NUMERICAL MODELING TECHNIQUE TO PREDICT THE DIELECTRIC PROPERTIES OF WOOD

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Microwave processing of materials is a developing technology, which already represents for many industrial applications a new and powerful material-processing tool. Based on its characteristics, microwave processing presents great opportunities and benefits in the timber industry as well.

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 the water, transport of the water through the wood material, etc. In order to optimize and control this process one needs understanding of the various phenomena involved. This understanding is achieved by experimental measurements and by building models which describe the various processes.

Wood is a very complex material with poor thermal conductivity (heat is not rapidly transported into the surroundings when some region becomes hot). 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 (no passageways for water to get out) due to the microwave heating characteristic to heat from interior to exterior (surface temperature stays colder during the initial periods of heating), the internal pressure increases according to the saturated pressure of water vs. temperature. In order to predict the dielectric properties of wood which are relevant to microwave heating, a numerical model able to simulate the dielectric behavior of wood at the microwave processing conditions (temperatures of up to 150°C and pressures of up to 5 atmospheres), has to be performed.

In general, this paper refers to the factor which determines the distribution of the electromagnetic fields and its absorption within the wood, namely, its complex permittivity. As structurally, wood is composed of fibers, rays, vessels and so on, the dielectric permittivity is different in various directions and strongly depends on the moisture content. To understand the dielectric properties of such complex configuration, a method for calculating the permittivity of any mixture of different materials, in addition to a specific model which describes the wood structure and composition is required.

A method for calculating the complex dielectric permittivity of an anisotropic wood structure at microwave frequencies and a numerical model for describing 3-D wood structure which contains fibers, rays and vessels with changeable dimensions and material composition is presented. The model is introduced into an efficient solver which calculates the effective dielectric permittivity of any three dimensional structure of dielectric materials.

Firstly, the article describes the experimental results which are modeled and discussed throughout this work. Besides the measured values of the dielectric properties of wood in the different directions, at different moisture contents, different temperatures and related pressures, the experimental results include also the measured and calculated general parameters of the considered wood (e.g. oven-dry density, fiber saturation point, moisture contents, etc.).

Secondly, the general method for calculating the permittivity of a complicated structure and the building of a general model for wood structure is presented. The developed solver for calculating the complex dielectric permittivity is based on a three dimensional box divided into a mesh of small cells, each having the specific dielectric properties. It calculates the equivalent structure dielectric permittivity in a sophisticated manner through the exact solution of Laplace equation. The general wood model, which includes the main basic elements found in wood, 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.

Subsequently, the software input instructions such as the dielectric properties of the wood constituents (e.g. wood substance, free water, bound water and air) which are relevant to microwave heating (established at high temperature and pressure conditions) are discussed as the literature does not offer the majority of such data. Finally, the calculated results for the complex permittivity are compared to the measured values and the very practical qualitative and quantitative agreement between all the measured and calculated values is shown. Using this numerical model we succeeded in theoretically reproducing the results of the measurements of the dielectric permittivity of wood in various directions, for various moisture contents and at appropriate temperatures and pressures.