NUMERICAL MODELING TECHNIQUE TO PREDICT THE DIELECTRIC PROPERTIES OF WOOD

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ABSTRACT

Microwave processing of wood involves many complicated physical phenomena. The process includes absorption of the electromagnetic energy, transport of the generated heat, shape and dimension changes of the wood, phase changes in water, water transport through the wood material, etc. In order to optimize and control this process, the understanding of the various phenomena involved is needed. This understanding is achieved by experimental measurements and by building models which describe the various processes.

The aim of this paper is to present a numerical model technique which simulates the dielectric behavior of wood at the microwave frequencies and predicts its dielectric properties which are relevant to microwave heating.

Wood is a very complex material with poor thermal conductivity. Therefore, during microwave heating the internal temperatures can reach values which are high above the boiling point of water at room conditions. Also, since wood is not a very permeable material, due to the microwave heating characteristic to heat from interior to exterior, the internal pressure increases according to the saturated pressure of water vs. temperature.

As wood is structurally composed of fibers, rays, vessels and so on, its dielectric permittivity is different in various directions and strongly depends on density, moisture content, temperature and pressure. To predict the dielectric properties of such complex configuration, a general method for calculating the permittivity of any mixture of different materials was approached. The main idea is to consider a three dimensional box divided into a mesh of small cells (each cell having the specific dielectric properties) and calculate the dielectric permittivity of the equivalent structure in a sophisticated manner through the exact

solution of Laplace equation. Based on this method, an efficient solver which calculates the effective dielectric permittivity of any three dimensional structure of dielectric materials was developed. However, to estimate the dielectric permittivity of different wood configurations (different densities and moisture contents), a numerical model for describing the 3-D wood structure was developed and introduced into solver. The general 3-D wood model (Fig. 1) was constructed by making the following assumption: the fibers have uniform size and square shape in the cross section, the vessels are cylindrical and the arrangement of the cells is regular.

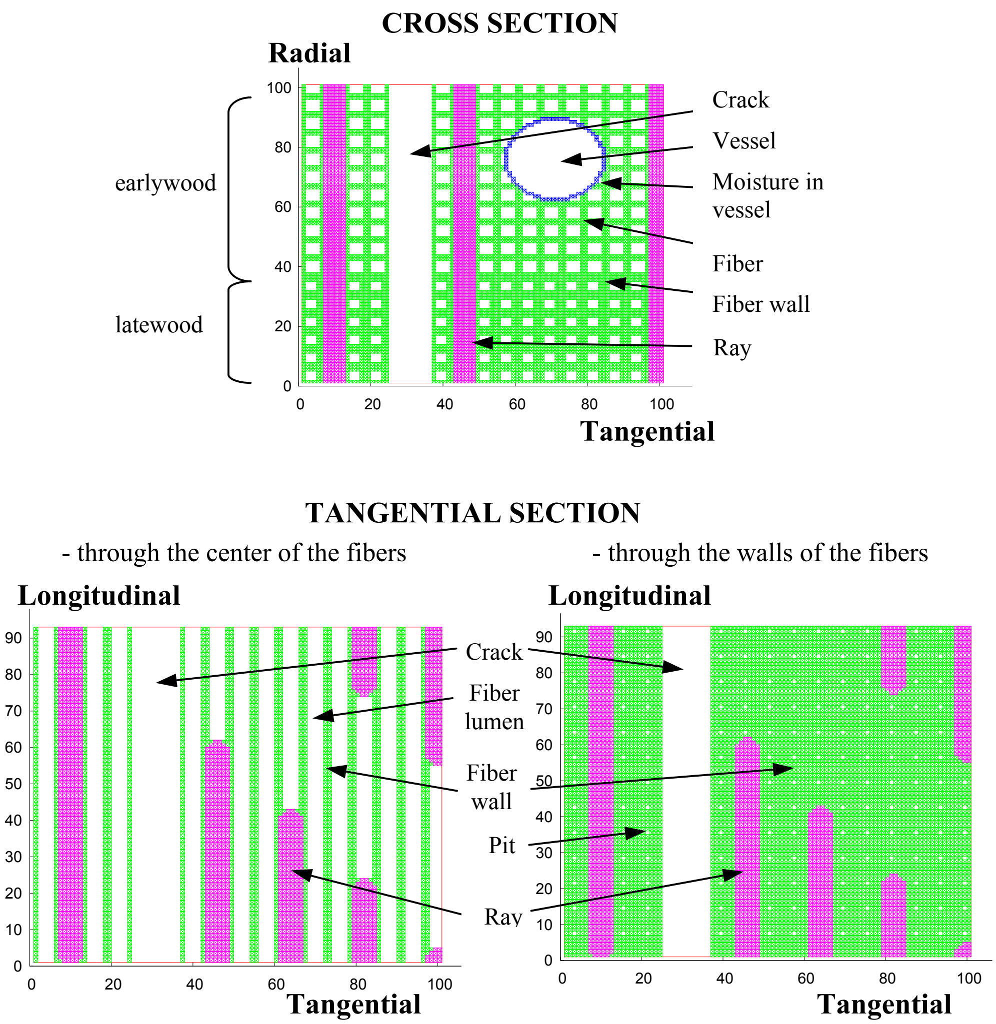

Figure 1: 3-D wood model

Overall, the software needs two groups of input instruction. One group is necessary for calculating the dielectric permittivity of the modelled structure and consists in supplying the software with the dielectric properties of the wood model constructing materials (i.e. air, wood substance/moist wood substance, free water, and rays). The other group of instructions is essential for creating the wood model flexibility. It is made up of the proportional volumes of the constructing materials, the dimensions of wood main elements, the number of rays per tangential millimetre, etc. The most part of these data can be found in literature or observed under electronic microscope. However, the values of dielectric permittivity for wood substance (cell wall substance) and rays at particular moisture contents have not been studied. They are calculated on the same principle (software) described in this paper. The moist wood substance is assumed to be a random mixture of bound water and wood substance while the ray model is constructed as a structure made up from many other structures similar to that of the ray cell.

By using the short-circuit line measurement technique, measurements of the dielectric properties of Blue Gum (*Eucalyptus globulus*) wood at different moisture contents and structural directions were carried out. For the same wood specifications (oven-dry density, moisture content, etc), the dielectric properties were calculated by means of the described software and the values were quoted in Table 1.

Table 1: Calculated and measured dielectric permittivity for Blue Gum wood samples (data collected and calculated at temperature 20^o-25^{o}C)

F (GHz)	ρ_0 (g/cm^3)	MC (%)	Structural direction	ε'		ε''	
				Calculated	Measured	Calculated	Measured
2.45	0.718	0	Tangential	1.76	1.89	0.19	0.04
			Radial	1.88	2.03	0.15	0.06
			Longitudinal	2.27	NA	0.30	NA
		10.8	Tangential	2.42	3.51	0.41	0.6
			Radial	2.79	3.89	0.39	0.6
			Longitudinal	3.53	NA	0.68	NA
		68	Tangential	13.38	11.43	3.17	2.73
			Radial	15.06	13.03	3.65	3.88
			Longitudinal	21.89	NA	4.11	NA
	0.601	95	Tangential	15.25	12.27	3.78	3.57
			Radial	19.77	15.47	4.91	4.96
			Longitudinal	27.07	NA	5.14	NA
		100	Tangential	16.09	NA	3.77	NA
			Radial	20.72	NA	5.05	NA
			Longitudinal	28.09	26.75	5.13	5.42

The comparison of the calculated and measured results shows how accurate the model explains the variation of the dielectric permittivity for different directions and moisture contents. The quantitative agreement is practical with an average deviations of ±10% in ε' and ±5% in ε". Moreover, an evaluation of the measured and calculated dielectric properties was also made for wood samples with high internal temperatures and pressures (Fig. 2). The considered samples were Mountain Ash (*Eucalyptus regnans*) wood with oven dry density of $0.75 g/cm^3$ and about 90% moisture content.

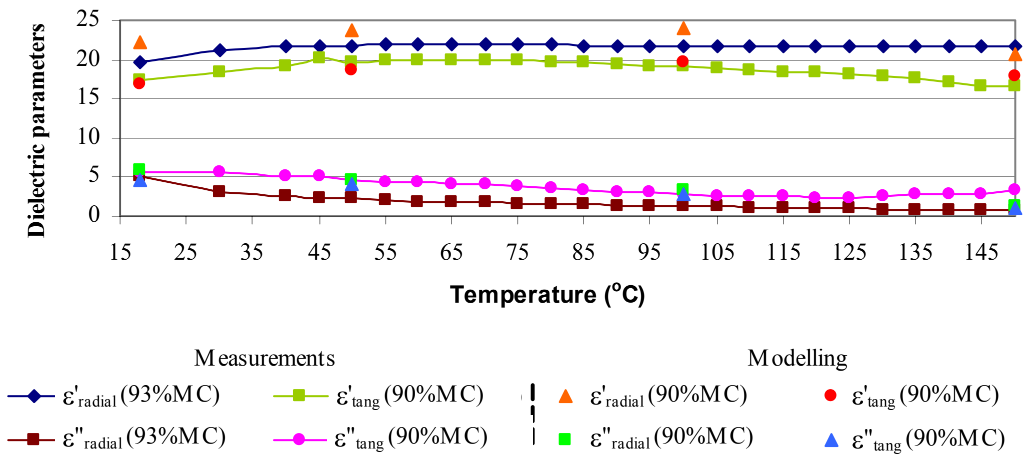

Figure 2: Measured and calculated dielectric properties for Mountain Ash wood samples with high internal temperatures and pressures of up to 5 atm.

The values show once more that by using this numerical model the measurement results of the dielectric permittivity of wood in various directions, for various moisture contents and at appropriate temperatures and pressures can be theoretically reproduced.

A numerical method for calculating the complex dielectric permittivity of wood at microwave frequencies was presented in this paper. Having an efficient modelling software is important because of two main reasons: firstly, it enables optimizing and minimizing the experimental work and secondly, it will serve as a crucial database for a full simulation of the heating process of wood by microwaves, as the dielectric permittivity is the most important factor in determining the electric field distribution and the power absorption profile within the log.