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Evaluation of Clay Deposits in Lafia, Awe & Keana Local Government Areas of Nasarawa State North Central Nigeria For Suitability as Electrical Porcelain Insulators for High Voltage Applications

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Abstract
In this study, an investigation was carried out to evaluate clay deposits in Lafia, Awe & Keana Local Government Areas of Nasarawa State North Central Nigeria for suitability as electrical porcelain insulators for high voltage applications. Dielectric properties like breakdown voltage, dissipation factor (tan δ) and insulation resistance were studied, the results obtained confirmed that standard porcelain insulators can be fabricated from locally available ceramic raw materials (clay and quartz) in Nigeria at optimized condition.
Keywords: *Porcelain, Insulator, Clay, Breakdown voltage, Dissipation factor (tan δ).*

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I. INTRODUCTION

Essentially, the function of electrical insulators is to prevent the passage of electricity to another device or area so that it does not harm or kill anyone touching areas or devices which are connected to the electrical insulators [1]. For safe transmission and distribution of electric power, application of insulator is very much essential to prevent the flow of current from the wire or conductor to the earth through the ground supporting tower or poles [2].

Among the insulation materials used in electric power transmission and distribution system porcelain insulator is the most commonly used material for overhead insulators [3]. Porcelain insulators were found to exhibit excellent properties such as high mechanical strength, high electrical stability (breakdown voltage, dissipation factor (tan δ), insulation resistance and corrosive resistance).

Insulators are extensively used for high voltage applications [4] In spite of the enormous wide range of application and availability of raw materials, insulators mostly used are still imported to Nigeria. It is therefore imperative to facilitate manufacturing of locally produced electrical insulators to meet increasing demand hence the need for research and development of techniques for the production of high-quality porcelain bodies that meets the required standards and also commercially viable.

Electrical porcelain insulators are the most complex multiphase ceramic materials used as overhead insulator for both low and high tension insulation [5]. It is basically produced from natural ceramic raw materials such as clay (ball clay, china clay or kaolin), feldspar and quartz [6][7]. These ingredients go through different physical changes and react together under controlled thermal conditions to produce the final product [5]. As it is with every manufacturing process, the quality and quantity of the raw materials play a significant role on the properties of porcelain that ultimately affects the performance of electrical porcelain insulators.

The production process involves the combination of clay [$Al_2Si_2O_5(OH)_4$] which is a bulk material and a binder with feldspar [$K_2O.Al_2O._36SiO_2$] which acts as a flux and also contributes silica and alumina to the mixture. Quartz (SiO_2) is also added as a filler material so as to keep the moulded porcelain body in shape during firing [8]. Researchers and scholars overtime have developed efficient high quality electrical porcelain insulators using ball clay as a plastic materials [9][10], but high-quality ball clay that makes up a large proportion of a porcelain insulator is very scarce and found in very few places around the world, as a result the sustainable development of porcelain insulator requires research for alternative clay materials that can partially or wholly supplement the current need of scarce ball clay.

The most desirable properties of a porcelain insulator for applications in electric power distribution and transmission system includes, high electrical resistivity, high dielectric strength, good mechanical properties, and excellent heat radiating and insulating capacity even in humid and corrosive environments [11][12], among the properties, breakdown voltage, dissipation factor (tan δ) and insulation resistance are the most important determinant properties which must be taken into consideration to produce quality electrical porcelain insulators [14].

With the abundance of raw materials for the production of electrical porcelain insulators in Nigeria, the need for the development of indigenous technology cannot be overemphasized [13]

Therefore, the present study was aimed to:

- develop good quality electrical porcelain insulators by replacing ball clay with locally available clay materials.
- characterize the properties of locally available ceramic raw materials.
- Optimize batch composition to influence important properties such as breakdown voltage, dissipation factor (tan δ), insulation resistance and mechanical strength by varying the quantity of clay and feldspar as well as firing temperature even in humid environment.

1.1 Porcelain

Porcelain is a ceramic material made by heating raw materials, mainly clay in the form of kaolin, in a kiln to temperatures between 1,200 °C (2,192 °F) and 1,400 °C (2,552 °F).

The properties of porcelain which includes strength, translucence and toughness could be attributed to the formation of glass during the firing process. The primary component of Porcelain is clay, feldspar and filler material, usually quartz or alumina. Clay [$Al_2Si_2O_5(OH)_4$] gives plasticity to the ceramic mixture, flint or quartz [SiO_2] maintains the shape of the formed article during firing and feldspar [$K_2O.Al_2O_{3}6SiO_2$] serves as flux [10]. These three components place porcelain in the phase system in terms of oxide constituents hence the term triaxial porcelain [11].

1.2 Important Properties of Porcelain Insulators

The worth of a material is determined by testing and studying its important properties. For porcelain insulators the important properties are breakdown voltage, dissipation factor (tan δ) and insulation resistance. These properties were used to derive the tests that were carried out on the specimens.

1.2.1 Dielectric Strength

The electric field which causes breakdown through an insulator placed between two electrodes across which voltage is applied is called dielectric strength. The breakdown depends primarily on the local electric stresses in the dielectric, and is influenced by the shape and to some extent by the nature and condition, of the electrodes [6]. Generally, dielectric strength is dependent on factors such as specimen thickness, application time of voltage stress and the presence of voids or structural flaws [7]. The presence of voids and flaws tend to quicken breakdown through secondary processes such as streamers, which occur at field strengths lower than the intrinsic strength of the material.

$$Dielectric\ strength\ = voltage\ across\ specimen\ (kv)\ /\ specimen\ th ickness\ (mm).$$

Liquid immersion testing technique was employed in carrying out the test which is in agreement with the American Society for Testing Materials (ASTM) standards [8]. According to ASTM, the apparatus for the measurement of dielectric strength shall be a disk approximately 50.8 mm in diameter, the flat sides being made plane and parallel. The specimen thickness shall be 6.35mm, 10.16mm, 19.05mm or 25.4mm. The thickness shall be within 10% of the above values. The tests were done with the specimen immersed in fresh transformer oil at room temperature at the High Voltage Laboratory of Isa Mustapha Agwai I Polytechnic, Lafia.

Table 1 represents the Breakdown Voltage of the samples

Table 1: Breakdown Voltage

Specimen	Lafia	Awe	Keana
1	8.667	8.645	7.979
2	8.663	8.545	7.878
3	8.560	8.442	7.774
4	8.339	8.280	7.675
5	8.175	8.066	7.574
Mean (kV/mm)	**8.376**	**8.578**	**7.478**

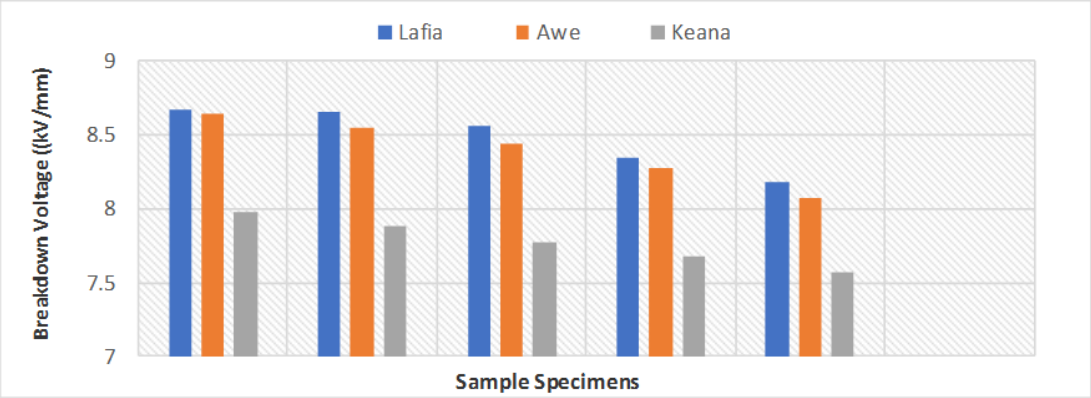

Figure 1: Breakdown Voltage of samples

1.2.2 Loss Factor

Dielectric loss is sensitive to electric stress, consequently, the tests are carried out at the highest stress level possible. Routine tests on low voltage (480V) equipment are usually carried out at high voltage and 50Hz. A 480V piece of equipment is thus subjected to about 22.5kV. This test is usually carried out after manufacture. High voltage is applied across the device under test through the output of cascaded transformers designed to have poor regulation so that if the device under test is faulty and breakdown occurs, the terminal voltage would drop due to high current. A resistor of about 1MΩ is used in series with the transformer to limit the current in the event of a breakdown to about 1A. The movement of charges across the test sample at high frequency and the polarity of electrodes might have changed before the charge carriers have travelled from one electrode to the other, so that they may go about halfway and turn back

1.2.3 Loss tangent (tan δ)

Loss tangent is the measure of signal loss due to the inherent dissipation of electromagnetic energy in a material, it is a measure of comparison between resistive and capacitive currents which is indicative of how lossy the dielectric material is.

$$Tan\ \delta = IR / IC$$

A large value of tan δ indicates that the material is very lossy. Materials with large values of tan δ have considerable losses when used in systems operating at voltage above 22kV [8]. Insulation failure could result from heat generated by these losses when the temperature exceeds that which the dielectric material can withstand.

Digital RLC bridge was the equipment used for this test. The bridge is designed to precisely give the values of R, L, C and the Q- factor. The loss tangent (tan δ) is related to the Q-factor by the expression below:

$$Tan\ \delta = (1/\ Qfactor)$$

Electrical energy absorbed by the insulating material and dissipated in the form of heat when an AC voltage is applied across it is the dielectric loss. Only vacuum and purified gases approach perfection in terms of dissipated energy; therefore, the leakage current does not lead applied voltage by exactly 90°. The phase angle is always<90°, thus the complementary angle (δ) is known as the dielectric loss angle, where its tan gives the dissipation factor.

$\delta = 90-\theta$, (tan δ) = dissipation factor

The Loss Factor of the samples is represented in table 2

Table 2: Loss Factor

Specimen	Lafia	Awe	Keana
1	0.16	0.34	0.16
2	0.55	0.51	0.78
3	2.87	2.46	1.72
4	2.66	3.76	3.68
5	3.41	4.29	3.59
Mean	4.22	5.55	4.53

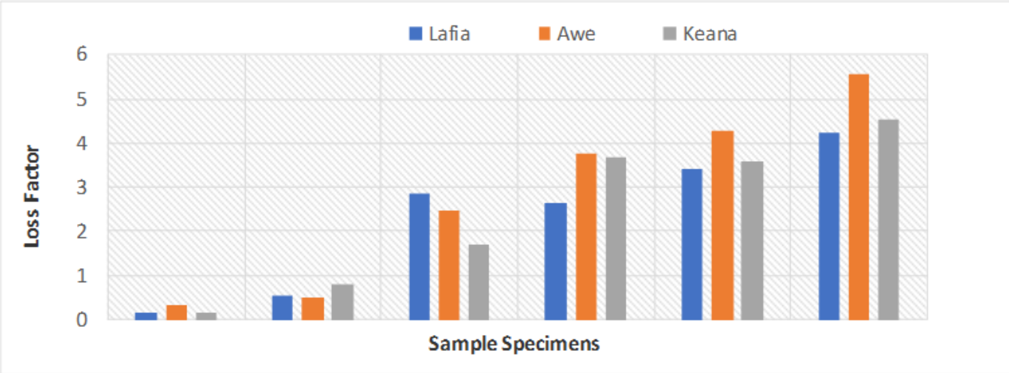

Figure 2: Loss factor of samples

1.2.4 Insulation Resistance

This parameter was tested using the Digital High Voltage Insulation Tester (Model TIN6N) to test the insulation resistance of the samples after having attained 1200°C of firing in a gas-operated kiln. Analogue pyrometer was used to measure the temperature with respect to time in hours. The insulators were fired for 8 hours as is the standard practice. Different voltages were applied to the samples to determine the breakdown voltage for each sample. The positive and negative terminals of the instrument were clipped at either end of the insulators and different voltages were applied by pressing the desired voltage button per time until the monitoring screen shows discontinuity sign which indicates the breakdown voltage.

Table 3 Indicates the Insulation Resistance of the samples

Table 3: Insulation Resistance

Specimen	Lafia	Awe	Keana
1	0.42	0.35	0.34
2	1.55	3.01	1.51
3	2.87	4.76	2.46
4	2.6	6.46	3.76
5	3.41	6.38	4.29
Mean (MΩ)	4.22	7.1	5.55

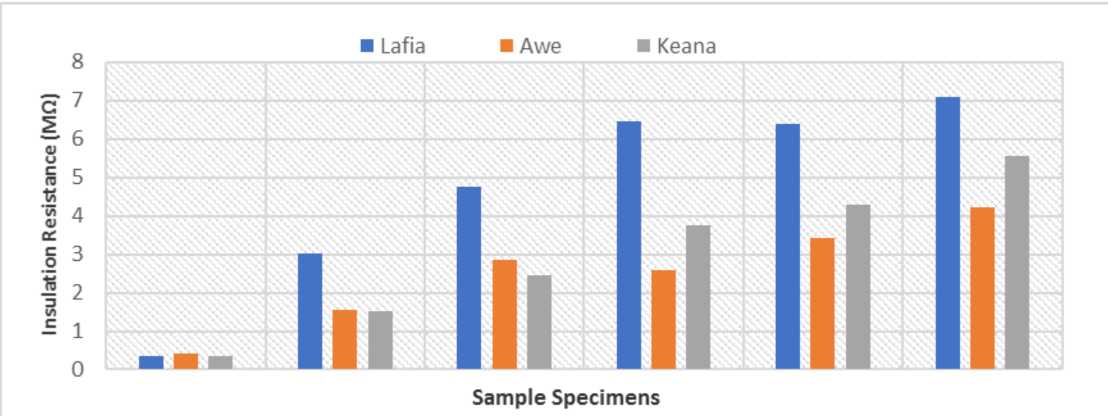

Figure 3: Insulation Resistance of samples

II. RESULTS AND DISCUSSION

Dielectric Strength from the test results shows that Awe sample was found to have the highest dielectric strength of 8.578kV/cm and Keana had the lowest breakdown strength of 7.478kV/cm. In the case of Keana sample it can be observed that the heavy presence of silica and relatively low presence of oxides (as compared to Lafia) contributed to its very low dielectric strength. This is because the heavy presence of silica gave rise to the sample being very porous as shown by the porosity test results. The air in the pores has very low dielectric strength compared to the porcelain body.

From the loss angle measurement results, it was found that except for the sample from Awe all the others had values within a close range. Awe had 5.55, Keana had 4.53, and Lafia 4.22. The high value of the loss angle for the Awe sample could be attributed to the presence of the air pores. Air and moisture in the pinholes increased the leakage.

The results of the insulation resistance test show that the sample from Awe exhibits the highest insulation resistance of 7.10MΩ as compared to 4.22MΩ and 5.55MΩ of Lafia and Keana respectively.

III. CONCLUSION

In this study locally available materials in Lafia, Awe & Keana Local Government Areas of Nasarawa State North Central Nigeria were used to produce a high voltage porcelain insulator by altering the percentage composition of silica in different samples depending on the specification desired in strength and load tolerance. Porcelain of different types and compositions can be manufactured for various applications. The results of the samples tested gave values very close to the results given by the imported samples, therefore, there is a potential opportunity in Nigeria to produce standard porcelain insulators by replacing the scarce ball clay with local clay materials using proper formulation and at optimized condition. However, future study should consider looking at the mechanical and chemical properties of the sample.

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