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Research Article

STUDY OF DIELECTRIC BEHAVIOR OF DRY AND MOIST *ACACIA INDICA* WOOD AT X-BAND FREQUENCY

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ABSTRACT
The present studies provide experimental data on the dielectric constant and dielectric loss for *Acacia indica* (Babool) wood having various gravimetric moisture contents at X-band microwave frequency (9.8 GHz). Studies are carried out for two structural directions of wood. The striking feature of these investigations is that the wood samples used possess natural moisture instead of dipping the dry wood samples in water. The dielectric constant and loss of wood increases in a non-linear manner with an increase in its Moisture Content (MC). The dielectric constant of wood has relatively larger value for electric fields parallel to the grain or fiber directions than perpendicular directions to it. Our results also show increase in the a. c. conductivity and relaxation time of the wood species with increasing MC/ dielectric constant. The possible applications of these studies in designing moisture sensors for wood and also passive microwave sensors for analyzing remote sensing data are discussed.

Key Words: *Dielectric Constant, Dielectric Loss, A.C. Conductivity, Relaxation Time, Microwave Frequency, Wood.*

INTRODUCTION
Wood is an anisotropic and hygroscopic material with poor thermal conductivity. Wood cells are of various sizes and shapes and are quite firmly cemented together. Majority of wood cells are considerably elongated and are called fibers. The length of wood fibers is highly variable within a tree and among species. Hence, the Moisture Content (MC) of wood is almost always undergoing some changes as temperature and humidity conditions vary. In moist wood, the water exists in wood either as bound water present in the cell wall or free water in the cell cavity. Bound water is bonded (hydrogen bonds) within the cell wall whereas; free water is present in the cell cavity of wood. When wood dries, most of the free water separates at a faster rate than bound water because of absence of bonding. The moisture content at which the cell walls are still saturated but virtually no water exists in the cell cavities is called the Fiber Saturation Point (FSP) for that wood species. Wood changes its dimension as the moisture content varies below FSP. The FSP for most of the woods usually varies between 21 and 28%.
Microwave remote sensing of natural earth materials such as wood, soil, plants/trees, and water has a very close dependence on their electrical parameters. The most important parameter is the dielectric constant. The dielectric properties of wood and their variation with Moisture Content (MC) and field direction provide clues for understanding the basic molecular structure of wood. Several researchers have reported dielectric studies of wood at microwave frequencies in the past by using various techniques/methods. The dielectric properties of wood varied with different factors related to wood and to the applied microwave frequency. Variations of dielectric properties with MC were studied by several investigators (James, 1977; James and Hami, 1965; Kabir *et al.,* 1997; Peyskens *et al.,* 1984; Dubey and Deorani, 1995 and Kabir *et al.,* 2001). The dielectric properties of wood are mainly depending on their moisture content. The presence of water produces strong dipole moments and increases the effective loss factor, making it suitable for processing high frequency energy. Bound water is tightly held and less rotationally free than the free water present in various cavities.
Available reports on the impact of wood density on dielectric properties of wood are contradictory. Some reported that the dielectric properties of the wood varied with density (Daian *et al.,* 2006 and Torgovnikov, 1993) while the others reported no significant variation of the dielectric properties with

wood density (Perre and Turner, 1999). In the later case, these results could be explained by the narrow range of studied densities and by the similarity in the wood structure of the tested species.

The anisotropy of wood also has effect on its dielectric properties of wood. Hamiyet and Nurgul (2004) determined dielectric properties of the hardwood species for three principal structural directions at six different moisture content ranging from 0% to 28%. Their results indicated that the behavior of all wood species studied is qualitatively similar. Their result showed increase in dielectric properties with rise in the moisture contents and also confirmed the anisotropic nature of wood species. However, experimental results of these and also of many earlier investigators were based on limited range of MC (James and Hami, 1965; Kabir *et al.,* 1997; Peyskens *et al.,* 1984 and Torgovnikov, 1993).

However, to our knowledge, almost no or very rare experimental studies or data on dielectric properties of wood have been reported in Maharashtra (India). Therefore, the work reported in the present paper provide the data on the dielectric constant (ε'), dielectric loss (ε''), a. c. conductivity (σ) and relaxation time (τ) for *Acacia indica* (Babool) wood species having various gravimetric moisture contents at X-band microwave frequency (9.8 GHz). The complex dielectric constant of wood species is measured by using waveguide cell method. The data obtained from this study will not only be useful for better understanding of the molecular structure of wood but also for designing the accurate and reliable moisture sensors for it. Such studies may also find applications in wood drying, gluing, and improving the quality of wood.

MATERIALS AND METHODS

Sampling Technique of Wood Specimens

The wood materials of *Acacia indica* (Babool) species studied were collected from the Dhule city. Dhule district is located in northern region of Mahrashtra state. All of these wood species were collected within the small area covering about 1 km^2. Because of this, the soil and other geographical and environmental parameters do not have much influence in our results. The height of these tree species lies between 8 to 15 meters and the diameter of wood core is about 15 to 28 cms.

Two sets of samples were prepared for each species as per their structural directions. Sample was cut according to their length/ thickness in longitudinal and tangential direction to the grains or fibers of wood. Our samples are of 2.286 cm X 1.016 cm cross section and have three different lengths 1.25 cm, 2.5 cm and 3.75 cm respectively. In this way, we have prepared six samples wood from *Acacia indica* tree species. All faces of samples were highly polished in order to make them as smooth as possible. After removal of branches from live tree, the sample was prepared within an hour or so. Then, the mass of each sample was recorded and it is immediately fixed in the solid dielectric waveguide cell for measuring its complex dielectric constant. Experiments were performed at room temperatures ranged between 30-35^oC.

Method of Measurement and Formulae

The waveguide cell method or Robert's and Von-Hipple experimental technique is used to determine the dielectric properties of wood samples. Figure 1 shows the X-band microwave set-up in the TE_{10} mode for measuring dielectric constant of wood by waveguide cell method. It consists of a Gunn oscillator operating in the X-Band frequency range. A crystal detector moves along the slotted section and measures output power/voltage at each point in the slot. The solid dielectric cell with sample is connected to the opposite end of the source of microwave bench setup. The signal generated from the microwave source is allowed to incident on the wood sample. The wood sample reflects part of the incident signal through the wood from its front surface. The reflected wave combined with incident wave to give a standing wave pattern. The values of power/voltage at different points of standing waves have been measured as a function of probe position. About (80-100) points were recorded for a single standing wave pattern for each length of wood species.

These standing wave patterns are then used in determining the values of shift in minima resulted due to before and after inserting the sample. All these measurements have been carried out at 9.8 GHz. The dielectric parameters such as dielectric constant (ε'), dielectric loss (ε''), a. c. conductivity (σ) and relaxation time (τ) for *Acacia indica* (Babool) wood species having various gravimetric moisture contents are then determined from the following relations (Eqns. 1-4):

$$\varepsilon' = \frac{g_\varepsilon + (\lambda_{gs}/2a)^2}{1 + (\lambda_{gs}/2a)^2} \tag{1}$$

$$\varepsilon'' = -\frac{\beta_\varepsilon}{1 + \left(\lambda_{gs}/2a\right)^2} \tag{2}$$

Where, a = inner width of rectangular waveguide
λ_{gs} = wavelength in the air-filled guide
g_ε = real part of the admittance
β_ε = imaginary part of the admittance

$$\sigma = \omega\varepsilon_0\varepsilon'' \tag{3}$$

Where, $\omega = 2\pi f$
f = microwave frequency

$$\tau = \varepsilon''/\omega\,\varepsilon' \tag{4}$$

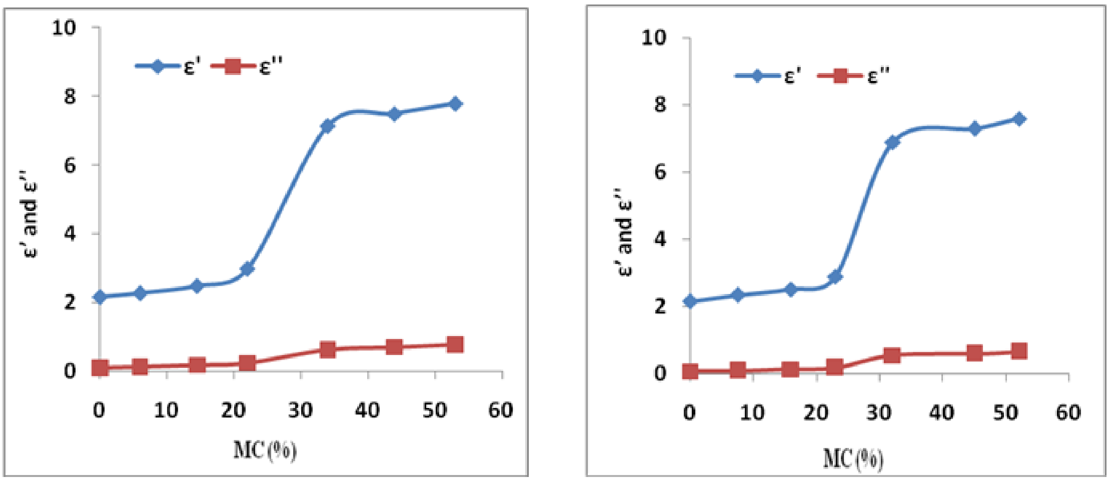
Figure 1: X-band microwave set-up for measuring dielectric constant of wood by waveguide cell method

Average value of dielectric constant ε' is then determined for *Acacia indica* wood species having different MC and for two structural orientations.

RESULTS AND DISCUSSION

The results of these dielectric parameters for dry and moist *Acacia indica* wood species at microwave frequency (9.8 GHz) are represented graphically in Figures 2 and 3. Figure 2 (a) and (b) show the variation of dielectric constant (ε') and loss with different MC (%) of *Acacia indica* for grain directions parallel and perpendicular to electric fields respectively. Since we have used fresh cut wood samples, our samples possess natural moisture. This initial natural dry base gravimetric MC for *Acacia indica* wood samples is 53% and 52% for Tangential and Longitudinal Sections respectively.

We observe a small rise in dielectric constant when MC (%) is raised from its oven dry (0 %MC) value to about 25 %. The above mentioned specific value of MC (%) nearly matches with FSP of corresponding wood species. Around this FSP, we observe sharp or almost step rise (about 2.5 times higher than earlier value) and the trend become concave upwards. Further, for MC values beyond FSP, our results either show almost constant or a little increase in the values of dielectric constants. From this study, it is observed that the relation between the dielectric constant and gravimetric water content is nonlinear. Further, the variations in dielectric loss with MC also show approximately similar general trends, except increase in its magnitude at or around FSP is comparatively far less than that of dielectric constant.



(a) Tangential Section **(b) Longitudinal Section**

Figure 2: Variation of dielectric constant and dielectric loss with moisture content (%) at frequency 9.8 GHz for *Acacia indica* wood

Further, the results (Figure 2, a and b) indicate qualitatively similar general behaviour for both type of sections for *Acacia indica* wood species. In general, the dielectric constant and loss increased with increase in the moisture contents. However, careful observation shows that the grain direction of the wood samples with respect to electric field orientation also play a significant role. The dielectric constant is relatively large for electric field (or polarization) parallel to the grain or fiber directions than perpendicular direction to it. It may be due to polar groups of cellulose and hemicellulose having more freedom of movement along the fiber direction than perpendicular electric field direction. Thus, curves shown in Figure 2 (a) have little more magnitudes of dielectric constant and loss than that for Figure 2 (b) at the same values of MC (%) of wood.

Variation of a. c. conductivity and relaxation time of *Acacia indica* wood species for electric field or polarization parallel to the grain or fiber directions (tangential section) and perpendicular to the grain or fiber directions (longitudinal section) are shown in Figure 3 (a) and (b) respectively. Boththese parameters for *Acacia indica* wood species, in general, show increase in their values with MC (%). However, these variations of a. c. conductivity and relaxation time for *Acacia indica* wood species with MC (%) are also nonlinear and have a faster rate at and around FSP. For this case also, a careful observation shows that the grain direction of the wood samples with respect to electric field orientation also play a significant role. The magnitudes of a. c. conductivity and relaxation time for *Acacia indica* wood species are relatively large for tangential section or electric field parallel to the fiber directions (Figure 3, a) than for longitudinal section or electric field perpendicular direction to it (Figure 3, b) at same values of MC (%).

Our experimental results thus show strong dependence of dielectric properties of wood on its MC and thus are in good agreement with the results of Hamiyet and Nurgul (2004) and Kabir *et al.* (1997). Our

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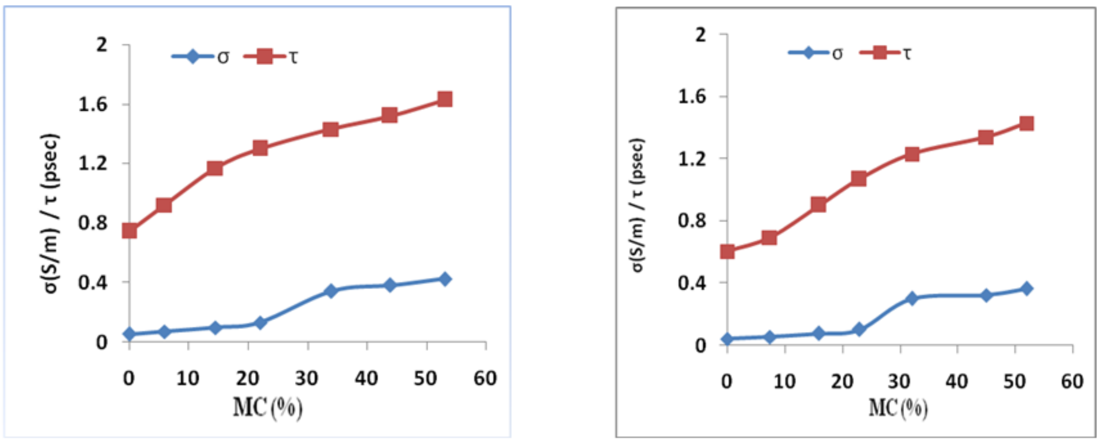
results also agree in many respects with earlier reported investigations (Peyskens *et al.*, 1984; Dubey and Deorani, 1995 and Torgovnikov, 1993), expect that in our case, we observe a sharp or step rise in dielectric constant at FSP. This striking feature in our result may probably be due to naturally moist wood samples used in our experiments instead of artificially wetted wood samples used by majority of earlier investigators. Moreover, very few of these investigators have studied the dielectric properties of wood species having MC beyond FSP.



(a) Tangential Section **(b) Longitudinal Section**

Figure 3: Variation of a. c. conductivity and relaxation time with moisture content (%) at frequency 9.8 GHz for *Acacia indica* wood

The accurate and reliable moisture detection method for wood utilizes its dielectric properties. So the present data on dielectric properties at different natural moisture content will be definitely useful in designing accurate moisture meter or moisture sensor for the wood. These sensors may also have potential applications in the remote sensing. The data on dielectric loss of wood having different MC at high frequency may be useful in industrial applications such as drying of wood. Such or similar studies will be useful for better understanding of the molecular structure of wood and also in wood industry. Moreover, the *Acacia indica* belongs to the group of medicinal tree species. Therefore, the work reported here may also find uses in medicinal applications.

Conclusion

Dielectric constant and loss of *Acacia indica* wood increases in a non-linear manner with an increase in its MC. Initially, the rise in dielectric constant is small for gravimetric MC (%) values up to FSP of wood. At FSP (20-30 % MC), dielectric constant increases sharply to about 2.5 times the earlier value. Further, for MC values beyond FSP, our results either show almost constant or a little increase in the values of dielectric constants.

Variations of a. c. conductivity and relaxation time for *Acacia indica* wood species with MC (%) are nonlinear and also have faster rate at and around FSP. This confirms the anisotropic nature of wood.

The dielectric constant, dielectric loss, a. c. conductivity and relaxation time for *Acacia indica* wood species are relatively large for tangential section or electric field parallel to the fiber directions than for longitudinal section or electric field perpendicular direction to it.

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