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Dielectric Properties and AC Conductivity in Some Refined and Unrefined Edible Oils

T.Sankarappa, M.Prashantkumar

Department of Physics, Gulbarga University, Gulbarga, India.
sankarappa@rediffmail.com

Abstract: *Dielectric measurements have been made on some refined and unrefined edible oils, which are predominantly used in south India, at 1kHZ in the temperature range of 293K to 348K. The values of dielectric constant and dielectric loss factors were found to be high compared to values of similar oil systems reported in the literature. These oils may be most useful in the capacitors and transformers as dielectric liquids. Both parameters have shown increasing tendency with increase of temperature. This is attributed partly to the presence of bound water molecules in the systems and partly to the variations in density and viscosity with temperature. The ac electrical conductivities were estimated and analyzed in terms of Arrhenius relation. The activation energies were determined and found to be lying in the range 0.25eV to 0.60eV.*

Keywords: *Edible oils, refined oils, dielectric constant, conductivity, bound water molecules, capacitor, transformer.*

1. INTRODUCTION

The depletion of petroleum resources coupled with harmful ecological effects due to toxicity and nonbiodegradability of polychlorinated biphenyls (PCB's), Askarel fluids, which are used in the liquid filled transformers as coolants, has stimulated research for the explore of liquids that are devoid of these problems. The search for such liquids has been on for more than three decades and in the process a variety of oil systems such as mineral oils, synthetic hydrocarbon fluids, silicon oil, easter fluids and vegetable oils have been investigated. Of these, the vegetable oils have emerged as promising sources to be dielectric fluids for capacitor applications and dielectric coolants in the liquid filled transformers [1-3]. The chemical constitution of the edible oils consists of triglycerides. The fatty acid segments are composed of straight chains having an even number of carbon atoms. The long term thermal stability of the oils when used in transformers is based on their degree of unsaturation of fats. The oil will be unstable if it contains more of unsaturated fatty acids. Further, purity of oils is also important as the presence of any elements having the tendency of oxidation can degrade the oils rapidly resulting in the fast failure of transformers. Edible oils offer a better biodegradability. In view of thermal stability, biodegradability and toxicity the natural vegetable oils can be considered to be suitable for use in electrical devices as coolants.

Many researchers have investigated dielectric properties in different edible oils such as rape seed oil, cotton seed oil, coconut oil, hydrogenated castor and groundnut oils [3-7] and found that castor oil with additives was more suitable for use in capacitors due to its higher dielectric constant and more viscosity. Structural properties were investigated through dielectric relaxation studies in some complex oil blends [8,9]. The insulation fluid developed from high oleic vegetable oil has showed high biodegradability and performs well in the life tests on distribution transformers [10]. To our knowledge, there are no reports in the literature on the electrical conductivity in vegetable oils.

In view of the above observations we have experimentally measured the dielectric properties and ac electrical conductivity as a function of temperature in some refined and unrefined vegetable oils, which are predominantly used in south India. Further, we have also been persuaded by an idea that the vegetable oils produced in different geographical regions of the world will measure different sizes of electrical properties because of some deviations in their fat content etc., and a hope to observe higher dielectric constants in the vegetable oils of south India.

2. EXPERIMENTAL

The measurements of capacitance, C, and dielectric loss tangent, tanδ, have been carried out in different kinds of refined and unrefined edible oils (See table 1) using PLCR-8C digital LCR meter (PACIFIC), at a static frequency of 1kHZ and in the temperature range of 293K to 348K. The dielectric constant, ε' and dielectric loss factor, ε", were calculated using the following relations [11].

$$\varepsilon' = (Cd/\varepsilon_0 A) \qquad (1)$$

$$\varepsilon'' = \varepsilon' \tan\delta \qquad (2)$$

Where d (=0.65 x 10^{-2}m) is the distance between the electrodes (size of the sample), A (= 0.25 x $10^{-4}m^2$) is the cross section of conducting plates and ε_o (= 8.8542 x 10^{-12} Fm^{-1}) is the permitivity of free space.

The ac conductivity was calculated using the following relation,

$$\sigma_{ac} = \varepsilon_0 \omega \varepsilon'' \qquad (3)$$

The errors on dielectric constant, dielectric loss factor and ac conductivity were calculated to be within 2% and the temperature was measured up to the accuracy of ±0.5K.

Table 1. *Oils and the industries, which have produced them [16].*

Name of the oil	Botanical name	Company/Firm Produced
Refined coconut oil Unrefined coconut oil	Cocos nucifera	KLF Oil Industries Irinjalakuda, Tamilnadu, India. Small Scale Industry, Bidar Karnataka, India.
Refined castor oil Unrefined castor oil	Recinus communis	Standard Laboratories Hyderabad, India. Small Scale Industry, Gulbarga India.
Refined sunflower oil Unrefined sunflower oil	Helianthus annus	Shalimar Agro Tech (P) Ltd. Hyderabad, AP state, India Small Scale Industry, Gulbarga India.
Refined groundnut oil	Arachis hypogea	ROSG Co-op, Raichur, India.
Unrefined safflower oil	Carthamus tinctorius	Small Scale Industry, Gulbarga India.

3. RESULTS AND DISCUSSION

The temperature variation of ε' and ε" with temperature of all the oils is shown in figures 1 and 2 respectively. It is observed that both ε' and ε" increase monotonically with increase of temperature. Among all the oils studied here, the refined coconut oil has shown the highest dielectric constant of 36.40 and the refined castor oil has shown the lowest dielectric constant of 14.78 at 293K. At 348K, among all the oils, the highest dielectric constant of 63.4 and the lowest of 39.1 have shown by refined sunflower and refined castor oils respectively. The ε' values of all other oils lie between 14.78 and 63.4.

Dielectric loss factor is a measure of the dielectric losses or energy dissipated as heat in an insulating fluid when exposed to an alternating field. It is a significant indicator of contamination or deterioration. At temperature 293K, the highest dielectric loss factor of 1.35 and the lowest of

0.2 were shown by unrefined coconut oil and unrefined castor oils respectively. Similarly at 348K, the highest dielectric loss factors of 12.75 and lowest of 5.4 were observed in unrefined coconut oil and unrefined safflower oils respectively.

It is well known that under the influence of a periodic electric field the polarized molecules will tend to oscillate following the direction of the applied field. The present oils provide viscous medium and the rotational motion of molecules through this medium would be opposed by friction and so lag in phase behind that of the field. Heat would be generated and this is observed as energy loss. Historically it has been argued that polar oscillations in liquids matter only at high frequencies and hence dielectric losses in oils at lower frequencies can be ignored. However, Kitchen and Muller [22] in 1928 itself explained that the orientation of molecules in dielectric fluids at frequency as low as 60 Hz may account for least a portion of the observed energy loss.

The dielectric constant determines the material's ability to transmit electrical potential energy. The density of the oil influences the temperature dependence of the dielectric constant. As the temperature increases the density decreases and that lead to weak interaction of molecules with electric field and which in turn decreases the dielectric constant of the oil [2]. Dielectric studies on castor and cotton seed oils revealed that they can be used in capacitors (with cellulose insulation) due to their higher dielectric constant values [2,5]. The present oils have measured higher dielectric constant and therefore can be proposed for use in capacitor as dielectrics.

The natural oils are mainly hydroxyl-acid or fatty acid based esters which are known as triglycerides. The acidic part is ricinoleic acid which determines the viscosity of the oil [2]. Higher the percentage of ricinoleic acid present more will be the viscosity of the oil. The viscosity of our studied oils is relatively high which indicate that these oils contain greater amounts of ricinoleic acid.

It may be noted that the above mentioned dielectric constants and dielectric loss factors are high compared to other oil systems [2-4,8,12] such as cotton seed oil, castor oil, ground nut oil, rape seed oil, rapessed oil blend, Indian beach oil whose dielectric constants were reported to be in the range 3 to 6. The variation of ε' and ε'' with temperature is significant and the nature of variation appear to be nonlinear in some of the oils. As the oils are complex and their molecular structure and composition changes with temperature it is difficult to predict the exact nature of variation of ε' and ε''. To show the nonlinear behavior, second order polynomials were fit to the data on some oils and they are shown in figures 1 & 2. It is interesting to note that ε'' also increases with temperature. It is not unusual as similar behavior has been observed in a biopolymer, enzyme diastase, and some capacitor oils [11].

As per Debye's theory [13-15] an ideal dielectric fluid, at a fixed frequency, should not show any variation in its dielectric properties with temperature except for changes in density and viscosity. The density and viscosity variations with temperature of the present oils have been investigated [16-17]. The measured densities varied from 900 kg/m^3 to 960 kg/m^3 and the viscosities have varied from 50 to 1000 milli-poise, in the temperature range of 298K to 333K. These viscosities are high compared to the reported values for other vegetable oils [2]. The density has decreased linearly with temperature and the viscosity has increased nonlinearly with temperature [16,18]. In deed, the dielectric relaxation studies in highly viscous medium have confirmed the dependence of dielectric properties on the viscosity variation with temperature [9]. So, the observed variation in ε' and ε'' with temperature may also partly be attributed to the variations in density and viscosity.

In case of biopolymers or biological fluids, the dielectric properties were observed to be affected by the presence of bound water molecules [11,17-21]. The bound water molecules shows usual water properties i.e., they freeze at low temperature and undergo transition from bound to free state at higher temperature and may also be easily removable by dehydration procedure. The dielectric behavior observed in the present oils can be linked to the presence of bound water molecules. Below 273K, all the bound water molecules are frozen and therefore do not contribute to the polarization. Above 273K, water molecules undergo gradual transition from bound to free-state and contribute to polarization. With the increasing temperature more and more water molecules become free and progressively contribute to the total polarization and hence dielectric constant increases with temperature. The present investigations were carried out up to the temperature of 348K only. If the temperature was further increased the decrease in dielectric properties due to the diffusion of free water molecules out of the system would have been witnessed as observed in enzyme diastase and other biological fluids.

The natural oils are electrically insulators. However, a very small amount of electrical conductivity exhibited by the oils is due to the presence of water content and other impurities such as dirt, micro-sized particles of different elements [1]. Temperature variation of electrical conductivity is analyzed using the relation,

$$\sigma = \sigma_0 \exp\left(-\frac{W}{k_B T}\right) \tag{4}$$

where, σ_o is the pre-exponential factor, k_B is Boltzman constant, T is the absolute temperature and the activation energy, W is the minimum energy required for the initiation of conduction process in the oils.

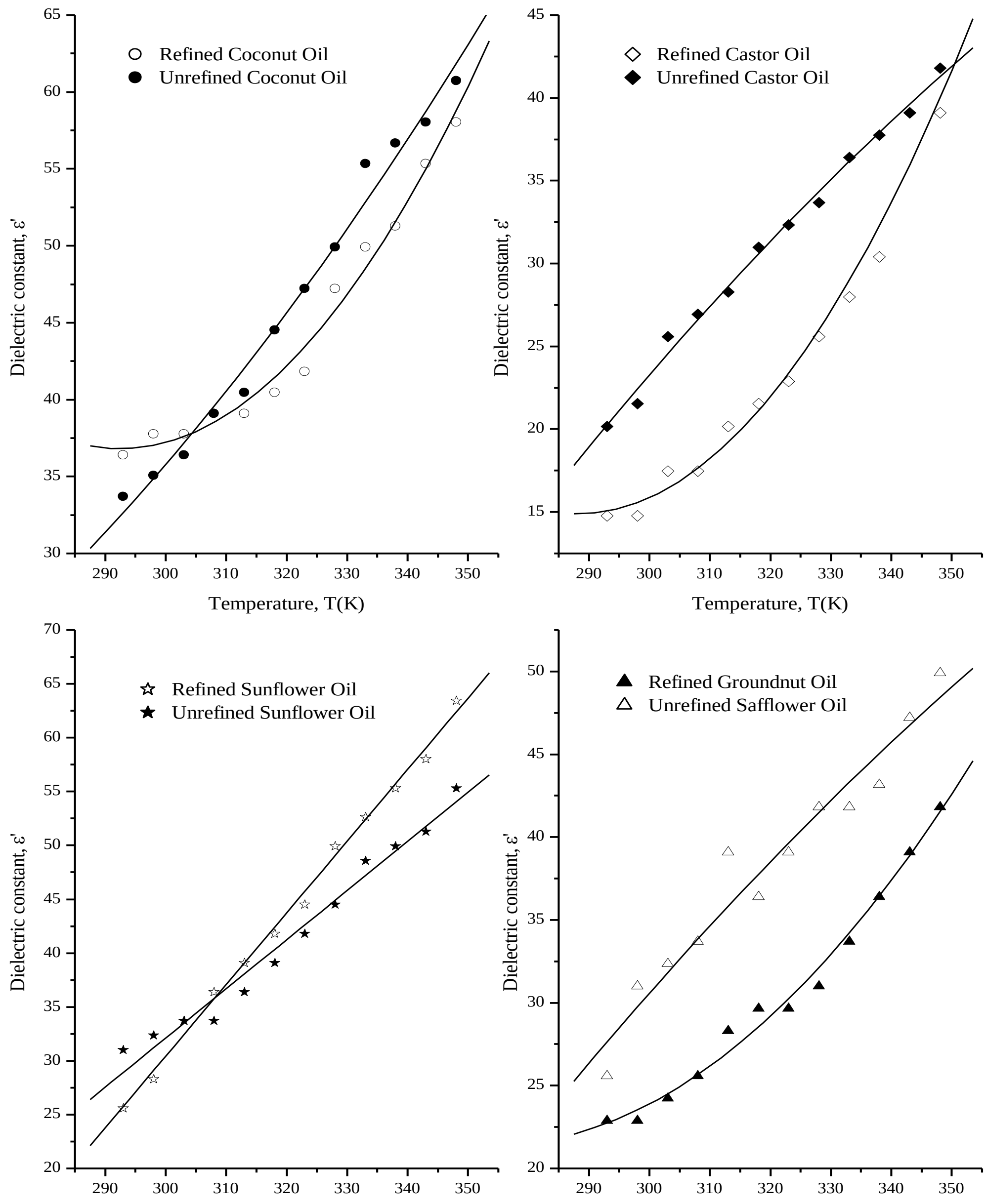

Fig 1. *Dielectric constant as a function of temperature*

The conductivity increased with increase in temperature indicating that it is a thermally activated process. This may be attributed to the gain in the mobility of ions or charged impurities present in the oils and could also be due any extra charge carriers generated due to the breakage of molecular bonds in the oils with increase in temperature.

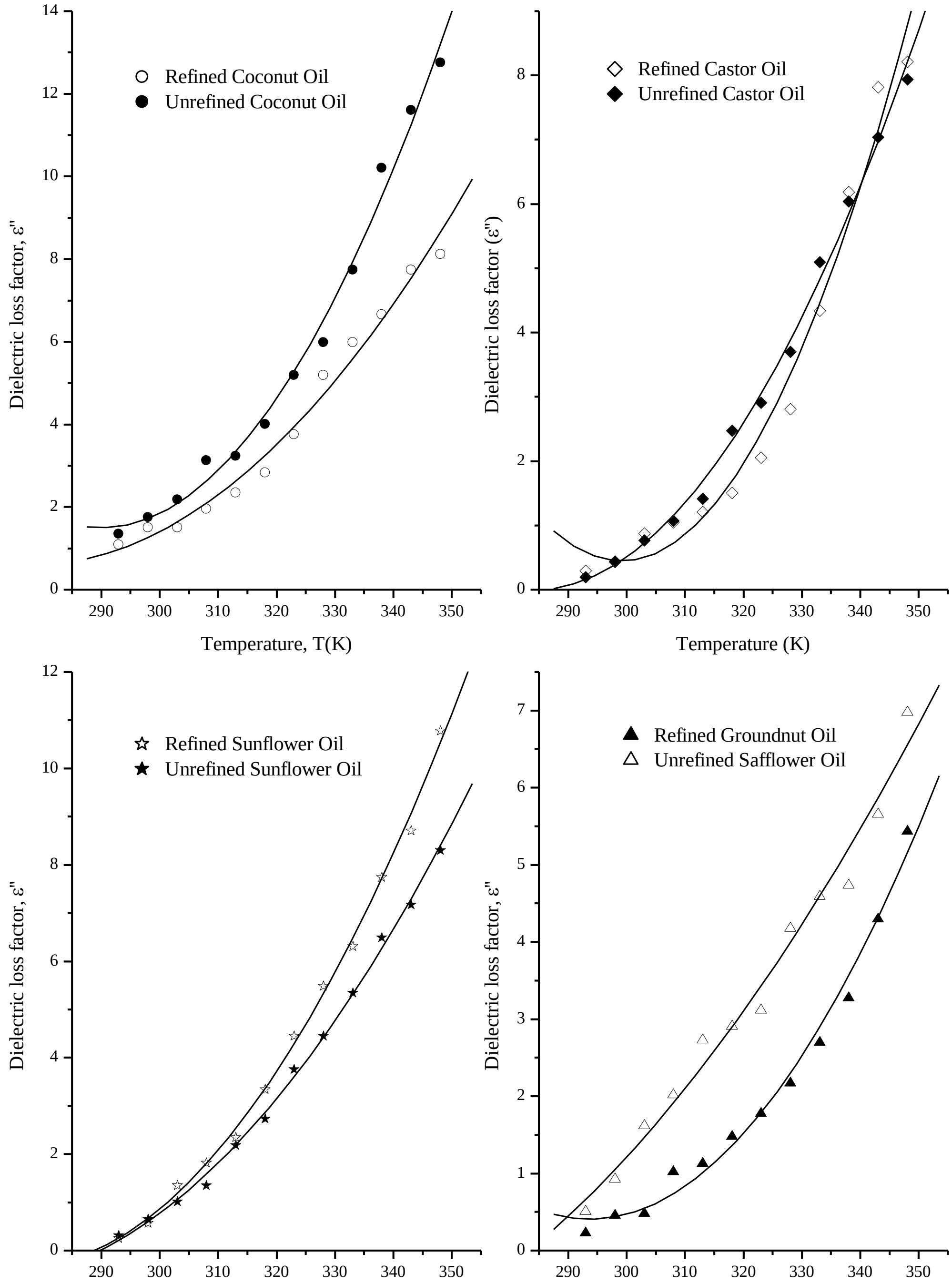

Fig 2. *Dielectric loss factor as a function of temperature*

As per Equation (4), the plots of $\ln(\sigma_{ac})$ vs (1/T) were made and they are shown in Fig.3. The data appeared to be linear above 310K and nonlinear below this temperature. This means the data corresponding to temperature above 310K obeys Arrhenius relation (Eqn.4). The least square linear lines were fit to the data corresponding to temperatures above 310K and activation energies were estimated from the slopes of these lines. The activation energies are in the range 0.253eV to 0.605eV (Table.2).

Table.2 *Activation energy, W and ac electrical conductivity at 323K.*

Name of the oil	Activation energy, W (eV) ±0.002	Conductivity, σ_{ac} at 323K ($ohm^{-1}m^{-1}$)
Refined coconut oil	0.380	$2.09x10^{-7}$
Unrefined coconut oil	0.369	$2.89x10^{-7}$
Refined castor oil	0.605	$1.15x10^{-7}$
Unrefined castor oil	0.469	$1.62x10^{-7}$
Refined sunflower oil	0.415	$2.48x10^{-7}$
Unrefined sunflower oil	0.450	$2.09x10^{-7}$
Refined groundnut oil	0.253	$1.74x10^{-7}$
Unrefined safflower oil	0.397	$9.90x10^{-8}$

There are no reports in the literature to compare the ac conductivity results presented here.

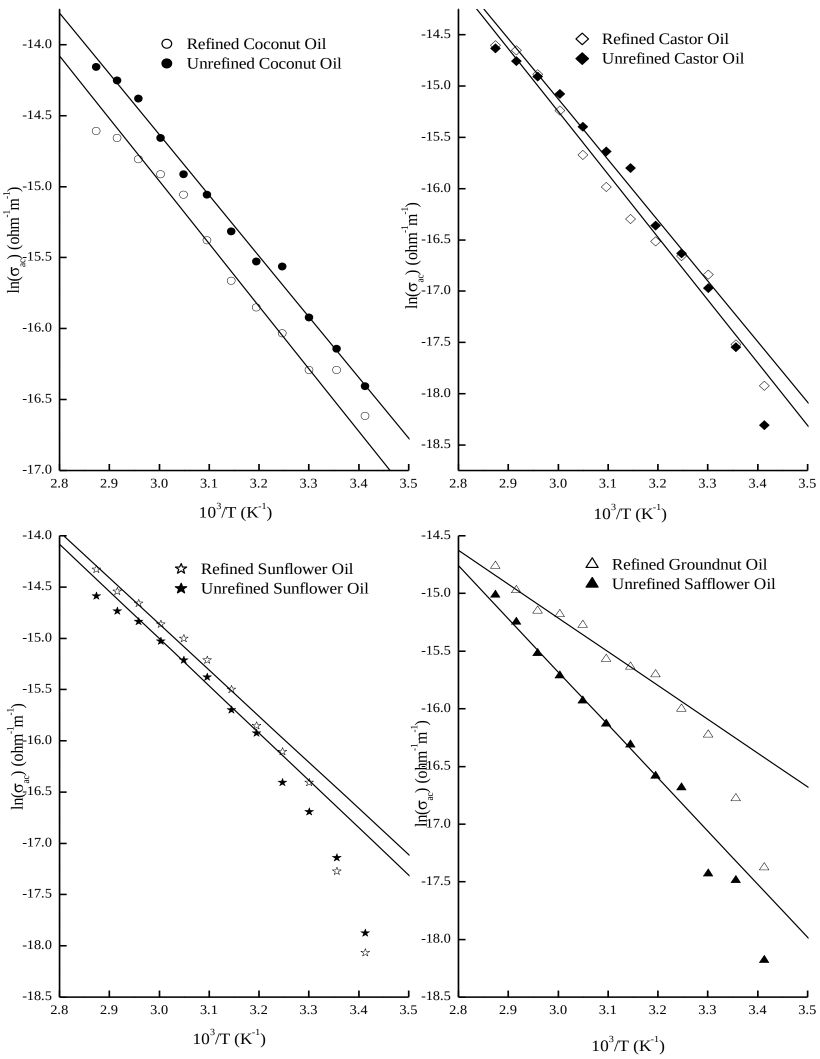

Fig 3. *Plots of ln(σ_{ac}) vs (1/T). Solid lines are the least square linear fits to the data.*

The viscosities and dielectric constants of the oils studied are very high and they are of favorable size for use in capacitors and transformers as dielectric coolants. Before considering for such applications the present oils must be purified so that their conductivity is reduced to the tolerable size. They need life tested as dielectrics and investigated for the factors such as flammability, biodegradability and dielectric breakdown strength. The oils must be less flammable, biodegradable and must possess high dielectric breakdown strength in order to be useful as dielectric coolants in transformers [1-6]. Dielectric break down strength defines the ability of the fluid to withstand dielectric stress. Due to unavailability of facilities these experiments have not been conducted on the studied oils and therefore can only be mentioned that the present glasses posses some favorable properties (viscosity and dielectric constant) for use as dielectric coolants.

4. CONCLUSION

Some of the edible oils (refined and unrefined), predominantly used in south India, have been investigated for their dielectric properties at a fixed frequency of 1kHZ and in the temperature range of 293K to 348K. The dielectric constant and dielectric loss are measured to be very high compared to other similar vegetable oil systems of different geographical origin and reported in the literature. The variation in these properties with temperature was also observed to be appreciable and it is attributed to the presence of bound water molecules in the systems. High dielectric constant and higher viscosity are some of the prerequisites for a dielectric liquid to be useful in capacitors and transformers and therefore, can be concluded that the vegetable oils studied here have these two properties of favorable size. The ac conductivities of these oils were also estimated and analyzed in terms of Arrhenius relation. Activation energies for ac conduction were determined.

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