West Indian Journal of Engineering Vol. 30, No. 1, (July 2007) Technical Paper (Inegbenebor & Adeniji) 17-26

Electrical Insulative Properties of Some Agro-Waste Materials

A.O. Inegbenebor[1] &
F.A. Adeniji[2]

Insulating materials are used in electrical power circuits to prevent leakages of current. This work investigates the possibility of using agro-waste materials: shells of coconut, mango endocarp, palm kernel, groundnut and bean as well as corncob and rice husk, as electrical insulators. Accordingly, electrical insulative properties: dielectric strength, resistivity, dielectric constant, moisture content and water absorption capacity of these waste materials were determined. Each of the materials was washed, air dried for 2 weeks, ground into powder, and sieved with, the U.S Standard Sieve No. 40. It was then bound with a 200 g/litre aqueous solution of gum Arabic, and moulded into various shapes and thicknesses which were air dried for a week. Their dielectric strengths were tested thereafter, using a variable transformer tester; their resistivities measured with an insulation tester, while both moisture contents and water absorption capacities were determined gravimetrically on dry weight basis. The results showed that the electrical insulative properties of these materials were comparable with the known standard values. However, their moisture contents and water absorption capacities were relatively high, thereby limiting their usefulness as insulators in their ordinary states. Based on their dielectric constants and a standard table, coconut, palm kernel and groundnut shells, with dielectric constants range of 3.5-5.5 fall into high voltage applications; mango shell, corncob, rice husk and bean shell, with dielectric constants less than 3.0, fall into the low voltage application category.

Keywords: *Agro-Waste, Electrical Insulative Properties, Moisture Content.*

1. Introduction

Electrical insulating materials offer high resistance to the passage of electric currents [1]. They are used in electrical systems to confine the current flow within the conductors of different phases and to isolate current carrying conductors from the ground.

The application of insulators is so varied that a choice must be made after consideration of the necessary properties including the weakness of the insulators as well as the special circumstance of installation. No single type of insulator has all the advantages and it should be chosen so that its disadvantages are not a detriment in the specific application [2].

Applications of insulators in the electrical system are those in:

(a) Power equipment (motors, transformers, capacitors, generators,

---

[1] Department of Mechanical Engineering, University of Maiduguri-Borno State, Nigeria

[2] Department of Agricultural Engineering, University of Maiduguri-Borno State, Nigeria

transmission lines, cables and switch gears).
(b) Electronic and communications.
(c) Home appliances such as pressing iron and air-conditioning

The common insulating materials are rubber, mica, mica compounds, micanite, chlorinated hydrogen, impregnated fabrics, thermosetting substances, thermoplastic resins, nylon, paper, silicone rubber, ceramics, glasses, polymetric (plastic) films, sulphur hexafluoride (SF_6), helium, nitrogen and carbon dioxide. Electrical insulation can either be solid, liquid or gaseous provided it acts as a medium of offering high resistance to the conduction of electrical current [3]. For a material to be considered for insulation, it must possess high values of: dielectric strength, resistance and resistivity, dielectric constant and thermal insulation capacity. [4]

The insulating properties of any material are dependent on dielectric strength or the ability to prevent leakage of small currents, and power losses or the absorption of electrical energy that is converted into heat [4]. An ideal insulator has **high** dielectric strength and resistance, mechanical strength and chemical stability as well as **low** moisture content and consequently **low** power loss. [5]

Dielectric strength is the maximum voltage that an insulating material between two parallel electrical conducting plates can withstand before it breaks down and begins to discharge. It is normally expressed in voltage-gradient terms, such as volts per millimeter. Normally, breakdown occurs at a much higher volt-per-mm value in very thin test pieces (a few millimeter thick) than in thicker sections.

Electrical resistance of a material expressed in ohms, is a measure of the tedium or difficulty with which an electrical current passes or is conducted through the material. Insulating materials are very poor conductors, offering high resistance. The relationship between resistance and resistivity is expressed by the equation.

$$\rho = RA/L \qquad (1)$$

in which, ρ is volume resistivity in Ohm-centimeter, R is the resistance (ohms), A is the cross sectional area (cm^2) of the material and L is the length (cm) between faces of the test piece [6].

The dielectric constant of an insulating material, is defined as the ratio of the capacitance of the material to the capacitance of the same electrode system with air replacing the insulation as the dielectric medium. It is also defined as the property of an insulator, which determines the electrostatic energy, stored within the solid material.

The values for most commercial insulating materials vary from about 2 to 10, air having the value of 1 [7].

One of the general characteristics of electrical insulating materials is that they are also good thermal insulators. This is true in varying degrees for the entire spectrum of insulating materials, including air, fluids, plastics, glasses and ceramics. However, the thermal insulating properties of electrical insulating materials are not important for electrical and electronic designs for systems considered for use under ambient temperature.

The disposable components of harvested agricultural products, referred to in this paper as agro-waste materials are becoming increasingly problematic in Nigeria, littering the rural and urban areas of the country, and constituting a serious threat to environmental health of the nation. This is one of the major motivations for this work, aimed at finding possible utilization in electrical industry for agro-waste materials, which otherwise would have constituted an environmental nuisance, marring the beauty of the landscape. The agro-waste materials considered in this work are shells of coconut, mango endocarp, palm kernel, groundnut, and bean, as well as corn cob and rice husk. Inegbenebor and Adam [8], had earlier determined the thermal conductivities of these agro-waste materials. Their thermal conductivity values obtained in that study showed that they can be used as insulators in building and preservation of agricultural products.

The objective of the present work is to determine the insulative properties of these agro-waste materials, with a view to using them in the electrical industry.

2 Materials and Methods

2.1 *Preliminary Treatments*

Seven agro-waste materials (shells of coconut, mango endocarp, palm kernel, groundnut and bean; corn cob and rice husk) were obtained from different local mills located in Benin City, Ibadan, Ogbomosho and Ilorin, all in the Guinea Savannah belt of Nigeria. In each of the collection locations, the agro waste materials were taken from dust bins where they had been discarded as disposable components in the processing of coconut, mango, oil palm fruits, ground nuts, beans, maize (corn) and rice. From these sources the agro- waste materials were collected in jute sacks, and brought to the University of Maiduguri physics laboratory. There they were washed with running water to remove the dirt on them, dried in the laboratory with freely circulating air for 14 days. The gravimetric moisture contents (using the dish-oven and weighing balance method) at this stage ranged from 10% for rice husk to 13% for the other six materials.

Apart from coconut shell which was the hardest of them all, the six other agro-waste materials used were ground to powder using mortar and pestle. The coconut shell, because of its hardness, was first filed with a rasp-cut file to obtain a coarse fraction which was later beaten to fine powder using mortar and pestle as the other six materials. Each of these was sieved with the US Standard sieve N0. 40 with a 425 μm aperture opening. The sieved powder of each agro-waste material was bound with a 200g/litre aqueous solution of commercial grade gum arabic and subjected to the following procedure according to [9].

TABLE 1: Specifications of the Samples (S) of the Seven Agro-waste Materials Studied with Gum Arabic as binder (B)

Serial No.	Name of Agro-waste Material*	Ground Sample			100(B/S)	Bulk Density, Mg/m^3 after Compression by a force of		
		Density, Mg/m^3		p*	% by Weight			
		Bulk	Real	%		19.62N	58.86N	98.10N
1	C'nut Shell	0.84	0.92	8.6	2.0	0.85	0.86	0.87
2	M. E Shell	0.75	0.81	7.7	2.0	0.75	0.76	0.77
3	P.K Shell	0.86	0.95	9.2	2.1	0.87	0.88	0.89
4	Corn Cob	0.76	0.83	8.2	2.2	0.77	0.78	0.78
5	G'nut Shell	0.79	0.86	8.0	2.0	0.80	0.81	0.82
6	Rice Husk	0.70	0.76	7.4	2.1	0.71	0.72	0.72
7	Bean Shell	0.81	0.88	7.7	1.9	0.82	0.83	0.83
	Mean	0.79	0.86	8.1	2.0	0.80	0.81	0.81
	Std Dev ±	0.05	0.06	0.6	0.1	0.05	0.05	0.05

Notes

*(1) C'nut = Coconut; M.E. = Mango Endocarp; P.K. = Palm Kernel; G'nut= Groundnut

(2) p= porosity = 100[1-(Bulk Density/Real Density)]

(3) B = 200g of commercial grade gum arabic "dissolved" in one litre of water.

2.2 *Determination of dielectric strength*

Dielectric strength determination was carried out using [9] to obtain the voltage gradient at which electric failure occurs. The failure is characterized by an excessive flow of current (arc) and by partial destruction of the material. The gum arabic-bound materials were moulded into rectangular samples 53mm by 35mm with thicknesses of 10mm, 8mm, 6mm, 4mm and 2mm and air-dried for seven days. Each sample was subjected to compression force of 98.1N, 58.86N and 19.62N using the Hounsfield Monsanto tensometer materials- testing machine with a loading capacity of 30kN. The choice of the thickness of the samples and levels of compressive forces were guided by the standard stipulated in laboratory manual of Nigeria National Electric Power Authority (NEPA). The procedure was repeated three times at room temperature of 30^{O}C for each thickness and for each level of compression lasting 10 minutes. The means and standard deviations of the sample variables are shown in Tables 2(a) and 2(b).

By using a variable transformer (BICC test Instrument 40 kV DC Test set model T103), the dielectric strength was measured through the thickness of the samples. This was possible by increasing the voltage on the variable transformer from zero at a predetermined speed of 1000 volts per second to break down. At the break down voltage, the equipment automatically switches off. The dielectric strength is expressed in volts per unit of thickness. The test was carried out at room temperature and at relative humidity of 40% measured with a durotherma-hygrometer.

2.3 *Determination of Resistivity*

Resistivity test yielded the resistance of the specimen to the flow of electric current. It is measured as the insulation resistance. The gum arabic-bound samples were moulded into a square shape for the surface resistivity tests.

For the volume resistivity test, the samples were moulded into cylindrical shape of diameter 15mm and length 110mm with a copper wire of diameter 2.5mm and length 180mm placed at the center of each sample. The samples were air dried for seven days.

The surface resistivities were measured using Kaise insulation tester model SK3010, in which the samples were placed between the two electrodes. The resistance is expressed in Ohms and resistivity was calculated from equation (1). For volume resistance a bare lead wire was wound round the samples, connected to the guard terminals and the earth lead to the surface of the sample while the probe was connected to the conductor.

2.4 Determination of dielectric constant

For the dielectric constant determination, the gum arabic-bound samples were moulded into circular plates of diameter 40mm and thickness 6mm and air-dried for seven days.

Figure 1 shows the plan of the experimental set up used for the determination of dielectric constant. It comprises a parallel-plate air capacitor, charge and discharge keys, battery, an accurate voltmeter for measuring the applied volts, and a sensitive calibrated charge electrometer. The sample was placed on the lower plate of the capacitor unit, the upper plate being positioned immediately on top of the medium (sample) under test. The capacitor was then charged from the supply battery and the charge (Q) taken recorded by switching the capacitor to the electrometer. The sample was then removed, keeping the air gap at the same thickness as the samples. The air capacitor was recharged (same supply volts) and the charge Q_1 taken in this case recorded by switching the capacitor to the electrometer [9].

In the first Case

$$Q = (\varepsilon AV)/d=(\varepsilon_r\varepsilon_o AV)/d \quad (2)$$

in which ε is the absolute permitivity of the medium (the sample in this case); ε_r,is the relative permitivity; ε_0, electric constant; A, is the surface area; V, is the applied voltage; and d, the thickness of the material.

In the second case,

$$Q_1 = (\varepsilon_0 AV)/d \quad (3)$$

which makes

$$\varepsilon_{\underline{r}} = Q/Q_1 \quad (4)$$

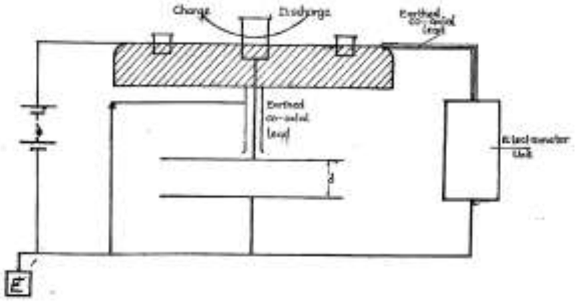

FIGURE 1: Parallel-Plate Air Capacitor Used to Determine Dielectric Constant

2.5 *Determination of Water Absorption*

The water absorbed by materials is specified as the percent weight gained by the material. The gum arabic-bound samples were moulded into cylindrical shape of length 100mm and diameter 15mm. They were air dried for seven days. The sample was weighed to the nearest 0.01g (M_1) and immersed in water for a period of two hours. It was subsequently removed from the water and allowed to drain by gravity before the sample was weighed again (M_2). The water absorbed was calculated as percent weight gain by the sample. Then,

Water absorption,

$$W_a = [(M_2 – M_1)/M_1] \text{ x } 100\% \quad (5)$$

2.6 *Determination of Moisture Content*

The moisture present in the samples has a significant effect on the dielectric strength and the resistivity of the materials. Therefore, the moisture content at the time of measurement needed to be specified. Gum arabic-bound samples were air dried for seven days. For each material, a weighing container was cleaned, dried and weighed to the nearest 0.01g (M_3). A sample of the air-dry material was placed in the container and the container with the sample was weighed to the nearest 0.01g (M_4). The container with its content was then placed in an oven for 24 hours at 105°C.

To go chemicalAfter drying, the container with its content was weighed again to the nearest 0.01g (M_5) . The moisture content was calculated as percentage of the dry samples from:

$$W_c = [(M_4 – M_3)/(M_5 – M_3)] \text{ x } 100\% \quad (6)$$

in which W_c is the percent moisture content (dry weight basis).

3. Results and Discussion

3.1 *Results*

Table 2(a) shows the means and Table 2(b), the standard deviations, of three replicates of the measured values of dielectric strength and moisture content of samples of the selected agro-waste materials. It was observed that air voids in the samples significantly affected their dielectric strengths. Samples compressed with a higher force of 98.10N had higher dielectric strength than those compressed by smaller forces. This is because highly compressed samples had lower void ratio than the less compressed ones. It was also observed that the dielectric strength increased with increasing thickness of the materials for a given compression. That is, the break down occurs at a much lower volt per millimeter value in very thin test pieces than in the thicker sections. It was observed that generally the lower the moisture content, the higher the dielectric strength of the material. Table 3 shows the variation of the measured surface and volume resistivities, dielectric constant and water absorption capacity with the moisture content of the samples.

Contrary to expectation, there was no consistent one-to-one relationship between moisture content and the measured values of resistivities and dielectric constant of the materials. The effect of moisture content might have been masked by other material factors. Table 3, however shows that the measured resistivities of the samples vary from one material to another. Coconut shell, palm kernel shell, rice husk and bean shell had relatively high resistivities, while corn cob, mango shell and groundnut shell had low values.

Table 3 further shows that the measured dielectric constants were not too high compared to the standard values (Table 4). This indicates that they are good for high frequency power application in order to minimize electric power losses. Table 3 shows in addition, a wide range of water absorption capacities of the materials varying from 3.4% for rice husk to 13.6% for mango shell.

TABLE 2(a): Mean * values of Three Replicates of Measured Dielectric Strengths and Moisture Contents of Seven Agro waste Materials with Gum Arabic as Binder.*

Material	Thickness, mm	2	4	6	8	10	2	4	6	8	10
	Compression, N	Dielectric Strength, kV/mm					Moisture Content, %Dry wt				
(1)Coconut Shell	19.62	19	23	20	25	30	12.3.	12.1	12.0	10.6	11.2
	58.86	23	24	26	35	40	11.8	12.0	11.8	10.4	11.0
	98.10	25	27	30	45	53	10.9	11.8	11.5	11.0	10.6
(2) Mango Shell	19.62	10	15	23	18	24	9.8	9.3	9.6	8.9	8.1
	58.86	14	18	16	19	20	11.8	10.6	9.1	9.5	9.3
	98.10	18	20	23	24	26	10.5	10.4	10	9.4	9.0
(3) Palm Kernel Shell	19.62	26	26	29	30	35	10.4	9.5	10.2	8.2	8.5
	58.86	28	30	31	40	43	9.8	9.6	9.3	9.3	8.8
	98.10	30	35	36	50	55	9.4	9.2	9.2	9.0	8.0
(4)Corn Cob	19.62	8	16	17	19	20	16.0	10.5	10.3	10.3	10.1
	58.86	9	17	20	24	24	14.3	10.2	8.6	10.0	9.9
	98.10	10	19	23	25	27	12.3	10.0	9.8	8.9	8.8
(5)Groundnut Shell	19.62	14	19	22	30	35	9.2	6.2	10.0	10.6	10.5
	58.86	18	22	29	31	40	9.0	6.1	8.9	6.2	10.0
	98.10	20	25	31	35	49	8.0	5.1	9.5	6.0	4.9
(6)Rice Husk	19.62	10	10	18	16	19	8.3	7.9	7.4	8.6	7.6
	58.86	11	12	18	19	22	7.8	6.8	6.1	8.1	7.2
	98.10	12	12	20	23	25	7.3	6.3	6.0	8.0	7.2
(7)Bean shell	19.62	10	9	10	11	13	12.5	11.10	9.1	10.7	12.3
	58.86	11	11	12	13	15	12.3	10.3	10.2	10.3	12.1
	98.10	11	12	15	15	20	12.0	11.3	11.2	11.3	11.0

Notes

* (1) The corresponding standard deviations are shown in Table 2(b)

(2) The binder is a 200g/litre aqueous solution of commercial grade gum Arabic.

TABLE 2(b): Standard Deviation (±) as a measure of Variability of Dielectric Strengths of Samples of Selected Agro-Waste Materials with Gum Arabic as Binder.

Material	Thickness, mm	2	4	6	8	10
	Compression, N	Std. Dev. (±) of Dielectric Strength KV/mm				
(1) Coconut Shell	19.62	2.2	1.7	1.6	0.8	1.4
	58.86	2.2	0.8	1.4	0.8	3.6
	98.10	1.4	1.4	2.2	0.8	2.2
(2) Mango Shell	19.62	2.2	2.2	1.6	0.8	1.7
	58.86	0.8	2.2	0.8	2.2	0.8
	98.10	1.7	1.0	2.2	2.2	2.2
(3) Palm Kernel Shell	19.62	1.7	2.2	1.0	1.7	0.8
	58.86	2.2	2.2	2.2	2.2	1.6
	98.10	1.6	2.2	1.7	2.2	2.2
(4) Corn Cob	19.62	0.8	1.6	2.2	1.9	2.2
	58.86	0.8	0.8	2.1	1.7	2.4
	98.10	0.8	0.8	1.7	2.1	2.2
(5) Ground nut Shell	19.62	1.7	1.7	1.0	2.6	0.8
	58.86	1.7	0.8	2.9	1.6	2.5
	98.10	1.0	1.7	1.7	2.5	0.8
(6) Rice Husk	19.62	1.6	2.2	0.8	2.1	2.6
	58.86	1.7	1.6	2.5	2.1	1.6
	98.10	0.8	1.7	1.7	2.5	0.8
(7) Bean Shell	19.62	0.8	1.0	1.6	1.7	0.8
	58.86	1.7	0.6	0.8	2.2	1.6
	98.10	0.8	1.7	1.6	2.1	2.9

TABLE 3: Measured Electrical Insulation Properties of Agro-Waste Materials with Gum Arabic Binder.

Material	Moisture Content % Dry wt.	Resistivity Ohm cm x10^6	Vol. Resist. Ohm cm x10^6	Dielectric Constant	Water Absorption % Dry wt.
1. Coconut shell	13.2	20	25	4.50	9.3
2. Mango shell	13.5	12	15	2.56	13.6
3. Palm Kernel shell	14.3	18	23	5.50	5.8
4. Corn cob	12.5	8	11	2.80	7.5
5. Groundnut shell	9.0	11	14	3.50	10.5
6. Rice husk	9.5	15	21	2.70	3.4
7.Bean shell	16.8	13	18	2.95	9.1

3.2 *Discussion*

Dielectric strength obtained in this study increased with increasing thickness of the insulating material – in line with work done by Harper [5].This is expected because for a given surface area of an insulator, its volume increases with its thickness; its volume on the other hand is a measure of its capacity to absorb energy which in turn is indicated by the dielectric strength of the material. Moisture is by far the major weakness of insulating materials; consequently, the absence of hygroscopic quality is desirable because moisture (humidity) impart a large surface leakage [9] effect on insulation materials.

With regard to the resistivity properties of a material, the higher the values of resistivity, the better for a good insulating material. However, the resistance value for a given material depends on a number of other factors. It is affected by humidity, moisture content, level of the applied voltage, and the time during which the voltage is applied. Therefore, comparing or interpreting data is difficult unless the test period is controlled and defined [5].

As earlier noted, the dielecric constant of most commercial insulating materials varies from about 2 to 10, air having the value of 1. Low values are best for high frequency or power applications, to minimize electric power losses [7]. Recently, Sipahioglu, [10] worked on modeling the dielectric properties of vegetables and fruits as a function of temperature and composition. He found that dielectric constant of the samples decreased with temperature and increased with moisture content. Dielectric loss factor first decreased then increased with temperature. However, in this work the values of measured dielectric constant were within the range for standard insulators and the range of water absorption capacity of the samples was broad.

The amount of water absorbed by the material in service will affect the service life of the material and even reduce the resistivity of the materials. Therefore, absorbed water reduces the insulation resistance [7]. Thus materials with low water absorption capacity would perform more efficiently in a high humidity environment than those with high water absorption capacity. Conversely, a device carrying a high water absorption capacity insulator would perform more efficiently in a low humidity (dry) environment than in a wet one.

Generally the values obtained for the dielectric strength of the samples are comparable to those of commercial electrical insulators and as such can be used effectively for either high or low voltage insulators. Although, the resistivities of the samples are a little bit low compared to the conventional insulation materials, they still meet the requirement of 10^6 Ohm.cm which is the minimum resistivity for an electrical insulator. These resistivities can be significantly increased if the moisture contents of the samples are reduced to lower level. The dielectric constants of the samples are comparable to standard insulating materials, because most commercial insulating materials vary from 2 to 10 (Table 4)and the values obtained in this work varied from 2 to 6 (Table 3). Specifically the materials examined in this study can be used effectively for high frequency or electric power line. The level of water absorption capacity of the samples are higher than those of commercial insulating materials. This shows that the materials will not perform well when put into service exposed to high humidity condition because moisture reduces electrical insulation, but when used in a dry enclosed area, the service life can be prolonged.

TABLE 4: Electrical Properties of Insulating Materials Regrouped after [11]

Material	Volume resistivity, Ohm cm	Dielectric constant 60 Hz	Dielectric Strength	
			V/mil	V/mm
Glass	17x 10^{9}	5.4-9.9	760-3800	(3-15) x 10^{4}
PolyVinyl chloride (flexible)	1011-10^{15}	5-9	300-1,000	(12-40) x 10^{3}
Phenolic (glass filled)	10^{12}-10^{13}	5-9	140-400	(5.5-16) x 10^{3}
Nylon	10^{14}-10^{17}	4-7.6	300-400	(12-16) x 10^{3}
Neoprene		7.5	600	23.5 x 10^{3}
Mica	10^{14}-10^{17}	4.5-7.5	1,000-4,000	(4-16) X 10^{4}
Porcelain	3 x 10^{8}	5.7-6.8	240-300	(9.5-12) x 10^{3}
Bakelite	5-30x10^{11}	4.5-5.5	450-1,400	(17-55) x 10^{3}
Epoxy	10^{14}	3.5-5	300-400	(12-16) x 10^{3}
Oils:- Mineral	21x10^{6}	2-4.7	300-400	(12-16) x 10^{3}
Paper, treated		2.5-4	500-750	(20-30) x 10^{3}
Polyimide	1016-10^{17}	3.5	400	16 x 10^{3}
Rubber	1014-10^{16}	2-3.5	500-700	(20-27) x 10^{3}
Paper		1.7-2.6	110-230	(4-9)x 10^{3}
Parafin	10^{15}	2.41	410-500	(16-22) x 10^{3}
Polyethylene	1015-10^{18}	2.3	450-1,000	(17-40) x 10^{3}
Magnesium oxide		2.2	300-700	(12-27) x 10^{3}
Fluoro carbons: Fluorinated ethylene propylene	10^{18}	2.1	500	20 x 10^{3}
Polytetrafluoro ethylene	10^{18}	2.1	400	16 x 10^{3}
Rubber butyl	10^{18}	2.1		
Asbestos board (ebonized)	10^{7}		55	2 x 10^{3}

3.3 *Possible Applications*

Electrical insulators are used in power transmission, electronics and communication, as well as in home and commercial appliances such as air-conditioning and farm machinery. Grouping insulators into relatively low and high voltage applications as suggested in [11] and modified for this study in Table 4, the seven materials studied here were sorted as shown in Table 5. Coconut, palm kernel and groundnut shells are in the relatively high voltage application category (≥ 3.50) while mango, corn cob and bean shells exhibit characteristics of low voltage insulators (< 3.5).

4 Conclusion

The electrical insulation properties of seven selected agro-waste materials (shells of coconut, mango, palm kernel, beans and groundnut, and corncob and rice husk) bound with gum arabic have been determined. The measured properties of the materials are comparable to those of standard insulators. However their moisture contents and their water absorption capacities are high, thereby reducing their usefulness as electrical insulators in their ordinary states. Nevertheless with appropriate technology, yet to be identified, their moisture contents and the humidity of the operating environment can be minimized to make them perform more effectively as electrical insulators. One method is to dry the powdered materials over a longer period and store in a drier (i.e lower humidity) environment.

TABLE 5: Categorization of the agro-waste mater as Electrical Insulators according to Voltage Level Application.

S/N	Material	Dielectric Constant	Voltage Level
1.	Coconut Shell	4.50	High
2.	Palm kernel Shell	5.50	High
3.	Groundnut shell	3.50	High
4.	Mango Endocarp Shell	2.56	Low
5.	Corn Cob	2.80	Low
6.	Rice Husk	2.70	Low
7.	Bean Shell	2.95	Low

Reference

[1] Jackson, K.G, (1973). Electrical Engineering Dictionary, butterworths London.

[2] McGraw-Hill, (1974). Encyclopedia of Science and Technology Vol. 7, Mc Graw-Hill New-York

[3] Michael, B.B., (1986). Encyclopedia of Materials Science and Engineering Vol. 2. Pergaman Press Ltd., U.S.A

[4] Saums, H.L., and Pendleton, W.W., (1973). Electrical Insulating and Dielectric Functions. Hoyden, New-York.

[5] Harper, C.A., (1972). Handbook of Wiring Cabling, and Interconnecting for Electronic. Mc Graw-Hill, New-York

[6] Fink, D.G., and Mcllenzie, A.D., (1975). Electronics Engineers handbook. First Edition McGraw-Hill, New-York.

[7] Vijh, A.K., (1977). Electrical Strength and Molecular Properties of Gaseous Dielectrics. IEEE Trans. Electrical Insulation, Vol. 12. No. 5 pp. 13-15.

[8] Inegbenebor, A.O., and Adam, M.K., (2002). Determination of Thermal Conductivities of some . Agro-Waste Materials. Nigerian Journal of Engineering and Technology. Vol. 1 No. 1. pp.1-9.

[9] Tyler, F., (1977). A Laboratory Manual of Physics. Fifty Edition. SI Version Edward Arnold Ltd. London.

[10] Sipahioglu, O., (2002). Modeling the dielectric properties of vegetables and fruits as a function of temperature and composition. Session 30D, Food Engineering: Physical and Chemical Properties. 2002 Annual Meeting and Food Expo-Anaheim, California. pp. 8 – 12

[11] Avallone, E.A and Baumeister III, T., (1997) Marks Standard Handbook for Mechanical Engineers. Tenth Edition, International Edition. McGraw-Hill New-York.