ASPECTS REGARDING THE WOOD PROCESSING IN HIGH FREQUENCY ELECTROMAGNETIC FIELD

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Abstract
The wood in a living tree contains large quantities of water. After the tree is harvested, the weight of water in the wood is often greater than the weight of the wood itself. This water must be removed to some degree to make the wood usable. This publication discusses the interaction of water and wood, reasons for drying wood, and the processes used to dry wood. Water presents a support for high frequency electromagnetic field conversion in heat. This characteristic presents an important advantage in drying process. The numerical and experimental results allow the establishment of optimum temperature for drying wood in high frequency electromagnetic field. We consider that the evaporation of water takes place only on the surface of the charge, the speed of vaporization depending on the difference between the temperature on the surface and the exterior temperature.

Key words: wood, humidity, microwave field, thermal diffusion

INTRODUCTION

The wood in a living tree contains large quantities of water. After the tree is harvested, the weight of water in the wood is often greater than the weight of the wood itself. This water must be removed to some degree to make the wood usable.

The durability of wood is often a function of water, but that doesn't mean wood can never get wet, quite the contrary. Wood is a hygroscopic material, which means it naturally takes on and gives off water to balance out with its surrounding environment. Wood can safely absorb large quantities of water before reaching moisture content levels that will be inviting for decay fungi (Reeb, 1997).

The mathematical model of the drying problems involves the solution to three problems, as follows: the microwave problem that involves the determination of the electromagnetic field; the thermal problems that involve the determination of the temperature field evolution in the charge; the mass problem that involves the evaluation of the evaporation speed of the water (Avramidis, 1999), (Zhang and Datta, 1999).

MATERIAL AND METHODS

To calculate the electric field we start from Maxwell equations which are proper for some initial conditions given (Metaxas and Meredith, 1983). Electric field equations in microwave regime and thermal field equations are those well known (Datta, 2001).

The equation for the electric field:

$$\nabla \times (\mu^{-1} \nabla \times \mathbf{E}) - \omega^2 \underline{\varepsilon} \mathbf{E} = \mathbf{0} \tag{1}$$

Polarization losses are customarily given as an imaginary part of a complex permittivity,

$$\underline{\varepsilon} = \varepsilon' - j\varepsilon'' \tag{2}$$

where ε' is the real part of $\underline{\varepsilon}$, and all losses are given by ε'' (Metaxas and Driscoll, 1974).

Thermal diffusion. The equation of the thermal field is:

$$-\nabla \lambda \nabla T + c \frac{\partial T}{\partial t} = p \tag{3}$$

where: λ is the thermal conductibility, c is the volume thermal capacity, and the specific losses in the dielectric are given by relation:

$$p = E^2 \omega \varepsilon' \mathrm{tg}\delta \tag{4}$$

where: the intensity of the electric field E is obtained from the electric field problem. The boundary condition is:

$$-\lambda \frac{\partial T}{\partial n} = \alpha (T - T_e) \tag{5}$$

where: α is the thermal transfer coefficient on the surface, and T_e is the temperature outside the charge.

The water evaporation from the wooden mass is done, to a lesser extent, inside the wood and, mostly, on the wood surface. Taking into consideration the inner evaporation, this implies the computation of a complicated water diffusion problem in which a non-homogeneous pressure field interferes due to the water vapours (Antti and Torgovnikov, 1995).

The strong anisotropy of wood, due to the orientation of the wooden fibre, makes the water diffusion problem to be almost impossible to be modelled with accuracy. In addition, for drying processes, the rapid apparition of water vapours from the interior of wood can determine its destruction. That is why the maximum temperature inside the wood must be limited (Leuca et al., 2010).

Thus, we can neglect the inner evaporation and take into consideration only that one on the surface of the wood. The evaporation speed on the surface unit depends on the difference between the temperature on the surface of the wood and the ambient temperature, on the degree of saturation of the vapours, on air pressure, on air flow in the proximity of the charge etc.

If Λ is the latent heat of vaporization volume, then the loss of heat due to the vaporization on the surface reduces the temperature on the surface in the manner of thermal convection. So, we can take into account the vaporization by introducing a fictive convection coefficient, according to the relation:

$$\alpha_{ech} = \alpha + \Lambda w \tag{6}$$

This coefficient is part of the boundary condition (5) and we have:

$$-\lambda \frac{\partial T}{\partial n} = \alpha_{ech}\left(T - T_e\right) \tag{7}$$

The equation (7) models in the simplest way the coupling mass problem with the thermal problem. Humidity defines the dielectric properties (ε', tgδ) useful to compute the losses volumic power density (Metaxas and Driscoll, 1974), (Leuca and Spoială, 2006).

In order to obtain the temperature field, first we had to solve the electromagnetic problem (Metaxas, 2001). For the solving of both problems we used the commercial software Comsol Multiphysics, which in the first stage solves the electromagnetic problem in the entire domain, and then using the specific losses as a source for the thermal problem, solves this problem only in the wood, because only here we are interested in the temperature distribution.

The numerical modelling results helped us to establish optimal values for both power of applicator and in terms of exposure time on microwave of wood (Metaxas, 2001).

For the experiments that were made, using as material – beech wood, which is a hardwood (Beldeanu, 2001), we used the stand within the Laboratory of Microwave Technologies, University of Oradea.

In Table 1 are presented the dielectric and thermal properties of beech wood we studied (Simpson and TenWolde, 1999).

Table 1

Dielectric and thermal properties of beech wood

Properties	Value	Description
ε'	4.1	Relative permittivity
tgδ	0.219	Loss factor
ρ [kg/m^3]	800	Density
λ [W/mK]	400	Thermal conductivity
c [J/kg·grad]	385	Specific heat
θ_a	22	Ambient temperature
α [W/m^2.^{0}C]	15	Convective heat transfer coefficient of the process

This microwave system has three base components: a microwave generator with a maximum power of 850W, waveguide and applicator. The microwave system also has a absorbent charge, a directional coupler and a impedance adapter with 3 divers.

The stand is supplied at the tension of 220V±5%, 50 Hz frequency. The monomode applicator of the microwave system is designed so that the hot/cold air stream may enter from downwards upwards in the applicator in order to eliminate the water on the surface of the wood, to avoid the hot spots and so to insure a homogenous temperature distribution.

With the help of the measurement devices we monitored the parameters of the process: the power of the microwaves, the direct power, the humidity of the hot/cold air stream at exit, the position of the divers at the adaptation of the charge impedance, the temperature of the air stream which is set so that it doesn't exceed 55^0C±5%, the temperature from the microwave and in the close proximity of the system. The temperature of the wood was taken with a special device - Material Moisture Wood Building Materials- Type Testo 616.

RESULTS AND DISCUSSIONS

Water is found in wood in three forms. Free water is found in its liquid state in the cell cavities or lumens of wood. Water vapour may also be present in the air within cell lumens. Bound water is found as a part of the cell wall materials.

As wet wood dries, free water leaves the lumens before bound water. Water can be removed from wood fairly easily up to the point where wood reaches its fibber saturation point (FSP). Wood does not start to shrink until it has dried below its FSP. FSP for most wood species falls in the range of 25 to 30% MC (Reeb, 1997).

Wood is divided, according to its botanical origin, into two kinds: softwoods from coniferous trees and hardwoods from broad-leaved trees. Due to its more dense and complex structure, permeability of hardwood is very low in comparison to softwood, making it more difficult to dry (Beldeanu, 2001). The general range of moisture content for green (not dried) hardwood lumber can range between 45% and 150%.

The experiment was made on preliminary moisturized wood and then on natural moisturized wood and compared the results.

For the first sample we used 18.43 g of preliminary moisturized beech wood. We tried to see what happens if we use a high power of 700W (See Fig. 3). From the numerical modelling we obtained the temperature distribution on wood surface when the power in applicator is P = 700W, shown in Fig. 1. We can see that the maximum temperature reaches 146^oC. After the experiment was made, we measure the temperature distribution acquired on the wood surface (Fig.2), and as we can see, the temperature field has over 120 ^{o}C, and a distribution similar to the simulation model. Off course that are differences between the simulation model and the experimental one, for many reasons as: we can't model the exact reality, we assume some simplified models close to reality, in the experimental part errors appear (measuring errors) etc., but the differences are acceptable.

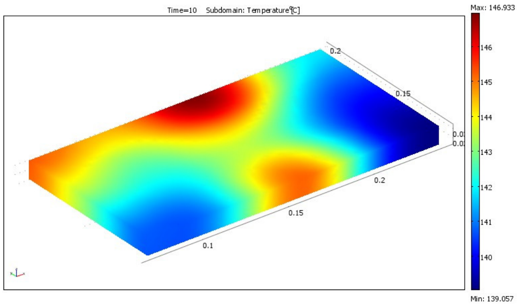


Fig. 1. Temperature distribution on wood surface at P = 700W

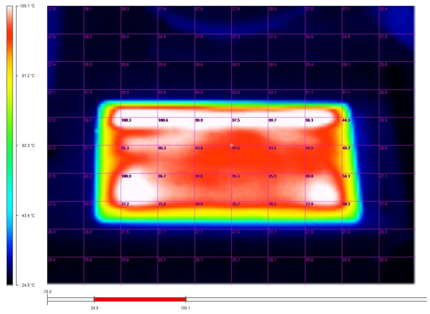
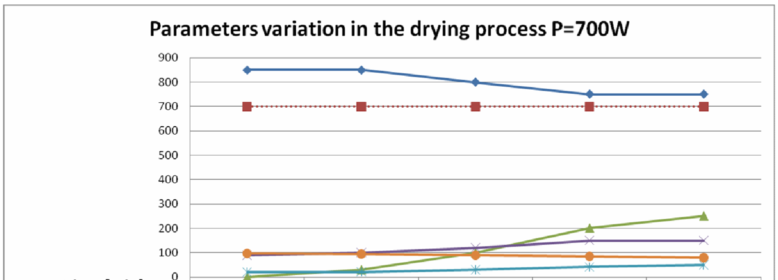


Fig. 2. Temperature distribution acquired on the wood surface

Because the material was preliminary moisturized and we used a very high power it resulted a quick drying of the wood in the first 2 minutes. The reflected power couldn't be adjusted to respect the condition to not exceed 20% of the direct power and that lead to the over warming of the water which was used as an artificial absorbent of the residual charge (Fig. 3).



Time [min]	0	0,5	1	1,5	2
Supply Power	850	850	800	750	750
Direct Power	700	700	700	700	700
Reflected Power	0	30	100	200	250
Wood Temperature	90	100	120	150	150
Output air temperature	20	21	30	41	49
Humidity	97	95	90	85	80

Fig. 3 Parameters variation in the drying process

Because we didn't use air stream we noticed on the back of the material black parts caused by the thermal instability. After drying for two minutes, the final mass of wood was 15.27 g of dried beech. As a conclusion, for the next sample we will use a lower power.

For the second sample we used 33 g of wet beech and we dried it at a power of 250W-300W-350W/ 3.5 minutes (Fig. 6). Even though we used a lower power, there was a quick drying, in the 3.5 minutes we lost 17.73g of evaporated water.

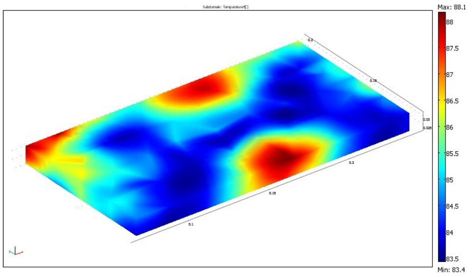


Fig. 4. Temperature distribution on wood surface

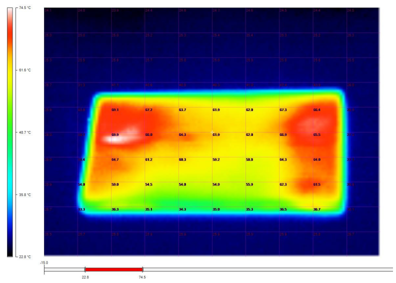
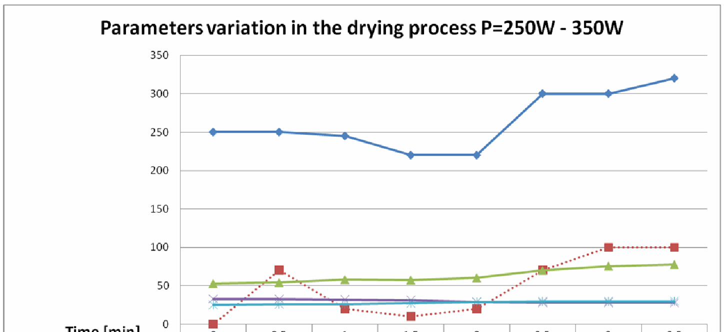


Fig. 5. Temperature distribution acquired on the wood surface

From the numerical modelling we can see that the maximum temperature reaches over 80 ^{o}C (Fig.4), thing confirmed by the temperature distribution acquired on the wood surface with the thermal imager (Fig.5) and the measured parameters during the experiment (Fig.6).



Time [min]	0	0,5	1	1,5	2	2,5	3	3,5
Direct Power	250	250	245	220	220	300	300	320
Reflected Power	0	70	20	10	20	70	100	100
Wood Temperature	53	54,4	58,2	57,7	60,5	70	75,8	77,8
Output air temperature	33	32,71	32	31,02	29,19	28,39	28,29	27,88
Humidity	25	26	26	27,5	29	29,54	29,8	30,05

Fig. 6 Parameters variation in the drying process

After the experiments made, we decided to study in the proper way the wood drying and to use wood with its natural moisturize. This thing was necessary because we need to find out the real time and power to dry wood in the microwave field.

We dried 39.44 g of wood with an initial power of 250W-300W for 8.5 minutes (See Fig. 9).

We observe that in this case we have a different distribution of the temperature on the wood surface (Fig.7) because we used different dielectric parameters for the natural moisturize wood and artificial moisturize wood, as we explained in the theoretical part. Fig. 8 presents the temperature distribution acquired on the wood surface, which is similar with the simulated one.

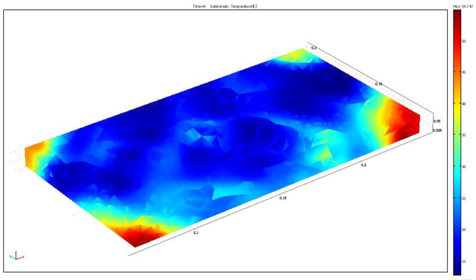


Fig. 7. Temperature distribution on wood surface

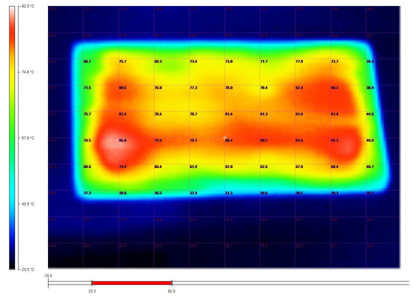
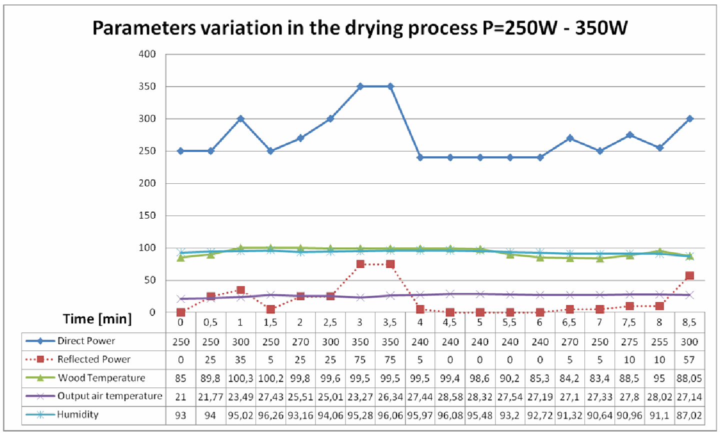


Fig. 8. Temperature distribution acquired on the wood surface

The wood being very porous there has been lost a big quantity of water. The final mass after drying was 12.68g, so there is a difference of weight of 26.76 g of evaporated water. By measuring the humidity of the air at exit we noticed a big efficiency of the drying, the average being over 95%. For this sample we succeeded in keeping the optimum value of the bearing between the direct power and the reflected power.



Time [min]	0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	5,5	6	6,5	7	7,5	8	8,5
Direct Power	250	250	300	250	270	300	350	350	240	240	240	240	240	270	250	275	255	300
Reflected Power	0	25	35	5	25	25	75	75	5	0	0	0	0	5	5	10	10	57
Wood Temperature	85	89,8	100,3	100,2	99,8	99,6	99,5	99,5	99,5	99,4	98,6	90,2	85,3	84,2	83,4	88,5	95	88,05
Output air temperature	21	21,77	23,49	27,43	25,51	25,01	23,27	26,34	27,44	28,58	28,32	27,54	27,19	27,1	27,33	27,8	28,02	27,14
Humidity	93	94	95,02	96,26	93,16	94,06	95,28	96,06	95,97	96,08	95,48	93,2	92,72	91,32	90,64	90,96	91,1	87,02

Fig. 9. Parameters variation in the drying process

The temperature measured in the wood exceeded 100.3^0C in the first minute, but after that decreases because at the same time with the water vaporization, the support of transforming electromagnetic power in heat disappears. For temperature measurements we used a Fluke Ti30, Industrial-Commercial Handheld Thermal Imager.

CONCLUSIONS

The electromagnetic field coupled with the thermal field and together with the mass problems, involves the knowledge of the temperature and humidity dielectric material properties dependence. The usual techniques at high frequency have the advantage that, at the same time with the water vaporization, the support of transforming electromagnetic power in heat disappears and the wood is cooling. We consider the drying of water is take place only at the surface and interferes in the thermal diffusion problem similarly to thermal convection. Is important that in the meantime of the moisture wood drying, the maximum temperature not exceed high values.

Numerical modelling has helped us to establish optimal values for both powers of applicator and in terms of exposure time on microwave of wood, to avoid the destruction of the wood. As we could see from the first sample, when we used 700W, we noticed on the back of the material black parts caused by the thermal instability. When heating the dielectric further, more than 2 minutes, the temperature in the center eventually reaches 160 °C and the water contents start boiling, drying out the center and transporting heat as steam to outer layers. This also affects properties of the wood. The simple microwave absorption and heat conduction model used here does not capture these nonlinear effects. However, the model can serve as a starting point for a more advanced analysis in the future.

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