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Evaluating the Effectiveness of Shea Butter Cake (SBC) as an Earth-Grounding Material Compared to Alternative Conductive Backfills

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***Abstract*: Electrical grounding systems play a crucial role in ensuring the safety and reliability of electrical installations and protecting equipment and personnel from electrical faults, surges, and lightning strikes. Conductive backfills are essential components of these systems, providing low-resistance pathways for the dissipation of electrical energy. This study mainly evaluates the effectiveness of shea butter cake (SBC) as an earth-grounding material compared to alternative conductive backfills. The study adopted an experimental design utilizing a Fall-of-potential" approach in investigating the problem. Shea butter residues, the experimental subject, serve as the thesis' principal source of information. Three (3) distinct types of sampled materials were prepared for testing. (a) local soil (reference experiment); (b) local soil with shea butter residues; and (c) local soil with shea butter residues and clay. It was discovered that the local soil's conductivity had less resistance to electrical flow when it was wet than when it was dry. The conductivity of soil depends on moisture content with variation on the kind of liquid present and the soil resistivity is influenced by the temperature, moisture content, and soil composition. The researcher suggests that Shea butter residue should be encouraged to be used in the country as it is economically cheap when compared to other grounding materials and also it is worthy of carrying out the backfills.**

***Keywords*: earthing system, electrical grounding systems, conductive backfills, shea butter cake, electrical conductivity, local soil.**

1. Introduction

Electrical grounding systems play a pivotal role in ensuring the safety and reliability of electrical installations. These systems provide a low-impedance pathway for fault currents to safely dissipate into the ground, thereby preventing electrical hazards and protecting equipment [1]. A critical component of grounding systems is the conductive backfill material surrounding the grounding electrodes, as it significantly influences system performance.

Traditionally, materials such as bentonite and graphite have been widely used as conductive backfills due to their favourable electrical conductivity properties. However, these conventional materials often come with drawbacks, including high costs, limited availability, and environmental concerns associated with their production and extraction processes [2].

Consequently, there is a growing need to explore alternative materials that are not only economical and readily available but also environmentally sustainable.

Despite the essential role of conductive backfills in electrical grounding systems, the search for suitable alternatives to conventional materials remains ongoing. While shea butter cake (SBC), derived from the Shea tree (Vitellaria paradox), has emerged as a potential alternative, its effectiveness and suitability as an earth-grounding material have not been comprehensively studied (Danikuu, Quainoo, & Sowley, 2016). SBC possesses promising properties, including significant electrical conductivity and corrosion resistance, owing to its high fat and oil content [3]. However, therefore SBC can be widely adopted as a conductive backfill material. Several key questions must be addressed. Firstly, how does the electrical conductivity of SBC compare to that of traditional conductive backfill materials commonly used in earthing systems? Secondly, what is the impact of using SBC as a conductive backfill material on key parameters such as resistance, voltage drop, and fault dissipation within the earthing? Answering these questions is crucial for evaluating the effectiveness of SBC and determining its feasibility as a sustainable alternative in electrical grounding applications.

Therefore, this study aims to fill this research gap by conducting a comprehensive evaluation of the measured performance of earthing systems using Shea Butter Cake (SBC) and comparing it to alternative conductive backfills. By addressing these research questions, this study seeks to contribute to advancing sustainable practices in electrical engineering and infrastructure development.

2. Literature Review

Shea butter cake (SBC) is an under-explored by-product of shea butter extraction with potential application in various fields, including soil improvement for grounding systems. Shea trees (Vitellaria paradoxa) are prevalent in Ghana and other parts of West Africa, with the fruit kernels containing around 60% edible fat, while the remaining product, shea cake, is rich in nutrients and serves as animal feed [4]. Despite its potential,

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Table 1
Chemical composition of shea butter and the fractionated products

Component Shea butter	Unrefined Shea butter	Liquid Concentrate	Shea butter
Glycerides (%)	92	90	75
Unsaponifiable (%)	8	10	25
Tacopheral (ppm)	100-150	150-200	250-300
Fatty acids (of glyceride Fraction):			
Palmiric	4	5	5
Stearic	42	27	9
Oleic	45	57	68
Linoleic	6	9	14

Source: [14]

shea butter cake (residues) has received limited attention in research compared to shea butter. The research gap presents an opportunity to explore its suitability as a backfill material for grounding systems, offering a sustainable alternative to conventional conductive backfills.

Tradition methods for achieving acceptable earth resistance levels involve chemical treatments, such as the application of inorganic electrolytes like sodium chloride. While effective initially, these treatments have environmental drawbacks, including groundwater contamination and short-term efficacy [5]. Shea butter cake emerges as a promising alternative due to its non-toxic nature and lack of chemical impact on the environment. Investigating its efficacy as a backfill material aligns with the grounding demand for sustainable solutions in grounding design and maintenance.

In addition to its environmental benefits, shea butter cake offers potential advantages in soil conductivity enhancement. Studies on similar organic backfills, such as palm kernel oil cake (PKOC) indicated their low resistance when used around earth rods [6]. Organic backfills like Shea butter cake can contribute to improved soil conductivity and reduced grounding system resistance, enhancing electrical safety and equipment protection.

Understanding soil conductivity is essential for optimizing grounding system performance. Soil electrical conductivity (EC) depends on various factors, including soil composition, moisture content, and electrolyte concentration. Commercially available methods for measuring bulk soil EC can inform decisions regarding, backfill selection and grounding system design [7]. Incorporating shea butter cake into the grounding system requires assessing its impact on soil EC and resistance to ensure reliable electrical grounding.

Enhancing the effectiveness of earthing systems is crucial for electrical safety and equipment reliability, while conventional methods involve chemical treatments and multiple ground rods, exploring natural alternatives like shea butter cake presents opportunities for sustainable infrastructure development [8]. By leveraging the unique properties of shea cake, such as its nutritional content and biodegradability, researchers can contribute to the advancement of eco-friendly grounding solutions.

A. Phytochemical Properties of Shea Butter as an Electrical Conductor

Shea nut cake, a by-product of shea butter production, is often overlooked. However, it has valuable benefits. Despite its dark and shapeless appearance, it contains essential minerals and plant-based chemicals that greatly impact its quality and potential uses. Its mineral composition, including nitrogen, potassium, and magnesium, makes it well-suited for agricultural purposes, especially in composting. Additionally, the presence of metals like copper and lead suggests its potential for electrical applications due to their conductive properties [9].

The resistivity values of the components of shea butter cakes suggest they could be used as electrical conductors in grounding systems.

Table 2
Mineral content of shea nut cake

Mineral	Mean±SD (mg/k)	P-Value
Nitrogen	2.96 ± 0.39	0.038
Phosphorus	022 ± 0.04	0.001
Potassium	4.05 ± 0.62	0.128
Sodium	4.05 ± 0.05	0.552
Magnesium	0.04 ± 0.65	0.472
Copper	0.09 ± 0.65	0.020
Mercury	0.10 ± 0.56	0.056
Lead	0.13 ± 0.07	0.5333

Source: [1]

Table 3
Phytochemical property of shea butter

Element	Resistivity value (nΩ-m)
Potassium	72.0
Sodium	47.7
Magnesium	43.7
Copper	16.78
Mercury	9.8×10^{-7}
Lead	208

Source: Retrieved from www.webelements.com, 2016

3. Methods and Materials

The study used the Fall-of-Pote-ntial method to measure the soil resistivity of three different samples. The field measurements were conducted using four probes, four insulated wire conductors, a 4-pole digital meter (megger earth tester), a measuring tape, a hammer, and the meter's user manual.

The main focus of the investigation was on shea butter residues, which were used as the experimental subjects. To ensure accurate conductivity measurements, only 100% shea butter residue was used, as any interference from other substances could have affected the- actual performance of the samples.

Three types of materials were tested:

a) Local soil (reference- experiment)
b) Local soil with shea butter residues
c) Local soil with shea butter residues and clay

Fig. 1. Samples of materials displays

Each sample was labelled for data analysis. The reference experiment used the original soil against soil mixed with additives aimed at either improving or reducing resistivity. For instance, the study sample aimed to improve the resistivity of the local soil, by mixing it with shea butter residues and clay.

A. Measurement Method

The fall-of-potential test was utilized in this experiment to assess the effectiveness of the earthing system and electrodes in dispersing energy from the location. This method, recommended by IEEE Standard 81-1983, is suitable for all types of ground impedance.

The test involves inserting the voltage test stake into the ground halfway between the earth electrodes and the current test stake. Measurements are taken with the voltage test electrode positioned at varying distances from the earth system to calculate D.C resistance.

Correct placement of test stakes is crucial, and any significant discrepancies between measurements indicate potential placement errors, requiring adjustment and repetition of measurements until consistent results are obtained.

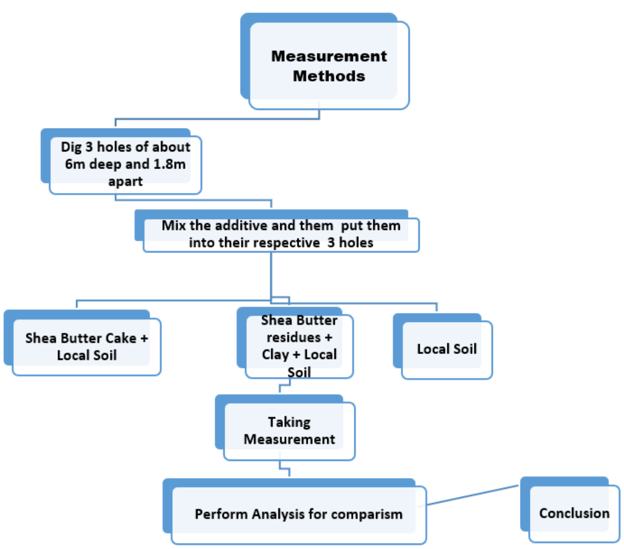

Fig. 2. Flow chart of the methodology

According to IEEE Std 81, 2012, the following are the steps for measuring grounding resistance:

- The instrument contains three terminals: Earth Terminal (Green), Potential Terminal (Yellow), and Current Terminal (Red), and the researcher linked.
- The sample-carrying earth electrode's earth connections.
- Terminal potential using a wire to rod 5 meters from the earth chamber and buried 0.3 meters into the ground.
- The terminal current with a wire to a rod buried in the ground at a distance of 10 meters from the earth chamber and at a depth of 0.3 meters.
- The researcher made sure both connections were made directly to the earth chamber.
- The researcher pressed the TEST button after verifying every link.
- The ground resistance value shown on the display screen was noted.
- To get the average ground resistance, which provides a good estimate of the soil resistivity at the position of the grounding electrode, the researcher performed steps 1 through 7 roughly five times.

When a voltage is placed between the two ends of a conductor or a resistance, a property of that material, resists the flow of electric current. Its measurement unit is the Ohm (Ω), and the typical sign for it is R. The well-known linear equation from Ohm's Law states that resistance is the ratio of the applied voltage (V) to the resultant current flow (I):

$$V = I \times R \tag{1}$$

Where:
V = Potential Difference across the conductor (Volts)
I = Current flowing through the conductor in (Amperes)
R = Resistance of the conductor in (Ohms)

The Resistivity (measured in Ohm-m or -m), the characteristic of a substance that defines its capacity to conduct electricity, is that feature of a conductor that depends on the material's atomic structure. A substance would act as a "good conductor" if its resistivity was low, and as a "poor conductor" if it were high. The most typical representation of resistivity is the (Greek symbol rho).

Resistivity may be used to calculate a conductor's resistance (R) as follows:

Calculation of Resistance using Resistivity: $R = \frac{\rho \times L}{A}$ (2)

Where,
$\boldsymbol{\rho}$ = the conductor material's resistivity (-m)
L = stands for conductor length (m)
A = Area of the cross-section (m^2)

Driven Rod:
Calculation of Apparent Resistivity for a Driven Rod:

$$\boldsymbol{\rho}\text{ad} = \frac{2\pi l R}{In\left(\frac{8l}{d}\right)} \tag{3}$$

Where,
$\boldsymbol{\rho}$ad = Apparent resistivity (Ωm)
L = Length of driven rod in contact with the earth (m)
d = Driven rod diameter (m)
R = Measured value of resistance (Ω)

For example, a 20mm rod of length 3m and soil resistivity of 20Ω was used which produced a resistivity of 17.7Ωm.

B. *Grounding Electrode Installation*

The experiment was carried out on the grounds of the UEW campus. Each of the three holes, which were drilled to a depth of 6m, was filled with a different additive. A rod of 3 meters long and having a 12.2mm diameter measuring the resistance of the local soil was pushed into the ground and another rod with the same length and diameter was placed into each hole.

Fig. 3. Three (3) different types of electrodes arrangements

Fig. 4. Installation process for the grounding system


Fig. 5. A DET 5/4R earth tester

C. *Measurement Apparatus*

The tools that were utilized to accomplish the measurement of grounding resistance were; a tape measure for measuring the distances between the spikes and earth rods that assisted in measuring the resistances. Using a DET 5/4R Earth Tester and the "Fall-of-potential" approach, resistance values were measured.

4. Results and Conclusion

This study is to assess the measured performance of the earthing system using Shea Butter Cake (SBC) and compare it to alternative conductive backfills. Three (3) distinct types of material samples were tested. After careful analysis of experimental data, and review of the chemical makeup of SBC in comparison to other conductive backfills these were the findings.

A. *Comparing the Earthing System's measured performance with observations of the effects of seasonal variation across almost five months*

The researcher examined the material's resistivity in both dry and wet conditions to determine the resistivity of the sample they had chosen (shea butter, shea butter and clay, and original soil). The readings were taken every two days (at equal intervals) between July 17 and September 7, 2015. Tables 4 to 6 provide the reading's findings.

Table 4
Group statistics of local soil with shea butter in wet and dry condition
(N= 25, t (23) = -1.961, p-value = 0.062)

Weather	N	Mean	SD
Dry	14	89. 4500	52.23768
Wet	11	2.521E2	306.61088

Source: Author's field survey
N = Number of measurements, SD = Standard Deviation

Table 5
Group statistics of local soil with shea butter and clay in wet and dry condition
(N = 27, t (25) = -3.726), p-value = 0.001)

Weather	N	Mean	SD
Dry	19	66.6474	25.35112
Wet	8	2.1906E2	178.84559

Source: Author's field survey
N = Number of measurements, SD = Standard Deviation

Table 6
Group statistics of local soil in wet and dry condition
(N = 27, t(25) = -2.520, p-value = 0.019)

Weather	N	Mean	SD
Dry	16	3.0931E2	45.22468
Wet	11	3.9845E2	131.64525

Source: Author's field survey
N = Number of measurements, SD = Standard Deviation

To analyse the acquired resistivity values and determine how to enhance the earthing distribution system and soil electrical conductivity, the researcher used the t-test. From Tables 4 to 5 above, the descriptive statistics (group statistics) are generated.

The group statistics of shea butter and clay resistance in dry and wet weather conditions are shown in Tables 4 and 6. It can be observed from the mean that electrical power passes through shea butter and clay more readily when they are wet than when they are dry since the mean statistics are 2.5215E2 and 2.1906E2 under wet circumstances, respectively, as opposed to 89.4500 and 66.6474 resistance values.

[10] Claim that "The electrical conductivity of soils changes depending on the quantity of moisture stored by soil particles" is supported by this information. [11] Have a high conductivity, sands have a low conductivity, and silts are in the middle. This is also in agreement with a document acquired those states "soil electrical conductivity corresponds extremely strongly with particle size and soil texture" since "sands have low conductivity and clays have high conductivity [12]. Another conclusion that may be drawn is that some materials have more resistivity power while dry than when wet. On the other hand, the original soil has a high resistive mean of 3.9845E2 in its wet condition and 3.0931E2 in its dry state. This suggests that much of the electrical current will be repelled by the original dirt. This

result can result from the soil's moisture content (the liquid) not reacting with the ions (electric current). This is because not all liquids are conductors (e.g. distilled water, paraffin, etc.).

Due to chemical composition, temperature, and moisture, soil resistivity is very variable. The three data above (tables 4–6) support the finding that "the soil at a Water Reclamation Facility was usually wet" from Engineer Educator, Inc.'s research on grounding and bonding electrical systems. Electrical engineers mistakenly believed that the consistent presence of water (caused by a high possibility that paralleled ground rods would be enough to provide a low resistance ground) would be sufficient to solve the grounding issues at the location (earth connection). The opposite, however, was true since it is impossible to precisely establish whether the soil's resistivity is due to moisture, temperature, salt, the kind of soil, or the chemical makeup of the soil. Figure 6 shows a further descriptive chat on the three samples selected.

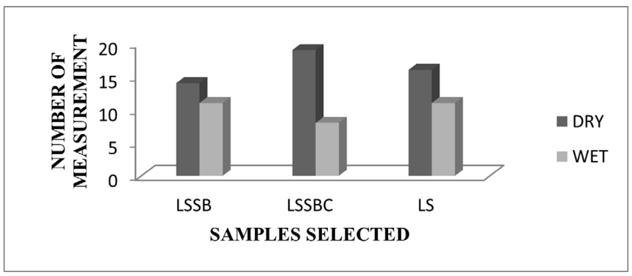

Fig. 6. Comparison of the weather conditions of the selected samples (Source: Author's field survey)

As observed in Figure 6, all three samples have higher resistivity levels in dry weather conditions than they do in wet weather situations. Yet, among these three dry states, Local Soil with Shea Butter and Clay (LSSBC) has the greatest level of resistivity, followed by Local Soil (reference experiment), and Local Soil with Shea Butter has the lowest level of resistivity. Because of the chemical makeup of SBC, which makes them excellent electrical conductors, this may be caused by the addition of shea butter to the soil (Potassium, Sodium, Magnesium, Copper, and Lead).

Given that it has the lowest soil resistivity and the same electrical conductivity as Local Soil with Shea Butter and Clay (LSSBC), LSSBC proved to be the optimal condition for earthing (grounding) under wet conditions. Based on the tables and figures above, it has already been determined that soil dryness generates more resistance to electrical flow than the weather that is moist.

Table 4 shows that local soil with shea butter residue in wet weather has higher soil conductivity and is better at increasing earthing in distribution systems than when it is in dry weather. This study discovered, based on this finding (table 4), that the electrical resistance of local soil in its wet condition with shea butter was statistically substantially lower (2.52 306.61) than in its dry weather condition state (89.45 53.24).

The test revealed a substantial difference between the dry state (2.19 178.85) and the wet condition (66.65 25.35) using local soil with shea butter and clay samples as well. The above two studies verify the assertion given by [13] that "the wetter the soil, the smaller the resistance it will have". In contrast to the other samples, local soil (the reference point) demonstrated the opposite. Even while a statistically significant measure does exist, it is biased toward dry weather (3.09 45.22) as opposed to rainy weather (2.98 131.65). This demonstrates that the reference location (local soil) has a substantially greater electrical conduction resistance when wet compared to when dry. The aforementioned causes are to blame for this (temperature, moisture content, and the type of soil).

5. Conclusion

In conclusion, this study highlights the significant influence of Shea Butter Cake (SBC) on the effectiveness of earthing systems compared to alternative conductive backfills. The findings underscore the importance of soil resistivity and moisture content in determining the electrical conductivity of the grounding system. The presence of elements like water and Shea Butter Cake was found to reduce resistance to electrical flow in local soil, particularly when moist.

Moreover, the study suggests that shea butter residue holds promise as a cost-effective and locally available alternative to imported backfill materials. Its composition, including minerals conductive to electrical conductivity, presents an opportunity to improve grounding installations economically.

However, it's essential to acknowledge the study's limitations, such as the need for further research to validate these findings across different soil types and environmental conductions. Future investigations could explore optimal ratios of shea butter cake to the soil for maximum conductivity and longevity of grounding systems.

In light of these findings, it is recommended that policymakers and practitioners consider integrating shea butte residue into grounding system designs, particularly in regions where shea butter production is prevalent. By doing so, not only can the cost of grounding installation be reduced, but local economies can also benefit from utilizing indigenous resources.

In summary, while this study provides valuable insights into the potential of shea butter cake as an earth-grounding material, ongoing research and practical implementations are necessary to fully realize its benefits and ensure the reliability and safety of electrical systems.

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