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RESEARCHES CONCERNING THE PROBLEM OF COUPLING BETWEEN THE ELECTROMAGNETIC AND THERMAL FIELDS FROM MICROWAVE INSTALLATIONS

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Abstract: *The paper presents aspects related to the solving of the coupled problems of the electromagnetic field, the thermal field and mass in the drying process of loads in motion, placed in the microwave field. Difficulties encountered in this sense are related to the solving of the electromagnetic field problems in microwave applicators, thermal diffusion problems with the load moves inside the cavity. This paper provides a tool for the prediction of the temperature and humidity of load during heating and drying, before the process starts. It also provides recommendations for the optimization of the technological process and for the choice of constructive solutions for the equipment.*

Key words: *electromagnetic field, thermal field, displacement of the load, optimization*

1. INTRODUCTION

One of the most important problems in the drying processes of dielectric materials in a microwave field is represented by the uniformization problem for electromagnetic and thermal fields, so that physical and chemical properties of the material may not be destroyed.

The specialty literature (Metaxas, 2001) presents theoretical aspects regarding the heating in microwave field, draws comparisons regarding the dielectric properties of materials and their behavior in a microwave field, and describes recent developments regarding the numerical techniques used in the simulation of different applications from the domain of microwave heating, respectively.

The most frequently used multimode applicators, a category which also includes ovens, are analyzed numerically (Molnar, 2006). To analyze the characteristics of a particular type of heating oven it is necessary to find the electromagnetic field distribution inside the applicator for real loads. This is possible using numerical techniques.

The heating and drying of dielectrics in a microwave field, taking into account factors such as temperature, pressure, humidity, water vapor concentration, nature of the dielectric and strength absorption of microwave energy, represent an interesting alternative for conventional methods (Molnar, 2006).

Other articles published on this subject present solutions regarding the numerical modeling of the electromagnetic field in cavities loaded with dielectrics with losses (Leuca et al., 2004), and (Soproni et al., 2009) present results of simulation regarding heating and treatment of dielectrics in a microwave field.

2. THE ELECTROMAGNETIC AND THERMAL FIELD IN THE MICROWAVE APLICATORS

The presentation of the mathematical method used for numerical modeling and optimization applications represents a very important aspect. The propagation of electromagnetic waves in microwave structures is closely related to the electromagnetic field of the wave with the charges or currents on the boundaries of the structure, with certain conditions of reflection at these boundaries, and not only. Knowledge of the electromagnetic field distribution of microwave structures makes it possible to know the values of the thermal field. If we consider a rectangular resonant cavity with a non-homogeneous dielectric with losses, the solving of the second order equations of the electromagnetic field is done using the Galerkin method, and we obtain the system of equations (1, 2), able to solve numerically the electromagnetic field in a microwave oven.

$$\int_{\Omega} \nu \,\mathbf{rot}\mathbf{N_n}\,\mathbf{rot}\underline{\mathbf{E}}\, d\Omega = \omega^2 \int_{\Omega} \mathbf{N_n}\,\varepsilon \underline{\mathbf{E}}\, d\Omega \quad \text{where n = 1,2, …, } m_1 \quad (1)$$

$$\int_{\Omega} \underline{\varepsilon}\, \underline{\mathbf{E}}\, \mathbf{grad}\,\psi_n\, d\Omega \text{, where n = 1, 2, …, } m_2 \quad (2)$$

In a Ω domain, bordered by the boundary $\partial\Omega$, the thermal diffusion phenomenon is described by equation (3) with the boundary condition (4):

$$-\operatorname{div} \mathrm{k}\, \mathbf{grad}\, \mathrm{T} + \mathrm{c}\frac{\partial \mathrm{T}}{\partial \mathrm{t}} = p \quad (3); \qquad -k\frac{\partial T}{\partial n} = \alpha(T - T_0) \quad (4)$$

where: k – thermal conductivity, c – specific heat, p – the volume density of the power transformed from electromagnetic energy into thermal energy, T_0 – the ambient temperature and α - the heat transfer coefficient on the surface. In a sinusoidal regime, if we consider the dielectric material with losses, we have:

$$p = \omega\varepsilon'' E^2 = \omega\varepsilon' E^2 tg\delta \quad (5); \qquad T = \sum_{k=1}^{N} \alpha_k(t)\varphi_k \quad (6)$$

The solutions for equation (3), under the imposed conditions, take the form (6), where φ_k are linearly independent form functions.

3. THE COUPLED ELECTROMAGNETIC FIELD, THERMAL FIELD AND MASS PROBLEMS

In order to solve the thermal diffusion problems, in this paper we preferred the finite difference method. This is perfectly coupled with the output files of the program used to model the electromagnetic field. For solving the thermal diffusion problem are taken into account the surface thermal convection coefficient values, heat capacity and thermal conductivity, the boundary conditions being influenced by the state of evaporation, through the latent heat of evaporation. Electromagnetic field, thermal field and mass problems are coupled together. Among the most important problems and necessary aspects of mathematical modeling for the coupling we mention here:

- the complex permittivity ε, which is non linear dependent on the material humidity and sometimes this also depends on the thermal field in the load;
- the electric field intensity and the losses in the dielectric depend on temperature and humidity;
- the thermal convection coefficient on the surface, the heat capacity, the thermal conductivity dependent on the humidity of the material;

- the boundary conditions depend on the evaporation speed of water at the boundary, the latent heat of vaporization and the vapor pressure of water at the ambient temperature in the vicinity of the sample, etc.

In the numerical modeling of the coupling between the electromagnetic field, thermal field and mass problems we will follow these steps: the electromagnetic field problem is solved; the file containing the actual values of the electric field are saved in all points on the dielectric surface, and with a software developed in Fortran language, we calculate the distribution of the average power based on the relation (5), obtaining the active power and the average power (7), values which describe the uniform or non-uniform distribution of the dielectric losses.

$$P_{act} = \int_{\Omega} \omega \varepsilon_0 \varepsilon'' E^2 dv \quad \text{and} \quad P_{med} = P_{act}/V \qquad (7)$$

The density values of power losses in a microwave field are taken from thermal program, thus establishing the temperature in all points of the material. With known values of the thermal field, on the surface of the dielectric, we determine the amount of water evaporated in each time step. The program stops when the humidity contained in the material is the initially imposed one. The dielectric materials heated in the microwave field make the loss factor to increase with increasing of temperature, so it amplifies the effect of irregularity. One of the methods of disposal of or reducing the non-uniformity of the electromagnetic and thermal field, respectively, is represented by the setting in motion of the load. To achieve an effective program, able to provide useful information on the problems mentioned taking into account the coupling of the load in motion, were made some assumptions, among which we mention:

- initially, we solved the microwave problem for a basic value of the complex dielectric permittivity, being obtained the losses in the load. With the changing of the humidity in time, the complex permittivity also changes, so the dielectric losses at a given moment are obtained from the electric field values calculated initially with a professional software, multiplied with the imaginary part of ε, corresponding to humidity at the considered time;

- the load is considered with a parallelepiped shape and isotropic structure;

- the water is removed as vapor from the load at its periphery. It is assumed that the water diffusion inside the load is instantaneous, and surface evaporation affects the thermal field problem through its boundary conditions. In adopted manner, the time coefficient for thermal convection is corrected.

- the time evolution of power losses in the load is given by the changes of the complex permittivity due to humidity evolution ε= *f*(M) and the displacement of the load inside the applicator.

4. RESULTS OF THE MODELING OF THE COUPLING WITH LOADS IN MOTION

We consider a resonant cavity with two wave guides. The applicator operates at a frequency of 2.45 GHz. We simulate the linear displacement of the load inside the oven by changing position along the axis 0y. In Fig.1 we have the electromagnetic field distribution on the surface of the load, for humidities of 20% and 40%. With this data files, knowing the maximum permissible temperature of the dielectric, the heat convection coefficient on the surface, the heat capacity, the thermal conductivity and the density of the material, we obtain with the Fortran program the results shown in Fig.2 and Fig.3.

5. CONCLUSIONS

The optimization of the cavities in given conditions (material parameters, geometric parameters, electrical parameters), according to a variable parameter (position, humidity) may be done by analyzing the electromagnetic field distribution in guide-cavity systems. The uniform distribution of the field on the dielectric surface leads to the emergence of uniform temperature surfaces. The Fortran program allows a detailed study on the drying time in the given conditions and the power required for the installation, so that the dielectric maintains its qualities.

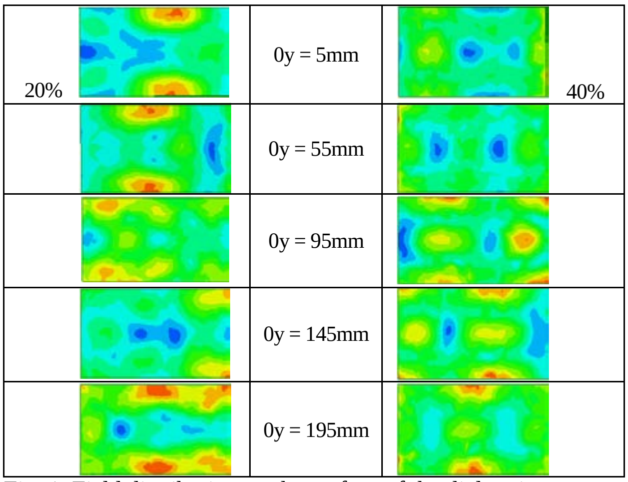

Fig. 1. Field distribution on the surface of the dielectric

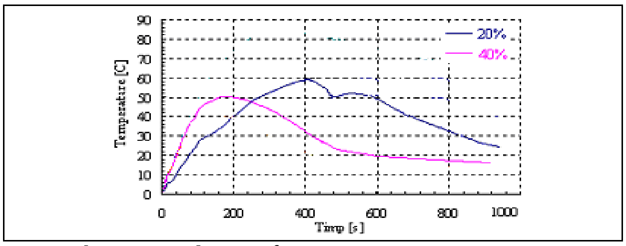

Fig. 2. The time evolution of temperature

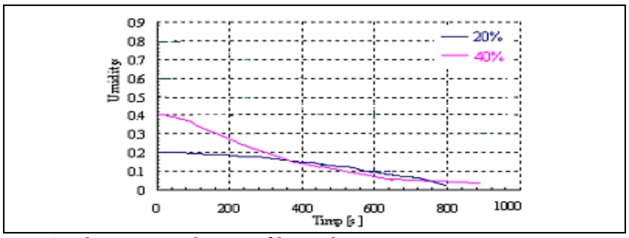

Fig. 3. The time evolution of humidity

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