MOULDY CORN SEEDS PROCESSING IN MICROWAVE FIELD. NUMERICAL MODELLING AND EXPERIMENTAL RESULTS

Palade Paula Alexandra*, Vicaş Simina Maria**

* University of Oradea, Faculty of Electrical Engineering and Information Technology, Department of Electrical Engineering, 1 Universității Street, Oradea, 410087, Romania, e-mail: ppalade@uoradea.ro
** University of Oradea, Faculty of Environmental Protection, Departament of Physics, Chemistry and Informatics, 26 Gen. Magheru Street, Oradea, 410059, Romania, e-mail: simina_vicas@yahoo.com

Abstract
This study presents aspects regarding the processing of mouldy corn seeds in a microwave field, combines modelling with the experimental results in the behalf of finding out the appropriate formula between the applied energy and the material properties. The results of the numerical modelling help us determine the drying time and the appropriate drying power. For the modelling part we used a 3D model and the Finite Elements Method. To determine the electromagnetic field we used the Ansoft HFSS 11.0 programme to study the heating of mouldy corn seeds, of parallelepiped shape, situated in a multimode applicator, excited with energy through a wave guide. The main problem which appears is represented by the homogeneity of the field and implicitly of the temperature in the seeds bed. In the experimental part our purpose is to find out the influence that drying with microwaves / cold air stream has on the mouldy corn seeds composition.

Key words: mouldy corn seeds, germination, electromagnetic field, dielectric properties

INTRODUCTION

The use of the energy of the high frequency electromagnetic field in the heating of the dielectrics offers multiple advantages, such as: the reduction of the energetic consumption, the reduction of the processing times, and the quality of the heating as well as economic advantages regarding the production costs (Zhang and Datta, 1999).

Modern technologies that have microwave heating at their base are known in many applications because of the advantages that they offer in front of the conventional ones.

One of the most important issues related to the processing of dielectric materials within a microwave structure is the homogenization of both the thermal and the electromagnetic field so that the physical and chemical properties of the material should be preserved intact (Palade et al., 2010).

Articles (Metaxas and Meredith, 1983) and (Metaxas and Driscoll, 1974) present a series of theoretical aspects concerning the industrial heating in a microwave field and compares the properties of dielectric materials and their evolution when exposed to radio-frequency and microwave, and (Metaxas, 2001) describes the recent steps forward made in relation to the numerical techniques that are used when simulating applications in the domain of microwave field heating.

Article (Dibben and Metaxas, 1995) deal with the numerical analysis of the most widely used multimode applicators, such as kilns. It is demonstrated that, in order to analyze the heating characteristics of a certain type of oven, it is necessary to solve Maxwell's equations for the field within the applicator, in other words to find the distribution of the electromagnetic field within the applicator for real charges. The utilization of numerical techniques makes this possible. In conclusion, it may be asserted that the method of the finite elements represents an important tool in the analysis of the heating systems using microwave, because it allows the utilization of uneven networks that correspond to the geometry of the problem.

The determination of the thermal field implies the calculation of the electromagnetic field in the interior of the applicator (Datta, 2001).

In (Zhang et al., 1999) are presented mixed methods of calculation of the field in the interior of the microwave applicator.

The works (Leuca et al., 2009), (Bandici et al., 2009) present studies on the distribution of the electromagnetic field in the applicator and in a dielectric situated in the interior of the applicator.

We follow this purposes:

- the drying of mouldy corn seeds 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 mouldy corn seeds (Nelson, 1995).

MATERIAL AND METHODS

The electromagnetic field inside the microwave oven can be represented by Maxwell's equations (Metaxas and Meredith, 1983):

$$\nabla \mathrm{x} \mathbf{E} = -\frac{\partial}{\partial t}(\mu \mathbf{B}) \qquad (1)$$

$$\nabla x\mathbf{B} = -\frac{\partial}{\partial t}(\varepsilon'\varepsilon_0\mathbf{E}) + \varepsilon''\varepsilon_0\omega\mathbf{E} \tag{2}$$

$$\nabla \cdot (\underline{\underline{\varepsilon}}\mathbf{E}) = 0 \tag{3}$$

$$\nabla \cdot \mathbf{B} = 0 \tag{4}$$

For dielectric materials, heating is done by electric field primarily through interaction with water and ions. The complex permittivity $\underline{\underline{\varepsilon}}$ is given by:

$$\underline{\underline{\varepsilon}} = \varepsilon' - j\varepsilon'' \tag{5}$$

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

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \tag{6}$$

Maxwell's equations can predict the electric field **E** as a function of position and time. The governing equation for the electric field is:

$$\nabla^2\mathbf{E} + k^2\mathbf{E} = 0 \tag{7}$$

For the electromagnetic field calculation, we used HFSS commercial software. HFSS is a commercial finite element method solver for electromagnetic structures from Ansoft Corporation. The acronym originally stood for High Frequency Structural Simulator. **HFSS** provides E- and H- fields, currents, S-parameters and near and far radiated field results. **HFSS** will automatically generate an appropriate, efficient and accurate mesh for solving the electromagnetic problem using the proven finite element method.

This programme uses the finite elements method and the nodal functions of the first order. The calculation domain is divided into tetrahedral subdomains and the field in each subdomain is properly defined by the values in the nodes of the tetrahedron.

We tried to obtain a very realistic model in our simulation. In the experimental part we considered a Teflon tray with mouldy corn seeds inside and in the numerical model we associated with each seed a parallelepiped with corresponding dielectric properties, as is shown in the next figures. In Fig. 1 we have the geometry for our simulation, and in Fig. 2 we can see that we defined different dielectric proprieties for the mouldy corn seeds and free from mould corn seeds.

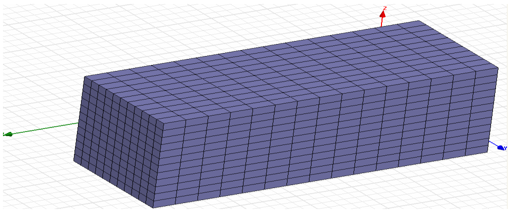


Fig. 1. The Teflon tray with mouldy corn seeds

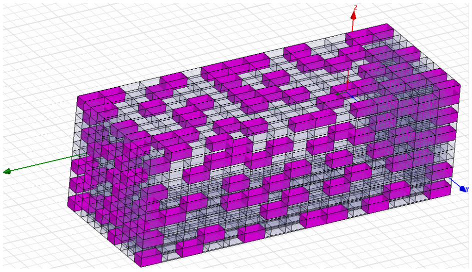


Fig. 2. Mouldy corn seeds and free from mould corn seeds

For this experiment we used an installation, microwave system, within the Laboratory of Microwave Technologies, Electrical Engineering Department, Faculty of Electrical Engineering and Information Technology, University of Oradea. 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.

As a result of the experimental data one may notice the necessity of the variation of the power generated by the magnetron for the adaptation of the charge impedance by modifying the position of the divers 1, 2 and 3 so that the reflected power would be zero or would tend towards 0. The maximum reflected power for an adapted enclosure must not exceed 20% of the direct power.

RESULTS AND DISCUSSIONS

In the research we have made using the lab installation with microwave system with cold air stream, we tried to see what happens if we dry mouldy corn and then we measured its rate of germination. The experiment was made on the corn seeds, type Turda Super (type semi early) using the power of the microwaves with and without air stream.

For each sample that we used we also did a numerical simulation, using the same microwave heating parameters as we used in the experimental part.

For the first sample we used 121.44 g of mouldy corn (kept into the water for one week). We dried it in the microwave field with cold air stream, using variable power (200W - 100W - 20W) for 15.5 minutes and then we obtained 105.01 g of corn.

From the numerical modeling we observe that the electromagnetic field has high values, as it can be seen in Fig. 3, that leading to high temperature area. This is the reason why we used cold air stream in the experiment, to limit the temperature in the seed bed.

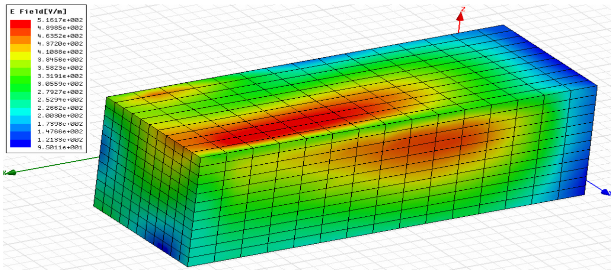


Fig.3 Electromagnetic field distribution in the mouldy corn seed bed

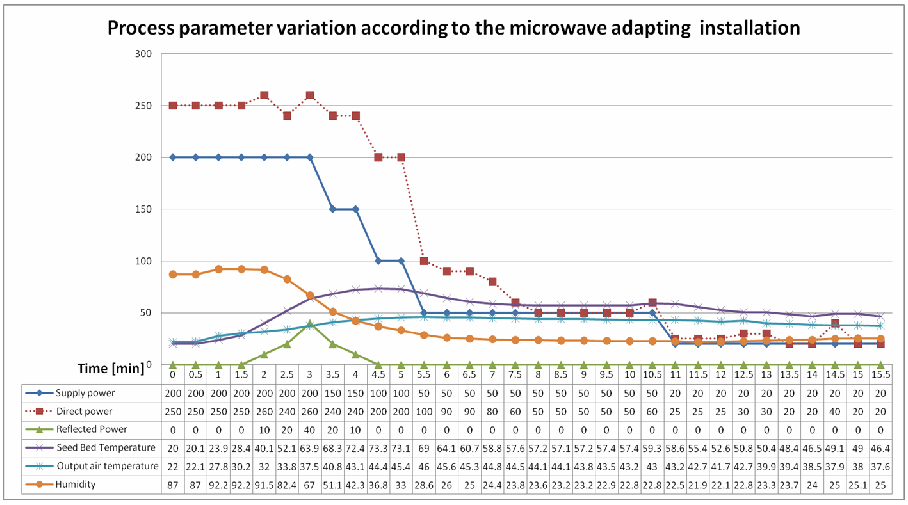
We remarked a difference between the initial and final mass of 16.43 g of eliminated water from the seed bed. The humidity eliminated from the seed bed is U=15.64%. Because we used only cold air stream, and not hot air stream, it can be seen that the water eliminated from the seed bed had a low value of 16.43 g. The temperature from the seed bed rose in the 5 minute at the value of 73.1^0C at a direct power of 200W (see Fig. 4).

Because we used a high power from the beginning, the humidity measured in the seed bed raised to 92.2 (see minute 1). The parameters obtained after drying are being presented in the next table (see table 1). The rate of the germination for this sample is G=5%, and the rate of the witness sample is G=10%.

Table 1

Parameters in variable heating

Variable Power	200W-100W-20 W/ 15.5 minutes
Initial weight	121.44 g wet corn
Final weight	105.01 g dried corn
Initial seed bed humidity	87%
Final seed bed humidity	25%
Humidity	U=15.64%
Germination	5%
Initial Seed Bed Temperature	20.1^0C
Final Seed Bed Temperature	46.4^0C
Initial temperature of the outside air stream	22.1^0C
Final Temperature of the outside air stream	37.6^0C



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
Supply power	200	200	200	200	200	200	200	150	150	100	100	50	50	50	50	50
Direct power	250	250	250	250	260	240	260	240	240	200	200	100	90	90	80	60
Reflected Power	0	0	0	0	10	20	40	20	10	0	0	0	0	0	0	0
Seed Bed Temperature	20	20.1	23.9	28.4	40.1	52.1	63.9	68.3	72.4	73.3	73.1	69	64.1	60.7	58.8	57.6
Output air temperature	22	22.1	27.8	30.2	32	33.8	37.5	40.8	43.1	44.4	45.4	46	45.6	45.3	44.8	44.5
Humidity	87	87	92.2	92.2	91.5	82.4	67	51.1	42.3	36.8	33	28.6	26	25	24.4	23.8

Time [min]	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5
Supply power	50	50	50	50	50	50	20	20	20	20	20	20	20	20	20	20
Direct power	50	50	50	50	50	60	25	25	25	30	30	20	20	40	20	20
Reflected Power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seed Bed Temperature	57.2	57.1	57.2	57.4	57.4	59.3	58.6	55.4	52.6	50.8	50.4	48.4	46.5	49.1	49	46.4
Output air temperature	44.1	44.1	43.8	43.5	43.2	43	43.2	42.7	41.7	42.7	39.9	39.4	38.5	37.9	38	37.6
Humidity	23.6	23.2	23.2	22.9	22.8	22.8	22.5	21.9	22.1	22.8	23.3	23.7	24	25	25.1	25

Fig.4. Parameters variation in variable heating 200W-100W-20 W/ 15.5 minutes., U=15.64%, G=5%, Using microwave heating with cold air stream

For the last sample we used the same mass of seeds as previous sample and we dried it at a constant power of 50W for 15.5 minutes using only the power of the microwaves, with no air stream (see Fig. 7).

The numerical simulation show that in this case that, using a lower microwave power of 50W, the electromagnetic field doesn't reach so high values (Fig. 5) as in the previous case, when we used even 200 W. Consequently, we could use only the power of the microwaves, with no air stream. Fig. 6 presents the electromagnetic field distribution in the mouldy corn seed volume.

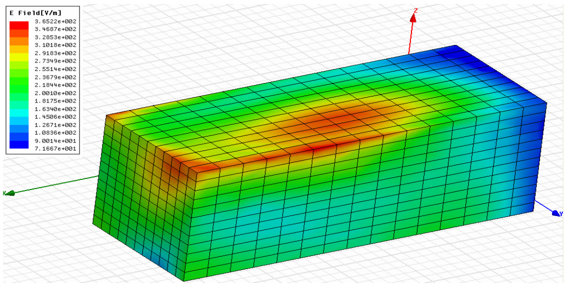


Fig. 5 Electromagnetic field distribution in the mouldy corn seed bed

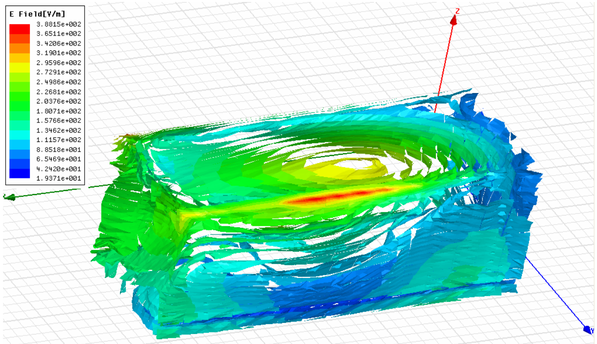


Fig.6 Electromagnetic field distribution in the mouldy corn seed volume

After drying we obtained 109.63 g of mouldy corn. The difference between the initial and final mass is 11.81 g of evaporated water from the seed bed. The humidity eliminated from the seed bed is U= 10.77 % (see Table 2).

The seed bed temperature had a constant growth from 19.3^{0}C to 52.2^{0}C and the outside air temperature from 24.04^{0} to 36.8^{0}C.

When testing we observed that there has been used more direct power because the mass is more compact. The rate of germination in this case is G=4%.

Table 2

Parameters in constant heating

Constant Power	50 W/ 15.5 minutes
Initial weight	121.44 g wet corn
Final weight	109.63 g dried corn
Initial seed bed humidity	62.73%
Final seed bed humidity	31.4%
Humidity	U=10.77%
Germination	4%
Initial Seed Bed Temperature	19.3^{0}C
Final Seed Bed Temperature	52.2^{0}C
Initial temperature of the outside air stream	24.04^{0}C
Final Temperature of the outside air stream	36.8^{0}C

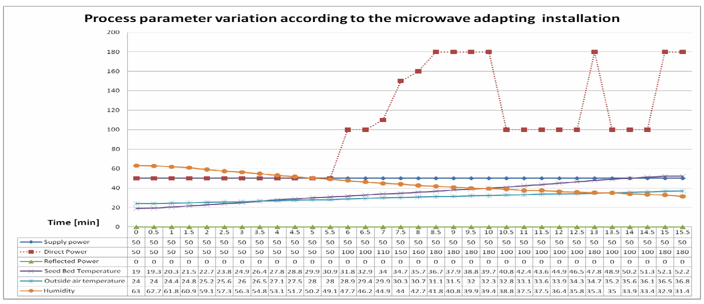


Fig. 7. Parameters variation in constant heating 50W/ 15.5 minutes., U=10.77%, G=4%, Using microwave heating

The germination is determined with germinators of type Linhard, sterilized; one uses filter paper moistened with tap water, kept under niche at $20^{0}C\pm2\text{-}3^{0}C$ (Boldor et al., 1981). The germination is considered finished when the root has a length equal to the length of the seed, and the stem has ½ this length (Davidescu and Davidescu, 1981). The germination rate of these two samples is being presented in the Fig. 8.

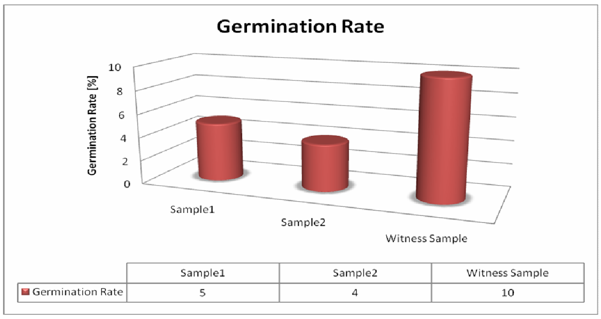


Fig.8. Germination Rate measured after 14 days

CONCLUSIONS

This study combines modelling with the experimental results in the behalf of finding out the appropriate formula between the applied energy and the material properties, with extension possibility for other cereal grains. The applicative part of this paper consists in the correlation between the numerical modelling and the experimental result. Considering the fact that this experiment was made on mouldy corn seeds, the germination of the witness sample being only 10%, this work is more interesting for the numerical model, but we want to extend it in future work, where the samples have higher germination. As a result of this experiment we may say that the continuous monitoring of the generated power is required, in order not to reach an excessive temperature.

The results of the numerical modelling help us determine the drying time and the appropriate drying power. For the first sample, when using a high microwave power, the numerical modelling show that the electromagnetic field has high values and based on these observations, we decided to use cold air stream in our experiment. For the second sample, the numerical modeling helped us decided the proper microwave power for which we could use only the power of the microwaves, without air stream.

We may say that it is important to use microwave with cold air stream to eliminate the high humidity and to have homogeneity of the temperature in the entire mass of the seeds.

REFERENCES

1. Bandici L., T. Leuca, P. A. Palade, 2009, Some Aspects Regarding the Optimization of the Electromagnetic Field Propagation in Microwave Structures, Journal of Electrical and Electronics Engineering, Vol.2, Nr.2, pp 7-12.
2. Boldor D., M. Trifu, D. Raianu, 1981, Fiziologia plantelor, Ed.Didact. si Pedag. Bucuresti.
3. Datta A.K., 2001, Mathematical modelling of microwave processing of foods An overview. Food processing operations modelling: design and analysis. New York, pp. 147-187.
4. Davidescu D., V. Davidescu, 1981, Agrochimia moderna, Editura Academiei R.S.R.
5. Dibben D.C., A.C. Metaxas, 1995, Time Domain Finite Element Analysis of Multimode Microwave Applicators Loaded with Low and High Loss Materials, Microwave and High Frequency, International Conferences, Cambridge (UK), pp. A3.1–3.4.
6. Leuca T., L. Bandici, P. A. Palade, I. Stoichescu, 2009, Numerical Analysis of the Electromagnetic Field in Microwave Processing of Forest Fruits, Journal of Electrical and Electronics Engineering, Vol.2, Nr.1, pp 64-67.
7. Metaxas A.C., 2001, The use of modelling in RF and microwave heating, HIS – 01, Heating by Internal Sources – Padua, September 12-14, 2001, pp. 319-328.
8. Metaxas A.C., J.D. Driscoll, 1974, Comparison of the Dielectric Properties of Paper and Board at Microwave and Radio Frequencies, Journal of Microwave Power.
9. Metaxas A.C., R.J. Meredith, 1983, Industrial Microwave Heating, Peter Peregrinus LTD (IEE), London, (UK).
10. Zhang H., A. K. Datta, I. Taub and C. Doona, 1999, Experimental and numerical investigation of microwave sterilization of solid foods, AIChE Journal.
11. Zhang H., Datta A. K., 1999, Coupled electromagnetic and thermal modeling of microwave oven heating of foods, Journal Microwave Power Electromagnetic Energy. - 1999. - Vol. 43.