ACTA TECHNICA JAURINENSIS
Vol. 15, No. 2, pp. 91-98, 2022
10.14513/actatechjaur.00648

Research Article

Dielectric properties of *Raphia* Fiber from *Epidermis* of young *Raphia Vinifera* leaflet

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Submitted: 03/12/2021 Accepted: 02/05/2022 Published online: 06/05/2022

Abstract: There are materials that could serve useful purpose(s) in many fields, but they are left unutilized due to lack of both the knowledge on their useful properties and availability of values as per such properties. Notably, the knowledge of dielectric properties of some materials of plant origin is lacking whereas such is necessary for industrial, agricultural, electrical, electronics, biophysical and medical applications as well as other uses of a material. In this research, *Raphia Vinifera* is a material of choice. The experimental determination and computation of some dielectric properties of *Raphia* fiber from *epidemis* of young leaflets of *Raphia Vinifera* is explored. The properties considered for determination were dielectric permittivity, loss angle and dissipation factor. A Schering Bridge arrangement was employed, with a fixed thickness and varying areas of sample at various select frequencies. The values of the investigated properties recorded for our research sample trended towards being dependent of frequency. At frequency values above 1 kHz, the values of the properties determined decreased with increase in frequency. The values compared favorably with those of the already known and commonly used dielectric materials. The preliminary investigation showed that *Raphia Vinifera* would have usefulness in the electrical and electronic industries as raw material for the production of capacitor among other uses.

Keywords: Capacitance; Dielectric permittivity; Dissipation factor; Frequency, Loss angle

I. INTRODUCTION

Dielectrics are a class of materials (insulators and high-E_g semiconductors) that show polarization effects (separation of the centres of positive and negative charges) upon the application of an external electric field [1]. The dipole orientation and charge migration in broad frequency, temperature and pressure range can be examined via dielectric spectroscopy [2]. Knowledge upon the dielectric properties of materials can be utilized in several fields of science, engineering and industry including agriculture, biophysics, electronics and electrical industry, and medical applications [1, 2, 3, 4, 5]. The most important and frequently used frequency-dependent dielectric formalisms include though not limited to namely relative permittivity, impedance, ac conductivity and electric modulus [6]. The use of the appropriate formalism is decided depending on the data and the electrical characteristics of the investigated materials. In recent times, the search for electrically-insulating materials has been of great concern with elaborate dielectric factors determining the behavior of such materials.

The use of new bioplastics, green polymers and plant-origin materials is a significant contribution towards a sustainable future [2, 7, 8]. This is achieved by employing economically attractive and environmentally friendly biodegradable materials to increase their disposability [8]. *Raphia vinifera* is commonly known as Bamboo palm while others commonly refer to it as the West African piassava palm, an evergreen tree growing to 6 m that is commonly found in Africa [9, 10]. It is a monocotyledon plant, characterized by solid unbranched trunks having fan-shaped pinnate leaves when fully matured [11, 12]. Each leaf is about twice as long as the stem and may contain as many as 80 to 100 leaflets. The soft silk-like fiber from the epidermis of the tender leaves of the *raphia* palm is an important fiber used locally for weaving of hats, mats, baskets, bags, ropes, and ceremonial costumes. *Raphia vinifera* belongs to the family called *Arecaceae* [13] and it is a native to Benin, Ghana, Nigeria, Gambia, Togo, Central African Republic, Democratic Republic of Congo, and Cameroun. With dielectric measurements, the molecular dynamics and structural behavior can be understood and contribute to the structure-property understanding for such materials [2].

In the present study, the dielectric properties of *raphia* fiber obtained from the epidermis of young leaves of the *Raphia vinifera* plant are presented at room temperature and in a frequency range of 0.10 to 100 kHz, a material that has not been investigated before dielectrically. The aim of this research is to provide data for plausible utilization of the fiber as dielectric material in electrical/electronic industry as well as other purposes it may be deemed fit based on its dielectric data. Since several fibers can be got from each leaf which is mostly discarded as waste, findings from this study will help to solve associated waste disposal problems while ensure sustainable development.

II. Materials and Method

1. Materials

The young leaves of *raphia vinifera*, which were used in this work, were obtained from Ididep village in Ibiono Ibom Local Government Area of Akwa Ibom State, Nigeria. The young leaves were randomly selected and used in this study. The epidermis of the young leaflets were, on arrival in the laboratory, separated from other parts of the leaflets and immediately placed on a flat dry clean transparent glass plate holding the extreme ends with strong adhesive tape to the glass. It was kept very flat and firm on the glass surface to avoid folding itself and kinking when dry. Several epidermises were gotten from many young leaflets and treated using the same procedure applied in each case. The samples were allowed to remain in their positions on the glass plate at room temperature ranging between 27°C and 30°C (monitored with digital thermometer using type-K probe with sensor) for 21 days. This was necessary to allow for complete dryness before the samples were removed from the glass plate. **Fig. 1** shows the *Raphia* (bamboo) palm and also its fiber (when subjected to drying).

2. Procedure for measurement of dielectric properties of the *raphia* fiber

A parallel-plate capacitor method employing Schering Bridge [14, 15, 16] was used to determine the dielectric permittivity of the *raphia* fiber in this research work. The fiber was placed between two parallel copper plates, each measuring $4.95\cdot10^{-4}$ m^2 in area, A to form a parallel-plate capacitor having electrical conducting leads attached to each plate at their outer surfaces. The formation was weighed down uniformly using a load of about 20N to leave the sandwiched *raphia* fiber with relatively no air gap between the fiber (employed as dielectric material) and the copper plates. Very importantly, care was taken to avoid direct contact between the two copper plates. A synthesized signal generator (Agilent 83732A) as AC source and a dual trace oscilloscope (Model CA620) as a display instrument to monitor the balance point were used with the Schering Bridge arrangement (**Fig. 2**).

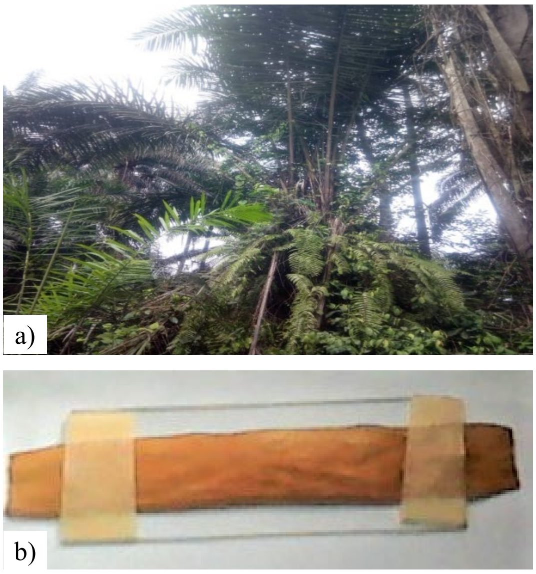

Figure 1. *Photographs of (a) Raphia vinifera palm (b) the raphia fiber under drying*

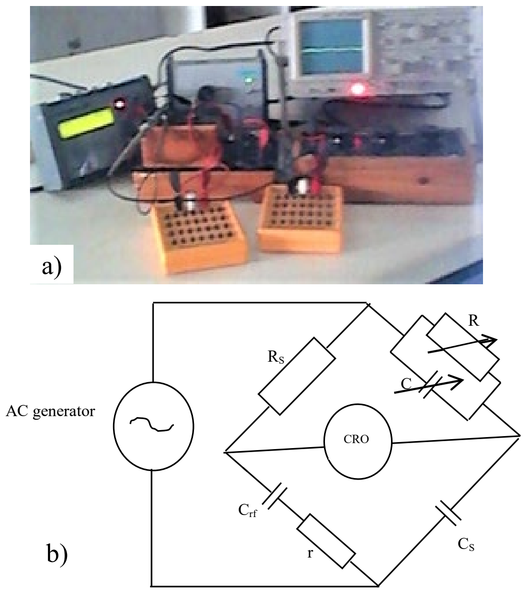

Figure 2. *Setup of Schering Bridge used in the study (a)Experimental photo (b) Schematic diagram*

The procedure was repeated for raphia fiber samples sandwiched between copper plates with areas measuring $4.40 \cdot 10^{-4}$ m^2, $3.63 \cdot 10^{-4}$ m^2, $3.30 \cdot 10^{-4}$ m^2, and $2.75 \cdot 10^{-4}$ m^2 while the thickness, d of the *raphia* fiber sample remained fairly constant (d =0.05mm), measured with digital vernier calipers at several positions along the length with a mean value. The experimental data obtained were employed, to compute the capacitance, dissipation factor, and loss angle of the *raphia* fiber sample at varying frequencies from 0.10 to 100 kHz. The measurement in each case was taken five times after which the mean value was calculated and recorded.

The capacitance, C_{rf}, of the *raphia vinifera* young leaflet fiber was calculated at the balance point of the Schering Bridge, in each case, using the mathematical formula given by several authors including [16]

$$C_{rf} = \frac{RC_s}{R_s} \tag{1}$$

The leakage resistance, r of the capacitor arrangement under test was obtained by employing the mathematical relationship

$$r = \frac{CR_s}{C_s} \tag{2}$$

Dissipation factor, D in each case was computed using the equation

$$D = \omega C_{rf} r = tan\emptyset \tag{3}$$

R_s and R are select resistance values from decade resistance boxes, C_s and $C$are select capacitance values from decade capacitance boxes, $\omega = 2\pi f$ (where f is the frequency of the applied AC signal), $\emptyset$ is the loss angle. Dielectric loss is affected by the loss angle, and dielectric loss is an essential element of power factor [17, 18]. It is believed to be determined by the amount of current wave being 90^o out of phase with voltage, a phenomenon known as dielectric loss angle.

By employing Origin software, the capacitance, C_{rf} values got at different frequencies versus the area, A were plotted for the *raphia* fibre investigated. The value of dielectric permittivity, ε_{rf} was deduced from the slope of the graph making use of the mathematical relationship as expressed by several authors including [19, 20, 21, 22]

$$C_{rf} = \frac{\varepsilon_o \varepsilon_{rf} A}{d} \tag{4}$$

where d is the common thickness of the *raphia* fiber, ε_{rf} is the dielectric permittivity of the *raphia* fiber investigated, ε_o is the relative permittivity of free space, which is $8.854 \cdot 10^{-12}$ Fm^{-1}.

By substituting for the actual values of d and ε_0 in equation (4), we have

$$C_{rf} = 1.7708 \cdot 10^{-7}\ \varepsilon_{rf} A \tag{5}$$

Every measurement taken was at room temperature of (28 ± 1)°C and relative humidity of 50%. Dielectric constant, otherwise known as relative permittivity values for conventional dielectric materials (as reported) were tabulated for the purpose of comparing with the results of our investigation in this research.

III. Results, Analysis and Discussion

The mean (with standard error) values of capacitance, loss angle, and dissipation factor at different frequencies deduced for the studied sample are shown in **Table 1**. It is evident in the expression that the capacitance of the sample decreases with increase in frequency.

Fig. 3 displays a linear relationship between the mean capacitance values and values of the sample's area at each frequency.

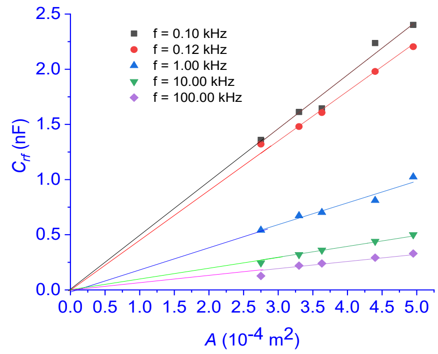

Figure 3. *Variation of Capacitance with the sample's area*

The values of dielectric permittivity were deduced from the slopes of the plots of mean capacitance at each frequency against area. The mean dielectric permittivity also decreases with increase in frequency. This is due to the fact that dipoles have less time (as the frequency progressively increases) to orient with the applied electric field resulting into decrease of real part of permittivity and hence the real part of capacitance. This is confirmed by equations (4) and (5). However, it has been observed that in some cases, dielectric permittivity values at frequencies below 1 kHz do not show significant variation from the values obtained at 1 kHz. This, essentially, means that there is no other dipolar relaxation process at a frequency below 1 kHz. As remarked by Halizan et al [23], good dielectric permittivity material has huge potential in capacitive energy storage devices for electronic applications. It can be clearly seen that loss angle values decrease with increase in frequency. The difference is very slight at frequency range below 1 kHz. It may not be wrong to aver that the value of loss angle is approximately constant for our test sample at a frequency range below 1 kHz.

The loss angle varies with frequency for our test sample. Values for dissipation factor (tan ∅) recorded for sample in **Table 1** reveal decreasing trend with increase in applied frequency. However, the decrease seems to be infinitesimal within the frequency bracket below 1 kHz. This relationship is illustrated using a log- log representation as shown in **Fig. 4**.

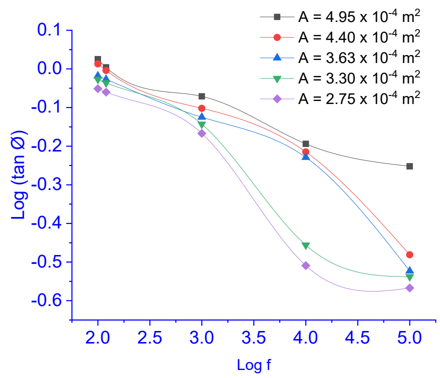

Figure 4. *Log-log representation of dissipation factor versus frequency*

Considering our research sample in terms of dissipation factor within the frequency range investigated, it is better at 100 kHz because the lower the dissipation factor, the better the dielectric is. Considering the trend, it is presumable that dissipation factor for this material will be lower at frequencies beyond 100 kHz, thus resulting in a better dielectric. The values of dielectric permittivity of our research sample at different frequencies are recorded in **Table 2**. It can be seen from the table that at the frequency of 1 kHz, the sample has a dielectric permittivity value of 11.14, but was greater at a lower frequency, thereby showing slight differences within the lower frequencies (below 1 kHz) bracket.

Table 3 shows the dielectric constant values reported in the literature for some commonly used dielectric materials. A dielectric permittivity value of 5.57 is recorded for our research sample at the frequency of 10 kHz. This value is slightly greater than the reported values for Mica (Muscovite) as 5.4; Bakelite as 5.0; Pyrex glass 3320, 7040, 7052, 7060, 7070, 7740, 7750, 7760, being 4.71, 4.65, 4.77, 5.07, 4.70, 4.0, 5.0 – 5.1, 4.28 and 4.5 respectively [24, 26, 28, 29] as seen in **Table 3**. At the frequency of 100 kHz, our investigated sample recorded 3.64 as the dielectric permittivity. This value is about the value of dielectric constant reported for paper (3.5), paper (bond) as 3.0, Mylar (3.2), rubber (3.0 – 4.0), plexiglass (3.4), titanium dioxide (3.0 – 4.0), Sulphur (sublimed) as 3.69 and PVC (3.18). Comparing the values of dielectric permittivity obtained for our chosen research sample within the radio frequency with the dielectric constant values of most of the commonly used dielectric materials as reported in the literature, it is correct to posit that our test sample exhibits a good and high ranking as a dielectric material. The manifestation of anomalous dielectric dispersion exhibited by our tests sample as clearly observed in **Fig. 5** has its support from the report of Vasudeva [24] and that of Salman [35] and Salman et al [36].

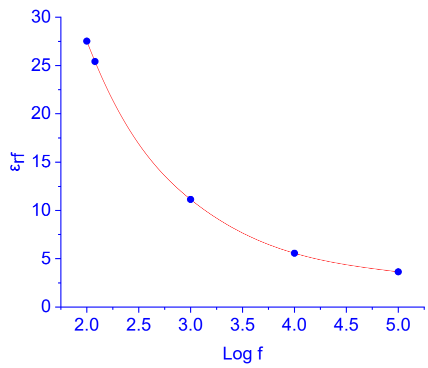

Figure 5. *Sample's dielectric permittivity versus log of frequency*

The value of dissipation factor obtained for the studied sample at the frequencies investigated follows the trend reported by Etuk et al [14] for some select eggshell membranes, which include those of eggs from Hen, Layers, Duck, Turkey, and Quail, which range between 0.173 and 0.350 at frequency of 100 kHz. It can be inferred that at frequency as high as 3 GHz, dissipation factor would also drop towards the range 0.002 to 0.005 even below as in the eggshell membrane. Values reported by Etuk et al [14] are approximately in the range reported by Fink and McKenzie [37] as (0.01 - 0.06), 0.04, (0.07 -0.028) 0.0011, and (0.0011 - 0.0025) for cellulose acetate, nylon 6, nylon 10, hard rubber, and glass mica respectively.

Table 1 *Results of capacitance, loss angle, and dissipation factor determinations for the studied sample*

$f\ (kHz)$	A = 4.95 x 10^{-4} m^2			A = 4.40 x 10^{-4} m^2			A = 3.63 x 10^{-4} m^2			A = 3.30 x 10^{-4} m^2			A = 2.75 x 10^{-4} m^2		
	$C_{rf}\ (nF)$	Ø (°)	Tan Ø	$C_{rf}\ (nF)$	Ø (°)	Tan Ø	$C_{rf}\ (nF)$	Ø (°)	Tan Ø	$C_{rf}\ (nF)$	Ø (°)	Tan Ø	$C_{rf}\ (nF)$	Ø (°)	Tan Ø
0.10	2.402 ± 0.006	46.90 ± 0.32	1.069 ± 0.012	2.237 ± 0.001	45.92 ± 0.04	1.033 ± 0.002	1.646 ± 0.003	44.10 ± 0.06	0.969 ± 0.002	1.612 ± 0.001	43.46 ± 0.02	0.948 ± 0.001	1.360 ± 0.003	41.86 ± 0.10	0.896 ± 0.003
0.12	2.204 ± 0.003	45.46 ± 0.04	1.016 ± 0.001	1.980 ± 0.004	44.94 ± 0.06	0.998 ± 0.002	1.607 ± 0.002	43.34 ± 0.06	0.944 ± 0.010	1.480 ± 0.002	42.80 ± 0.06	0.926 ± 0.002	1.321 ± 0.001	41.12 ± 0.02	0.873 ± 0.001
1.00	1.024 ± 0.002	40.56 ± 0.12	0.856 ± 0.004	0.811 ± 0.004	38.52 ± 0.16	0.796 ± 0.005	0.702 ± 0.002	37.18 ± 0.08	0.759 ± 0.002	0.672 ± 0.002	36.10 ± 0.12	0.729 ± 0.003	0.541 ± 0.002	34.32 ± 0.06	0.683 ± 0.001
10.00	0.500 ± 0.002	32.68 ± 0.06	0.642 ± 0.001	0.440 ± 0.002	31.76 ± 0.08	0.619 ± 0.002	0.360 ± 0.002	30.62 ± 0.08	0.592 ± 0.002	0.320 ± 0.003	19.62 ± 0.16	0.356 ± 0.003	0.245 ± 0.001	17.48 ± 0.04	0.315 ± 0.001
100.00	0.330 ± 0.002	29.34 ± 0.10	0.562 ± 0.002	0.292 ± 0.001	18.50 ± 0.04	0.335 ± 0.001	0.240 ± 0.001	17.14 ± 0.08	0.309 ± 0.007	0.220 ± 0.001	16.26 ± 0.06	0.292 ± 0.001	0.127 ± 0.001	15.20 ± 0.08	0.272 ± 0.001

Table 2 *Dielectric permittivity of the sample at different frequencies*

Frequency, f (kHz)	0.10	0.12	1.00	10.00	100.00
Dielectric permittivity, ε_{rf}	27.52	25.42	11.14	5.57	3.64

Table 3 *Distinctive values of dielectric constant of some commonly used dielectric materials as reported in the literature [14, 24, 25 – 34]*

Material	**Dielectric**	**Material**	**Dielectric**	**Material**	**Dielectric**
Rubber	3.0 – 4.0	Pyrex 7070	4.0	Polysulfones	3.13
Mylar	3.1	Pyrex 7720	4.5	Poly phenylene oxide	2.59
Bakelite	5.0	Pyrex 7740	5.0 - 5.1	Natural rubber	2.6
Paper (bond)	3.0	Pyrex 7750	4.28	Polychloroprene	6.6
Mica	3.0 – 8.0	Pyrex 7760	4.5	Polycrylonitrile	5.5
Paper	3.5	Vycor 7230	3.83	Glass bonded mica	6.3 – 9.3
Teflon	2.1	Vycor 7900	3.9	Soda lime glass	7.2
Air (1 atm)	1.00059 – 1.0006	Vycor 7910	3.8	Cordierite	4.02 – 6.23
Air (100 atm)	1.0548	Vycor 7911	3.8	Fluorocarbons	2.1 – 3.6
Vacuum	1.0	Germanium	16.0	Paraffin wax	2.0
Corning 8877	9.5	Porcelain	6.5	Poly vinylidene fluoride	12.2
Corning 0120	6.65	Plexiglass	3.4	Polymethyl methacrylate	3.12
Corning 0080	6.75	Polyethene	2.25 – 2.60	Polychlorotrifluoroehtyle	2.65
Corning 0010	6.32	Polyvinyl chloride	3.18 – 5.3	Polybutadiene	2.5
Glass	5.0 – 10.0	G.E. Clear (Silica	3.81	Sulphur (sublimed)	3.69 – 4.44
Mica (Canadian)	6.9 – 7.3	Quartz (Fused)	3.75	Polyceram 9606	5.57
Mica (Muscovite)	5.4 – 8.7	Titanium dioxide	3.0 – 4.0	Cellulose acetate	3.5 – 7.5
Pyrex 1710	6.0	Polypropylene	2.2	Alumina	8.0 – 10.0
Pyrex 3320	4.71	Neoprene	6.7 – 16.0	Polycarbonate	2.92
Pyrex 7040	4.65	ABC (Plastic)	2.4 – 3.8	Polyoxymethylene	3.8
Pyrex 7050	4.77	Barium titanate	5.0 - 450.0	Nylon 6 and nylon 10	3.5 – 3.6
Pyrex 7052	5.07	Forsterite	6.2 – 6.5	Borosilicate	4.1 – 4.9
Pyrex 7060	4.7	Hard rubber	2.95 – 4.80	Boron nitrite	4.15

IV. Conclusion

The dielectric permittivity of a material used for separating conductive plates of a capacitor determines the amount of energy that a capacitor can store when voltage is applied. A measure of loss-rate of energy known as dissipation factor of a dielectric material is another determining factor. This factor represents the tangent of the measure of current wave deviation from being 90o out of phase with voltage, designated loss angle.

The values of dielectric permittivity obtained for our study sample (*raphia* fiber from epidermis of young *Raphia vinifera* leaflet) in comparison with dielectric constant values of several already known and commonly used dielectric materials makes our investigated sample an alternative material of choice as dielectric material. The values obtained for the studied parameters give a very strong suggestion that the *raphia* fiber is a potential raw material for capacitor fabrication. *Raphia vinifera* young leaflet epidermis fiber is a biological membrane, though of plant kingdom. It grows well along creeks. The material is environmentally friendly and sustainable. Based on the afore-stated findings, it is highly recommended for electrical/electronic industry utilization. For future research, the influence of temperature on the investigated properties could be examined.

Author Contributions

S.E. Etuk: Conceptualization, Supervision, Writing – Original draft, review and editing.

S.S. Ekpo: Resources, Data curation, Writing - Review and editing.

U.W. Robert: Methodology, Investigation, Writing – Original draft, review and editing,

O.E. Agbasi: Visualization, Resources, Writing - Review and editing.

E.A. Effiong: Resources, Writing - Review and editing.

Disclosure Statement

We have no conflict of interest to declare.

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