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Using parallel plates capacitor (10 cm × 10 cm) at the mains frequency (50 Hz), the static dielectric constant of lophiralanceolata oil (LLO) was measured at different temperatures. The results show that the static dielectric constant decreases with increasing temperature according to the Clausius-Mosotti equation for polar dielectrics. From dielectric measurements, some properties of LLO which include total polarizability, permanent dipole moment and molar refraction of the molecule were determined. Our results show that LLO is a polar dielectric which is an important indicator of oil quality. Even though our technique is cheap, simple and agrees with existing theories, there are several sophisticated methods for more accurate measurements.

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# Temperature Dependence of Static Dielectric Constant of Lophiralanceolata (Echinacea) Oil

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**Keywords:** static dielectric constant, Lophiralanceolata oil, Temperature, permanent dipole moment, total polarizability, molar refraction.

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## I. INTRODUCTION

Lipids or fats are naturally occurring inorganic or organic substances that are soluble in organic solvents but not soluble in water. Most fats containing organic materials are made up of carbon, hydrogen, oxygen and some elements like phosphorus. Chemically, fats are carboxylic acids (esters) derived from the single alcohol, glycerol,

and are known as glycerides. Liquid fats are referred to as oils. Oils are mostly extracted from living animals and plants as well as their dead remains in rock underground. The physical and chemical properties of oil depend on its molecular weight (atomic elements present) and the arrangement of atoms in the molecules or molecules themselves that constitute the acid chains of the oil (Yerima, 1988; Eromosele and Eromosele, 1993). A host of authors have studied both Physical and chemical properties of oils (Eromosele et al., 1994; Eromosele and Pascal, 2002, Carey, 1998; Manji et al. 2006; Nkafamiya et al., 2007; Miller et al., 2005). Oils are used as fuel (kerosene, gasoline), lubricants (in moving parts of machines/engines to reduce friction and heat), cream (body and hair), medicinal purposes (e.g. shear butter, lophiralanceolata, cobra, etc. oils are used to cure diseases like aromantism, rashes, bone fracture and many other diseases), in cooking (vegetable oils), in making paints/soap and as dielectrics in capacitors to mention a few (Carey and Hayzen, 2001).

A dielectric material or an insulator has no free electric charges (electrons) under normal circumstances. This does not mean that they cannot modify the electric field into which they are introduced. In other words, a dielectric is one that has poor conductivity, but an ability to hold a charge with an applied electric field. Examples of dielectrics include air, oil, paper, wax, ceramic, mica, and so on. In fact the most important and interesting electrical property of a dielectric is its ability to become polarized under the action of an external electric field. The atoms and molecules of dielectrics are influenced by an external electric field and hence the positive particles are pushed in the direction of the field while the negative

particles in the opposite direction from their equilibrium position. Hence dipoles are developed and they produce a field of their own. The process of producing electric dipoles out of neutral atoms and molecules is referred to as polarization. A dipole is an entity in which equal positive and negative charges are separated by a small distance. In this case, the dipole moment has magnitude which is the product of charge and separation between the charges represented by a vector pointing from the negative charge in the direction of the positive charge. The units of the dipole moment are the Debye's (1 Debye =  $3.33 \times 10^{-30}$  Coulomb-metre). The dielectrics are mostly useful engineering materials. Their extensive applications as insulators and capacitors as well as their properties can predetermine the electrical performance and quality of such devices (Miller et al., 2005). The first fundamental experimental result discovered by Faraday showed that the capacitance of a capacitor is increased if the space between the conducting parallel plates is filled with a dielectric material (Yerima, 1988). If  $C_0$  is the capacitance of the capacitor with the space between the conductors evacuated and  $C$  its capacitance when the space is filled with a dielectric, then the ratio  $C/C_0 = k$  is called relative permittivity or dielectric constant which is independent of the shape or dimensions of the conductors and is solely a characteristic of the dielectric medium (Serway, 1996). The dielectric constant is a measure of its ability to transmit electrical potential energy. In electrical systems such as capacitors, the effectiveness of dielectrics is measured by their ability to store electrical energy. For fixed potential difference between the plates of a capacitor, the charge on the capacitor and its capacitance increase by a factor  $k$  while for fixed charge, the electric field intensity and potential difference between the plates decrease by  $1/k$  of their original values before the dielectric is introduced between the plates (Yerima, 1988). The permittivity of the dielectric medium is defined as  $\epsilon = \epsilon_0 k$  where  $\epsilon_0 = 8.854 \times 10^{-12}$  Fm<sup>-1</sup> is an electric constant representing the permittivity of free space or

vacuum. In another vein, the dielectric constant is a simple number, that is, the ratio of the speed of an electric field in a vacuum or air to the speed of the electric field in a material. The dielectric constant of a material is a directly measurable quantity which expresses on a macroscopic scale the overall result of the interaction which occurs on a microscopic scale between an externally applied electric field and the atoms or molecules of the material. In a nutshell, it is a macroscopic quantity that measures how effective an electric field is in polarizing the material.

When the dielectric constant of oil is measured, changes in the dielectric constant of the oil may be due to the presence of contaminants (water, particles, etc.) or changes in the chemistry of the oil (additive depletion or oxidation). In general, the value of the dielectric varies with the frequency of the applied field. This paper discusses static dielectric constant that is below electric field frequencies of 10<sup>6</sup> Hz (Carey, 1998; Carey and Hayzen, 2001). Dielectric constants at these frequencies are called static because the dielectric constant of materials shows virtually no frequency dependence in this frequency region. Temperature affects the value of the dielectric constant although the effects are relatively small (0.05 %) or hydrocarbons lubrication oils (Carey and Hayzen, 2001). The density of the oil also influences the dependence of the dielectric constant on temperature- the less dense an oil, the fewer number of oil molecules per unit volume. A smaller number of molecules per unit volume means that there is less interaction with the electric fields and therefore a decrease in the dielectric constant. As the temperature increases, the density decreases and hence the dielectric constant of the oil also decreases. Other things that will change the dielectric constant of oil include an increase in viscosity, changes in acid number or base number and additive depletion or decrease in viscosity caused by addition of less dense oil will result into decrease in dielectric constant (Manji et al, 2007).

It is easy to distinguish different classes of oil by measuring the dielectric constant. The only other

common technology capable of this is infrared spectroscopy (Carey and Hayzen, 2001). However, this method typically requires an expensive instrument and expert interpretation. By contrast, measuring the dielectric constants using capacitors offers a quick, simple, low cost alternative to permit the differentiation between different classes of oil.

In this study, the parallel plates capacitor technique is employed and the dielectric constant of interest is one of the Nigerian vegetable oils known as lophiralanceolata oil (LLO). This oil is extracted from the seed of Lophiralanceolata plant (ochracea) popularly known in northern part of Nigeria in "Hausa language" as "Namijinkadanya". Previous studies have shown that it has some medicinal (David, 2008) and biomass potentials (Samuel and Maimuna, 2007) and its present use as lubricant (David, 2008) in sewing machines in Mapeo village in Ganye Local Government, Adamawa state, Nigeria. In this paper, our chief interest is to investigate the potential of (LLO) as dielectric in capacitors.

## II. THEORY

The charge on the plates of a parallel plate capacitor connected to a power supply kept at constant voltage  $V$  with air between its plates is  $Q_{\text{air}} = C_{\text{air}}V$  and the charge with oil between its plates is  $Q_{\text{oil}} = C_{\text{oil}}V$  where  $C_{\text{air}}$  and  $C_{\text{oil}}$  respectively are the capacities of the capacitor with air and oil between its plates. Taking the ratio of the two charges and noting that the dielectric constant,  $k$  of a dielectric between the plates of a parallel plate capacitor is defined as the ratio of the capacity of the capacitor with oil as dielectric between its plates to that with air as dielectric. Thus, from the two equations, we can see that  $k = Q_{\text{oil}}/Q_{\text{air}}$ . Since charge is proportional to current or deflection in a galvanometer then this equation becomes  $k = \theta_{\text{oil}}/\theta_{\text{air}}$ . Using very sensitive galvanometer this method has been successfully employed to measure the dielectric constant of lophiralanceolata oil at various temperatures. It is worthy to note that the theory is cheaper and

simpler compared to other methods such bridge, frequency, infrared spectroscopy and so on.

## III. METHOD

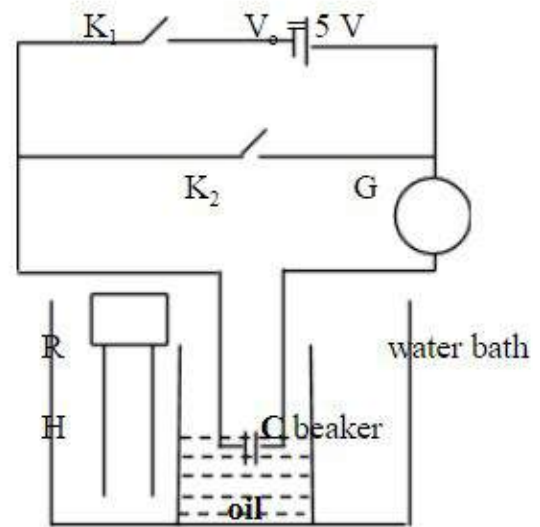


Fig. 1: Schematic diagram for measuring static dielectric constant of LLO

First, a parallel plate capacitor of dimensions  $10\text{ cm} \times 10\text{ cm}$  and plates separation of  $1\text{ mm}$  was constructed. With air as dielectric, when  $K_1$  was closed and  $K_2$  opened, the capacitor  $C$  was charged to maximum voltage  $V_0 = 5\text{ V}$ . When  $K_1$  was opened and  $K_2$  closed, the maximum deflection  $\theta_{\text{air}}$  on the galvanometer was recorded. The space between the plates of the capacitor was completely filled with lophiralanceolata oil (LLO). The capacitor was gently immersed in water in the water bath with its open end just slightly above the water meniscus in the water bath. The capacitor with oil between its plates was immersed in the water in the bath was heated to a constant temperature by means of an electric heater (H) and stirrer which are elements of the automatic bimetallic temperature regulator R (PHYWE 08482.93, Nr 986, 220V 50 Hz 3.5A). With LLO as dielectric, the procedure of measuring maximum deflection  $\theta_{\text{oil}}$  was repeated at various temperatures with the capacitor dipped in the water bath in such a way its open end was slightly above the water surface (Fig.1). The expression for dielectric constant  $k = \theta_{\text{oil}}/\theta_{\text{air}}$  as developed earlier in the theory was used to

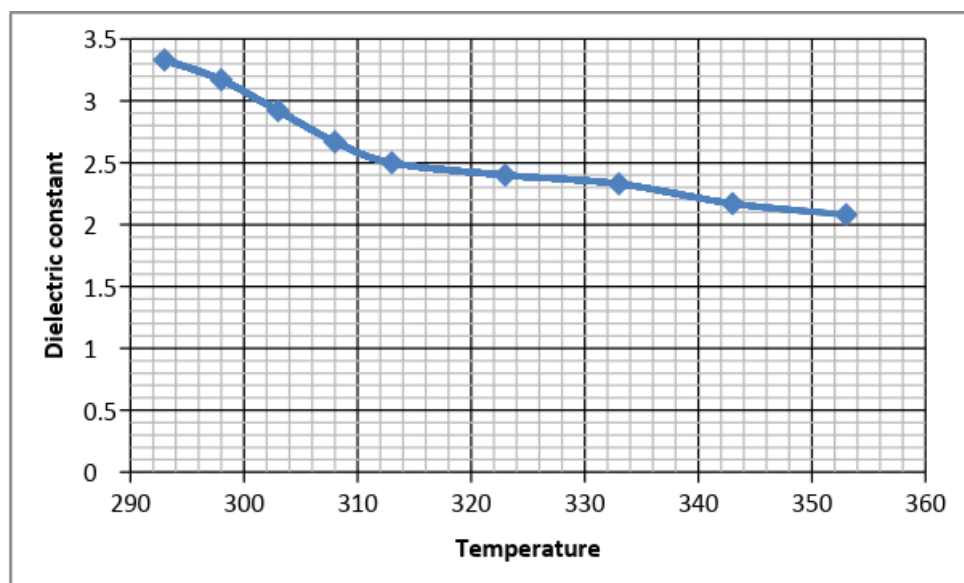
calculate the static dielectric constant of LLO at the mains frequency (50 Hz) at various temperatures (Table 1). The variation of the capacitance of a parallel plate capacitor with temperature up to 60 K above room temperature

with air as dielectric is assumed to be negligible (Yerima, 1988). In the light of this, the value of  $\theta_{\text{air}} = 1.2$  determined at room temperature 293 K was kept constant in the calculation of the values of  $k$  in the temperature range 293-353 K (Table 1).

### III. RESULTS AND DISCUSSION

*Table 1:* Dielectric constant of LLO, ( $\theta_{\text{air}} = 1.2$ ;  $V_{\text{air}} = 5$  V)

T(K)	$\theta_{\text{oil}}$	$k = \theta_{\text{oil}}/\theta_{\text{air}}$	$n = \sqrt{k}$
293	4.0	3.33	1.824
298	3.8	3.17	1.780
303	3.5	2.92	1.708
308	3.2	2.67	1.634
313	3.0	2.50	1.581
323	2.9	2.40	1.549
333	2.8	2.33	1.526
343	2.6	2.17	1.472
353	2.5	2.08	1.442



*Fig. 2:* Variation of dielectric constant of LLO with temperature

The values of dielectric constant,  $k$  of LLO were determined at various temperatures (Table 1). Fig.2 shows that the dielectric constant of LLO decreases with increasing temperature  $T$  in the range 293- 353 K. On heating, oils are known to undergo thermal degradation and decomposition as a result of some secondary reactions that produce polar compounds such as free fatty acid, hydroxyl compounds, diperoxides, and mono- and di-triglycerides which decreases  $k$  with  $T$  (Manji et al, 2007; Hwang et al, 1994). Also the decrease in

$k$  with  $T$  may be attributed to larger polarizable hydrocarbon molecules in LLO just like most seed (groundnut, palm, peanut, sesame, cotton, sunflower, corn) oils reported to contain fatty acids and mainly 16-18 carbon atoms (Carey and Hayzen, 2001). The value of dielectric constant ( $3.33 \pm 0.48$ ) determined at room temperature is higher than that of previous workers (2.14) (Samuel and Maimuna, 2007). Even though Samuel and Maimuna (2007) did give error in their result, the difference may be attributed to

the age and amount of slurry particles present depending on the different methods of extraction. The amount of slurry particles present is expected

to affect the density and hence the dielectric constant.

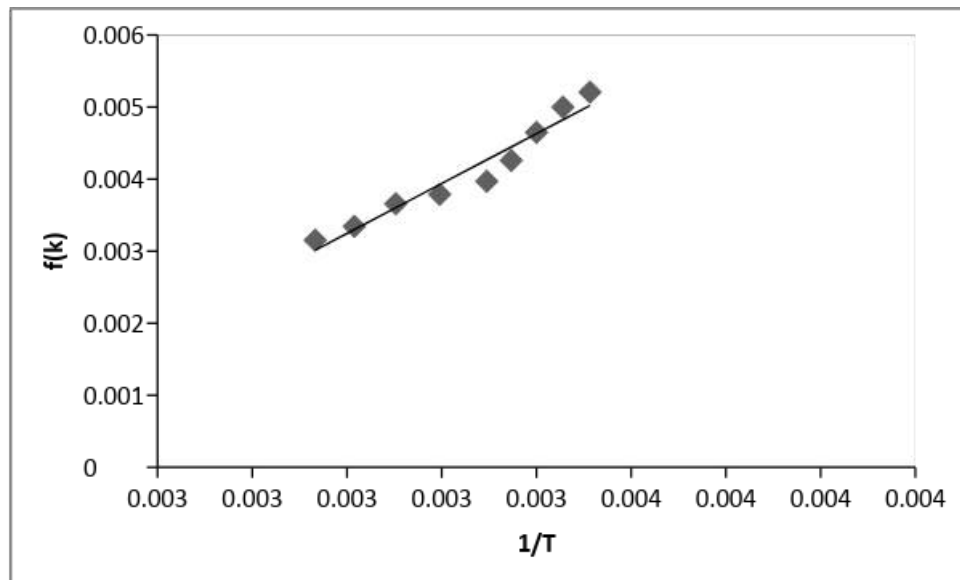


Fig. 3: Variation of  $f(k)$  with  $1/T$

Figure 3 represents the plot of the function  $f(k) = \left(\frac{k-1}{k+2}\right)V_m$  against  $1/T$  according to the Clausius-Mosotti or modified Debye equation

$$\left(\frac{k-1}{k+2}\right)V_m = a + \frac{b}{T}$$

where  $V_m$ ,  $a$  and  $b$  are constants

with  $a = \frac{\alpha N_A}{3\epsilon_0}$ ,  $b = \frac{N_A \mu_m^2}{9\epsilon_0 k_B}$ . Applying the Clausius-Mosotti equation to LLO and using the constant  $V_m =$  molar volume of LLO  $= 11.91 \times 10^{-3} \text{ m}^3$  (David, 2008),  $N_A =$  Avogadro's number  $= 6.02 \times 10^{23}$ ,  $\epsilon_0 =$  permittivity of free space  $= 8.854 \times 10^{-12} \text{ Fm}^{-1}$  and  $k_B =$  Boltzmann's constant  $= 1.38 \times 10^{-23} \text{ JK}^{-1}$ , the quantities  $\alpha =$  total polarizability and  $\mu_m =$  permanent dipole moment using least square were calculated to be  $-1.32 \times 10^{-35} \text{ Fm}^2$  and  $79.5 \times 10^{-30} \text{ Cm}$  from the intercept and slope respectively.

The total polarization  $P$  is equal to the sum of induced polarization  $P_i$  (atom-polarization  $P_a$  due to nuclei distortion + electron-polarization  $P_e$  due

to electron distortion) plus orientation polarization  $P_o$  i.e.  $P = P_a + P_e + P_o = P_i + P_o$ . Maxwell showed that for the same electromagnetic wave, the refractive index ( $n$ ) of a medium is related to its dielectric constant ( $k$ ) by the equation  $k = n^2$ . Therefore, the total polarization  $P = \left(\frac{k-1}{k+2}\right)V_m$  appears replaceable by

the molar refraction  $R_m = \left(\frac{n^2-1}{n^2+2}\right)V_m$ . But this is not strictly so. The refractive index is measured with visible radiations of higher frequency ( $\sim 10^{14} \text{ Hz}$ ) whereas the static dielectric constant is measured with long waves ( $< 10^2 \text{ Hz}$ ). The refractive index changes somewhat with wavelength. The correction for refractive index ( $n$ ) for lower frequency can be obtained with the

empirical Cauchy formula  $n = n_\infty + \frac{a}{\lambda^2}$  (Rakshit, 1997) where  $n =$  refractive index at wavelength  $\lambda$  and  $n_\infty$  at very high wavelengths;  $a$  is a constant whose value may be ascertained from two

measurements of  $n$  at known frequencies in the visible region.

In refraction only electrons are affected by the radiation. Even when corrected for long waves the refractive index gives the effect of the long waves on the electrons only. The nuclei remain unchanged. Thus, the electron-polarization equals

the molar refraction  $R_m = \left( \frac{n_e^2 - 1}{n_e^2 + 2} \right) V_m$ . (Rakshit, 1997). Substituting the values  $V_m = 11.91 \times 10^{-3} \text{ m}^3$  and  $n = 1.463$  obtained by David (2008) gives  $R_m = 3.28 \times 10^{-3} \text{ m}^3$  at  $30^\circ \text{C}$ .

#### IV. CONCLUSION

At various temperatures the static dielectric constant of LLO was determined using AC source operated at the mains frequency (50 Hz). The results show that the static dielectric constant decreases with increasing temperature obeying the Clausius-Mosotti relation for polar dielectrics. Using the values of measured dielectric constant, other properties of LLO such as total polarizability, permanent dipole moment and molar refraction (electron-polarization) were deduced. However, there is still room to improve on the accuracy of our results more especially if the empirical Cauchy formula for correction for the refractive index for lower frequency is employed. We also observed that LLO has potentials to be used as coolant in refrigerators and rheostats, inhibitor of oxidation and corrosion, lubricant in non-vehicle engines and dielectrics in capacitors.

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