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Changing Parameters of the Microwave Field in the Grain Layer

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Abstract: Thermal treatment is used for different grain crops during the processes of drying, disinfection and preparation to feeding, etc. The high cost of the processes is caused by the cost of energy and the energy-output ratio of the processes. The development of the processing regimes with the use of electric technologies in general and electromagnetic fields in particular can reduce the cost of the mentioned processes. It's necessary to take into account the types of the applied electric technologies, for example, Infrared (IR) fields, Microwave (MW) fields, etc. The use of MW fields allows reducing the cost of the thermal treatment on 15-20% depending on the process and type of the processing material.

Key words: Microwave field, thermal processing of grain, field strength, direct heating, dielectric

INTRODUCTION

Such processes of the postharvest treatment of grain crops as drying, disinfection, micronization and preparation for feeding require a thermal impact. All these processes possess a high ratio of energy consumption. The analysis of literature shows, that such consumption during the postharvest treatment is up to 20% on average in the countries with the developed agriculture, but with the unfavorable weather conditions.

This index reaches 40% for the countries with the unfavorable climate. Currently the equipment working on gas, diesel or other types of fuel tends to be used for such thermal treatment. At first the drying agent (working body) is heated by the flame of a burner, then there is a convective heating of the grain material which is ventilated by the drying agent. In this case there are significant losses due to the intermediate heating of the drying agent and raised energy consumption on drying because of the opposite direction of the gradients of the thermal processes. Considering all this, the development of energy saving technologies of the effects on agricultural materials including the use of the electro physical effects, is of special significance and importance (Kraszewski and Nelson, 1989; Nelson, 2008). Such devices as a microwave-convective dryer of the agricultural material and a microwave-disinfectant of the agricultural and food products are being developed.

The present research deals with the basics of dielectric heating which provides a direct heating of the grain material.

MATERIALS IN METHODS

Dielectric properties of materials: Dielectrics are a class of materials that are poor conductors of electricity, in contrast to materials such as metals that are generally good electrical conductors. Many materials, including foods, living organisms and most agricultural products, conduct electric currents to some degree but they are still classified as dielectrics. The electrical nature of these materials can be described by their dielectric properties, which influence the distribution of electromagnetic fields and currents in the region occupied by the materials and which determine the behavior of the materials in electric fields. Thus, the dielectric properties determine how rapidly a material will warm up in RF or microwave dielectric heating applications. Their influence on electric fields also provides a means for sensing certain other properties of materials which may be correlated with the dielectric properties, by nondestructive electrical measurements. Therefore, dielectric properties of agricultural products may be important for quality-sensing applications in the agricultural industry as well as in dielectric heating applications.

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A few simplified definitions of dielectric properties are useful in discussing their applications. A fundamental characteristic of all forms of electromagnetic energy is their propagation through free space at the velocity of light, c. The velocity of propagation v of electromagnetic energy in a material depends on the electromagnetic characteristics of that material and is given as:

$$v = \frac{1}{\sqrt{\mu.\varepsilon}} \tag{1}$$

Where:

μ = The magnetic permeability of the material

ε = The electric permittivity

The absolute permittivity, ε_a, can be represented as a complex quantity:

$$\varepsilon_r = \varepsilon'_a - j\varepsilon''_a \tag{2}$$

where ε_0 is the permittivity of free space (8.854 10^{-12} farad/m); the real part ε'_r is called the dielectric constant and the imaginary part ε''_r is called the dielectric loss factor. These latter two quantities are the dielectric properties of practical interest and the subscript r will be dropped for simplification in the remainder of this book. The dielectric constant ε' is associated with the ability of a material to store energy in the electric field in the material and the loss factor ε'' is associated with the ability of the material to absorb or dissipate energy, that is, to convert electric energy into heat energy. The dielectric loss factor, for example, is an index of the tendency of the material to warm up in a microwave oven. The dielectric constant is also important because of its influence on the distribution of electric fields. For example, the electric capacitance of two parallel conducting plates separated by free space or air will be multiplied by the value of the dielectric constant of a material if the space between the plates is filled with that material.

Agricultural materials such as cereals are polar dielectrics. In this case, the dielectric properties depend on the frequency of the acting field, material temperature, moisture content and other factors. The properties of water are also dependent. Water, in its liquid state, is a good example of a polar dielectric. The microwave dielectric properties of liquid water are listed in Table 1 for several frequencies at different temperatures as selected from data in the literature.

Penetration depth: When electromagnetic waves propagate to a loss material, part of the waves is reflected. The remaining part will penetrate into the material. But the strength reduces with distance. Figure 1 shows schematically the distribution power flow from two counter-sources when an electromagnetic wave strikes a dielectric material with high loss factor.

Table 1: Dielectric properties of water

	Temperature (°C)			
	T = 20		T = 50	
Frequency (Ghz)	ε'	ε"	ε'	ε"
0.6	80.3	2.75	69.9	1.25
1.7	79.2	7.90	69.7	3.60
3.0	77.4	13.00	68.5	5.80
4.6	74.0	18.80	68.5	9.40
7.7	67.4	28.20	67.2	14.50
9.1	63.0	31.50	65.5	16.50
12.5	53.6	35.50	61.5	21.40
17.4	42.0	37.10	56.3	27.20
26.8	26.5	33.90	44.2	32.00

The literature gives a great range of dielectric characteristics of agricultural material (Venkatesh and Ragavan, 2004; Grundas *et al*., 2008) but it's important to take into account that they can significantly differ even for the different varieties in the single crop.

The electric field penetration depth (d_p) of a material, is defined as the distance (m) at which an incident electromagnetic wave penetrates perpendicularly beneath the surface of a material before its intensity diminished by a factor of 1/e (e, Na Prion base, equal 2.71828) of its amplitude at the surface. The electric field penetration depth is expressed as:

$$d_p = c_1/(2\sqrt{2\pi f}[\varepsilon'(\sqrt{(1+(\varepsilon''/\varepsilon')^2)})+1]^{1/2}) \tag{3}$$

where, c_1 is speed of light in free space (3×10^8 m sec^{-1}) or calculated as:

$$d_p = (\lambda.\sqrt{\varepsilon'})/(2\pi.\varepsilon'') \tag{4}$$

Simulation of microwave exposure: It is necessary to develop new equipment for the carrying out of energy saving thermal treatment processes of the agricultural products including the use of high-frequency and super-high frequency currents for the mathematical modeling of the electromagnetic wave propagation and the thermal field in the product.

The software products of different developers are widely used for such work. One of such products is CST Microwave Studio. The results obtained by this software product are based on the method of the finite integration (Finite Integration Technique, FIT) which is a consistent sampler circuit of the Maxwell equations in an integral form. The obtained matrix equations of sampled fields can be used for the numerical modeling on the modern computers.

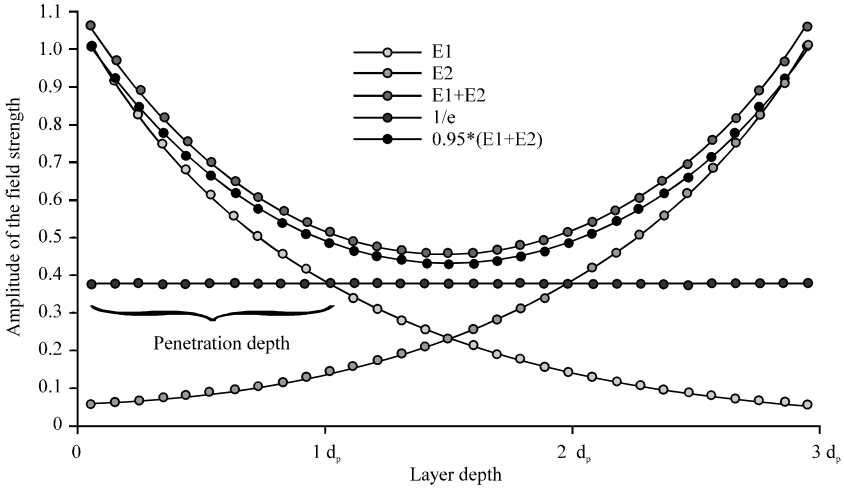

Fig. 1: Power flow from two counter-sources when an electromagnetic wave strikes a dielectric material with high loss factor

Besides, the algebraic properties of this theory of the sampled electromagnetic field allow using the laws of energy saving and the charge for the discrete formulation analytically and algebraically and providing a stable algorithm of the calculation by the numerical method in the time domain.

RESULTS AND DISCUSSION

At Fig. 1 the curve E1 characterizes the distribution of the electrical intensity from one source of the field; the curve E2 characterizes the distribution of the electrical intensity from the source, directed to the first one.

The line 1/e shows the rate of electrical intensity, that characterizes the penetrating depth of the field into the material.

The curves E1+E2 and 0.95x(E1+E2) characterize the total field of two oppositely arranged sources without losses and with them respectively.

The information about the d_p values of different materials depends on the dielectric properties and is necessary to calculate the constructive parameters of the zones of microwave impact.

Using the information from the literature (Vankatesh and Ragavan, 2004; Grundas *et al*., 2008; Warchalewski and Gralik, 2010) the zone of microwave-treatment of grain material has been designed in the programming complex CST Studio (Fig. 3). The electromagnetic wave spreads from the source along waveguide. At the waveguide outlet there is a flu or plastic screen which prevents the processed material from entering into the waveguide. The grain moves vertically down along the products pipeline. In this case the products pipeline is completely full.

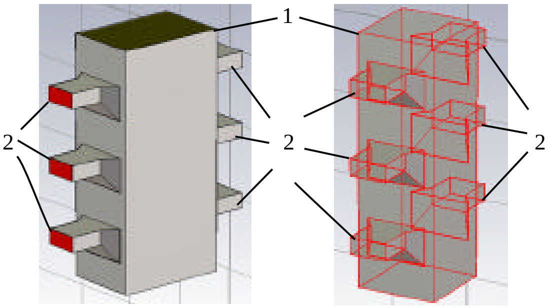

Fig. 2: Three-dimensional model of microwave exposure zone; 1: product pipeline (microwave band-processing); 2: sources with microwave waveguides

Figure 2 shows the example of the results of modeling the electromagnetic field intensity distribution in the zone of microwave impact. It is worth mentioning that the modeling has been carried out at the complete filling of the zone of electro magnetic impact with the processed material.

Beside the graphic picture of the results of the modeling we received the numerical characteristics of the field intensity which were recorded into the separate file and were used in the further work.

Figure 4 shows the graphs of matching of the results of the calculated and experimental data on the electromagnetic field propagation.

The curve 1 characterizes the exponential law of the electromagnetic wave decay in the material and it has been obtained from:

$$E = E_0 \cdot e^{-kx} \tag{5}$$

Where:

E_0 = A field amplitude at the waveguide outlet
k = A coefficient of decay, caused by the dielectric properties
x = A coordinate (position)

The curve 2 shows the numerical values, obtained in the software complex CST studio for the zone with 1 magnetron. The image of the curve 2 is caused by the wave character of the field distribution. The curve 3 shows the data, received by the measuring device at Fig. 2. All curves have been given per unit to exclude the efficiency effect of the source and show the matching of the character of the obtained experimental and theoretical dependences. In some cases the deviations of the data received by the model developed in CST Studio and the experimental data differ on 30% because of the wave distribution of the field as has already been mentioned above.

Thus, the deviations of the experimental data and the data, described by the exponential dependence are within 10% at the distance equal to the depth of field penetration

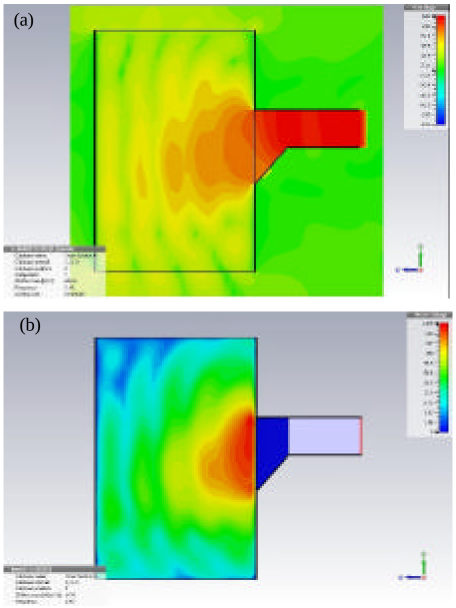

Fig. 3: Results for barley modeling humidity of 17.6%; a) the amplitude of the microwave field, b) heating power losses in the material due to microwave heating

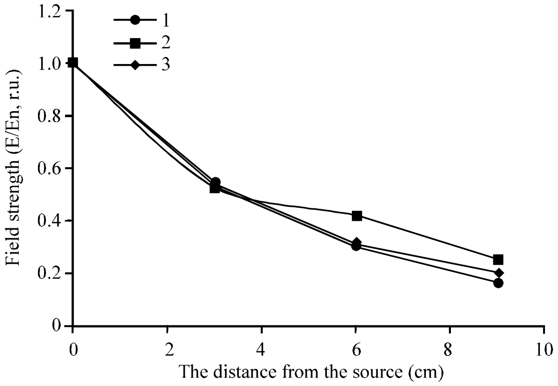

Fig. 4: Distribution of the field strength with distance from the source; 1: exponential law of distribution (calculated); 2: calculated according to the model, resulting in CST studio; 3: by the experimental data

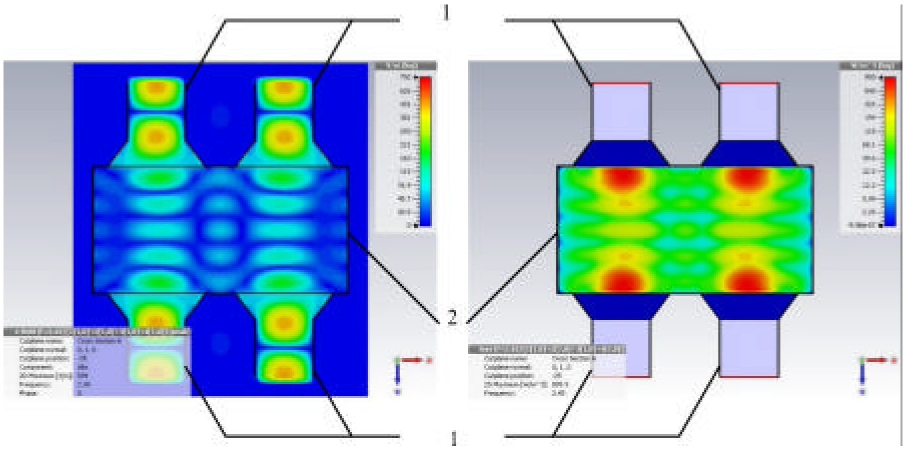

Fig. 5: Distribution of the electromagnetic wave energy in the dielectric layer with a high dielectric loss factor; a) field strength; b) dissipated power; 1: sources of the microwave field with waveguides, 2: the microwave processing chamber

into the layer of kernels. With such application of the device, the zone of microwave impact is a cylindrical chamber, where the products pipeline is located coaxially with the outer casing. Thus, the material, passing from the loading zone to the source and to the unloading, is undergone the increasing impact of EMF. Such application allows providing the required a uniform heating of grain, but in case of high initial grain moisture the speed of the heating is too high that results in the damage of its hull and in grain micrionization. The magnetrons with the capacity of 0.5÷3 kW and the field frequency of 915 MHz or 2.45 GHz can become the other variant of the applied sources (Antic and Hill, 2003; Yadav *et al*., 2008; Nelson, 2015; Tireki *et al*., 2006; Mohapatra *et al*., 2014). These sources are more affordable and require less maintenance. They do not need any water cooling as a rule. In this case, the supply of microwave energy to the product pipeline can be done either over the conveyer where the grain moves or through the waveguides installed in the side walls if the material vertically passes in a dense flow.

The depth of the electromagnetic wave penetration into the material is a limiting factor in the application of this variant. The depth of penetration is considered a thickness of a layer on which the field weakens in e times. To provide field uniformity, the sources can be situated in opposition to each other (Fig. 5).

In this case the depth of penetration affects the uniformity of microwave field propagation and the energy, released in the definite layers of the material.

CONCLUSION

According to the mentioned above we can make a conclusion that to develop of the equipment for electro physical drying and disinfection of grain products it is necessary to take into account the following:

- The uniformity of heating of the processed material can be achieved with the uniform distribution of electromagnetic field which can be ensured by the waveguide form, the form of the chamber of microwave-treatment and the scheme of the position of sources
- The thickness of the layer treated with microwave field should be $2d_p$ to provide uniformity
- It's necessary to use the packages of software application (COMSOL, FEMLAB, QW3D, CST Studio, ANSYS) to reduce the cost of the development of such difficult equipment
- Dielectric properties of food materials govern efficiency and uniformity of dielectric heating. There has been a general lack of those dielectric property data for most food products as influenced by temperature and moisture contents

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