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Comparative Deterministic Analysis of Bentonite, Pig Dung and Domestic Salt and Charcoal Amalgam as Best Resistance Reducing Agent for Electrical Earthing Applications

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Abstract— This paper presents a comparative evaluation of bentonite, pig dung and domestic salt and charcoal amalgam as artificial compounds for earth resistance reduction. The properties which demonstrate effectiveness of these compounds as resistance reducing agent are investigated in this study. Moisture content, moisture retaining capacities and electrical conductivity were the properties considered. The effect of these compounds on soil resistivity is demonstrated using the Wenner Array soil resistivity measurement set up in a soil box. Pig dung yielded the best result, reducing the resistivity of the soil from 74.94Ω-m to 8.26Ω-m followed by bentonite, 9.25Ω-m and salt and charcoal, 10.87Ω-m. Also, it was observed that the pig dung decomposed after a certain period of time bringing about a reduction in the reacting mass and moisture content of the dung and consequently affecting the value of the earth resistance. Again, domestic salt leaches away into the soil over time and the charcoal corrodes the earth electrode while no significant demerit was discovered for bentonite. Based on its limited demerit, this study recommends bentonite as the best resistance reducing agent for electrical earthing applications.

Index Terms— bentonite, charcoal, comparative deterministic analysis, domestic salt, earthing, earth resistance, pig dung

1 Introduction

THE earthing system is an essential part of power networks at both high- and low-voltage levels. There are several important reasons why an earthing system should be installed but the most important reason is to protect people and equipment [1]. From point of view of a good operation in an electrical and electronic system, the earthing system must complete high-priority functions [2] which include:

- Providing stable tensions between active phases and ground when a single-phase fault takes place in an electric power system;
- In the event of fault to ground, provide a low impedance route;
- In the event of atmospheric discharges, drive this great energy to ground;
- Establishment of a voltage reference level etc.

To minimize the effects of faults, designers and installers of electrical earthing systems are required to design the system so that faults are cleared in the quickest possible time. This requires that the earthing system be constructed to achieve the lowest practical resistance [3].

There exist cases where the high resistivity of soil makes it difficult or even impossible to obtain low resistance values in the construction of an earthing system thereby posing some challenges. Thus, there are, at present, natural and artificial means of modifying the resistivity of such soils which cover ground electrodes.

This is done by replacing soil within effective resistance area of an earth electrode with backfill materials or artificial compounds to lower its resistivity, thereby improving the conductivity of the soil [2]. For this to be realistic, it will be necessary to limit the backfill to the area very close to the earth electrode and judged to be accounting for a substantial percentage of the total earth resistance. This area is referred to as critical resistance area and its radius as critical resistance radius [4].

Although several backfill materials or artificial compounds can be used to achieve this purpose, this study focuses on the critical analysis of the three most abundant and cost-effective resistance reducing agents utilized by designers and installers of electrical power systems in Nigeria. These compounds are bentonite clay, pig dung, and amalgam of domestic salt and charcoal.

The bentonite clay is a natural earth soil (clay) containing the mineral montmorillonite, which was formed by volcanic action years ago. It is non-corrosive, stable and has a resistivity of 2.5Ωm at 300% moisture [5]. Its low resistivity results main-

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ly from an electrolytic process between water, Na_2O (soda), K_2O (potash), CaO (Lime), MgO (Magnesia) and other mineral salts, that ionizes forming a strong electrolyte with pH ranging from 8 to 10 [5]. The bentonite clay is also highly hygroscopic in nature. These properties account for its effectiveness as an earth resistance reducing agent.

The pig dung is a waste product of metabolism from the animal's digestive tract expelled through the anus during a process called *defaecation* [6]. It is an organic compound with very high moisture content, moisture absorption capacity, high electrical conductivity and low pH [7]. Pig dung is chosen over other animal dung in this research because it has the highest nitrogen to phosphorus ratio and also the highest percentage moisture content by volume compared to other animal dung. The high nitrogen to phosphorus ratio is as a result of the highly leguminous content of the animal's feed compared to other ruminants whose feed are predominantly composed of forages. Also, the absence of sweat glands in pigs necessitates the ubiquity of water in the pig's sty or barn which accounts for the high percentage moisture content by volume of the pig dung. These properties and its chemical constituents account for effectiveness of pig dung as an earth resistance reducing agent.

Domestic salt and charcoal are soluble additives. Domestic Salt also known as common salt, sodium chloride, table salt or halite, is an ionic compound with formula NaCl [8]. Charcoal is a light black residue consisting of carbon, and any remaining ash, obtained from animal and vegetation substances [9]. Charcoal is 'carbon' and domestic salt is 'sodium chloride', both are electrolytes with very good conductivity hence if buried in the soil surrounding the electrodes, soil resistivity is reduced. While the salt percolates, the charcoal absorbs water to keep the soil wet. Domestic salt and charcoal are highly conductive in water solution and reduces the resistivity of the soil when dissolved in the moisture in the soil, after which additional quantity does not serve the purpose. This is evident in [10] where it is stated that 5% moisture in salt reduces soil resistivity rapidly and further increase in salt content gives a very little decrease in soil resistivity.

These artificial compounds have their different levels of merits and demerits. When added to the soil, the overlying soil shows an extremely favourable earth resistance for some period after the treatment. However, the chemicals might be carried away by surface run-off water and subsoil water during rainfall, thus the effect of these chemicals may last only for a period ranging from several months to 3 years at most depending on the chemical, the mean effective period being about 2 years [2], [4]. Accordingly, the chemical treatment must be repeated after certain period. However, such repeated treatments, maintenance, and inspection are very difficult in remote and deserted places. Also questions regarding environmental impact of these chemicals remain unanswered. Others have raised concerns about ground water contamination from the chemicals [2]. It is therefore necessary to maximize the merits and eliminate the demerits of these compounds by choosing the best artificial compound that will serve as a resistance reducing agent for electrical earthing applications.

2 SOIL RESISTIVITY

Resistance is that property of a conductor which opposes electric current flow when a voltage is applied across the two ends. Its unit of measure is the Ohm (Ω) and the commonly used symbol is **R**. It can also be defined by the well-known linear equation of Ohm's Law:

$$V = I \times R \quad (1)$$

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

The Resistance of a conductor depends on the atomic structure of the material or its resistivity (measured in Ω-m), which is that property of a material that measures its ability to conduct electricity.

The resistivity ρ of a conductor is written as:

$$\rho = \frac{RA}{L} \quad (2)$$

Where:
ρ = Resistivity (Ω-m) of the conductor
L= Length of the conductor (m)
A = Cross sectional area of the conductor (m^2)

This factor among others is important in deciding which of many protective systems to adopt.

It depends on a number of soil properties such as: i) nature and arrangement of soil constituents, ii) moisture content of soil and iii) soil temperature.

2.1 Nature and arrangement of soil constituents

The electrical conductivity is related to the particle size and the electrical charge density at the surface of the solid constituents. In clay soil, the electrical charges located at the surface of the clay particles lead to greater electrical conductivity than in coarse-textured soils because of the magnitude of the specific surface [11]. The geometry of the pores (void distribution and form) determines the proportion of air and water according to the water potential. The resistivity varies with the structure of the soil materials hence revealing that high and low resistivity values were related to porosity [11].

2.2 Moisture content of soil

Electrical current in soils is mainly electrolytic, i.e. based on the displacement of ions in pore water. Thus, electrical current in soils depends on the amount of water in the pores and on its quality. The electrical resistivity decreases when the water content increases [12], [13].

2.3 Soil temperature

Ion agitation increases with temperature when the viscosity of a fluid decreases. Thus, there exist an inverse relationship between soil resistivity and water content [12].

In [12], a list of different types of soils, their resistivity and its variation with moisture content of soil and temperature were presented.

3 Soil Resistivity Testing Procedure

The purpose of resistivity testing is to obtain a set of measurements which may be interpreted to yield an equivalent model for the electrical performance of the earth, as seen by the particular earthing system. However, the results may be incorrect or misleading if adequate investigation is not made prior to the test or the test is not correctly undertaken. To overcome these problems, data gathering and testing can be done using one of Wenner array (WA), Schlumberger array (SA) and driven rod (DR) method [12], [13].

Although the WA method is the least efficient from an *operational* perspective because it requires the longest cable layout, largest electrode spreads and for large spacing one person per electrode is necessary to complete the survey in a reasonable time [13]; it is the most efficient in terms of the ratio of received voltage per unit of transmitted current [12]. This test method was applied in this research due to the latter reason. See Fig.1 for illustration of this method.

The apparent resistivity was obtained from the field measurements using the following formula:

$$\rho_{a\omega} = 2\pi aR \qquad (3)$$

ρ_{aw} = Wenner method apparent resistivity (Ω-m)
a = probe spacing (m)
ΔV = voltage measured (V)
I = injected current (A)
R = measured resistance (Ω) = $\Delta V/I$

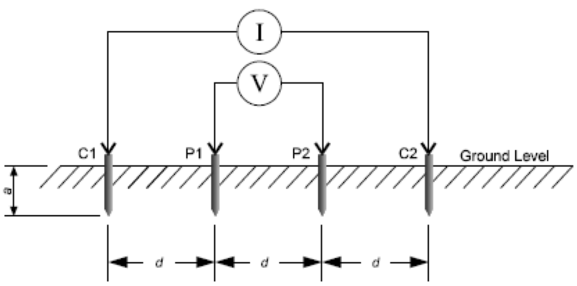

Fig. 1: Wenner 4 pin method

In SA method, economy of manpower may be gained since the outer electrodes are moved four or five times for each move of the inner electrodes [12]. Nonetheless, erroneous (lower) voltage readings often result when using this method. The DR (also called three Pin or fall-of-potential) method is normally suitable for use in circumstances such as transmission line structure earths, or areas of difficult terrain, because of: the shallow penetration that can be achieved in practical situations, the very localized measurement area, and the inaccuracies encountered in two layer soil conditions [12], [13].

4 Analysis of the Chemical Properties of Earth Resistance Reducing Agents

The artificial compounds which are applied to the soil in order to lower its resistivity constitute chemicals or elements. Thus they undergo sequences of chemical reactions that attest to their resistivity reduction capabilities. Amongst the properties of these compounds, the most essential property which determines to a large extent, their effectiveness as good earth resistance reducing agents is the hygroscopic nature**.** Hygroscopy is the ability of a substance to attract and hold water molecules from the surrounding with the absorbing material becoming physically charged as water molecules become suspended between the materials molecules in the process [6].

The analyses of the chemical reactions that attest to the hygroscopy as well as other chemical properties of the various compounds are discussed in this section.

4.1 Pig dung

The application of pig dung to soil is an economical and environmentally sustainable method for the utilisation of the nutrients and other components in the manure.

The pig dung is an organic compound with very high moisture content, moisture absorption capacity, high electrical conductivity and low pH [7]. These properties and its chemical constituents account for its effectiveness as an earth resistance reducing agent.

The moisture content of the pig dung average about 95% and does not vary greatly among the different types of barns [6]. See table 1 below.

Table 1: Moisture Content and percent solids of pig dung samples

	Fresh dung	Dung from building
Moisture (%)	90.8	98.0
Solids (%)	9.2	2

(Source: [29])

Nitrogen is one of the principle components of pig dung. The nitrogen content of the dung can vary dramatically, depending upon animal species, feeding regime and overall management practices [7]. Pig dung contains organic nitrogen sources derived from partially digested feed and faeces; and inorganic nitrogen sources derived from the urea contained in urine and the bacterial transformation of the organic nitrogen sources. Nitrogen is predominantly present in the form of nitrogen (IV) oxide (NO_2), an acid anhydride, which dissolves in water to form nitric acid (HNO_3) [6], [7].

The phosphorus (P) in pig dung is initially present in both

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organic (up to half of the total P) and inorganic forms [6]. The availability of the organic phosphorus in manure depends on the rate of mineralization, the process whereby micro-organisms convert the organic phosphorus into inorganic phosphorus. The microorganisms that mineralize organic phosphorus are active in soil and in manure storage systems. This is present in the form of phosphorus (IV) oxide (P_2O_5) which dissolves in soil water to form phosphoric acid (H_3PO_4) [6, 7]. See table 2.

Table 2: Forms of Nitrogen and phosphorus in pig dung samples

	Fresh dung	Dung from building
	---------LB/ 1000 GAL--------	
NH^{4+}(Ammonium)	28.6	11.4
Organic nitrogen	22.7	5.6
P_2O_5	36.5	12.5

(Source: [29])

Furthermore, the electrical conductivity (EC) which is the measure of salt content of pig dung can be quite high mainly because of the presence of nutrients (for example, ammonium), the use of dietary salts, and in some instances groundwater containing salts [6]. The dominant ions that contribute to electrical conductivity in hog manures are ammonium, sodium, calcium, magnesium, chloride and sulfate. EC of the pig dung varies with type of barn and ranges between 8.65 and 27.50 dS/m [6, 7].
The sodium adsorption ratio (SAR) of solutions is used to provide an indication of the possible harmful effects of sodium on soil structure [6]. A build-up of excess sodium in the soil relative to calcium and magnesium can have adverse effects on soil structure, such as surface crusting. The SAR is a measure of amounts of sodium added to soil in relation to amounts of calcium and magnesium added. Solutions with SAR values of 0 to 4 have little or no effect on soil quality, and solutions with SAR values of 4 to 9 have slight to moderate effects on soil quality [6]. Approximately two-thirds of the pig dung samples had SAR values between 0 and 6. The mean SAR of the pig dung samples was 5. Thus, the majority of pig dung would have little or no sodicity hazard [6, 7].

Also, pig dung exhibits hygroscopy as a result of ammonium salts (ammonium phosphate and ammonium nitrate) formed when pig dung is subjected to soil conditions. The chemical reaction of pig dung can be summarized below.

i) Hydrolysis of Urea: After application to soil, urea ($(NH_2)_2CO$), which is present in the animal dung will hydrolyze (combine with water) to form ammonium carbonate. This reaction is driven by the enzyme urease, which is present in the soil. Ammonium carbonate is very unstable and decomposes into water, ammonium ion and carbon dioxide. The ammonium ion further reacts with hydroxyl ion in the soil to form ammonia gas and water [14].
These chemical reactions are shown below:

$$(NH_2)_2CO + 2H_2O \xrightarrow{\text{Soil and urease}} (NH_4)_2CO_3$$

Equation 1: Hydrolysis of urea to form ammonium carbonate

$$(NH_4)_2CO_3 + 2H^+ \longrightarrow 2NH_4^+ + CO_2 + H_2O$$

Equation 2: Chemical decomposition of ammonium carbonate in soil

$$NH_4^+ + OH^- \longrightarrow NH_3 + H_2O$$

Equation 3: Further reaction of ammonium ion with hydroxyl ion

ii) Reaction of Ammonia with HNO_3 and H_3PO_4: Ammonia formed from the hydrolysis of urea in the soil reacts with the nitric and phosphoric acid present in the pig dung to form ammonium phosphate and ammonium nitrate salts. These ammonium salts are highly hygroscopic in nature, and account for the hygroscopy of pig dung [15].
The chemical reactions of ammonia with nitric acid and phosphoric acid are shown thus:

$$NH_3 + HNO_3 \longrightarrow NH_4NO_3$$

Equation 4: Chemical reaction of ammonia with nitric acid

$$NH_3 + H_3PO_4 \longrightarrow NH_4HPO_4$$

Equation 5: Chemical reaction of ammonia with phosphoric acid

4.2 Bentonite

Bentonite is moisture retaining clay used as an earth electrode back fill to help lower the resistivity of the soil. Its low resistivity results mainly from an electrolytic process between water, Na_2O (soda), K_2O (potash), CaO (Lime), MgO (Magnesia) and other mineral salts, that ionizes to form a strong electrolyte. This electrolyte will not gradually leach out as it is part of the clay itself (one advantage of bentonite as a back fill material).
Provided with enough amount of water, it swells up to 13 times its dry volume and will adhere to nearly any surface it touches [16]. It has a hygroscopic nature which enables it act as a drying agent thus drawing any available water from the soil and surrounding environment.
Bentonite needs water to obtain and maintain its beneficial characteristics. Most soils have sufficient ground moisture so that drying out is not really a concern.
The hygroscopic nature of bentonite will take advantage of the available water to maintain its installed condition. It may not function well in a very dry environment as it may shrink away from the electrode thus increasing the electrode resistance.
The bentonite clay can be categorised into:

- Sodium Bentonite (the predominant element in it is Na)
- Calcium Bentonite (the predominant element in it is Ca)

The type of bentonite used for earthing purposes is the sodium bentonite. This is because it swells more than the calcium type and also has better water retention capability.

i) Hygroscopic nature of bentonite

Bentonite chemical is highly hygroscopic. This is due to the formation of chemical solutions of the constituent element in the bentonite chemical, when it comes in contact with water. Sodium for instance, (which is the dominant element in the slurry) reacts with moisture in the soil to form sodium hydroxide (NaOH). This sodium hydroxide accounts for the hygroscopy of the bentonite chemical.

Its hygroscopic nature makes it a good drying agent drawing any available moisture from the soil and the surrounding in the general, since bentonite needs water to obtain and maintain its beneficial characteristics.

The formation of the hygroscopic sodium hydroxide is sequential, as the sodium atoms first combine with the oxygen in the air to form sodium oxide as illustrated below.

$$Na_{(s)} + O_{2\,(g)} \longrightarrow Na_2O_{(s)}$$

Equation 6: Chemical reaction of sodium and oxygen gas

This oxide normally absorbs water from the air to form sodium hydroxide which is highly hygroscopic.

$$Na_2O_{(s)} + H_2O_{(l)} \longrightarrow 2NaOH_{(aq)}$$

Equation 7: Chemical reaction of sodium oxide and water

This sodium hydroxide formed reacts further with excess carbon (IV) oxide, CO_2 in the air to form sodium trioxocarbonate (IV) salt.

$$2NaOH_{(aq)} + CO_{2\,(g)} \longrightarrow Na_2CO_{3\,(aq)} + H_2O_{(l)}$$

Equation 8: Chemical reaction of sodium hydroxide with carbon dioxide

Since the CO_2 is in excess, the sodium carbonate formed, further reacts with it to form sodium hydrogen trioxocarbonate (IV).

$$Na_2CO_{3\,(aq)} + H_2O_{(l)} + CO_{2\,(g)} \longrightarrow 2NaHCO_{3(s)}$$

Equation 9: formation of sodium hydrogen trioxocarbonate (IV)

Sodium hydrogen carbonate decomposes on heating to form anhydrous sodium carbonate (Na_2CO_3).

$$2NaHCO_{3(S)} \longrightarrow Na_2CO_{3(S)} + H_2O_{(g)} + CO_{2\,(g)}$$

Equation 10: decomposition of sodium hydrogen carbonate

The sodium trioxocarbonate (IV) forms an efflorescent salt that is highly alkaline, making electrical conduction in the soil easier.

$$Na_2CO_{3(s)} + H_2O_{(L)} \longrightarrow Na_2CO_3.10H_2O_{(s)}$$

Equation 11: Formation of the alkaline salt

The significance of this hygroscopic and alkaline nature of bentonite is that it enables it to absorb moisture from the soil hence reducing the resistivity of the soil as moisture tends to form a conducting path in the soil. This makes bentonite an ideal back fill material for earth resistance reduction and thus for electrical earthing applications.

ii) Swelling of bentonite

Bentonite is noted for its high affinity for water and its tremendous swelling property. This swelling property is achieved when the bentonite slurry comes in contact with water. It has been noted that bentonite expands to over 13 times its dry weight when mixed with water. The expansion is faster if the bentonite is actually poured into the water but rather slow if done the other way round [5].

Prior to the application of water, the bentonite slurry (Sodium bentonite in this case), has some avalanche of positive ions due to the sodium atoms. When it eventually comes in contact with water, hydration occurs. Consequently, the platelet is replaced with negative ions. This is as a result of a simple redox reaction that involves the simultaneous oxidation of sodium and reduction of water molecules, thus leading to the balancing of charges.

Hence, the result is an avalanche of negative ions. Since like charges repel, the swelling of the bentonite is due to the continuous repelling of the like charges on the bentonite slurry. The chemical reaction is expressed below.

$$2Na_{(s)} + 2H_2O_{(l)} \longrightarrow 2NaOH_{(aq)} + H_{2\,(g)}$$

Equation 12: chemical reaction of sodium with water.

From the above equation, sodium is oxidized to sodium hydroxide (NaOH), while the water molecule is being reduced to hydrogen molecule. This swelling property of bentonite helps in the protection of the copper electrode as the bentonite tends to swell around the electrode thus depositing some moist minerals around it. This will consequently lower the resistance of the copper electrode and hence that of the earth.

iii) Self Sealing Property

The ground is prone to frequent rifting movement, drilling actions, cracking, tearing, ripping and some other ground movements that would break concrete or synthetic lines. This would consequently have effect on the bentonite material being buried in the ground for electrical earthing purposes. The effect of this ground movement causes voids and cavities on the bentonite clay hence attempts to alter its shape. The ability of bentonite to recover to its initial shape and size after it must have undergone this effect is referred to as its self-sealing property.

The scattering of dry bentonite over the surface of the water impoundment in question will frequently allow the hole to be sealed effectively by the swollen bentonite settling through the entire unsealed area [17]

iv.) Water Retention Capability

Water is retained in the soil when the adhesive forces of attraction of water for soil particles and the cohesive force water feels for itself are capable of resisting the force of gravity

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which tends to drain water from the soil. When a field is flooded, the airspace is displaced by water. The field would drain under the influence of the force of gravity until a point called the field capacity is reached where the smallest pores are filled with water and the largest with water and air [16]. The water retention capability of the soil is dependent on the type of soil in question, as different type of soil have varying characteristics as regards the ability to hold water.

Bentonite supplements this ability of the soil to hold water. Sandy soil for example holds water the least (of all the various soil samples). This is due to its porosity, causing water to flow through its numerous pores. The application of bentonite to this soil would make the soil impermeable. As earlier stated, bentonite swells immensely in contact with water, thus filling the pores and voids in the soil. This continues until a tough leathering mineral called "mastic" is formed through which water cannot readily move through [16].

4.3 Domestic salt and charcoal

4.3.1 Domestic salt

It is chemically composed of Sodium and Chlorine (NaCl). When NaCl is dissolved in water, it dissociates into Na^+ (positive cation) and Cl^- (negative anion).

$$NaCl_{(aq)} \longrightarrow Na^{(+)} + Cl^{(-)}$$

Equation 13: Dissociation of sodium chloride into sodium ions and chloride ions

The presence of this soluble salt in large amounts in the soil increases its electrical conductivity.

The clay and organic matter of the soil supplies the negative charges which attract the sodium ions (Na^+) and repel the chloride ions (Cl^-) thereby increasing the availability of the basic ions, thus increasing conductivity [18,19].

The sodium ions produced from the dissociation of sodium chlorides further reacts with oxygen and water to form hydroxides which further reacts with the acids present in the soil to form more salt and water that will also further help to improve resistivity as soil pH is increased.

This is explained with the chemical reaction below;

$$Na_{(s)} + O_{2(g)} \longrightarrow Na_2O_{(S)}$$

Equation 14: Oxidation of sodium to form sodium oxide

$$Na_2O_{(s)} + H_2O_{(l)} \longrightarrow 2NaOH_{(s)}$$

Equation 15: Hydrolysis of the sodium oxide to form sodium hydroxide

$$H\,(+) + Cl\,(-) \longrightarrow HCl$$

Equation 16: Reaction of chloride ion and hydrogen ion, obtained from the dissociation of sodium chloride and water respectively, to produce HCl.

$$HCl_{(aq)} + NaOH_{(s)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$$

Equation 17: Reaction of sodium hydroxide and hydrochloric acid to produce more salt and water.

Furthermore, sodium Chloride is said to be hygroscopic in the soil. This is due to formation of $NaNO_3$ as a product of the reaction between sodium chloride and the soil salts. $NaNO_3$ is a very strong hygroscopic compound used as drying agents in many industrial applications [30]. The reactions are described below with their corresponding chemical equations [20, 21].

$$Na_{(s)} + O_{2(g)} \longrightarrow Na_2O_{(S)}$$

Equation 18: Oxidation of sodium to form sodium oxide.

$$Na_2O_{(s)} + H_2O_{(l)} \longrightarrow 2NaOH_{(s)}$$

Equation 19: Hydrolysis of the sodium oxide to form sodium hydroxide

The sodium hydroxide above further undergoes double decomposition reaction with salts (say Ca $(NO_3)_2$) present in the soil to form sodium nitrate which is very hygroscopic. This reaction is shown below;

$$Ca\,(NO_3)_{2(aq)} + 2NaOH_{(s)} \longrightarrow Ca\,(OH)_{2\,(s)} + NaNO_{3\,(s)}$$

Equation 20: Double decomposition reaction between calcium nitrate and sodium hydroxide to produce calcium hydroxide and sodium nitrate.

4.3.2 Charcoal

Charcoal is composed of carbon, hydrogen, oxygen and nitrogen in proportions varying with the kind of wood. The general chemical formula for charcoal is "C_7H_4O" with carbon as its main element having a percentage by mass of approximately 80% [21]. In charcoal, not all four valence electrons are used for bonding. While each carbon atom is bonded to three others, the fourth electron is delocalized i.e. it is not attached to any particular atom. These delocalized electrons are free to move about thus increasing conductivity. Carbon atoms are arranged in layers made up of hexagonal rings with interstitial spaces in form of pores [21]. This porous nature of charcoal increases the Cation Exchange Capacity of the soil thus increasing conductivity.

The charcoal used in earthing are not water washed, thus contain a considerable amount of ashes which are rich in basic cations which help increase soil pH thus improving soil resistivity.

Apart from the fact that carbon has pores that retain water in the soil to increase conductivity, when mixed with sodium chloride in the soil, various reactions take place to produce the very hygroscopic $NaNO_3$. These reactions are shown below.

$$C_{(s)} + O_{2\,(g)} \longrightarrow CO_{2\,(g)}$$

Equation 21: Oxidation of sodium to form sodium oxide

$$Na_{(s)} + O_{2(g)} \longrightarrow Na_2O_{(S)}$$

Equation 22: Oxidation of sodium to form sodium oxide

$$Na_2O_{(s)} + H_2O_{(l)} \longrightarrow 2NaOH_{(s)}$$

Equation 23: Hydrolysis of the sodium oxide to form sodium hydroxide

ISSN 2229-5518

$$2NaOH_{(s)} + CO_{2(g)} \longrightarrow Na_2CO_{3(S)} + H_2O_{(l)}$$

Equation 24: Reaction of sodium hydroxide and carbon (IV) oxide to form sodium carbonate

$$Na_2CO_{3(S)} + Ca(NO_3)_{(aq)} \longrightarrow CaCO_{3(aq)} + 2NaNO_{3(s)}$$

Equation 25: Double decomposition reaction between sodium carbonate and calcium nitrate to produce calcium carbonate and sodium nitrate.

5 MATERIALS AND METHODS

5.1 Description of study area

The study was carried out in Ihiagwa, Owerri West Local Government Area, Imo state, Nigeria. It is located at a latitude of 5°, 2′ 60N and longitude of 7°, 22′ 60E at an altitude of about 156 meters (511 feet) above sea level [23]. The mean annual maximum and minimum temperatures are 33.5°C and 22.5°C respectively and the relative humidity is 80%. The mean annual rainfall of the study area is 789mm [24].

5.2 Materials Used For Soil Resistivity Measurement

Materials used for this experiment include:

i. Soil box (dimensions 180 cm × 90 cm × 60 cm)
ii. 4 copper electrodes (60cm long).
iii. 12 volts, 70 amperes heavy duty battery (D.C source for providing required power supply to the soil).
iv. Ammeter for measuring electrical current flowing through the soil.
v. Voltmeter for measuring potential between electrodes.
vi. 4 X 1-core, 16mm^2 copper cable (90cm from battery to current electrode and 80 cm each from the positive and negative terminals of the battery to each current electrode).
vii. Weighing scale maximum capacity, 6000g and readable 5g (0.09%) of test load.
viii. Ihiagwa reddish brown soil (obtained 2ft. below earth surface).
ix. Pig dung.
x. Bentonite.
xi. Domestic salt.
xii. Charcoal.
xiii. Distilled water.

5.3 Experimental Procedure

Samples of soil and reducing agent, collected in a sack were weighed and transferred to the soil box. 10 litres of distilled water was added to the mixture at room temperature (25°C) and mixed thoroughly in the soil box until water was uniformly dispersed throughout the soil. Mixture was allowed to settle for 20 minutes. Mixed soil was then compacted with a wooden stick to ensure a firm contact of soil with the incoming electrodes. The copper electrodes were inserted into the firm soil (Inter electrode distance of 25cm and penetration depth of 20cm). 16mm^2 copper cables were used to link the two outer electrodes to achieve series connection for current measurement. Current was then introduced into the system from the direct current source through the electrodes and the resulting value was measured using a clamp-on ammeter. Also, voltmeter was connected across the potential electrodes to measure voltage. Voltage of the battery prior to system coupling was also measured and recorded. Additional 10 litres of distilled water was added to the mixture (total of 20 litres) and allowed to settle for 20 minutes. Current and voltage were then measured and recorded. The results were used to calculate the soil resistivity at different moisture levels.

The process was repeated for each of the reducing agent using same soil sample.

At each stage, circuit was reconnected and current and voltage values were measured and recorded.

5.4 Laboratory analysis of experimental soil

Several soil tests were carried out on the experimental soil in the Soil Science laboratory of the Federal University of Technology Owerri, Imo State, Nigeria, to determine its physiochemical properties. Table 3 shows the tests carried out. Soil texture was determined by hydrometer; pH of soil was measured using a pH meter in a 1:2.5 (soil to water) ratio. Therefore readings of EC measurement were taken. Soil organic carbon was determined by the Walkley-Black method and total nitrogen (N) by the Kjeldahl method. Available phosphorous (P) was determined using the Bray I extraction method. Total exchangeable bases were determined after leaching the soil with ammonium acetate. Amounts of Ca^{2+} and Mg^{2+} in the leachate were analyzed by atomic absorption spectrophotometer. K^+ and Na^+ were analyzed by flame photometer.

Table 3: Physicochemical properties of the experimental soil

Soil Parameter	Description
Sand (%)	20.00
Silt (%)	40.00
Clay (%)	40.00
Textural Class	Clay
pH-H_20	6.30
Electrical Conductivity (mhos)	0.021
Organic Carbon (%)	2.29
Total Nitrogen (%)	0.39
Available phosphorus (ppm)	26.40
Exchangeable K (meq/100gm)	0.76
Exchangeable Na (meq/100gm)	0.87

Exchangeable Ca (meq/100gm)	13.87
Exchangeable (meq/100gm)	6.91

6 RESULTS AND DISCUSSION

6.1 Effect of artificial compounds on the resistivity of the experimental soil

Table 4 shows the different values of measured voltage, injected current, battery terminal voltage and the calculated resistivity of the different sub-samples of the experimental soil. The different soil samples denoted by alphabets in table 4 are defined in table 5.

Table 4: Effect of Artificial Compounds on Soil Resistivity

Soil Sample	*E (V)*	*V (V)*	*I (A)*	*ΔV= E-V (V)*	ρ_{aw} *(Ω-m)*
A	11.00	1.23	23	9.77	74.94
B	10.49	7.24	62	3.25	9.25
C	10.54	6.04	73	4.50	10.87
D	10.61	8.41	47	2.20	8.26
E	10.42	8.36	72	2.06	5.05
F	9.99	6.40	70	3.59	9.05
G	9.89	5.92	71	3.97	9.86
H	9.64	6.15	70	3.49	8.82

Table 5: Description of Soil Samples

Soil samples	*Description*
A	Dry soil
B	Wet soil + bentonite
C	Wet soil + salt-charcoal mixture
D	Wet soil + pig dung
E	Wet soil + bentonite + pig dung
F	Wet soil + bentonite + salt-charcoal mixture
G	Wet soil + pig dung + salt-charcoal mixture
H	Wet soil + pig dung+ bentonite + salt-charcoal mixture

The resistivity of the dry soil sample tested was 74.94Ω-m as seen in table 4 above. The respective compounds were then introduced separately and in succession to the soil sample and values of soil resistivity calculated.

Salt-Charcoal mixture gave a resistivity value of about 10.87Ω-m – a sharp fall from initial value of soil resistivity. Application of pig dung gave a resistivity value of 8.26Ω-m and bentonite finally resulting to 9.25Ω-m. Hence the pig dung gave the lowest resistive value of all the back fill materials, when applied separately to the soil sample. Amalgamation of more than one of the soil conditioners showed a further variation in soil resistivity. Bentonite and salt-charcoal amalgam gave an improved value of 9.05Ω-m. Salt-charcoal and pig dung mixture yielded 9.86Ω-m while the bentonite and pig dung amalgamate produced the least value of soil resistivity 5.05Ω-m. Combination of the three compounds resulted in a resistivity 8.82Ω-m. This is illustrated in Fig. 2.

The test carried out thus shows that an appropriate combination of bentonite and pig dung mixture reduces to a tolerable minimum, the soil resistivity and that of the earth in similitude.

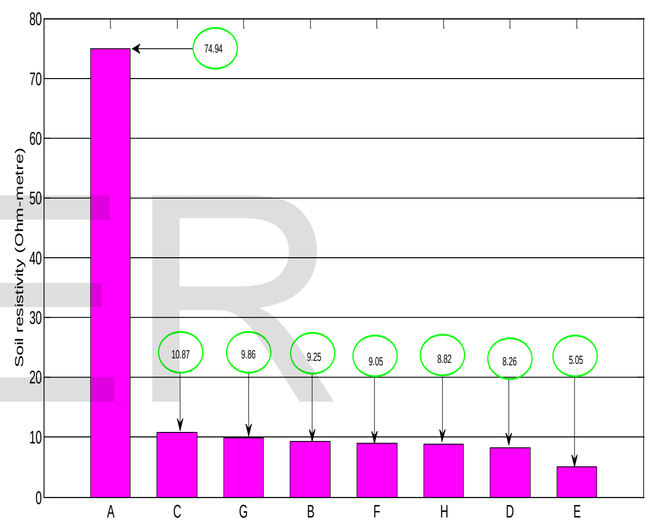

Fig. 2: Effect of artificial compounds on resistivity of experimental soil

6.2 Effect of moisture on soil resistivity

Further experiment was carried out on the different soil samples to ascertain beyond doubt that the moisture content of the soil affects its resistivity and hence the conclusion that the variation in resistivity of the soil after the application of these compounds is as a result of their hygroscopic nature which defines their ability to attract water to the soil thereby improving its moisture content. The results obtained are shown in tables 6, 7, 8 and 9.

Table 6: Effect of moisture on the soil sample

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S/N	Quantity of water (L)	E (V)	V (V)	I (A)	ΔV (V)	$\rho_{aw}(\Omega m)$
1	10	11.00	1.11	26	9.85	66.83
2	20	11.00	1.00	40	10.00	44.10

Table 7: Effect of moisture on the soil and bentonite mixture

S/N	Quantity of water (L)	E (V)	V (V)	I (A)	ΔV (V)	$\rho_{aw}(\Omega m)$
1	10	10.49	7.24	62	3.25	9.25
2	20	10.49	7.23	65	3.26	8.86

Table 8: Effect of moisture on the soil and salt-charcoal mixture

S/N	Quantity of water (L)	E (V)	V (V)	I (A)	ΔV (V)	$\rho_{aw}(\Omega m)$
1	10	10.54	6.54	64	4.00	10.87
2	20	10.54	7.13	66	3.41	9.06

Table 9: Effect of moisture on the soil and pig dung mixture

S/N	Quantity of water (L)	E (V)	V (V)	I (A)	ΔV (V)	$\rho_{aw}(\Omega m)$
1	10	10.61	8.41	47	2.20	8.26
2	20	10.61	8.59	44	2.02	8.07

At a very dry state, the resistivity of the soil was very high; approximately 75Ω-m. However, after the addition of 10 litres of water, the soil resistivity decreased to 66.83Ω-m. Further addition of same quantity of water gave a reduced resistivity value of 44.10Ω-m, indicating an inverse relationship between the soil resistivity and the amount of water in the soil. Hence, the more the availability of soil water, the better the soil resistivity.

Bentonite yielded maximum resistive value of 9.25Ω-m on addition of 10 litres of water. This value reduced sharply after the application of 10 litres of water to 8.86Ω-m The Bentonite chemical was observed to expand immensely on successive application of water. This is as a result of bentonite high affinity for water. As seen in table 9, pig dung yielded the least soil resistivity value of 8.26Ω-m. This value dropped further to 8.06Ω-m after additional 10 litres was applied to the mixture.

Also, salt-charcoal gave a soil resistive value of 10.87Ω-m on addition of 10 litres of water. Similar to the other backfill materials, this value decreased sharply with increase in moisture to 9.06Ω-m after 20 litres of water was applied to the mixture.

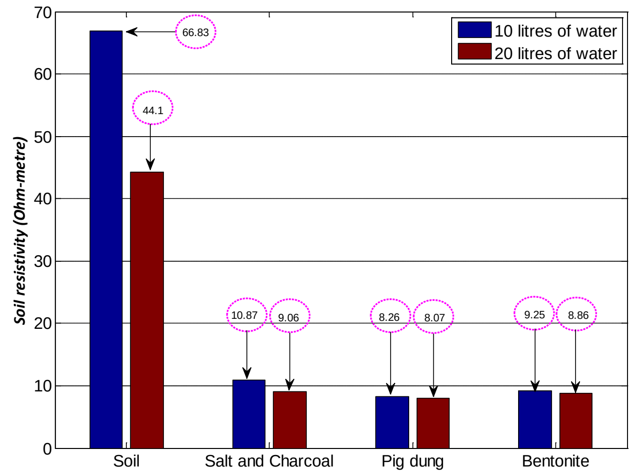

Figure 3: Effect of Moisture on Soil Resistivity

7 Conclusion

The principal objective of this project is selecting the best choice of artificial compound that improves the soil resistivity and hence reduce the earth resistance value. This compound must not only be reliable, but also efficient and cost-effective when used as resistance reducing agent for electrical earthing applications. With the best choice of artificial compound made, the resistivity of the soil is reduced, the cumulative resistance of the earthing system is enhanced, the objective of earthing is satisfied and the power systems will thus have safe operation.

In this work; having analyzed comparatively the characteristics of each compounds and painstakingly conducted soil resistivity experiments using the various compounds, the following conclusions can thence forth be made:
a) Application of pig dung to the soil, gave a resistivity value of 8.26Ωm- a sharp fall from the initial soil resistivity value of 74.94Ω-m (about 89% reduction). Salt and charcoal mixture yielded a resistivity value of about 10.87Ωm (approximately 85% drop) while the Bentonite chemical resulted in a resistivity value of 9.25Ω-m.
b) Although pig dung yielded the best result in terms of soil resistivity, the relative limited demerit of bentonite makes it the best artificial compound for electrical earthing application.

The following points further explain why bentonite is more preferable to the other artificial compounds:
i) Bentonite does not corrode the earth electrode like salt and charcoal mixture. This non- corrosive property of bentonite promotes the durability of the electrode in the soil and hence ensures stability and longevity of the earthing system.
ii) The swelling property of bentonite makes it a very economical tool as a comparative lesser amount of bentonite is needed

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for earthing.

iii) Most soil in Nigeria contains a reasonable amount of moisture hence bentonite chemical can conveniently thrive therein.

iv.) Bentonite is an inorganic compound and would therefore not undergo decomposition over time like pig dung.

v) Finally, bentonite is insoluble in water and would therefore not leach away into the soil unlike salt and charcoal mixture.

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