# Experimental Determination of Electrical Insulating Properties of Dry Coarse Sand and Dry Fine-Medium Sand in Comparison with those of MgO Powder by Ohm's Law Method

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Abstract—*The objective of the study was to compare electrical insulating properties (electrical resistance, electric resistivity, electric conductivity, and current density) of dry coarse sand (0.50-1.00 mm); dry fine-medium sand (0.125-0.50 mm) and MgO powder. Ohm's law method was adopted and used to investigate electric insulating properties of the samples by allowing currents to flow through equal cylindrical length of 0.015 m and cross-sectional area of $1.131 x 10^{-4}$ $m^2$ of the samples when potential differences of 100-300 volts were created across them. The two sand samples were sieved through sieves of apertures 2.00 mm, 1.00 mm, 0.50 mm, 0.25 mm, and 0.125 mm to obtain the required particle sizes for the experiment. Sample of MgO powder, an electrical insulator used in conventional electrical heating devices, was also obtained. Results showed that, the two dry sands possessed comparatively good electrical insulating properties and can serve as reliable and efficient alternative electric insulators in place of MgO powder in electric irons and kettles.*

Keyword— Current Density, Electric Conductivity, Electric Intensity, Electrical Resistance, Electric Resistivity, Ohm's Law

## 1 INTRODUCTION

CONVENTIONAL electric irons and kettles are some of the most widely used house-hold electrical heating devices in Nigeria, especially in urban areas where electricity supplies are comparatively higher than in rural areas. Most of these heating devices are being imported from China and other developed countries of the world into Nigeria. As a developing country, Nigeria is still lagging behind in terms of industrial development for manufacturing of these basic electric heating devices. Many people in developing countries, including Nigeria, rely solely on the use of fuel wood for cooking and for boiling water leading to deforestation [1]. This calls for the need for scientists and engineers to close ranks and re-direct the nation's industrial sector towards the development and manufacturing of such electric heating devices that are affordable, efficient and reliable.

Thermal properties of dry coarse sand and dry fine-medium sand in comparison with those of MgO powder had been determined [2] and the result showed that dry sand possessed good thermal properties that could be harnessed in electrical heaters as electrical insulator in place of MgO powder. In addition, the time rate of heat transfer through both coarse sand and fine-medium sand at 0% moisture content is higher than through MgO powder [3]. However, thermal properties of these sands alone cannot justify their potential for use in the fabrication of electrical heating devices such as electric irons and kettles. Their electrical insulating properties are therefore as important as their thermal properties.

The objective of this study was to compare some electrical properties (electrical resistance, electric resistivity, electrical conductivity and current density) of dry coarse sand, dry fine-medium sand and MgO powder, an insulator used in domestic electrical heating devices [4]. These electrical properties are the most important determinant of a material's potential to serve as electrical insulator in electric heating devices. Knowledge on electrical insulating properties of dry sands can also be applied on buried cables below the earth's surface at regions containing predominantly sandy soils and/or other soil types. In this case, the presence of soil moisture regimes beneath the earth and the possibility of ionic conduction due to the presence of ions in the soil solution is possible particularly where cable insulators are damaged [5].

The samples of dry coarse sand and dry fine-medium sand employed for use in this study were at 0% moisture contents to avoid errors resulting from electrolytic conduction associated with saturated soils. The mineral present in sandy soil is predominantly quartz. This mineral is an excellent electrical insulator. Also, the soil gas phase is mostly air which is a bad conductor of electricity and, like quartz, it opposes the flow of electric current [5]. Dry sands at 0% moisture contents, containing non conducting air and quartz can therefore be considered as reliable alternative electrical insulators in electric irons and kettles. In addition, the vast availability of sands on the surface horizon, in comparison with MgO powder, could render them to be the most preferred natural resource materials to be used as alternative electrical insulators in electric heating devices.

## 2 THEORETICAL

Electrical resistivity is a property which expresses its ability to oppose flow of electric charges. It depends on the geometrical structure of the material and it is a factor that relates the distribution of electric field and the flow of electric charge in the material. It is given by Ohm's law as follows [5]:

$$E = \rho j \quad (1)$$

where $E$ is the electric field intensity (i.e. potential gradient) and $j$ is the current density (i.e. current per unit cross sectional area). Thus;

$$Current\ density, j = \frac{i}{A} \quad (2)$$

Consider a cylinder composed of uniform MgO powder or sandy soil material, having a length, $L$, and at each of its ends, a cross-sectional area, $A$ (Figure 1). An electric current, $I$, defined as the flow rate of electric charge, is applied at one end of the cylinder and exits the other. The cylinder to a greater or lesser extent, opposes this through flow of electric current, thereby causing a drop in electric potential, $\Delta V$, which occurs along the coulomb's length from the end where $I$ enters to the end where $I$ exits the cylinder.

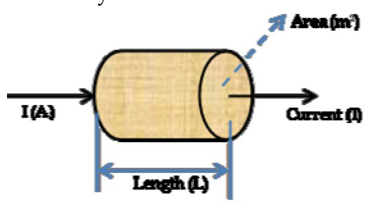


**Figure 1**: Current flow through a uniform cylindrical soil (adapted from [5]).

Electric potential can be described as the potential energy for a unit charge resulting from its position within an electric field. As indicated in Equation (3) below, $\Delta V$ is proportional to $I$, and the proportionality constant is the resistance, $R$, which is the characteristic of the cylinders overall ability to oppose current flow:

$$\Delta V - RI \text{ from which } R - -\frac{V}{I} \quad (3)$$

The negative sign in Equation (3) simply indicates that current flow is in the direction opposite to that of increasing electric potential. Equation (3) is referred to as Ohm's law, and the resistance, $R$, of the cylinder can itself be expressed as:

$$R = \rho \frac{L}{A} \text{ from which } \rho = \frac{RA}{L} \quad (4)$$

where again, $L$ and $A$, are the length and cross sectional area of the cylinder respectively, and $\rho$ is the resistivity. Electric intensity is therefore given as:

$$Electric\ intensity, E = \frac{V}{L} \quad (5)$$

As stated earlier, resistivity is a property only of a material composing the cylinder and represents the capability of that material to oppose the flow of electric current. The $\rho$ values for soils and rock materials are typically reported in units of Ohm-meters (Ωm). Electrical conductivity, $\sigma$, is the reciprocal of $\rho$ and is the property indicative of a material's ability to convey electrical current. It is also expressed as;

$$\text{Electrical conductivity}, \sigma = \frac{j}{E} \text{ or } \sigma = \frac{1}{\rho} \quad (6)$$

## 3 EXPERIMENTAL

### 3.1 Sample Preparation

To determine electrical insulating properties of dry coarse sand and dry fine-medium sand, sand sample of varying grain sizes was obtained within the bank of River Benue in Yola, Adamawa State, Nigeria. The sand sample was light brown, loose and granular without any bonding mechanism. It was also free from sandstones, scattered surface rocks and other soil types.

The size ranges of sand particles originally proposed by Glossop and Skepton in 1945 [6] was adopted in this study. These size ranges as defined in BS 5930:1981 and also U.S Department of Agricultural system is presented in the table below.

Table 1: Particle sizes of dry sandy soil

| *Class name* | *Particle size (mm)* | *Test procedure* |
|---|---|---|
| Very coarse sand | 1.0-2.0 | |
| Coarse sand | 0.5-1.0 | |
| Medium sand | 0.25-0.5 | Sieve analysis |
| Fine sand | 0.125-0.25 | |
| Very fine sand | 0.05-0.125 | |

(Adopted from [6])

Before the dry sand sample was sieved, aggregates and organic matter must be broken down and removed [6]. The sand sample was first air dried and sieved through a 2.00 mm sieve. Hydrogen peroxide ($H_2O_2$) was added to the sand, well stirred and left to stand overnight in a container of known weight. $H_2O_2$ was used to destroy the organic matter present in the sand [7]. The container and its content were placed on a hot plate for few minutes in order to destroy the remaining organic matter after which it was washed with distilled water. More $H_2O_2$ was added to ensure that all organic matter was removed. The container and its content were heated again to decompose any remaining peroxide in the sand. At this point, enough distilled water was added and well stirred, cooled and allow to stay over-night. The remaining organic matter that was seen floating on the surface of the water was removed carefully by decantation. The sand was sun dried for three consecutive days. After sun drying, the container and the sand were weighed. Subtracting the weight of the container from the total weight gave the weight of the sand free from organic matter. The sand was then ready for particle size analysis.

The sand sample was sieved through sieve sets of apertures 2.00 mm, 0.25 mm, 1.00 mm, 0.50 mm, and

0.125 mm. The initial mass of the sand sample used in this study was 500 g. The sieves were arranged in descending order from the largest aperture to the smallest. The sand sample was released into the first sieve and the whole assembly was put in a mechanical shaker to shake for 5 minutes. Each of the samples retained in the sieve was weighed (weight retained). This was applicable to all sieves in the series. It was from this particle size analysis that dry coarse sand of particle sizes 0.50-1.00mm and dry fine-medium sand of particle sizes 0.125-0.50 mm were obtained.

MgO powder was also obtained. Few conventional electrical heaters were purchased and destroyed to get the sample. The powder was then packed in a closed container to avoid dust and other particulates from contaminating it.

### 3.2 Experimental Setup

Ohms law method was adopted in this study for use in the determination of electrical insulating properties of the sample materials. This was done by putting each of the three samples respectively in three identical tubes of same dimensions of length, cross-sectional area, thickness, and inner and outer diameters. Their electrical insulating properties (electrical resistivity, current density, electrical resistance and dielectric) were determined.

Figure 2 shows the circuit diagram for the experimental set-up. Equal volumes of the three samples were enclosed respectively in three identical cylindrical tubes and compacted to a denser state. Lead wires were connected at both ends of each of the tubes. The cross-sectional area and length of the samples in each of the tubes were $1.131 \times 10^{-4}$ m$^2$ and 0.015 m respectively. Each of the three samples was connected to circuit one after the other while a potential difference of 100-300 volts were connected across their respective terminals. Readings of currents and current densities were obtained and tabulated.

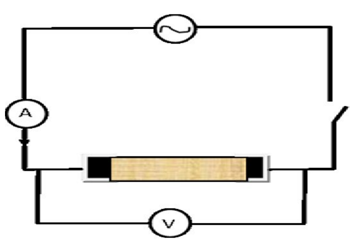


Figure 2: Circuit diagram for determination of electrical insulating properties of sampled materials

## 4 RESULTS AND DISCUSSION

### 4.1 Particle size distribution

Particle size distributions of sand affect both its thermal and electrical insulating properties. Thermal properties of sand increase with increase in its particle size and degree of compaction [8]. In order to draw up a particle size distribution curve, it was necessary to calculate the cumulative percentage by mass of particles finer than each sieve aperture size that was passing each sieve. Table 2 gives the results of the particle size analysis while the particle size distribution curve is shown in Figure 3.

Table 2: Results of particle size analysis of dry sand with initial mass m=500g.

| *Sieve size (mm)* | *Mass retaining (g)* | *Cumulative mass passing (g)* | *Percentage passing (%)* |
|---|---|---|---|
| 2.00 | 0 | 500 | 100 |
| 1.00 | 20 | 480 | 96 |
| 0.50 | 180 | 300 | 60 |
| 0.25 | 234 | 66 | 13.2 |
| 0.125 | 62 | 4 | 0.8 |

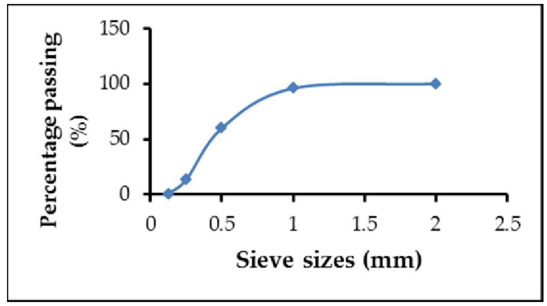


Figure 3: Percentage passing (%) against Sieve sizes (mm)

The interpretation of particle size analysis requires the drawing of a graph as in Figure 3. The shape and position of the graph provides qualitative information about the abundance of dry coarse sand and dry fine-medium sand samples required in the study. Thus, the analysis provides the basis for classification systems and their abundance in a given sample of soil. It was through this particle size analysis that dry coarse sand (0.50-1.00 mm) and dry fine-medium sand (0.125-0.50 mm) were obtained and used in this study.

### 4.2 Variations of Electrical Insulating Properties of the Sampled Materials with Potential Difference (p.d.)

Tables 3 shows the electrical insulating property data for the materials when potential differences of 100-300 V were created at the ends of their respective cylindrical lengths, While electric currents were obtained directly from ammeter reading at each potential drop, other values of electrical properties, example; resistances, resistivity, electric intensity and electric conductivity were calculated from Equations (3, 4, 5 and 6) respectively.

The electrical insulating properties of sands and of MgO powder were observed to vary with increase or decrease in potential difference generated across the ends of their cylindrical lengths. Data of electrical insulating properties of the materials presented here were used to study these variations. Graphs of potential differences against their corresponding values of electric current, electric intensity and current density of the sampled materials were plotted accordingly and are shown in Figures 4 and 5. Equations of trend lines of the various plots are displayed on the plot areas. The slope of regression of potential differences and measured values of currents for each of the three samples equals to their respective electrical resistances. Thus, using Equation 3, the resistances through MgO powder, dry coarse sand and dry fine-medium sand were found to be $3.835 \times 10^5\ \Omega$, 3.835 x $10^5$ $\Omega$ and 3.835 x $10^5$ $\Omega$ respectively.

**Table 3:** Electric current, electric intensity and current density data for the sample materials at p.d (100-300 V) across the length of 0.15m

| *p.d. (v)* | *$i_m$ ($x10^{-6}A$)* | *$i_c$ ($x10^{-6}A$)* | *$i_f$ ($x10^{-6}A$)* | *E ($x10^2$ $Vm^{-1}$)* | *$j_m$ ($x10^{-2}Am^{-2}$)* | *$j_c$ ($x10^{-2}Am^{-2}$)* | *$j_f$ ($x10^{-2}Am^{-2}$)* |
|---|---|---|---|---|---|---|---|
| 100 | 37.76 | 37.80 | 37.95 | 66.7 | 33.386 | 33.421 | 33.554 |
| 120 | 45.07 | 45.56 | 45.42 | 80.0 | 38.849 | 40.282 | 40.159 |
| 140 | 52.85 | 52.92 | 53.37 | 93.3 | 46.728 | 46.790 | 47.188 |
| 160 | 60.41 | 60.45 | 60.56 | 106.7 | 53.412 | 53.448 | 53.545 |
| 180 | 67.96 | 68.04 | 68.13 | 120.0 | 60.088 | 60.159 | 60.238 |
| 200 | 75.51 | 75.60 | 75.70 | 133.3 | 66.763 | 66.843 | 66.931 |
| 220 | 83.03 | 83.16 | 83.28 | 146.7 | 73.412 | 73.527 | 73.633 |
| 240 | 96.75 | 90.72 | 90.84 | 160.0 | 85.543 | 80.212 | 80.318 |
| 260 | 98.17 | 98.28 | 98.41 | 173.3 | 86.799 | 88.540 | 87.011 |
| 280 | 105.71 | 105.90 | 106.00 | 186.7 | 92.926 | 93.633 | 93.722 |
| 300 | 113.26 | 113.41 | 113.60 | 200.0 | 100.141 | 100.274 | 100.442 |

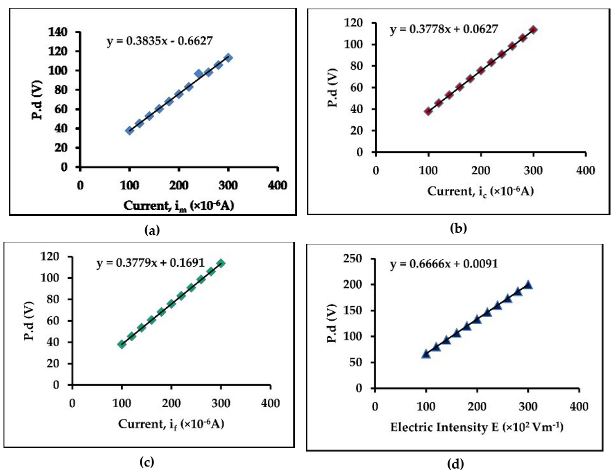


Figure 4: Variation of (a) potential difference with current through 0.015m length of MgO powder; (b) potential difference with current through 0.015m length of dry coarse sand; (c) potential difference with current through 0.015m length dry fine-medium sand; and (d) potential difference with electric field intensity across 0.015m lengths of the sample materials.

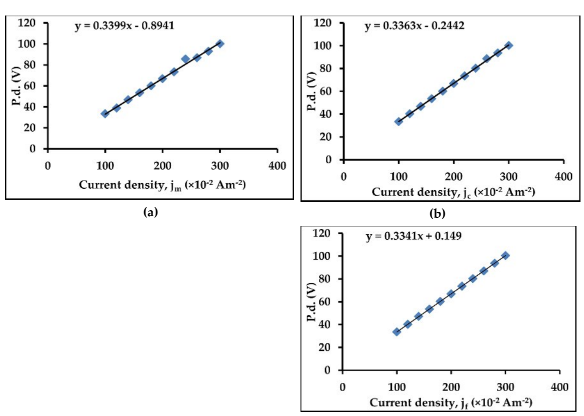


Figure 5: Variation of (a) potential difference with current density across 0.015m length of MgO powder; (b) potential difference with current density across 0.015m length of dry coarse sand; and (c) potential difference with current density across 0.015m length of dry fine-medium sand.

Employing Equation (5) and substituting the length 0.015 m, cross-sectional area 1.131 x $10^{-4}$ $m^2$ and the slope s, the electrical resistivity of each the samples were found, using the relation $\rho = \frac{SA}{L}$ ,where s is the respective slope of the graphs in Figure 5. With this relation, resistivity of MgO powder, dry coarse sand and dry fine-medium sand were found to be 2891.59 Ωm, 2840.612 Ωm and 2849.66 Ωm respectively. Since, electrical conductivity, $\sigma$, is the reciprocal of electrical resistivity, the electrical conductivities of MgO powder, dry coarse sand and dry fine-medium sand were also calculated (using Equation (6)) to be 3.50 x $10^{-4}$ $\Omega^{-1}m^{-1}$, 3.52 x $10^{-4}$, $\Omega^{-1}m^{-1}$ and 3.51 x $10^{-4}$ $\Omega^{-1}m^{-1}$ respectively.

The slope of the trend line for variations of electric intensities with potential differences across the sample materials was 66.7 m while the slopes of the trend line for variations of potential differences generated across the length of each of the sample materials and current densities was obtained in units of volts meter squared per ampere ($Vm^2A^{-1}$) to be 3.399 x $10^5$ $Vm^2A^{-1}$ for MgO powder, 3.363 x $10^5$ $Vm^2A^{-1}$ for dry coarse sand and 3.341 x $10^5$ $Vm^2A^{-1}$ for dry fine-medium sand It is evident from the foregoing that the electrical conductivities through the sample materials were very low due their high resistances. The electrical resistivities, on the other hand, were found to be greater in magnitude than those of electric conductors and semiconductors. For instance, silver which is the best conductor of electricity has a resistivity of 1.6 x $10^{-8}$ $\Omega^{-1}m^{-1}$ while silicon, a semiconductor material, has the highest resistivity of 2300 $\Omega^{-1}m^{-1}$ than those of other semiconductors [9]. Thus, since resistivity of semiconductors falls immediately between those of conductors and insulators [9], it is clear from the results obtained in this study that dry coarse sand and dry fine-medium sand, whose resistivity values fall under insulators, possessed good electrical insulating properties with the potential for use as substitute to MgO powder in electrical irons and kettles.

It is important to note that the electrical resistance of a very dry human skin is 500 kΩ [10]. Hence, electric currents in the order of microampere through the sand samples as presented in Table 3 are not high enough to cause muscular spasm due to this skin resistance. Therefore, kettles and electric irons made with dry coarse sand or dry fine-medium both at 0 % moisture content as electrical insulators are liable to be free from electrical shock.

## 5 CONCLUSION

In this study, we have shown that it is possible to substitute MgO powder used in these electrical house-hold heating devices with dry coarse sand and dry fine-medium sand at 0 % moisture content. Using Ohm's law method, the electrical resistance to flow of electric current through MgO powder of cylindrical length 0.015 m and cross-sectional area of $1.131 \, x \, 10^{-4} \, m^2$ was determined and found to be $3.835 \, x \, 10^5 \, \Omega$ while the respective resistances to flow of current through same cylindrical length and cross-sectional area of dry coarse sand and dry fine-medium sand were $3.778 \, x \, 10^5 \, \Omega$ and $3.779 \, x \, 10^5 \, \Omega$ respectively. The percentage difference between the resistance in MgO powder and those of the two sand samples were approximately 1.5 % in each case. Using relevant formulae, the respective electrical resistivity and electrical conductivity of the samples were found to be $2891.59 \, \Omega m$ and $3.50 \, x \, 10^{-4} \, \Omega^{-1} m^{-1}$ for MgO powder; 2840.612 $\Omega m$ and 3.52 x $10^{-4} \, \Omega^{-1} m^{-1}$ for dry coarse sand and 2849.366 $\Omega m$ and 3.51 x $10^{-4} \, \Omega^{-1} m^{-1}$ for dry fine-medium sand.

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