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INFORMATION TECHNOLOGIES IN TIMBER PROCESSING

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ABSTRACT

Microwave heating and drying technology in wood and timber industry is almost unknown in Serbia. However, during the last two decades its development has been mainly focused on damp wood drying in microwave dry – rooms which are based on dielectric wood – heating. This kind of heating may be considerably economical since it is based on dielectric rising wood constant and its quality. In this study the latest experiences have been described as well as microwave drying advantages over classical wood drying.

Key words: microwave heating, dielectric heating, drying, wood

1. INTRODUCTION

Microwaves are part of the electromagnetic spectrum, which include radio waves and visual light. Microwaves are radio waves with high frequency electromagnetic field which changes about 2 trillion times per second. These are unionized rays whose range of microwave frequencies approximately ranges from 0.3 GHz to 30 GHz with a corresponding wavelength in a vacuum from one meter to one millimeter.

Polar molecules, such as water, when placed under microwave irradiation are trying to orient in the direction of the electromagnetic field. However, due to high frequency electromagnetic field of microwaves by water molecules vibrate very quickly resulting in heat generation. This is the reason why many water containing materials start to heat up under the microwave power. Microwave heating is heating inside the material and it is more effective than conventional methods of heating which is why it is more and more used for numerous industrial and medical purposes.

A typical microwave system consists of two components: microwave source (generator) and a metal chamber in which the treated material is heated. Common name for microwave sources (generators) is a magnetron. In 1940 appeared magnetrons with operating frequency 2450 MHz and 915 MHz that were intended for microwave heating foods in cooking.

Microwave heating and drying technology applies in timber industry since 1960. With a magnetron power of 50 kW and 915 MHz frequency 25mm thick pine lumber dries for about three hours and immediately after drying it moves in kilns that operated the hot air [1]. In this way it provided a very quick final product with very low moisture content in the thin surface layer of wood, which left after the primary air dry. In addition, during this period microwave drying of thin wood veneer started. In this way, reason of microwave wood drying was because of the fact that microwaves can apsorb large water content in wood, especially in its humid holes. Microwave drying was used as an additional way of drying with warm air in order to achieve better quality of wood. However, a prototype microwave dryer was made which fully independent and continuously dried grated soft rail (the Douglas fir) to 50mm thickness in the range of 5 to 10 hours. Antti scientist has demonstrated that it is possible to dry pine and spruce even 20-30 times faster than other conventional methods. In addition, for hard wood such as beech, birch etc. the drying time is approximately half shorter than the time required for drying softwood [1].

In order to solve problems related to increasing of intensity, penetration depth and magnetic field distribution through treathened wood, multiregim applications of dryers were suggested for further development. In developing this concept first we used two magnetrons, each with 3 kW and operating frequency of 2450 MHz, which adried 50 mm thick beech rail with vacuum dryers in order to improve the quality of the dried material [1].

Experience gained through research and development of microwave drying gave only answer on basic questions about physical processes.Torgovnikov collected information for completely understanding of this problem. This stimulated new researchers, one by one, to improve microwave technology with the appropriate microwave application. The initiative was given by positive experience with a newer, almost mass usage of the magnetron for cooking purposes, and its stable performance in service with the fact that the microwave heating can achieve extreme speed limit of wood drying.

2. ELECTROMAGNETIC WAVES

Electromagnetic waves include two components: electric (*E*) and magnetic (*H*) field. These two fields oscillate vertically relative to each other and to the polarization axis y.

Monochromatic electromagnetic wave is sinusoidal wave determined with one frequency and a wavelength (λ). Directed electric field is defined with polarisation. For example, when a wave is horizontally polarised, the electric field is horizontal. Wave, polarized along the y - axis can be described as a harmonic wave with following expressions [3]:

$$E(x,y,z,t)=E_0\cdot e^{j\omega-\gamma\cdot y} \tag{1}$$

$$H(x,y,z,t)=H_0\cdot e^{j\omega-\gamma\cdot y} \tag{2}$$

where: E_0 and H_0 are maximum values for vector of velocitiy of electric and magnetic field oriented along *y* – axis. Thus, ω is angular frequency and γ is comlex factor of spreading, defined as:

$$\gamma = j\omega\sqrt{\varepsilon\mu} = \alpha + j\beta \tag{3}$$

where μ is magnetic permeability.

For wood, which is not magnetic material, magnetic permeability μ is equal to vacuum permeability, $\mu_0 = 4\cdot\pi\cdot 10^{-7}\frac{H}{m}$. α is attenuation factor and β factor of the phase shift of electromagnetic wave through the wood in relation to vacuum. ε is relative dielectric constant of wood defined as:

$$\varepsilon = \varepsilon_0\left(\varepsilon' - j\varepsilon''\right) \tag{4}$$

where: ε_0 - dielectric constant of vacuum ($\varepsilon_0 = 8{,}855\cdot 10^{-12}\frac{F}{m}$), ε' - relative dielectric constant and ε'' - relative dielectric factor of loss.

Relative dielectric constant of wood ε' shows how much slower an electromagnetic wave penetrates through the wood in relation to vacuum. Relative dielectric loss factor ε'' includes all losses which can occur during penetration of electromagnetic wave through wood. These losses are consequence of

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translator and rotational moving of electrons and ions under the effect of inercial, elastic and friction forces which magnetic field produces onto water molecules in wood. Relative dielectric wood constant ε' and relative dielectric loos factor ε'' in wood are completely explored [2]. These researches show that dielectric properties of wood depend on moisture content (mc), wood density and temperature.

If the wood density increases or decreases, the relative value of dielectric wood constant ε' and relative loss factor ε'' also increases or decreases. Figure 6 shows that relative dielectric loss factor ε'' increases with increasing of moisture content in wood but with this amount, apsorbed energy decreases, along with rising of temperature.

Values for relative dielectric wood constant ε' and relative dielectric loos factor ε'' are achieved according to Torgovnikov measuring [2].

Combining equations (3) i (4) the real part can be divorced from imaginary part of complex propagation factor γ and equations for attenuation factor α and phase shift factor β can be achieved:

$$\alpha = \omega\sqrt{\varepsilon_0 \mu_0}\left(\frac{\varepsilon'}{2}\left(\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}-1\right)\right)^{\frac{1}{2}} \tag{5}$$

$$\beta = \omega\sqrt{\varepsilon_0 \mu_0}\left(\frac{\varepsilon'}{2}\left(\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}+1\right)\right)^{\frac{1}{2}} \tag{6}$$

By combining of equation (3) with wave equation (1) you can see that maximum value of electric field exponentialy decreases with passing through wood according to law $e^{-\alpha \cdot y}$ and this field is phase-shifted for $\phi = \beta \cdot y$ relative to the one which could be inside the vacuum.

Heating of wood, which occurs during penetrating with microwaves is the result of converting electromagnetic energy into heat. Conversion of electromagnetic energy into heat is determined by Poynting theorema, according which the mean value of apsorbed power is equal to [3, 4]:

$$P_{av} = \omega\varepsilon_0 \varepsilon'' E_{rms}^2 \cdot V \tag{7}$$

where: E_{rms} - Mean effective value of the electric field, V - wood volume.

The depth of penetration of electromagnetic fields through the wood is defined as the depth at which the electromagnetic field weakens for *1/e* relative to the value on its surface and it is defined with expression [3]:

$$D_p = \frac{1}{2 \cdot \alpha} \tag{8}$$

The depth of penetration of microwaves depends on dielectric properties of wood. High density and moisture content in wood (mc) cause the reduction of the depth of penetration. Regardless of moisture content the depth of penetration is higher in the softer wood. Beside that, the depth of penetration is higher in frozen wood than wood at room temperature.

3. ELECTROMAGNETIC HEATING OF WOOD

While microwave is passing through the timber, the heat that absorbs moisture caught generates. Inside the timber, microwave energy is transformed into heat, creating steam pressure in cells of wood. As wood has densely and sparsely almond atomic structure of cells through which nutrients are transported, the pressure of the steam breaks this structure of cells with forming micro cavity effect which ultimately leads to increased dielectric constants of wood.

Micro-cavities easily transport liquid and vapor through the wood. If the microwave field strength increases, an increasing number of cells in the wood structure breaks and channels along the dry wood can be formed. These channels help the rapid transport of the remaining moisture from the wood, but it also can be used for casting a variety of liquid pesticides into a timber.

However, when wood absorbs microwave energy, heat will not be uniform through affected volume due to the nature of microwaves and modified material properties. Thermal conductivity of wood depends on moisture content (mc), wood density, temperature and direction of the fibrous structure of wood cells [3, 4]. Increased concentrations of moisture, density and temperature of the wood lead to an increase in its thermal conductivity. In addition, the thermal conductivity in the direction of nutrient vessels of wood is higher. Therefore we can say that through a volume of wood that is covered by microwaves, the temperature changes from one area to another. Recognizing the fact that the perceived volume heat transfers by conduction and convection, the temperature can be described by the following equation [3,4]:

$$\rho \cdot C \frac{\partial T}{\partial t} - \nabla\left(k \nabla T\right) - Q = 0 \tag{9}$$

where: T – temperature, ρ - density of moisture wood, t – time, C – specific heat capacity, k – thermal conductivity of wood and Q – external heat.

Specific heat capacity C is in the function of specific heat capacity of wood and water. External heat resists heat generating with the microwave field in wood and it is determined by the following expression:

$$Q = \frac{1}{2} \mathrm{Re}\left[\left(\sigma |E|^2 - j\omega\left(ED^*\right)\right)\right] \tag{10}$$

where: σ - electric conductivity, E – electric field strength and D^* - conjugated value of the electric displacement.

As noted above, the increasing strength of microwave energy increases the internal pressure through the wood, which leads to the formation of narrow channels in the radial and longitudinal direction of wood. Number of holes, their size and distribution through the tree can be controlled through regulation of the microwave field strength generated by the magnetron. Manifold increase in physical permeability of the wood with microwave drying provides high resistance to moisture and gases. Also, other physical and technological characteristics of wood with microwave drying are improved. In fact, beside increasing the physical permeability of wood, the thermal conductivity reduces (it is better heat isolator), shrinkage and swelling of wood reduce and acoustic properties increase (better sound isolator) [2].

On the basis of the said it is clear that the development and commercialization of microwave technology, following problems can be solved in the wood industry: very long drying time, high material waste, energy losses, costly process of drying by conventional methods, difficulties in the impregnation of timber with preservatives, the pressure rise and collapse in a tree [2].

4. CONCLUSION

In developing this technology, many products and applications for drying veneer and grated boards are developed. However, microwave heating is now used for dry and wooden beams of large dimensions that are difficult or even impossible to be dried by conventional drying methods. In addition to large-scale, today different kinds of timber can be treated with microwave heat which achieves a very fast drying and final product obtained without the loss on drying. Wood dried with microwave heating is more resistant to moisture and gases, it provides better heat and sound insulation compared to conventional wood that is dried.

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