of leachate on the Atterberg limits showed increase in liquid and plasticity index values with the increase in the leachate content, thus: Liquid Limit (wl) and plastic index (Ip) at 0% is 51 and 23.08, at 25% (wl = 52.92, Ip =26.48, at 50% (wl =53, Ip =29.28), at 70% (wl =53.22, Ip =32.17) at100 %( wl =54.2 and Ip = 34.13). The hydraulic conductivity of the natural lateritic soil was recorded as 1.40 x $10^{-6}$cm/s and 1.30x$10^{-7}$cm/s using British standard light (BSL) and British standard heavy (BSH) compactive efforts respectively at 0 day curing time. There was corresponding increase in the hydraulic conductivity of the lateritic soil with increase in the percentage contamination, thus: 25%( 4.75x$10^{-6}$cm/s and 2.78x$10^{-7}$cm/s ), 50%( 6.94x$10^{-6}$cm/s and 4.52x$10^{-6}$cm/s), 75% (7.90x$10^{-6}$ cm/s and 6.10x$10^{-7}$cm/s) and finally 100% (5.44x$10^{-6}$cm/s and 7.33x$10^{-7}$cm/s) using BSL and BSH compactive effort respectively. Generally, increase in percentage contamination of lateritic soil by leachate caused increase in the hydraulic conductivity, liquid limit, plasticity index and optimum moisture content while maximum dry density decreased.*

**Keywords:** Compaction, Contamination, Leachate, Lateritic soil, Municipal solid waste.

## INTRODUCTION

A landfill is an engineered facility used for disposing solid wastes on land without creating nuisances or hazards to public health or safety, and are provided to accommodate the solid waste generated at specific site and at minimal cost in several parts of the world (Amadi, 2007). Recently, the volume of municipal solid waste (MSW) generation has increased in many countries due to the increasing population, increasing standard of living and urbanization (Chen, 2018; Vaverková *et al.*, 2020). The landfill is the most common method used for the final disposal of MSWs, as it is the most economical, simplest, and appropriate method available (Adhikari *et al.*, 2014; Vaverková *et al.*, 2020). It is known that 95% of the total MSW collected worldwide is disposed of through landfills (Tamru and Chakma 2016; Luo *et al.*, 2019). Despite these benefits, leachate is a threat to the environment due to the presence of toxic inorganic and organic constituents in the leachate. Leachate from the solid waste dump has a significant effect on the chemical properties as well as the geotechnical properties of the soil. Leachate can modify the soil properties and significantly alter the behavior of soil. Past studies by Goswami and Choudhury (2013); Khan and Pise (1994); Khan *et al.* (1994); Nayak *et al.* (2009) and Foreman & Daniel (1986) have shown that the index and engineering properties of soil contaminated with leachate lead to changes due to chemical reactions between the soil mineral particles and the contaminant. In connection with any possible applications, knowledge of the behavior of contaminated soil is required and hence the present investigation is carried out. The decrease in porosity and pore size in porous media leads to a decrease in hydraulic conductivity (Vinten *et al.*, 1983; Vangulck & Rowe, 2004; Banihashem & Karrabi, 2020). Suspended solids in the leachate accumulate in the soil pores, causing physical clogging of the soil and a decrease in hydraulic conductivity. Metzger *et al.* (1983) reported that unfiltered wastewater (containing suspended solids) causes about 50% reduction in soil hydraulic conductivity, while filtered wastewater causes a reduction in hydraulic conductivity.

This paper presents the results of a laboratory testing program carried out to determine the effect of leachate contamination for a period of 14 days on the geotechnical characteristics (consistency limits, compaction characteristics and hydraulic conductivity) of lateritic soils.

## MATERIALS AND METHODS

### *Lateritic Soil*

The Lateritic soil used for this study was collected from a borrow pit in Lapai-Gwari Road, Lat: $9^0$31'15" N and $9^0$32'30" N and Longitude $6^0$26'15" E and $6^0$28'00" E Minna, Nigeria. The sample was obtained from a depth not less than 1.5m to avoid organic top soil from mixing up with the sample. The soil is a reddish brown lateritic soil, air dried and passed through sieve 425 μm before carrying out laboratory tests on it.

### *Municipal Solid Waste Leachate*

Municipal Solid Waste (MSW) leachate sample was collected from a selected active non engineered landfill site in Minna. The leachate was scooped from a sump, stored and stored in a covered container placed in an incubator to avoid further reactions. The waste stream is mainly domestic and some percentage of commercial wastes. The site has no form of cover hence the wastes are exposed to direct sun and rainfall. The waste stream is mainly domestic and some percentage of commercial wastes.

## METHODS

### *Test Programme*

Laboratory tests were conducted to determine the index properties, compaction characteristics and hydraulic conductivity of natural and contaminated lateritic soil according to standard procedures in BS 1377 Part 2 and 4 (1990) and Head (1994). Contaminated samples were prepared by mixing the lateritic soil with varying amount of leachate content, at step concentration of 0, 25, 50, 75 and 100% by weight to vary the degree of contamination.

The hydraulic conductivity test was carried out and measured using the falling head permeability test condition as recommended by BS 1377 (1990) together with Head (1994). Two energy levels to simulate compactive effort expected in the field namely British Standard Light (BSL) and British Standard Heavy (BSH) were used. After compaction, specimens were cured from 0 to 56 days, thereafter, they were soaked for at least 24 hours in tap water.The hydraulic conductivity (k) was ten calculated using equation 1.

$$k = \frac{aL}{AT} \text{Ln} \frac{H1}{H2} \qquad (1)$$

where a=The area of the stand pipe

L= Height x Thickness= 9.4 $cm^2$

A= Area of the sample

T=The time interval between two heads

$H_1$ and $H_2$ = The falling height of water

## RESULTS AND DISCUSSION

### *Compaction Characteristics of Natural and contaminated lateritic soil*

Compaction tests were carried out on leachate contaminated soil specimens at a step concentration of 25%, 50%, 75% and 100% leachate by weight. The results for BSL compaction are presented in Fig. 1.

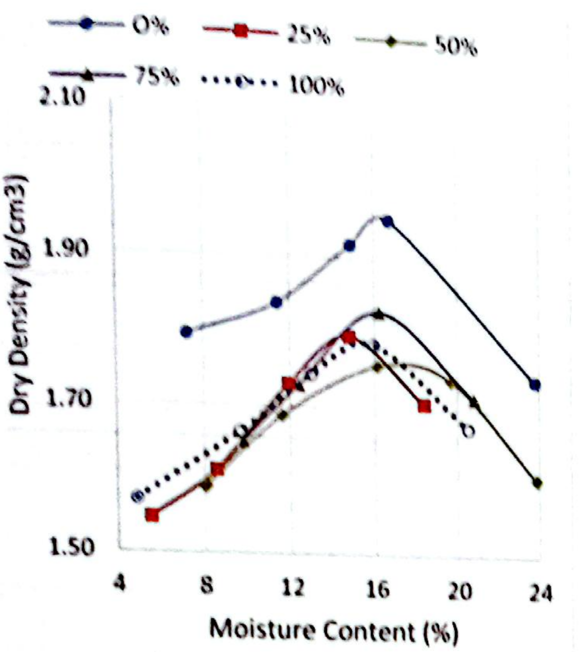


**Fig. 1:** Effect of Leachate on BSL Compaction Characteristics of lateritic soil.

The maximum dry density for the natural lateritic soil is 2.28g/cm$^3$ at the optimum moisture content of 16.4%. With the presence of leachate 25% to 100% the compaction characteristics changed achieving maximum dry density and OMC were 1.79 g/cm$^3$ and 14.9%, 1.77g/cm$^3$ and 18.0%, 1.83g/cm$^3$ and 16.3% and finally 1.78g/cm$^3$ and 16.3% respectively.

Thus, the maximum dry density of the laterite soil decreased with increasing concentration of leachate while optimum moisture content increases with increasing concentration of leachate. This is mainly due to the chemical reaction between the minerals present in the soil and the compounds present in the leachate. The presence of chemicals in leachate, changes the structure of pore fluid in soil, thereby affecting the properties of soil. Maximum reaction occurred at a leachate concentration of 75%. The decrease in maximum dry density reflects the effect caused by chemical reaction (due to change in the nature of the pore fluid) between the leachate and the soil. Hence it is anticipated that in the present study the decrease in maximum dry density is due to chemical reaction between the leachate and the soil. From 25% to 100% leachate concentration, significant amount of leachate is already present in soil, which can cause chemical reaction between the leachate and soil particles.

### *Effect of leachate on Atterberg limits of Lateritic soil*

Contaminants alters the properties of their host soils. The variation of liquid limit (wL) of soil with percentage leachate added is demonstrated in Fig. 2. It can be deduced from Fig. 2 that the leachate has notable implication on the liquid limit of the soil. The liquid limit of the lateritic soil increased with increase in percentage leachate added. This can be attributed to leachate characteristics. Mineralogical analyses of lateritic soil revealed the presence of kaolinite mineral in addition to montmorillonite, quartz, and calcite. The liquid limit behaviour of a montmorillonite soil is controlled essentially by diffuse double layer forces and that of kaolinitic soil by shearing resistance at particle level (Osinubi and Nwaiwu, 2005). In the case of lateritic soils, because of its low cation exchange capacity, the effects due to changes in diffuse double layer are negligible. However, the increase in liquid limit (wl) of the lateritic soil are mainly due to increase in clay content of the lateritic soil. As illustrated in Fig. 2, the liquid limit of the soil has increased from 51% to 54.2% (when leachate concentration increased from 0 to 100%) while the plasticity index (Ip) of the lateritic soil increases with the increase in the leachate concentration. The plasticity index of the soil has increased from 23.08% to 34.13%.

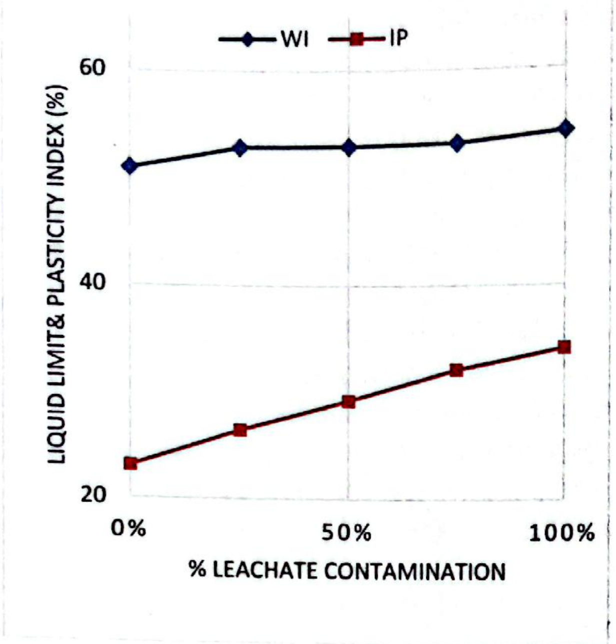


**Fig.2:** Variation of Liquid Limit and Plasticity index with Percentage contamination.

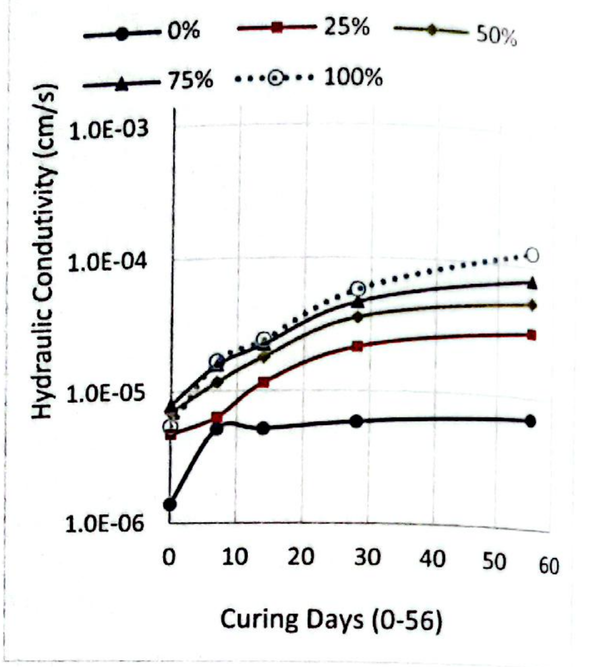


**Fig.3:** Variation of Hydraulic Conductivity with Percentage contamination at different curing days using BSL Compactive effort.

## HYDRAULIC CONDUCTIVITY

### *Effect of Leachate on the Hydraulic Conductivity of Compacted Lateritic soil*

The leachate used in the present study has basic characteristic (pH=8.14). Figs. 3 and 4 shows that the hydraulic conductivity of the soil increased when compared to its base value.

With increase in leachate concentration the hydraulic conductivity of the lateritic soil increases. This increase in hydraulic conductivity of the soil is attributed to chemical reaction between the basic leachate and the clay minerals.

It is reported in literature that strongly acidic and strongly basic liquids can dissolve clay minerals (Uppot and Stephenson, 1989).

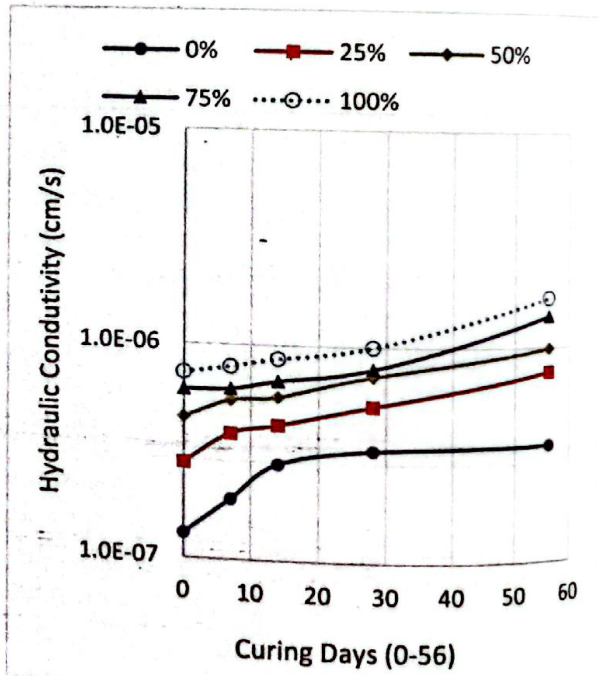


**Fig.4:** Variation of Hydraulic Conductivity with Percentage contamination at different curing days using BSH Compactive effort

The dissolution of clay mineral particles by basic leachate increases the effective pore space and the hydraulic conductivity increases. It can be concluded that the hydraulic conductivity of the compacted lateritic soil using two compactive efforts (BSH and BSL) at 7 to 56 days curing time increases with increase in the leachate concentration. Hence the increase in hydraulic conductivity of lateritic soils after contamination with the leachate is attributed mainly to the following reasons:

a) Chemical reaction between the leachate and the clay minerals;

b) The structural changes which occurred in a soil after contamination with leachate i.e. when pore water is replaced by leachate, voids ratio increases compared to that with water as pore fluid.

## CONCLUSION

The purpose of this research was to investigate the effect of leachate on the properties of lateritic soil. An extensive laboratory testing program was carried out to achieve the objectives. To alter the degree of contamination, the amount of leachate mixed with soil varied up to 100%. The following important conclusions are made based on test results:

- Leachate contamination leads to increase in the hydraulic conductivity of the soil tested. This is attributed to the chemical reactions with the leachate and the soil particles. It was observed that at 25% leachate concentration, the hydraulic conductivity of the lateritic soil increased to $4.75 \times 10^{-6}$ cm/s and $2.78 \times 10^{-7}$ cm/s from $1.40 \times 10^{-6}$ cm/s and $1.30 \times 10^{-7}$ cm/s of the base soil using BSL and BSH compactive efforts respectively at 0 day curing time. At 50% leachate concentration the hydraulic conductivity of the soil tested increased to $6.94 \times 10^{-6}$ cm/sec and $4.52 \times 10^{-6}$ cm/s using BSL and BSH compactive efforts respectively. At 75% leachate concentration the hydraulic conductivity of the tested soil increased to $7.90 \times 10^{-6}$ cm/s and $6.10 \times 10^{-7}$ cm/s using BSL and BSH compactive efforts respectively. Similarly, when the soil was mixed with 100% leachate the increase in hydraulic conductivity was $5.44 \times 10^{-6}$ cm/s and $7.33 \times 10^{-7}$ cm/s using BSL and BSH compactive efforts respectively.

Highly acidic or basic leachate can have significant effect on the index and engineering properties of the soil.

- Experimental results indicated that with the increase in percentage of leachate, maximum dry density ($\rho_d$) decreased from an initial value of 15.89 g/m$^3$ to 14.03 g/m$^3$ and optimum moisture content increased to 24.8% from an initial value of 20.1%.

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