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EFFECT OF PACKING DENSITY AND TEMPERATURE ON DIELECTRIC PARAMETERS OF LAC IN MICROWAVE REGION

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ABSTRACT

To obtain useful information on biophysical properties of various kinds of natural products, the study of dielectric behaviour from microwave absorption is of great value. The dielectric parameters are generally dependent on frequency, temperature, packing density and other factors such as material structure and composition. The behaviour of dielectric substance is changed by the application of external electric field. The important concept in dielectric theory is that of an electric dipole moment which is measure of electrostatic effect of a pair of opposite charges separated by a finite distance. The present paper examines the effect of packing density and temperature on dielectric parameters of natural Lac from *Samanea saman* tree (Rain tree). The wave guide cell was designed for holding Lac sample in the form of powder. The reflectometric technique was used for the measurement of dielectric constant and loss factor. Measurement of Lac powders of different packing fractions at 9.85 GHz microwave frequency are reported. The results indicate that, the values of dielectric constant (ε'_p), dielectric loss (ε''_p), relaxation time (τ_p) and conductivity (σ_p), increases with the increase of relative packing fraction (δr) 0.9501, 0.9685, 1.000, and decreases with the increase in temperature 0^0c, 10^0c, 20^0c and 30^0c. The experimental values have been used to obtain transformation to 100% solid bulk, using co-relation formulae of Landu-Lifshitz, Looyanga and Bottcher. The results show that there is a fair agreement between the experimental and theoretical values of dielectric constant and dielectric loss.

KEYWORDS: Lac, Dielectric constant, Relaxation time, Conductivity, Packing density.

1. INTRODUCTION

Lac is a natural animal- produced resin and wax mixture, which is utilized in a broad spectrum of applications. When applied as a finish to wood, lac imparts a depth, glow and beauty, hard to match with any other product. Lac is also used as an adhesive or as a film forming finish for wooden objects, metals etc. the versatility of the resin has proven invaluable for verity of applications. This resinous exude material from the *Laccifer Lacca* beetle is often referred to as Lac.[1] Lac has been an integral part of Indian history and culture for thousands of years, beautifying wood as a coating, used as thermoplastic molding material, as well as having medicinal and cosmetic qualities within ayurvedic medicine. This shows a familiarity with the resin and it uses within the ancient world. In its raw form, Lac contains laccaic acid or lac dye, a dye that in water soluble in alkali solution and used as a red colorant in food and for dying natural fibers, such as wool and silk. India and Thiland are the two main exporters of Lac. Minor producers are Indonesia, Bangladesh, Myanmar, Vietnam and Srilanka. In India Lac comes from Jharkhand, Chattisgarh, Madhyapradesh, Bihar, West Bengal, Orissa and Maharashtra. The main Lac hosts in India are, Kusum (*Schleicheraoleosa*), Ber (*Ziziphus Mauritania*) and Palash (*Butea Monosperma*). Host trees do have an impact on the quality and quantity of the resin produced. Lac is a very important cash crop for the rural and tribal people in the forested areas of India. With increasing universal environment awareness, the importance of Lac has assumed special relevance in the present age, being an ecofriendly bio-degradable and self-sustaining natural material.[2] With this background we have undertaken to investigate the dielectric behavior of the natural Lac complex from *Samanea saman* tree for different packing density and temperature at microwave frequency.

2. Experimental Details

To determine the dielectric parameters of Lac, the samples of various particle sizes were prepared by using sieves of different sizes. The samples transferred in to the glass bottles and sealed immediately to avoid moisture intake. To determine the relative packing fraction (δr), the densities were measured for each powder samples. Measurement of dielectric constant (ε'_p) and loss factor (ε''_p) for these powder samples of different packing fractions was made using reflectrometric technique at 9.85 GHz of X-band microwave frequency[5,6] for different temperature.

Fig. X - band Microwave set-up for measurement.

The accurate measurement of dielectric wavelength (λ_d) was done by introducing the very small quantity of Lac powder in the sample holding dielectric cell in steps and applying constant 98 N force on the sample. The corresponding reflection coefficient is measured by using crystal pick-up in the directional coupler. The relationship between reflected power and sample column position is approximately given by damped sinusoidal curve. The distance between two adjacent minima gives half of the dielectric wavelength (λ_d). Kalamse G. M. and Kalamse V. G have designed and developed the dielectric cell to hold the powder sample such that one can introduce the sample in the cell conveniently by raising up the plunger without taking the cell outside.[3] Due to this arrangement, equal pressure can be applied by the plunger on the powder column in the cell. In addition to this, jacket is provided to the dielectric cell for the circulation of water at required temperature.

To determine the dielectric constant (ε_p') and loss factor (ε_p'') for Lac powder at microwave frequency, relations were used.

$$\in' = \left(\frac{\lambda_0}{\lambda_c}\right)^2 + \left(\frac{\lambda_0}{\lambda_d}\right)^2 \qquad \ldots\ldots(1)$$

$$\in'' = \frac{1}{\pi}\left(\frac{\lambda_0}{\lambda_d}\right)^2 \alpha_d \beta_d \qquad \ldots\ldots.(2)$$

Where,λ_0, λ_c, λ_g and λ_d are the free space wavelength, the cutoff wavelength, guide wavelength and wavelength in dielectric respectively. ρ is the inverse voltage standing wave ratio (VSWR) and $\frac{d\rho}{dn}$ is the slope of ρ versus 'n' where n = 1, 2, 3… such that $n\frac{\lambda_d}{2}$ represents the length of dielectric filled in wave guide. For low loss materials, dielectric constant (ε_s') and loss factor (ε_s'') for bulk materials can be co-related with their powder form by the relations derived independently by Landu, Lifshitz and Looyanga.[4]

$$\varepsilon_s' = \frac{(3\delta_r + 2\varepsilon_p' - 2)\varepsilon_p'}{(3\delta_r - 1)\varepsilon_p' + 1} \quad \ldots\ldots(3)$$

$$\varepsilon_s'' = \left(\frac{\varepsilon_p''}{\delta_r}\right)\left(\frac{\varepsilon_s'}{\varepsilon_p'}\right)^{2/3} \quad \ldots\ldots(4)$$

Where, (ε_s') represent the dielectric constant for the material in bulk and (ε_p') is the dielectric constant for the powder at relative packing fraction δ_r. (ε_s'') and (ε_p'')are the dielectric losses for solid and powder respectively.

The experimental results can verify with the values obtained from Bottcher's relations for bulk permittivity (ε_s') and loss factor (ε_s'')

$$\varepsilon_s' = \frac{(2\varepsilon_p' + 3\delta_r - 2)\{(3\delta_r - 1)(\varepsilon_p'^2 + \varepsilon_p''^2) + \varepsilon'_p - 2\varepsilon_p''^2\}}{(3\delta_r - 1)^2(\varepsilon_p'^2 + \varepsilon_p''^2) + 2\varepsilon_p'(3\delta_r - 1) + 1} \quad \ldots\ldots(5)$$

and

$$\varepsilon''_s = \frac{2(3\delta_r - 1)\left(\varepsilon_p''^3 + \varepsilon_p'^2 + \varepsilon''_p\right) + \varepsilon''_p\,(3\delta_r - 2) + 4\varepsilon_p'\varepsilon''_p}{(3\delta_r - 1)^2(\varepsilon_p'^2 + \varepsilon_p''^2) + 2\varepsilon_p'(3\delta_r - 1) + 1} \quad \ldots\ldots(6)$$

The conductivity (σ_p) and relaxation time (τ_p) were obtained by using the following relations.[5]

$$\sigma_p = \omega\varepsilon_0\varepsilon''_p \quad \ldots..(7)$$

$$\tau_p = \frac{\varepsilon''_p}{\omega\varepsilon'_p} = \frac{\tan\delta}{\omega} \quad \ldots..(8)$$

$$tan\delta = \frac{\varepsilon''_p}{\varepsilon'_p} \quad \ldots..(9)$$

Where, $\omega = 2\pi f$ and f is the microwave frequency used (f = 9.85 GHz),

ε_0- permittivity of free space.

3. RESULT AND DISCUSSION

The values of dielectric constant (ε'_p), dielectric loss (ε''_p), loss tangent (tanδ), relaxation time (τ_p) and conductivity (σ_p) obtained experimentally for different packing fractions (δ_r) and temperature of Lac samples at 9.85 GHz microwave frequency are shown in table (1).

The results indicate that, the values of dielectric parameters, dielectric constant (ε'_p), dielectric loss (ε''_p), loss tangent (tanδ), relaxation time (τ_p) and conductivity (σ_p) increase in relative packing fraction δ_r = 0.9501, 0.9685 and 1.000. Also these values of dielectric parameters decrease along with the increase in temperature. This type of dielectric behavior is expected, because with higher values of relative packing fraction (δ_r), the inter particle hindrance offered to dipolar motion of material, in an electromagnetic field at microwave frequencies, for a compact medium is much higher than for a material constituting less bounded particles. For higher temperatures the polar molecules are large, then under the influence of the electromagnetic field of high frequency, the rotatory motion of the polar molecules of a system is not sufficiently rapid to attain equilibrium with the field. The polarization then acquires a component out of phase with the field and displacement current acquires a conducting component in phase with field, resulting in thermal dissipation of energy. Thus, the dielectric loss is proportional to the A.C. conductivity.[6]

The increase in relaxation time (τ_p) with increasing values of packing fraction is due to increasing hindrance to the process of polarization. Again the decrease in relaxation time (τ_p) with increase in temperature may be due to the increase in effective length of dipole. Increase in temperature also causes as increase in energy loss due to the large number of collisions and thereby decrease in relaxation time. The increase in conductivity (σ_p) suggest that, at higher compaction no micro cracks develop in the Lac samples due to high mechanical pressure. The dielectric loss values depend directly on the number of dipoles participating the loss, the dielectric loss (ε''_p) values increases with increase in packing fraction.

The measured and computed values of dielectric constant and dielectric loss for bulk, from powder measurements are listed in table (2). The results reported for δ_r = 1 are those measured on the finest crushed powder sample packed closely in a sample holding dielectric cell at 98N force, to obtain minimum voids between the particles. The sample having minimum particle size is about 70 or less micrometer in this case. We assumed this system as solid bulk for getting correlation between powder and solid bulk. To obtain transformation to 100% solid bulk, the correlation formulae of Landu-Lifshitz, Looyanga and Bottcher were used.

Table 1: The values of dielectric constant (ε'_p), dielectric loss (ε''_p), loss tangent ($\tan\delta$), relaxation time (τ_p), conductivity (σ_p) of Lac powder at different temperature and packing fraction (δ_r).

Temp. ^{0}c	Packing fraction (δ_r)	Dielectric constant (ε'_p)	Dielectric loss (ε''_p)	loss tangent ($\tan\delta$)	Relaxation time (τ_p) p.s.	Conductivity (σ_p) 10^{-2}
0	0.9501 0.9685 1.0000	2.298993 2.360172 2.384834	0.08910 0.10592 0.12995	0.03875 0.04431 0.05449	0.627 0.717 0.881	4.88 5.80 7.11
10	0.9501 0.9685 1.0000	2.279239 2.358466 2.381287	0.07715 0.08509 0.10681	0.03384 0.03607 0.04485	0.547 0.583 0.725	4.22 4.66 5.85
20	0.9501 0.9685 1.0000	2.210985 2.266245 2.375984	0.05129 0.07557 0.08890	0.02320 0.03334 0.03742	0.375 0.539 0.605	2.81 4.14 4.87
30	0.9501 0.9685 1.0000	2.186557 2.234356 2.348070	0.04603 0.04843 0.07517	0.02105 0.02167 0.03201	0.340 0.350 0.518	2.52 2.65 4.11

Table 2: The measured values of dielectric constant (ε'_p), dielectric loss (ε''_p) and calculated values of dielectric constant (ε'_s), dielectric loss (ε''_s), for solid bulk at different temperature and packing fraction (δ_r).

Temp. ^{0}c	Packing fraction (δ_r)	Dielectric constant (ε'_p)	Dielectric constant (ε'_s) for solid bulk Calculated		Dielectric loss (ε''_p)	Dielectric loss (ε''_s) for solid bulk Calculated	
			Bottcher	Landu		Bottcher	Landu
0	0.9501 0.9685 **1.0000**	**2.3848**	2.384 2.447 **2.385**	2.382 2.443 **2.380**	**0.130**	0.096 0.111 **0.130**	0.096 0.111 **0.130**
10	0.9501 0.9685 **1.0000**	**2.3813**	2.363 2.414 **2.381**	2.361 2.411 **2.380**	**0.1068**	0.083 0.089 **0.107**	0.083 0.089 **0.107**
20	0.9501 0.9685 **1.0000**	**2.3760**	2.290 2.317 **2.376**	2.290 2.315 **2.370**	**0.0889**	0.055 0.079 **0.089**	0.055 0.079 **0.089**
30	0.9501 0.9685 **1.0000**	**2.3481**	2.264 2.284 **2.348**	2.263 2.283 **2.346**	**0.0752**	0.050 0.051 **0.075**	0.049 0.051 **0.075**

4. CONCLUSIONS

It was found that experimentally measured values of (ε') and (ε'') at ($\delta r = 1$) are similar to those calculated from Landau-Lifshitz-Looyenga formulae. There was fair agreement between the values obtained experimentally and calculated theoretically by using Bottcher's formulae. It may be thus, predicted that Lac powder is having cohesion in its particles and serve as a continuous medium.

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