

# Assessment of Lime Stabilization on the Index Properties and Compaction Characteristic of Vermi-Remediatted Crude Oil Contaminated Lateritic Soil

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**Abstract-** This study considered the used of lime to stabilized lateritic soil to be used as landfill liner and cover material. The laterite soil used for this study was collected by method of disturbed sampling from a laterite soil formation located in Shika, Zaria, Kaduna state (Latitude 11015' N and longitude 70 45' E). It was treated with lime at 2%, 4%, 6% and 8% lime content. The result of index properties of the soil were determined as liquid limit 47.0%, plastic limit, 27.30%, plasticity index 19.70%, shrinkage limit 22.86% and specific gravity 2.63. Which revealed that the soil belongs to the A-7-6 (12) group according to the AASHTO (1996) classification system, and is classified as CL (Low clay plasticity) under the Unified Soil Classification System (USCS, ASTM 1992). The soil appears grayish-black in colour, transitioning between shades as it moves from wet to dry conditions. Compaction results revealed that the untreated soil exhibited lower maximum dry density (MDD) and higher optimum moisture content (OMC) due to the lubricating effect of residual crude oil. Vermi-remediation improved soil structure, resulting in more defined compaction curves. British Standard Light (BSL) compactive effort produced the lowest MDD and highest OMC This trend is attributed to increased water demand associated with lime hydration and pozzolanic reactions. Despite the reduction in MDD, lime-treated soils exhibited more uniform and stable compaction behaviour. Lime contents, typically between 4% and 6% achieved successful results.

**Keywords:** Lime, Specific Gravity, Atterberg Limit, Sieve Analysis, Compaction Characteristics

## I. INTRODUCTION

Lateritic soils formed under intense tropical weathering are rich in iron and aluminium oxides and often contain kaolinitic clay fractions. Their natural cementation and fines content make properly compacted laterites suitable for earthworks; however, their surface chemistry also makes them sensitive to coatings and organic loading. Recent region-specific

studies confirm that when laterites are contaminated by petroleum products they show marked changes in Atterberg limits, compaction curves and strength parameters compared with uncontaminated material (Akinwumi et al., 2014; Oyegbile and Ayininuola, 2013). These studies underline the need to remediate contaminated laterites before engineering reuse. Butcher and Sailie (1984) investigated the swelling behavior of compacted lateritic soils in order to understand their suitability for engineering and construction purposes. Lateritic soils are widely used in tropical regions for road construction and earthworks, but their tendency to swell when exposed to moisture can affect their performance as subgrade materials. The study examined the influence of factors such as moisture content, compactive effort, and soil composition on the swelling characteristics of compacted lateritic soils.

Crude-oil contamination of soils is a widespread environmental problem in many oil-producing tropical regions (Ismail et al., 2021). Spills and leaks release a complex mixture of hydrocarbons (light-end aliphatics, aromatics including PAHs, and heavier TPH fractions) and sometimes associated metals into the vadose zone and near-surface soils. In lateritic soils the deeply weathered, iron- and aluminium-rich soils that dominate much of the tropical belt (including large areas of Nigeria) these contaminants can adhere to clay and iron-oxide surfaces, fill pore space, alter soil structure, and harm soil fauna and vegetation. Contaminated sites may pose risks to groundwater, ecosystems, and human health and thus commonly require remediation and, where waste is to be contained on-site (e.g., landfarm, containment cell, or restored borrow pits), engineered liners and cover materials with predictable geotechnical and hydraulic performance (Ismail et al., 2021).

Vermi-remediation refers to the use of earthworms (and associated microfauna and microbes) to remediate contaminated soils. Mechanisms include: Bio-accumulation and bio-transformation: Earthworms and their gut microflora can accumulate, transform and mineralize organic contaminants. Gut passage and microbial activity can enhance degradation of petroleum fractions. Stimulation of microbial communities: Earthworm activity increases soil aeration, mixing, nutrient cycling, and enhancing indigenous microbial biodegradation of hydrocarbons. Physical processing of soil: Earthworm casting and burrowing change particle contacts, pore structure, and organic distribution (Blanchart et al., 1999).

Stabilization with chemical binders (lime, cement, fly ash, etc.) is a standard engineering response to improve strength, reduce plasticity, and decrease permeability of problematic soils. Lime stabilization is particularly common for lateritic and clayey soils. In the context of vermi-remediated oil-contaminated lateritic soil, lime stabilization is proposed to: Restore or improve mechanical strength degraded by contamination or organic residues. However, lime addition may also affect residual biodegradation (e.g., high pH may inhibit ongoing microbial activity), and interaction between residual organic matter from vermi-remediation and lime chemistry may influence compaction behaviour, setting of cementitious products, and long-term durability.

## II. MATERIALS AND METHODS

### 2.1 Materials

#### 2.1.1 Lateritic Soil

The laterite soil used for this study was collected by method of disturbed sampling from a laterite soil formation located in Shika, Zaria, Kaduna state (Latitude 11°15' N and longitude 7°45' E). The soil sample was collected at depths between 1.5 and 2.0 m corresponding to the B – horizon usually characterized by accumulation of material leached from the overlying A - horizon.

#### 2.1.2 Water

Tap water used in the study was collected from the Soil Laboratory of the Department of Civil

Engineering, Nigerian Defence Academy, Kaduna, Nigeria.

2.1.2 Crude Oil: The crude oil was obtained from Port Harcourt, Rivers state, (Latitude 4° 82' N and longitude 7° 05' E) Nigeria.

2.1.3 Lime: The lime used for the study is hydrated lime and was purchased in the open market at Bayyajidda street, Kaduna central market, Kaduna (Latitude 10° 31' 35" N and longitude 7° 26' 20" E).

2.1.4 Earthworms (*Eudrilus Eugeniae*): The earthworms were obtained from river kaduna axis around Kabala Doki area (Latitude 10° 50' N and longitude 7° 44' E).

### 2.2 Methods

#### 2.2.1 Mixing scheme for the laterite-crude oil-vermin mixtures

The soil sample from the borrow site was air dried and hand sorted to remove the pebbles and vegetative matter if any. The soil was further air dried, pulverized and sieved through BS NO 4 Sieve (4.76mm aperture) to remove gravel fraction. The air dried and sieved soil was then stored in airtight bags and ready to use for mixing with the crude oil. The laterite soil was then contaminated with crude oil at a rate of 75cl of crude content per 10kg of the soil sample and 1000 ml of water. The contaminated sample was then fully covered and kept for a period of one month for full contamination. After a period of one month, the crude oil contaminated soil was then remediated with vermin (earthworms) at a rate of 40, 50, 60, 70 per 40kg of contaminated soil sample respectively, making a total of 300 worms per 200kg of soil sample. The sample was then placed in a large perforated tank in an aerated open place for a month for remediation to take place while adding water to the remediation tank on a daily basis and making proper observations.

#### 2.2.2 Total Petroleum Hydrocarbons (TPH)

The total petroleum hydrocarbon (TPH) present in the soil before and after remediation was then determined using the gravimetric

method based on American Society for Testing and Materials (ASTM, 1992).

### 2.2.3 Natural moisture content

BS 1377 (1990) Part 2 was used to determine the natural moisture content of the soil obtained from the site. Three weighing containers were thoroughly cleaned and weighed to the nearest 0.01g (M1). The sample was crumbled and loosely placed in the containers, and the containers with the samples were weighed together to the nearest 0.01g as M2. The containers were then dried in an oven at 105-110oC for 24 hours. After that, the containers and samples were removed and weighed dry to the nearest 0.01g as M3. The natural moisture content (as collected on site) is calculated as the average of the three oven dried samples given by eqn. (1):

$$w = \frac{M_2 - M_1}{M_3 - M_1} \times 100 \quad (1)$$

### 2.2.4 Particle size distribution

Particles size analysis was performed in accordance with BS 1377; 1990 Part 2. To obtain the particle size distribution, dry sieving was performed on 200g of soil sample. The same procedure was carried out on all SBHA -treated soils

### 2.2.5 Specific gravity

The specific gravity was determined using the BS 1377 (1990) test (B) for fine-grained soils. The density bottle and stopper were weighed precisely to the nearest 0.001g (m1). The air dried soil was placed in the density bottle, and the bottle, contents, and cover were all weighed as m2. After adding just enough water to cover the soil, the solution was gently stirred to remove any air bubbles. After that, the bottle was completely filled and covered. The covered bottle was then wiped dry, and the entire assembly was weighed to the nearest 0.001g (as m3). The bottle was then emptied and completely filled with water, wiped dry, and weighed to the nearest 0.001g (m4). The bottle was then emptied and completely filled with water, wiped dry, and weighed to the nearest 0.001g (m4). Eqn. (2) is used to calculate specific gravity:

$$G_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_1)} \quad (2)$$

The same procedure was carried out on all of the SBHA treated soils.

### 2.2.6 Atterberg limits

The test consists of determining the liquid limits, plastic limits, and plasticity index for natural and stabilized soils. They were also carried out in accordance with BS 1377 (1990) Part 2 Test1 (A) for natural.

### 2.2.7 Compaction characteristics

#### 2.2.7.1 Maximum dry density

The compaction tests were carried out for the natural soil and the stabilized soils (in different percentages); all according to BS 1377 (1990) Part 4, using the British Standard light, West African Standard and the British Standard heavy, in accordance with the Nigerian General Specifications (1997). About 3kg of the soil/soil- lime- TE mixtures sample were mixed thoroughly with 8% of water (and the water was added at 8% for each of the compactions). The sample was then compacted into the 1000cm<sup>3</sup> (of mass m1); in three layers of approximately equal mass with each layer receiving 27 blows of 2.5kg rammer falling through a height of 300mm, for the British Standard light compaction; 10 blows of 4.5kg rammer in five layers for West African Standard compaction and 27 blows of 4.5kg rammer in five layers for the British Standard Heavy. The blows were uniformly distributed over the surface of each layer. The collar was then removed and the compacted sample leveled off at the top of the mould with a straightedge. The mould containing the leveled sample was then weighed to the nearest 1g, m2. Two small quantities were then taken from the compacted soil from top and bottom for the determination of moisture content. The sample was then removed from the mould, crushed and additional water was added (2%) and the same procedure was repeated until minimum of five set of samples were taken for moisture content determination. The bulk density in Mg/m<sup>3</sup> was later calculated for each compacted layer using:

$$\rho = \frac{m_2 - m_1}{1000} \quad (3)$$

The dry density was also calculated using the equation:

$$pd = 100p(100 + w) \quad (4)$$

Where  $w$  is the moisture content of each compacted layer.

The values of the dry densities as obtained from eqn. (4) were plotted against their respective moisture contents and the maximum dry density (MDD) was deduced as the maximum point on the resultant curves.

#### 2.2.7.2 Optimum moisture content

The corresponding values of moisture contents at maximum dry densities (MDD), deduced from the graph of dry density against moisture contents, gives the optimum moisture contents (OMC).

### III. RESULTS AND DISCUSSION

#### 3.1 Characteristics of Natural Lateritic Soil

The preliminary index properties test conducted on the natural soil in accordance with BS 1377 (1990) showed that the soil is fine-grained, with a natural moisture content of 16.70 %. A study of the geological map of Nigeria after Akintola (1982) and the soil map of Nigeria after Areola (1982) reveals that the soil belongs to the group of ferruginous tropical derived from acid igneous and metamorphic rocks. The summary of these properties is shown in Table 1. The particle size distribution curve is shown in figure 1. The soil is light brown in colour with a liquid limit of 47.00%, plastic limit of 27.30 % and plasticity index of 19.70 %. The soil is classified as CL soil in the Unified Soil Classification System,

USCS (ASTM, 1992) or A-7-6 (12) according to AASHTO soil classification system (AASHTO, 1996). The natural soil also has a linear shrinkage of 11.43% and specific gravity of 2.66 with 64.00 % passing BS Sieve No 200 (0.075mm aperture). Such characteristics suggest that, in its natural state, the soil may present challenges for engineering applications, particularly as a subgrade or foundation material, unless properly stabilized or treated to improve its strength and reduce its plasticity.

Table 1: Characteristics of natural sandy soil

Property	Quantity
Percentage passing No. 200 sieve	64
Natural Moisture Content (%)	16.7
Liquid limit (%)	47.00
Plastic limit (%)	27.30
Plasticity Index (%)	19.70
Linear Shrinkage	11.43
Specific gravity	2.66
AASHTO Classification	A-7-6 (12)
UCS Classification	CL
colour	Light brown
Dominant clay miner	Kaolinite

#### 3.2 Sieve Analysis

The particle size analysis test was carried out in accordance with BS 1377: 1990 part 2. Dry sieving was conducted by weighing 200 g of the dry soil sample passing sieve No.4 (4.75mm). The dry sample was then mixed with the optimum moisture content of the mix obtained from compaction test and air drying it in the laboratory for 48 hours. Dry sieving was carried out on the dried sample to obtain the particle size distribution. This same procedure was then repeated for each of the sample with lime and TE mixtures.

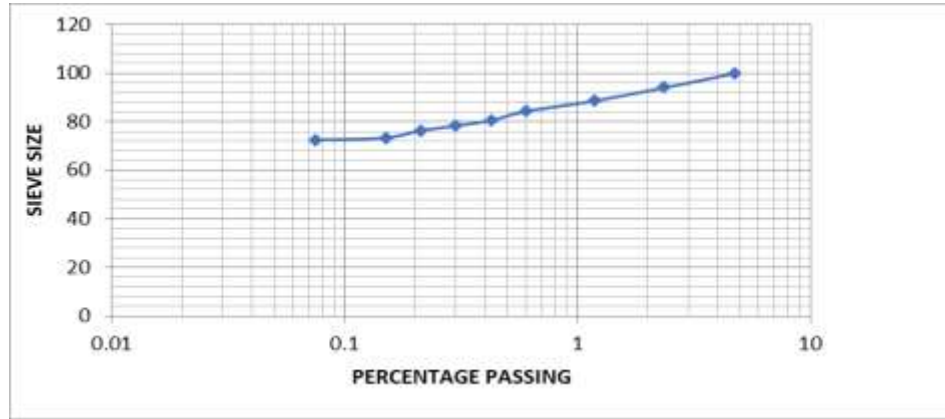


Fig. 1: Particle size distribution curve of the natural soil.

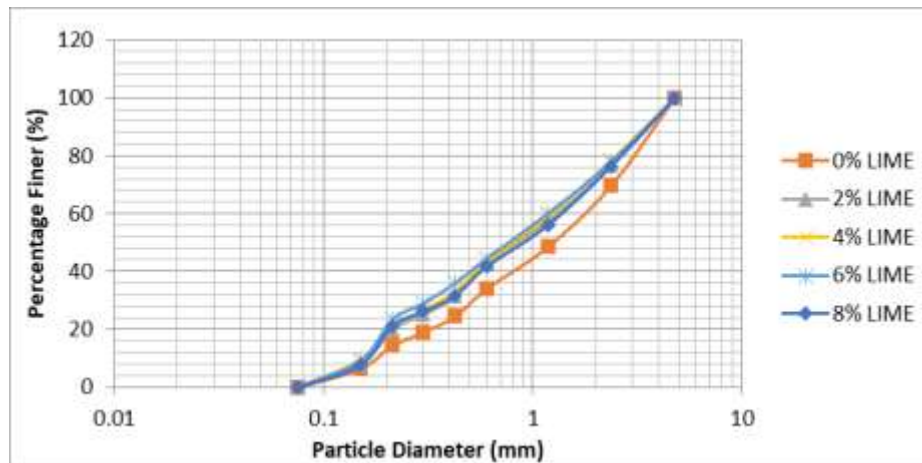


Figure 2: Particle size distribution curve for vermi-remediated crude oil contaminated lateritic soil (BSL compaction energy)

The sieve analysis curves soil treated with varying lime contents (0%, 2%, 4%, 6% and 8%) show a systematic shift in gradation with increasing lime content. All curves exhibit a smooth, continuous gradation pattern, indicating a well-distributed range of particle sizes without abrupt gaps. The untreated BSL (0% lime) curve lies consistently to the left of the lime-treated samples, while progressive addition of lime shifts the curves slightly to the right, indicating changes in effective particle size distribution due to lime–soil interactions.

At 0% lime, the BSL soil shows a higher percentage of fines, reflected by higher percentages passing the smaller sieve sizes. This behavior is typical of fine-grained soils where clay and silt fractions dominate.

Such soils generally exhibit high plasticity and low permeability. With the introduction of 2% and 4% lime, a noticeable reduction in the percentage of fines is observed (Moses, 2012). This shift is attributed to flocculation and agglomeration, where lime causes clay particles to bond together, forming larger aggregates. As a result, the soil behaves more like a coarser material even though the mineral composition remains unchanged. At 6% and 8% lime, the PSD curves show further rightward movement, especially in the finer sieve ranges. This indicates a significant reduction in clay-sized particles and an increase in effective sand- and silt-sized aggregates. The curves for 6% and 8% lime are closely spaced, suggesting that lime stabilization approaches an optimum state, beyond which additional lime results in marginal

changes to gradation is consistent with the finding of (Amu and Babajide, 2011; Moses, 2014).

### 3.3 Atterberg Limit

The Liquid Limit of the lime-treated vermi-remediated crude oil contaminated lateritic soil exhibits a slight increase from approximately 48% to about 50% with increasing treatment intensity. This behavior can be attributed to the interaction between lime and clay minerals through cation exchange and flocculation, which alters the soil structure and increases its affinity for water. Similarly, the Plastic Limit decreases progressively from approximately

35% to about 31% with increasing lime content. This reduction is primarily due to the modification of clay particles caused by lime addition.

Consequently, The Plasticity Index shows a moderate increase from approximately 13% to about 18% with increase in lime content. The observed increase in PI suggests enhanced deformability and sealing potential, allowing the soil to accommodate stress without cracking (Bell, 1996; Amu and Babjide, 2011; Ingles and Metcalf, 1972).

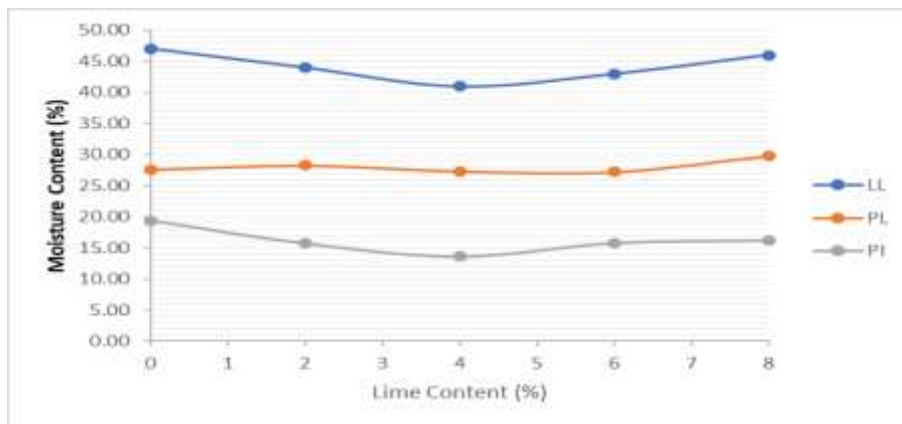


Fig 3: Variation of Liquid limit, plastic limit, plasticity index

### 3.4 Linear Shrinkage

The values of linear shrinkage of the soil recorded were 12.79%, 13.21%, 10.71%, 13.57% and 9.29% for vermi-remediated crude oil contaminated soil treated soil at 2%, 4%, 6% and 8% lime content respectively. Such behavior is characteristic of contaminated fine-grained soils with active clay minerals where moisture loss during drying leads to significant volume reduction. This process leads to flocculation and agglomeration of clay particles, resulting in a temporary increase in water retention capacity (Bell, 1996; Amu and Babajide, 2011; Ingles and Metcalf, 1972).

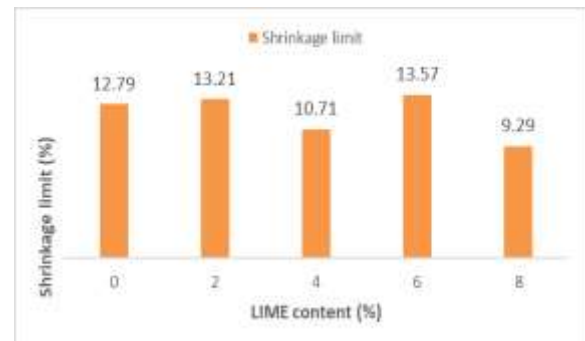


Fig 4: Effect of lime content on shrinkage limit of soil

### 3.5 Specific Gravity

The values of specific gravity recorded were 2.68, 2.82, 2.88 and 2.80 for vermi-remediated crude oil contaminated lateritic soil and stabilized soils at 2%, 4%, 6% and 8% lime content. Vermi-remediated soil further improved the specific gravity values from

2.40 at 0% lime content to 2.68, 2.82, and 2.88 at 2%, 4%, and 6% lime contents respectively. This progressive increase indicates that lime stabilization significantly enhanced the density and engineering properties of the soil. The improvement may be attributed to cation exchange, flocculation and agglomeration of clay particles, as well as pozzolanic reactions between lime and soil minerals leading to the formation of cementitious compounds such as calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH).

Bell (1996) explained that lime stabilization modifies soil structure and improves soil properties through pozzolanic reactions and particle bonding. Osinubi (2006) similarly reported that lime treatment improves the engineering performance of lateritic soils by enhancing soil stability and density characteristics.

The highest specific gravity value of 2.88 was obtained at 6% lime content, suggesting that this percentage represents the optimum lime content for stabilization of the vermi-remediated crude oil contaminated soil. However, at 8% lime content, the specific gravity slightly decreased to 2.80. This reduction may be due to excess lime remaining unreacted within the soil matrix after the optimum lime requirement had been exceeded. Sherwood (1993) noted that excessive lime content may reduce stabilization efficiency because surplus lime particles may not fully participate in pozzolanic reactions.

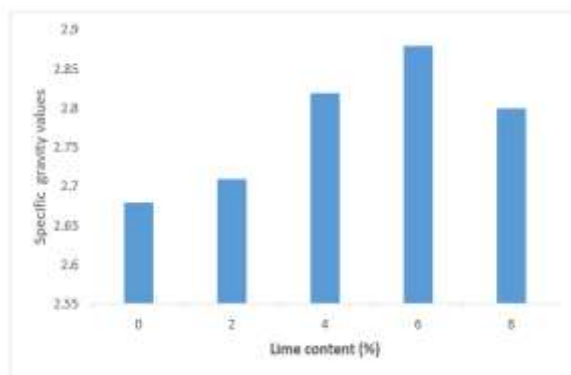


Figure 5: Specific Gravity graph of black cotton with lime content

### 3.6 Compaction Characteristics

#### 3.6.1 Maximum dry density

The corresponding MDD values initially reduced slightly from 1.62 Mg/m<sup>3</sup> at 0% lime to about 1.60 Mg/m<sup>3</sup> at 4% lime, before increasing significantly to 1.69 Mg/m<sup>3</sup> at 8% lime. The initial reduction in MDD is associated with the formation of flocculated soil structures that introduce larger voids under low compactive energy. However, at higher lime content, cementitious products from pozzolanic reactions improve particle bonding, leading to an increase in dry density. The corresponding MDD values initially reduced slightly from 1.62 Mg/m<sup>3</sup> at 0% lime to about 1.60 Mg/m<sup>3</sup> at 4% lime, before increasing significantly to 1.69 Mg/m<sup>3</sup> at 8% lime. The initial reduction in MDD is associated with the formation of flocculated soil structures that introduce larger voids under low compactive energy. However, at higher lime content, cementitious products from pozzolanic reactions improve particle bonding, leading to an increase in dry density is conformity with the finding of (Bell, 1996; Osinubi, 1999; Amu and Babajide., 2011; Little, 1995).

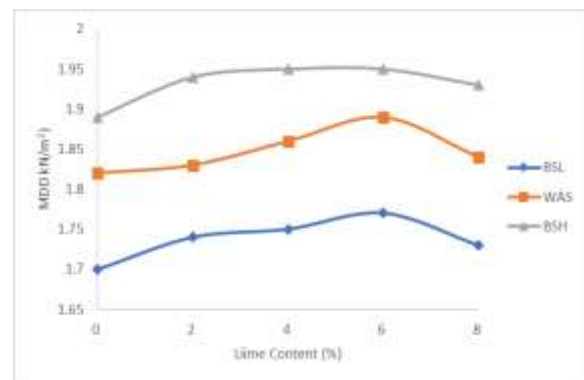


Fig. 6: Graph of Maximum Dry Density with Lime content

#### 3.6.2 Optimum Moisture Content

Under BSL compaction, the OMC decreased steadily from 22.32% at 0% lime to 16.40% at 8% lime. This progressive reduction in OMC indicates that lime treatment reduced the soil's affinity for water. The reduction can be attributed to cation exchange and flocculation of clay particles, which results in larger aggregated particles with reduced specific surface area and, consequently, lower moisture demand is

conformity with the finding of (Bell, 1996; Osinubi, 1999; Amu and Babajide, 2011; Little, 1995).

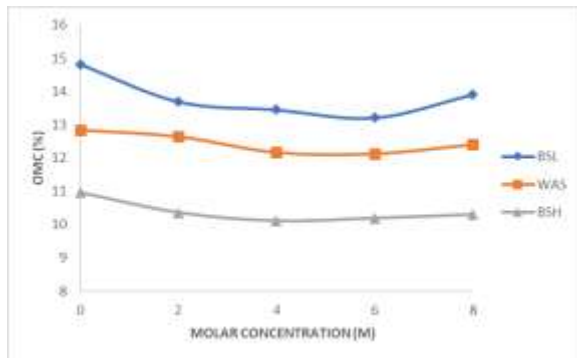


Fig. 7: Graph of Optimum Moisture Content with Lime content

#### IV. CONCLUSION AND RECOMMENDATION

The preliminary characterization of the natural lateritic soil obtained from Shika, Zaria, Kaduna state Nigeria, revealed that the soil belongs to the A-7-6 (12) group according to the AASHTO (1996) classification system, and is classified as CL (low clay plasticity) under the Unified Soil Classification System (USCS, ASTM 1992). The soil exhibited a liquid limit of 47.0%, plastic limit of 27.3%, and a plasticity index of 19.7%, indicating a low degree of plasticity. Additionally, the soil recorded a linear shrinkage of 11.43%, and a specific gravity of 2.88, falls within the typical range for clay minerals, supporting the inference that the soil contains a significant proportion of fine-grained clay particles, likely dominated by kaolinite or similar minerals. Compaction results revealed that the untreated soil exhibited lower maximum dry density (MDD) and higher optimum moisture content (OMC) due to the lubricating effect of residual crude oil. Vermiremediation improved soil structure, resulting in more defined compaction curves. British Standard Light (BSL) compactive effort produced the lowest MDD and highest OMC. This trend is attributed to increased water demand associated with lime hydration and pozzolanic reactions. Despite the reduction in MDD, lime-treated soils exhibited more uniform and stable compaction behaviour. Lime contents, typically between 4% and 6% achieved successful results

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