LOW FREQUENCY DIELECTRIC PROPERTIES OF KAIL WOOD

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Dielectric properties of kail wood in the frequency range 0.5 – 100 kHz are measured. Assuming disc-shaped pores randomly distributed throughout the sample, application of three component mixture theory gives values of dielectric constant (relative permittivity) very close to those obtained experimentally. Conductivity loss is dominant at low frequencies. At high frequencies the loss is mainly due to cellulose dipoles.

INTRODUCTION

Wood is abundantly found in nature and is known to be an insulator. The dielectric constant of wood lies in the range 1.4–7.00. When a freshly cut piece of wood is dried in an oven, the evaporating water leaves behind small cavities throughout the volume. Takeda and Nukasawa [1] made measurements on wood–water system at microwave frequencies.

Since wood is found in many varieties, its physical and electrical properties also show wide variation [2]. A series of measurements is proposed to be made on different types of wood to relate their properties with structure and composition. With this idea some preliminary results on the dielectric properties of kail wood are presented in this paper.

Sample Preparation and Experimental Set Up. Three circular pieces were cut from seasoned kail wood, which belongs to the well known coniferous family of wood. Since electrodes of the sample holder are flat the surfaces of the samples were made smooth and parallel by gently using different grades of sand paper. The surface were finally cleaned under vacuum to remone fine grains of sand still sticking to the sample. The final diameter of the sample was 5.08 cm and thickness 2–3 mm. All measurements were made with field tangential to the grain direction.

The sample holder [3] is formed of two circular electrodes. The surfaces of these electrodes are optically ground to be plane within a few wavelengths (as claimed by the manufacturer). A precision-ground micrometer screw drives the movable grounded electrode with respect to the fixed insulated electrode. The screw adjustment is a convenient size instrument-type knob, in contrast to the small thimble employed in the usual machinist's micrometer commonly employed for this purpose. The spacing of the electrodes is indicated by the large legible calibration on the drum. The smallest division is one-half mil with 1/10th mil easily readable, whereas one mil is equal to 2.54×10^{-3} cm. The micrometer screw is electrically shunted by a flexible copper bellows to assure low and constant resistance and inductance in the current path to the movable electrode. The lower electrode is supported in position by VYCOR insulator, which are well away from the field between the electrodes.

A unique feature of the design is the method of driving the movable electrode. A spring-loaded drive is used so arranged that, when movable electrode comes into full contact with the specimen (or the bottom electorde), the drive disengages. Two important results are achieved by this design feature : (1) the movable electrode assumes the plane of the top surface of the specimen, thus assuring best possible contact even if the faces of the specimen are not rigorously parallel, and (ii) straining of the micrometer screw is avoided since the drive disengages at a predetermined pressure.

The electrode assembly is mounted in a rugged aluminum casting, which shields the assembly on four sides. The shielding is completed by two aluminum side panels which can be swung out of the way to insert and remove the specimen.

The usual practice in the case of solid specimens is to evaporate some conducting material on both the flat surfaces of the sample for good electrical contact. Some conducting paint (silver) or colloidal graphite is also sometime used. This was intentionally avoided as the specimen had to be dried to drive out water at different intervals. More-

over, wood being a porous material, it was feared that conducting material may not enter the surface pores, thus altering the electrical properties of the specimen under test.

A GR capacitance measuring assembly type 1610-A with 716-C capacitance bridge of General Radio, and 1690-A dielectric sample holder was used to measure the capacitance and dissipation factor of the sample by using substitution method [4]. The bridge has an accuracy of ±0.2% or ±2PF whichever is larger, for capacitance, and ±0.00005 or ±2% of the change in dissipation factor, when the change is less than 0.06.

The dielectric constant and dissipation factor were measured in the frequency range 0.5–1000 kHz. The samples were then placed in an over at a constant temperature of 80° for different time periods. They are taken out of the oven and placed in a desiccater to bring their temperature down to the ambient temperature. The samples were weighed before and after the measurements were made and the average weight is noted. The measurements were repeated each time the samples were heated. The entire procedure was repeated several times till a constant weight (dry weight) of the samples was acheived. The difference in the average weight and the dry weight is the weight of the water displaced. [5]. To be sure that the loss of weight on heating was due to evaporated water, the dry samples were finally placed in open atmosphere and the gain in weight was noted.

RESULTS AND DISCUSSIONS

The values ϵ' and tan δ for each volume fraction of moisture content are plotted in Fig. 1 – 7. The values of dielectric constant versus moisture content at a spot frequency of 1 kHz are plotted in Fig. 8. The Cole-Cole plot is plotted [6] in Fig. 9. The important features of the graphs are:

1. The dielectric constant of the sample in its original form is considered as a mixture of wood, air and water. The value of ϵ' increases with the increase of water content Fig. 8. This is attributed to the increase of free water molecules which contribute to the total polarization of the specimen. The dielectric constant of dry wood in this case is 3.6 whereas the dielectric constant of water at low frequency is 80. Thus the increase in ϵ' with the increase of water content is considered mainly due to the polarization of the free water molecules. The water molecules may free some inorganic ions which will only contribute towards tan δ. This is shown in the value of tan δ. Water molecules are considered to be dispersed in a matrix of wood and air.

2. For each volume fraction of water there is a dispersion

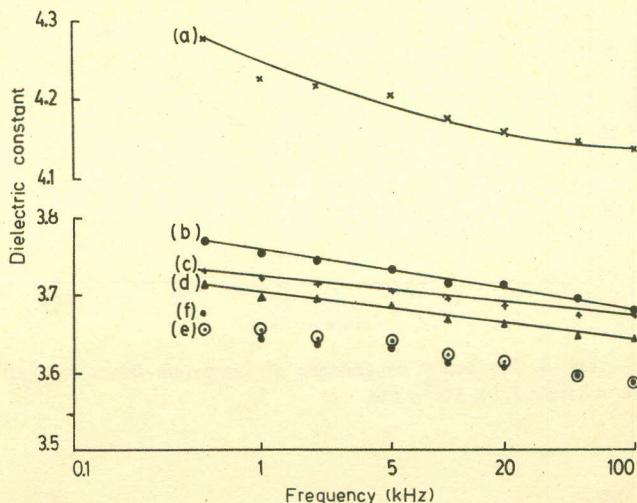Fig. 1. Frequency dependence of dielectric constant (ϵ) of kail wood when the vol. fraction of water in the wood is (a) 10.6 × 10-3 (b) 2.9×10^{-3} (c) 2.7×10^{-3} (d) 1.5×10^{-3} (e) 0.4×10^{-3} (f) zero.
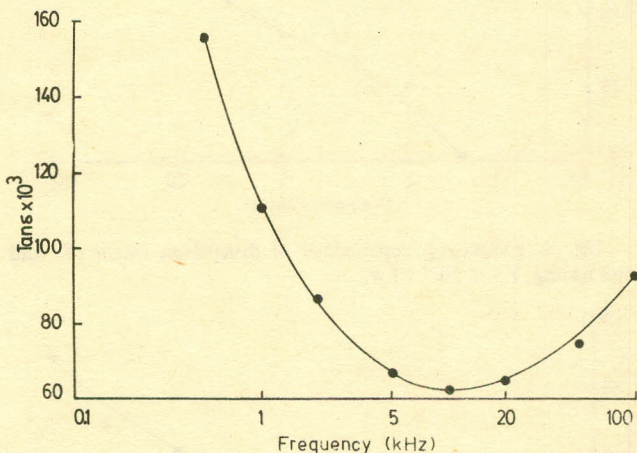

Fig. 2. Frequency dependence of dissipation factor of kail wood having 10.6×10^{-3} vol. fraction of water (v.f.w.).
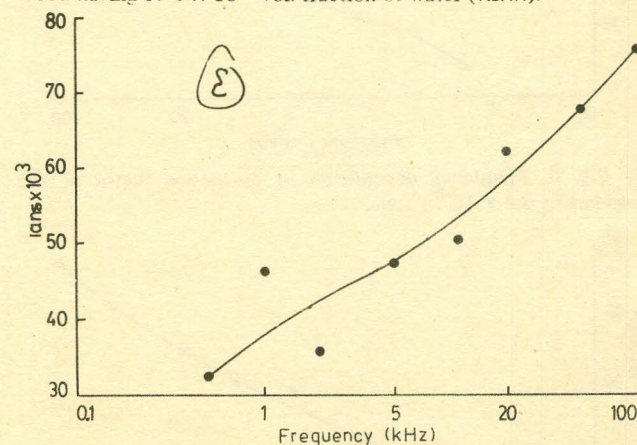

Fig. 3. Frequency dependence of dissipation factor of kail wood hahving 2.9×10^{-3} v.f.w.

region in the measured frequency range. Since the frequency range of measurement is very low, the variation in values of ϵ' and tan δ with frequency cannot be due to the presence of water molecules. Relaxation time of water
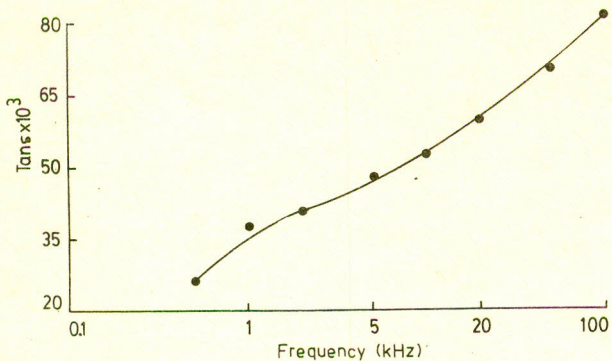
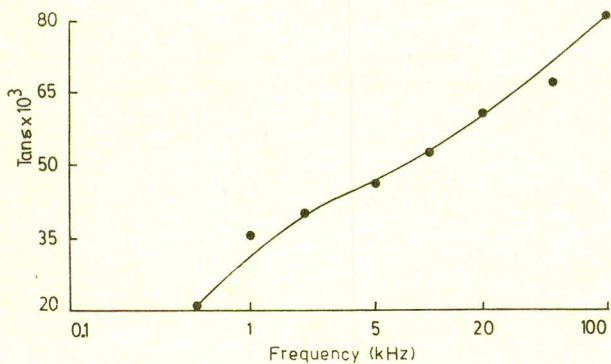Fig. 4. Frequency dependence of dissipation factor of kail wood having 2.7×10^{-3} v.f.w.

Fig. 5. Frequency dependence of dissipation factor of kail wood having 1.5×10^{-3} v.f.w.
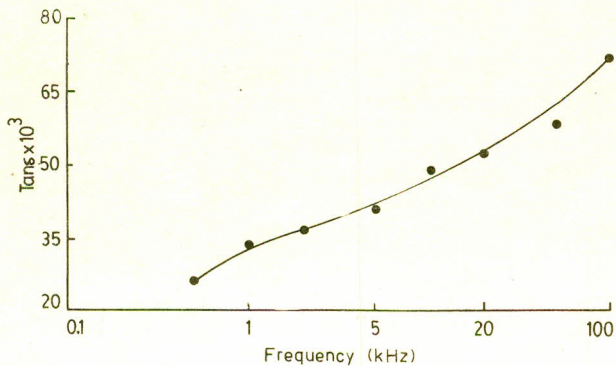

Fig. 6. Frequency dependence of dissipation factor of kail wood having 0.4×10^{-3} v.f.w.
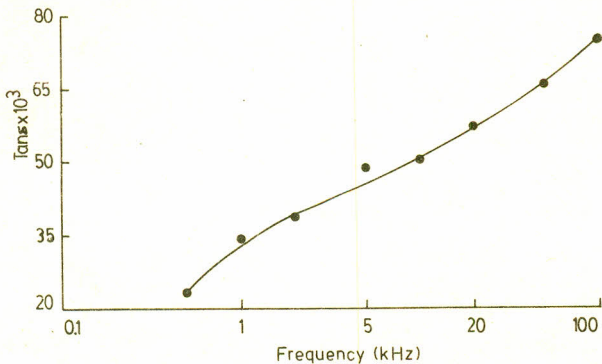

Fig. 7. Frequency dependence of dissipation factor of kail wood having zero. v.f.w.
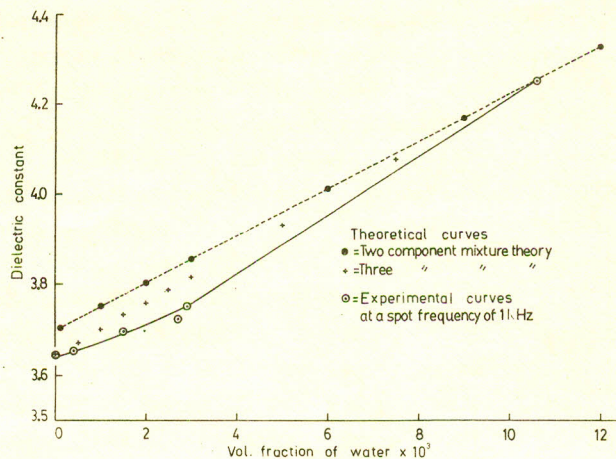

Fig. 8. Experimental and theoretical variation of kail wood dielectric constant with vol. fraction of water
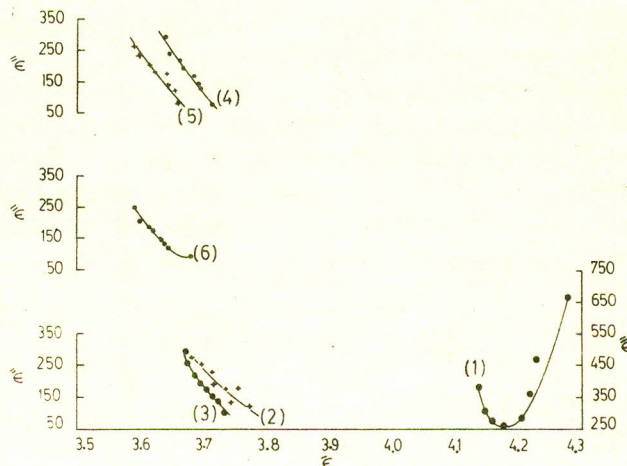

Fig. 9. The Cole-Cole plot of kail wood having different amount of v.f.w.

falls in the microwave region which is far away from the range of frequencies used in the present measurements. This variation is considered to be due to the relaxation of the cellulose molecules, which are larger in size and thus have larger relaxation time and have lower freqency range. Cellulose is the main constituent of wood. The dielectric constant of cellulose decreases with the increase of frequency and loss tangent increases with frequency. These results are in agreement with those reported by earlier workers [2].

3. For maximum volume fraction of water the Cole-Cole plot shows a minimum which is not observed in Cole-Cole plots for relatively dry samples.

The dielectric constant of wood decreases and the

dissipation factor increases with the increase of frequency. Wood containing small amounts of water also show a minima in the dissipation factor versus frequency curve around 10 kHz (Fig. 2). The low frequency loss which decreases with the increase of frequency is considered to be due to the increase of certain ions suspected to be present in the mixture. This loss is mainly due to ionic conductivity [7], there might be some contribution due to Maxwell— Wagener [8] effect. The high frequency loss is due to the dipole character of cellulose. The presence of moisture at high frequencies influences the vibration of cellulose dipoles and the loss in this frequency region is mainly due to the dipole character of cellulose. Measurements of Kroner and Pungs [9] also support this view

The Cole-Cole plot also shows a minima in the low frequency region, when the moisture content is 0.0454 g. No such minima is observed when the samples are relatively dry presumably due to the substantial decreases in ionic mobility. This is also confirmed by the reduced low frequency loss region (below 10 kHz) in dry samples. Since the range of our frequency was not large enough, the relaxation time of cellulose could not be calculated.

Application of Three Component Mixture Theory. A piece of wood under normal conditions consists of wood material behaving as a continuous medium, in which air and water is present as a dispersed media. The effect of drying is to reduce the volume fraction of water with a corresponding increase in the voluem fraction of air.

Mixture theory is applicable to heterogeneous and isotropic substances when the particles of the dispersed medium are distributed in the continuous medium at random such that each particle is surrounded on the average by the same arrangement and properties of the material, as any other in the mixture [10]. Wood is known to be anisotropic medium [10–13]. Application of mixture theory cannot be fully justified in this case. However, it has been reported in the literature that mixture relations can be used to such systems with good results [14].

The dry weight, and volume of the sample is noted. The sample is saturated with water under vacuum and the volume of water used to saturate this sample is noted by the difference in the dry and wet weights of the sample. This gives the volume of cavities in the sample. Dielectric constant of a mixture is highly dependent upon the shape of the dispersed particles. From the measured dielectric constant of the dry sample (a mixture of wood and air) and the volume fraction of air, the dielectric constant of wood is calculated for the cases when the cavities are (i) sphere [15] (ii) disc, and (iii) needles [16].

Using the value of dielectric constant of wood thus obtained in each case, the dielectric constant of mixture (wood and water) is calculated. The value, obtained with disc shaped cavities gives good agreement with the experimental values of dielectric constant of water and air, the dielectric constant of three component mixture (the natural state of wood) with different values of volume fraction of water is calculated, using the method adopted by Hasted and Shah [17]. The experimental and theoretical values are plotted in Fig. 8. The two values agree fairly well. The difference might be due to our assumptions regarding isotropy of wood and random distribution of cavities.

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