PROCESSING OF BOXTHORN FRUITS IN A MICROWAVE ELECTROMAGNETIC FIELD

Livia BANDICI[1]
University of Oradea, Romania, e-mail: lbandici@uoradea.ro

ABSTRACT: the paper includes aspects regarding the role of the high frequency electromagnetic field in the processing of boxthorn fruits. for the analysis of the electromagnetic field we used a 3d model and the method of the finite elements. we solved problems regarding the coupling of the electromagnetic field with the thermal field and the mass.

KEYWORDS: Microwaves, propagation, boxthorn fruits, electromagnetic field, dissipation

1. INTRODUCTION

The continuous development of the branches of the food industry imposes both the modernization and the development of some existing technological processes, and the elaboration and implementation of some new methods of processing, using technological lines of maximum efficiency.
The drying of wet products is a very difficult thermal and diffusion process. For complex systems, like boxthorn, the drying process has two components: the thermo-physical component and the thermo-technological component, respectively [1].
H.C. Reader, 1997, [2], developed a method for the determination of distribution of the electric field, which develops between the interior surfaces of the applicator – on the interior metallic surface of the applicator there is a tangential component of magnetic field and a phase different perpendicular component of electric field which develop in space.
The scope we follow is to secure optimum conditions for the processing of the dielectrics, the realization of a microwave installation which can accomplish the following processes:
- the processing of the dielectrics, optimum moisture content and the active substance for the securing of an adequate storing process;
- the successful elimination of different bacterial and micotic pathogenic through the treating with microwave of the dielectrics.
The thermo-physical component of the drying process determines only the transfer of heat and moisture through the thickness of the product layer; the thermo-technological component presents the combination of the processes of heat and moisture transfer, associated with chemical, biochemical and structural-mechanical transformations.
The choice of the drying procedure, of the optimum regime and of the construction of the drying installation must be closely connected with the characteristics of the material and the drying technology of one product or the other, based on the scientific theories of the drying technology [2].
Nowadays, the technology of the drying process is connected with the basic laws of the heat and moisture transfer in different products including food products. The intensification of the drying process of food products, including horticultural products must be directly connected with the characteristics of the product and must develop with the securing of the quality of the finite product.
Dried boxthorn represents a valuable product due to the wide range of nourishing substances that it possesses. The most useful for drying are considered the boxthorn fruits with dense, succulent pulp (the mass of a fruit is 0,7 gram/piece).

2. THE INFLUENCE OF THE CHARACTERISTICS OF THE MATERIAL ON THE DRYING PROCESS OF BOXTHORN USING THE HIGH FREQUENCY ELECTROMAGNETIC FIELD

One of the main components that characterize boxthorn as a dielectric material is the oil contained in the pulp of the fruits. The pulp of the fruits contains almost 8 % fat oil, and in the kernel up to 12 %. Boxthorn in fresh state has the moisture of 83 % [2].
In the presence of the high frequency electromagnetic field, boxthorn heats depending on the dielectric losses,

determined by the values of the relative dielectric permeability ε'' and the tangent of the dielectric loss angle tgδ.
The frequency of the electromagnetic field, the intensity and the electrophysical characteristics of stone fruits influence the heating power and speed. The elaboration of the technological regime for the drying of fruits is possible when the electrophysical properties and the dependences of these properties on the electric field, temperature and moisture of the fruits are known [3].
The dielectric constant (ε') represents the capacity of the material to store electromagnetic energy. The dielectric loss factor (ε'') represents the capacity of the material to convert electromagnetic energy into thermal energy. The calculation relation for permittivity is the following:

$$\underline{\varepsilon} = \varepsilon' - j\varepsilon'' \quad (1)$$

The tangent of the loss angle is the relation between the dielectric loss factor and the dielectric constant:

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \quad (2)$$

The values of the dielectric constant and of the dielectric loss factor are used to estimate the penetration depth in the case of the processing of a material in a microwave field. The penetration depth is calculated with the relation:

$$\delta_p = \frac{c_0}{2\pi f\sqrt{2\varepsilon'\left[1+\sqrt{\tan\delta^2}-1\right]}} \quad (3)$$

where: $c_0=3\cdot10^8$ [m/s]; f = 2,45 [GHz].

3. THE ANALYSIS OF THE DISSIPATION OF THE ELECTROMAGNETIC FIELD IN A DIELECTRIC SITUATED IN THE INTERIOR OF THE MICROWAVE APPLICATOR

The power dissipated in the heating systems with microwaves is proportional with the frequency, the dielectric properties and the distribution of the electric field [5]:

$$\Delta P = \sigma \cdot E^2 = 2\pi \cdot f \cdot \varepsilon_0 \cdot \varepsilon'' \cdot E^2 \quad (4)$$

The electric field oscillating at the frequency of 2,45 [GHz] is calculated with the relation:

$$E = E_0 \cdot e^{-\alpha z} \quad (5)$$

where:

$$\alpha = 2\pi \cdot f\left(\frac{\mu_0 \cdot \mu' \cdot \varepsilon' \cdot \varepsilon_0}{2}\right)^{0,5}\sqrt{\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}-1} \quad (6)$$

Subdomain settings - Electromagnetic Waves:

$$\nabla x\left(\frac{1}{\mu_r}\nabla x E\right) - k_0^2\left(\varepsilon' - j\frac{\sigma}{\omega\cdot\varepsilon_0}\right)E = 0 \quad (7)$$

where: ε'- dielectric constant;
σ - electric conductivity;
μ_r - relative permeability.

Boundary Settings – Electromagnetic Waves:

$$n\cdot\mathbf{E}=0 \quad (8)$$

The theoretical models for the distribution of the temperature and moisture during the drying process with microwaves of the dielectric materials, including the food products has been studied in detail by [6], [7], [8].
The fundamental theory of the heating and mass transfer in the interior of a microwave oven was adopted taking into account a continuous distribution process of the electric field along the wave guide.
The attenuation constant in this case must be adjusted taking into account the presence of the dielectrics in the centre of the applicator according to the relation:

$$\alpha = 17{,}37\pi\varepsilon''\frac{w\cdot\lambda_g}{a\cdot\lambda_0'^2} \text{ [dB/m]} \quad (9)$$

Subdomain Settings - General heat transfer:

$$\delta_{ts}\cdot\rho\cdot C_p\frac{\partial T}{\partial t} + \nabla\cdot(-k\cdot\nabla\cdot T) = Q \quad (10)$$

where: T- temperature;
δ_{ts} - time scaling coefficient;
ρ - density;
C_p - heat capacity at constant pressure;
Q - heat source.

Subdomain settings - General heat transfer:

$$\nabla\cdot(-k\cdot\nabla\cdot T) = Q \quad (11)$$

The thermal transfer equation, neglecting the losses through convection and radiation during the process of drying with microwaves is given by the relation:

$$\frac{\partial T}{\partial t} = \alpha_T\nabla^2 T + \frac{\varepsilon_v}{C_p}L_h\frac{\partial M_1}{\partial t} + \frac{\Delta P}{\rho\cdot C_p} \quad (12)$$

The solving of the coupled problems regarding the phenomena of thermal and mass transfer is extremely difficult, that is why we will consider some simplifying hypotheses; we will divide the process into three regions: in the first we will consider the losses through convection and radiation, in the second we will consider the process of drying with microwaves, and in the third the heating without drying.

4. NUMERICAL RESULTS

In this paper it is shown an application of 3D numerical modelling, of a multimode applicator and in its interior we considered four boxes in which there are placed boxthorn fruits using the Method of the Finite Elements [9], [10]. The results we obtained allow the evaluation of the uniformity grade of the electric field both in the interior of the dielectrics and on their surface. The boxthorn fruits are static and have the same humidity (M= 50 %). The boxthorn fruits are considered uniform and homogenous, with constant dielectric and thermal properties. In fact, they are non homogenous, and the dielectric constants vary with the temperature.

In fig.1, we present the geometry of the microwave applicators.

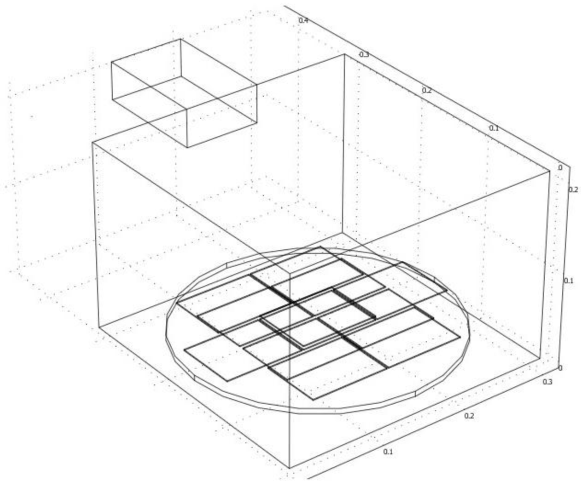

Fig. 1. The geometry of the applicator

In fig. 2, 3, we present the distribution of the electric field in a perpendicular and parallel plane, on the surface of the boxthorn fruits.

In fig. 4, 5 we present the temperature distribution in the boxthorn fruits and the variation of temperature after 15 s.

In fig.6 we present the variation of temperature in time on the surface of the boxthorn fruits.

In fig. 7 we present the variation of the temperature in the mass of boxthorn fruits determined experimentally using a multimode applicator. The duration of the drying process is of 4 min. at the power of the applicator of 350 W. The initial moisture of the fruits is 50%, and the final moisture after 4 min. reaches the value of 17%.

In fig. 8 we present the variation of the temperature using a power of 350 W in the initial drying phase (T1=60s, T2=90s), and in the final drying phase, when the temperature is stabilized, a power of 550 W (T1=120s, T2=90s). In this phase, the final moisture reaches the value of 9%.

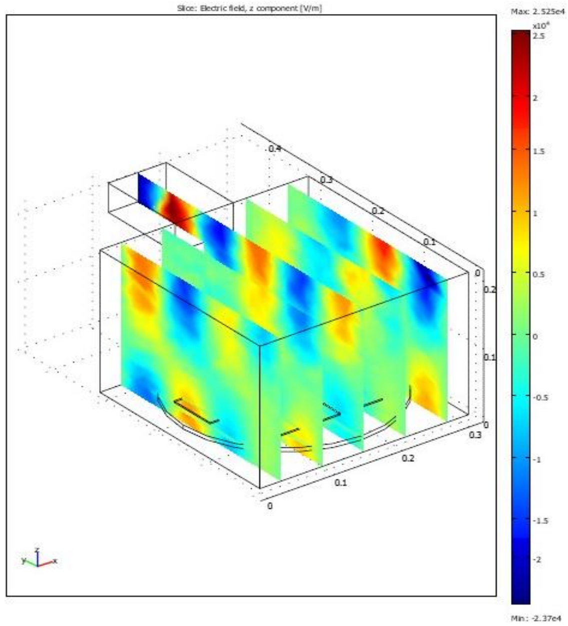

Fig. 2. The electric field in a perpendicular plane on the surface of the boxthorn fruits

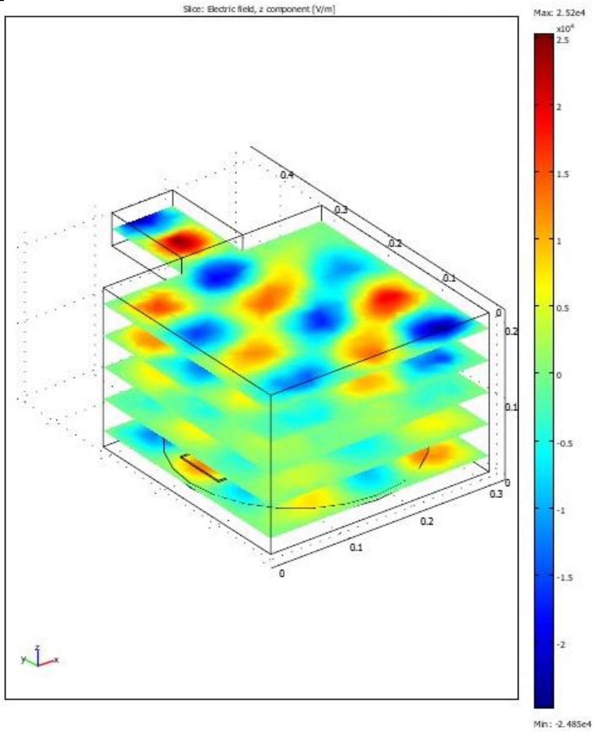

Fig. 3. The electric field in a parallel plane on the surface of the boxthorn fruits

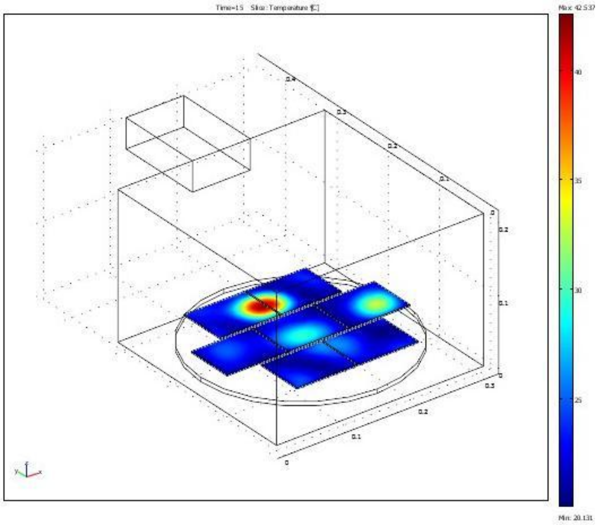

Fig. 4. Temperature distribution in the boxthorn fruits

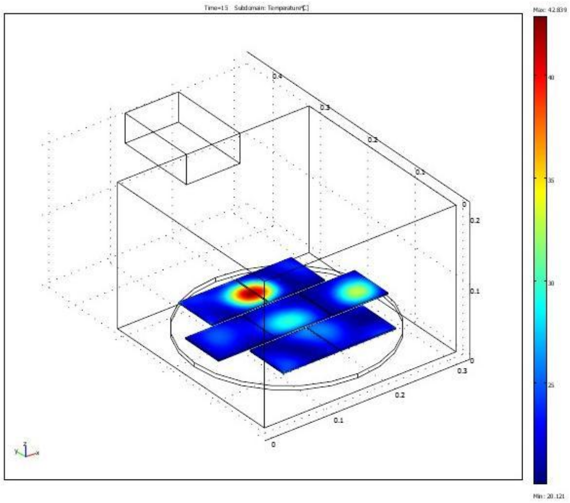

Fig. 5. Temperature distribution in the boxthorn fruits after 15 s.

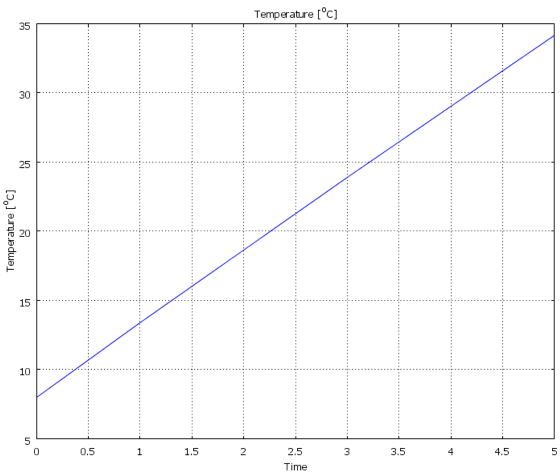

Fig.6. Variation of the temperature in time

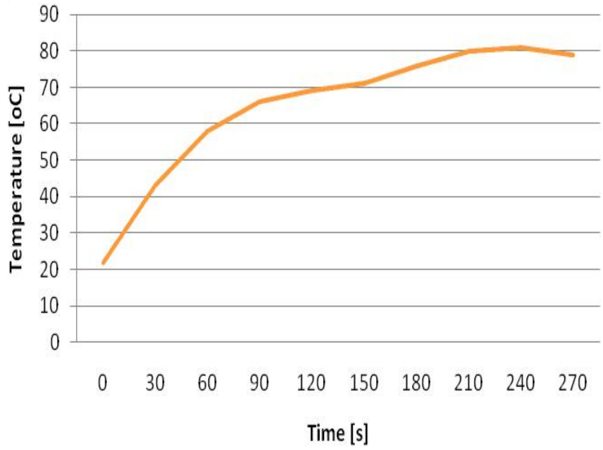

Fig.7. Variation of temperature at the power of the applicator P=350 W

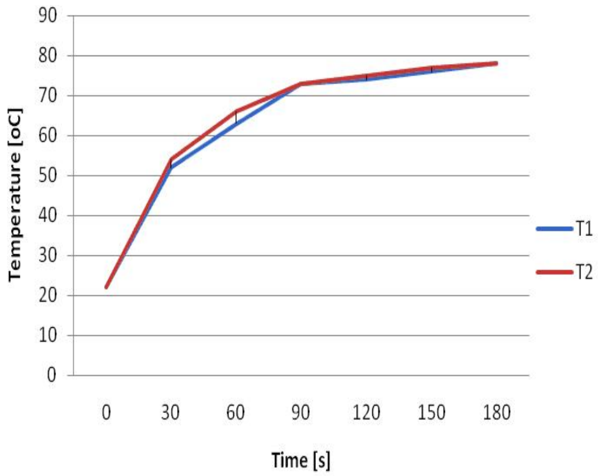

Fig.8. Variation of temperature at the power of the applicator P=550 W

In the first phase of heating, when the risk of thermal agitation appears, we used a lower power (350 W), reducing the risk of deterioration of the boxthorn fruits. In the final phase of the drying process we increase the power to the value of 550 W, thus reducing the drying time from 4 min. to 3 min.

5. CONCLUSIONS

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.
Taking into account all these problems which appear during the processing in a microwave field, we can however state that the transfer phenomenon of the electromagnetic field in microwave structures is performed faster, assuring thus higher efficiency and the

absence of the energy losses through thermal radiations.
At the same time with the increasing of the temperature, the conductivity coefficient of the moisture increases suddenly; this phenomenon is determined on one hand by the size of the coefficient of the diffusion of the water vapour, and on the other hand on the decreasing of the viscosity of liquid water in capillaries.
In the first phase of the heating, the moisture of the boxthorn fruits does not decreased significantly, due to the negative gradient of temperature that exists in that moment.
In the period of actual drying, the temperature reaches the highest value, and then it decreases gradually as the moisture approaches the balance moisture, but without reaching it.

REFERENCES

[1] A. Gherghi, I. Burzo. *Biochimia şi fiziologia legumelor şi fructelor.* Editura Academiei Române, 2001.

[2] T. Funebo, T. Ohlsson. *Dielectric properties of fruits and vegetables as a function of temperature and moisture content*. Journal of Microwave Power and Electromagnetic Energy. 34(1): 42-54, 1999.

[3] S.O. Nelson. *Dielectric properties of agricultural products*. IEEE transactions on Electrical Insulation", 26(5): 845-869, 1991.

[4] J.Tang. *The Microwave Processing of Foods. Woodhead Publishing Limited*. Schubert, H., and Regier, M. (Eds) Cambridge, England 22-42, 2005.

[5] A.C. Metaxas, R.J. Meredith. *Industrial microwave heating*. Peter Peregrinus Ltd, London, UK, 1983.

[6] A.K. Datta. *Mathematical modelling of microwave processing of foods An overview*. Food processing operations modelling: design and analysis, New York, pp. 147-187, 2001.

[7] L. Lu, J.Tang, X.. Ran. *Temperature and Moisture Changes During Microwave Drying of Sliced Food*. Drying Tech, 17(3):413-432, 1999.

[8] Livia Bandici, T. Leuca, Paula Alexandra Palade. *Some aspects regarding the optimization of the electromagnetic field propagation in microwave structures*. Journal of Electrical and Electronics Engineering, 27-29 May, Oradea 2009, pp. 7-12, Vol. 2, nr.2

[9] Livia Bandici. *The Influence of the High Frequency Electromagnetic Field on the Processing of Forest Fruits***.** 13th IGTE Symposium on Numerical Field Calculation in Electrical Engineering, September 22 – 24, 2008, pp. 375-378.

[10] T. Leuca, Livia Bandici, Paula Alexandra Palade, I. Stoichescu. *Numerical analysis of the electromagnetic field in microwave processing of forest fruits*. Journal of Electrical and Electronics Engineering, 27-29 May, Oradea 2009, pp.64-67, Vol. 2, nr.1.

AUTHOR

1 Associate Professor Livia BANDICI, Faculty of Electrical Engineering and Information Technology, Universităţii Street, 1, Oradea, Romania, Tel: (+40)-259-408146, fax: (+40)-259-408408, e-mail: lbandici@uoradea.ro