Numerical Analysis of the Electromagnetic Field in Microwave Processing of Forest Fruits

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Abstract* – In the paper we present the numerical analysis of the power density distribution in the forest fruits in microwave systems. The processing in a microwave field of forest fruits offers the processor a new tool, strong and at the same time different from the conventional methods, improving the characteristic performances of the product. Our purpose is to simulate the drying of the fruits in electromagnetic field-microwave field and to obtain a homogenous temperature distribution, which does not create overheating points like the tangent points between the spheres that, sometimes, can destroy at a local level the forest fruits from the applicator. The drying of forest fruits is done by eliminating the water from the products up to 15-25 % moisture, thus securing the concentration of the sugars and of the acids.

***Keywords:* electromagnetic field, microwave heating, forest fruits, numerical analysis.**

I. INTRODUCTION

The heating in a microwave field is one of the most modern procedures of the drying of the dielectrics, having the great advantage that the power density can be distributed in the volume of the material. Nevertheless it is very important that this distribution does not create overheating points that, sometimes, can destroy at a local level the load of the applicator.

In [1] is presented the heating mechanisms of the dielectric materials. This effects are due, on the one hand, to the polarisation of the loaded particles in the material by the electric field of high frequency, and on the other hand, to the Joule effect, due to the conduction of the free loads at the action of the electric field.

The processing (pasteurization, sterilization, drying) in a microwave field of forest fruits (bilberries, box thorn, black gooseberries, wild strawberries, blackberries, sloes, raspberries) offers the processor a new tool, strong and at the same time different from the conventional methods, improving the characteristic performances of the product.

One of the most important issues related to the drying processes of dielectric materials within a microwave field is the homogenization of both the thermal and the electromagnetic fields so that the physical and chemical properties of the material should be preserved intact.

We follow this purposes:

- the drying of forest fruits to an optimum moisture content and the active substance for the securing of an adequate storing process;
- to reduce the drying time and the used energy, from economical efficiency reasons;
- the use of unconventional methods of protection (microwave technologies) against the pest insects found in the stored products, taking into account that the chemical control against the pest insects has two great disadvantages: it does not protect the environment and it reduces the quality of the fruits;
- the successful elimination of different bacterial and micotic pathogenic through the treating with microwaves of the forest fruits.

II. MATHEMATICAL MODELS

The guiding of the electromagnetic waves through the microwave structures is realized through the close relation between the electromagnetic field of the wave on the one hand and the loads or currents on the boundaries of the structure, with certain conditions of reflection on these boundaries, and not only. In most cases, the guiding structures of the electromagnetic waves are rectangular structures and have conductive boundaries. The knowledge of the distribution of the electromagnetic field in the microwave structures makes possible the knowledge of the constant of propagation of the waves, of its dependence on frequency, of the propagation speed, of the phase and attenuation constant, etc.

Modelling represents a phenomena using set of mathematical equations. The solutions to these equations are supposed to simulate the natural behaviour of the material.

Modelling can be a design tool to develop food that will provide optimum heating results in the microwave oven. In the modelling work, the food system is represented as being made up of many small elements in the simulation process. These discrete elements are joined together to make up the product [2].

Modelling of microwave drying process can involve two separate parts, one being modelling of heat and mass transfer and another being modelling the electromagnetic field inside the microwave oven cavity for calculating heat generation term [3]. Modelling of electromagnetic field arises when Maxwell’s equations are used for calculating the heat generation term.

Modelling of heat and mass transfer equations uses standard heat transfer equation and the mass transfer terms are included in the boundary conditions of the governing heat transfer equation.

Therefore, a wave equation for electromagnetic waves is a partial differential equation of second order in the form shown as follows:

$$\nabla^2 \mathbf{E} - \mu\varepsilon \frac{\partial^2 \mathbf{E}}{\partial t^2} = -\frac{\rho_v}{\varepsilon} \tag{1}$$

Electromagnetic waves can be described using partial differential equations for the electric fields. In the simplest case of waves travelling uni-dimensionally in the z-direction, in a charge-free space ($\rho_v = 0$) the set of equations becomes what is known as Helmholtz equations,

$$\frac{\partial^2 \mathbf{E}}{\partial t^2} - u^2 \frac{\partial^2 \mathbf{E}}{\partial z^2} = 0 \tag{2}$$

where u is the velocity of the wave which is a function of the frequency of the wave.

These materials are called loss dielectrics due to the loss of electromagnetic energy into heat.

$$\nabla^2 \mathbf{E} - \gamma^2 \frac{\partial^2 \mathbf{E}}{\partial t^2} = 0 \tag{3}$$

III. THE PROPAGATION OF THE ELECTROMAGNETIC FIELD IN MICROWAVE SYSTEMS

An electromagnetic system functions at resonance if in a harmonious regime the reactive power received by the system is null.

The systems with resonant microwaves are part of the category of devices used in the heating of the dielectric materials in a microwave field.

These are enclosures with metalic walls, conductors, feeded through one or more wave guides.

The sizes of the microwave systems are large in comparison to the wave guide we used. The number of modes that can appear in comparison with the wave length depends generally on the volume of the system and the working frequency.

In the practical realization of the microwave systems there appear problems regarding the choice of the form and of the sizes, so that the heating is uniform, fast and does not destroy the qualities of the processed material.

There are cases in which in the cavity we introduce auxiliary devices able to perturb the field, and, when it is possible, the body exposed to heating can start moving.

At resonance, the behaviour of a system is purely resistive, from the point of view of the alimentation source there takes place an exact compensation of the electric energy with the magnetic one in the interior of the system, and the contribution of active power supplied by the source is compensated by the consumption of active power in the dissipative elements of the system.

At different resonance frequencies, over the resistive behaviour we add a reactive behaviour determined by the lack of balance between the average electric energy and the average magnetic energy in the system, in the oscilating process maintained by the source [5].

Generally, the study of the microwave systems is approached in the hypothesis of the absence of the losses on the boundary, admiting that the walls are made of a material „perfect E” type. If there is nevertheless some losses in the conductive walls, these will be small enough, in order not to affect significantly the distribution of the electromagnetic field.

In the interior of a cavity we consider a linear medium, characterized by the electric permittivity ε, the magnetif permeability μ and the conductivity σ. If we consider that the applicator is with no losses ($\sigma = 0$), then the equations of the electromagnetic field in the interior of the system are obtained from the relations:

$$\mathbf{rotE} = -\frac{\partial \mathbf{B}}{\partial t} = -\mu \frac{\partial \mathbf{H}}{\partial t} = -\frac{1}{\nu}\frac{\partial \mathbf{H}}{\partial t} \tag{4}$$

$$\mathbf{rotH} = \frac{\partial \mathbf{D}}{\partial t} = \varepsilon \frac{\partial \mathbf{E}}{\partial t} \tag{5}$$

The unknowns of these equations are the measures **E** and **H**. The equation of the second order written for the measure **E**, known under the name of wave equation, is obtained by applying the operator **rot** to the relation (4):

$$\mathbf{rot}\, \nu\, \mathbf{rotE} + \varepsilon \frac{\partial^2 \mathbf{E}}{\partial t^2} = 0 \tag{6}$$

In a permanent sinusoidal regime we have:

$$\begin{aligned}\mathbf{E}(x,y,z,t) &= \mathbf{i}\mathrm{E}_x(x,y,z)\sqrt{2}\sin(\omega t + \varphi_x) + \\ &+ \mathbf{j}\mathrm{E}_y(x,y,z)\sqrt{2}\sin(\omega t + \varphi_y) + \\ &+ \mathbf{k}\mathrm{E}_z(x,y,z)\sqrt{2}\sin(\omega t + \varphi_z)\end{aligned} \tag{7}$$

The image in the complex, is:

$$\underline{\mathrm{E}} = \mathbf{i}\underline{E}_x + \mathbf{j}\underline{E}_y + \mathbf{k}\underline{E}_z\,, \tag{8}$$

where: $\underline{\mathrm{E}}_x = \mathrm{E}_x e^{j\varphi_x}$, $\underline{\mathrm{E}}_y = \mathrm{E}_y e^{j\varphi_y}$, $\underline{\mathrm{E}}_z = \mathrm{E}_z e^{j\varphi_z}$.

The equation of the waves can be written in a complex form like this:

$$\mathbf{rot}\, \nu\, \mathbf{rot}\, \underline{\mathbf{E}} - \omega^2 \varepsilon \underline{\mathbf{E}} = 0 \tag{9}$$

We note with $\lambda = \omega^2\varepsilon$, and obtain the equation that describes a problem of functions and own form values:

$$\mathbf{rot}\, \nu\, \mathbf{rot}\, \underline{\mathbf{E}} = \lambda \underline{\mathbf{E}} \tag{10}$$

We apply to the relation (10) the operator div, taking into account that div**rot** = 0, we obtain a Coulomb condition of inplicite standardization: $div\,\underline{\mathbf{E}} = 0$.

It can be shown that the operator $\mathbf{rot}\,\nu\,\mathbf{rot}\,\underline{\mathbf{E}}$ is symmetrical on the multitude of functions, with the boundary condition null which checks the standardization condition [4].

The resonance frequency in the cavity must verify the relation $\omega^2\varepsilon\mu = \lambda$ where:

$$\lambda = \left(\frac{k\pi}{a}\right)^2 + \left(\frac{l\pi}{b}\right)^2 + \left(\frac{m\pi}{c}\right)^2 \qquad (11)$$

At the resonance frequency there is an electromagnetic field without the applicator to be excited from the outside. For this we will find the solutions of the equation (9) imposing the condition $\mathbf{E}_t = 0$ on the boundary $\partial\Omega$.

IV. RESULTS

Starting from the theoretical considerations we presented, we tried the numerical modelling of the electromagnetic field from an applicator with the sizes: (310 mm x 310 mm x 210 mm). The geometry of the applicator is shown in fig. 1.

To obtain a more realistic model, we modelled the forest fruits with spheres of 15 mm radius.

For its solving we chose an adaptable solution, which delivered results regarding the uniformity of the electric field, in the inner of the dielectric.

The adaptable solution is the solution in that we create a mesh of finite element that is automatically refined. The frequency is 2,45 GHz, and the sizes of the guide are chosen to filter at the entrance of the applicator just the propagation mode TE_{10}.

The solving of the electromagnetic field problem was made with the help of the Ansoft HFSS 10 programme.

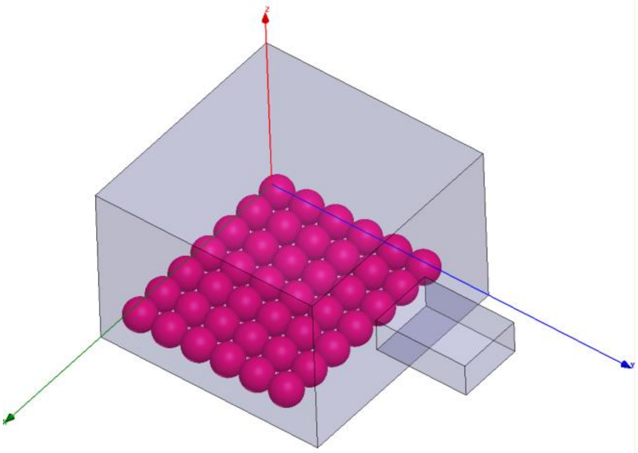

Fig. 1 – The geometry of the applicator

In fig.2 we present the distribution of the electromagnetic field in complex measurements on the inner faces of the applicator and in the port.

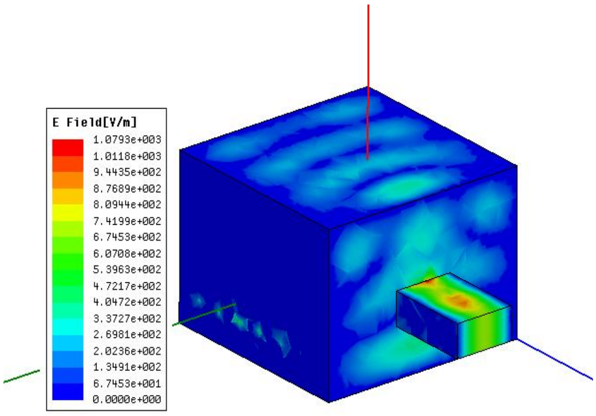

Fig. 2 The distribution of the electromagnetic field in complex measurements on the inner faces of the applicator and in the port

In fig. 3 we present the distribution of the electromagnetic field in the fruit mass.

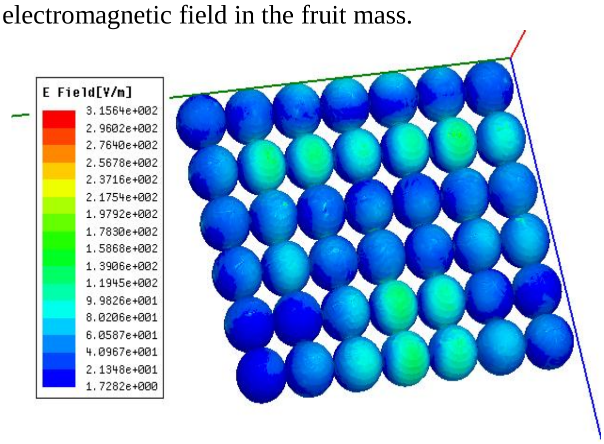

Fig. 3. The distribution of the electromagnetic field in the fruit mass

We can see from fig. 3 that the distribution of the electromagnetic field in the fruit mass is not homogenous. The phenomenon of non uniformity can be removed by modifying the position of the wave guide, the use of the modes agitators or, in the case of the cavities of large sizes, through the movement of the load in the interior of the oven [5].

In fig. 4. we present the distribution of the electromagnetic field in the fruit tangent points.

From the below model we can see that in the points were sphere fruits are tangent the electromagnetic field has higher values and this can cause overheating and even can destroy the products if it is not held under control.

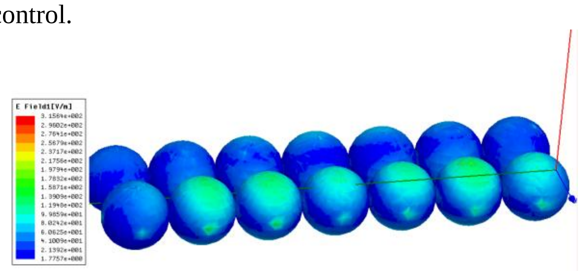

Fig. 4. The distribution of the electromagnetic field in the fruit tangent points

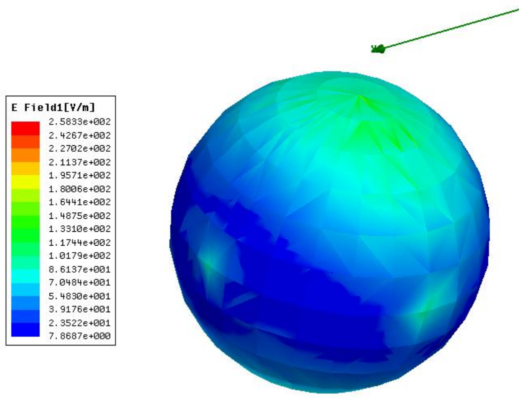

Fig. 5. The distribution of the electromagnetic field in one sphere-fruit and in tangent points

If we can set a higher limit to the temperature distribution in the forest fruits mass, than we can avoid the product losses.

It is very important that the power density distribution is controlled, that it does not create overheating points like the tangent points between the spheres, that, sometimes, can destroy at a local level the forest fruits from the applicator.

In order to obtain a uniform distribution of the high frequency electromagnetic field it is required either the use of some mode agitators, or the combined use of microwaves-warm air.

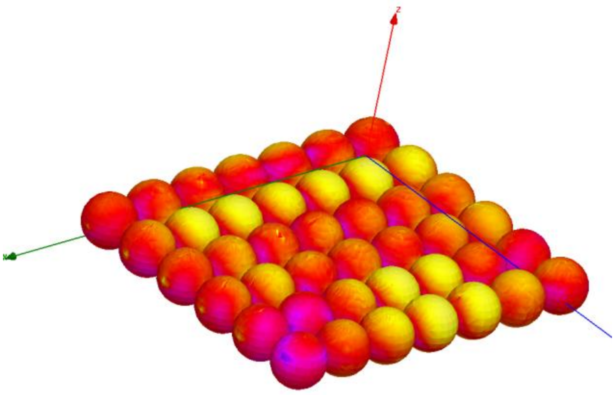

Fig. 6. The distribution of the temperature field in the fruit mass

In fig.6 we have the temperature distribution between 26 ^{0}C and 76 ^{0}C.

The drying of the bilberries can be made at about 60 ^{0}C. The process is considered to be finished when the fruits have the soft consistency of raisins.

After the drying, the fruits are left for 2-3 days, after which they are assembled. From 7-8 kg of fresh fruits results 1 kg of dried fruits. The final content of moisture is recommended to be between 14-16 %. For the drying of the bilberry leaves, the recommended maximum temperature cannot exceed 40 ^{0}C [2]. The drying of the fruits is done by eliminating the water from the products up to the moisture of 15-25 %, thus securing the concentration of the sugars and acids. From 100 kg of fruits we obtain in dried state 10 kg [2].

V. CONCLUSIONS

The artificial drying is made through the evaporation of a part of the water found in fresh products with the help of heat in drying rooms thus built that, through drying, the nutritive value, the flavour, the taste and the alimentary features characteristic of the fruits should not be affected.

An important problem is the temperature distribution. It has to be held under controll, because it can destroy the forest fruits.

The air flow is realized through a natural way, due to the difference of temperature from the drying room and the exterior environment. Good results are obtained when we use ventilators (mode agitator) through which the speed of the air is adjusted, which determines a reduction of the duration of drying and an improvement of the quality of the products.

The moisture of the air is determined according to the nature of the products (ex. for the stone fruits it will be of 20-25% and for the others of 50-60 %).

The drying ratio R_u, allows the calculation of the quantity of water which has to be evaporated, of the thermal energy necessary for the evaporation.

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