Abstract

This paper will review some recent results using finite elements in the quest to acquire informed design knowledge in some of these processes. The work described in this paper uses a 3D finite element software, in the personal computer. Where possible validation with other numerical techniques or by thermal imaging will also be presented. The use of symmetry allows larger systems to be modelled.

Index Terms

Microwave heating, high frequency, finite elements, dielectric, multimode cavity, modelling.

1. Introduction

It is known that in the last years it was put a great accent on the heating of the dielectric materials at microwave frequencies. The appearance of the microwave ovens has a great effect on the industry, because it offers a clean and quick mode for the heating of different materials, although for most of the industrial applications, the coupling of the microwaves at the load cavity needs special techniques and is executed using systems called applicators.

Heating in a microwave field is based on the principle of the interaction between the electromagnetic field and the dielectric materials. The specialty of the process consists in the fact that the heating takes place in the material, in depth, without heat transfer by conductivity. The absorbed power is concentrated in the zones in that the material has dielectric losses, the heating being sudden and selective. The medium that surrounds the material is not heated, and the energetic efficiency of the process is very good. From the industrial point of view, the microwave installations can easily integrate in the classical technological process.

The domains in that these techniques are applied vary for the drying on a large scale of textile materials, of wood, of paper to the heating of alimentary products. Although such processes were used a lot at dielectric heating, solitary or combined with conventional energy to form combined systems, the specific design is still based on attempt, respectively error and experience. This is the reason why, in the last years it was accentuated the using of the computer assisted technique, that led at the reduction of the number of prototypes that must be made before the realization of the complete commercial system. This is also the reason why in this paper we will review some recent obtained results, using finite elements, to assimilate some knowledge regarding the design in some of these processes.

2. The modelling of heating devices in a microwave field

The heating process with microwaves in the industry and domestic domain is in a quick increase, due to the short time that is necessary for the heating and the advantages offered by this. The development of CAD instruments made possible the attainance of this object, in the conditions of a very good relation quality-price.

The calculation of the distribution of the electromagnetic field in 3D finds its application also in this domain. This is the reason why many algorithms were realizes and developed for the solving of the 3D electromagnetic wave propagation. In the case of the microwave heating, both fields – electromagnetic and thermic, need to be determined local. The algorithms that can be used for the solving of partial differential equations for the two fields present different aspects regarding the precision, the facility grade of the implementation, the calculation time – CPU. These algorithms are very bounded to the physical phenomena, the mathematical formulations and the numerical methods.
that are used. The choosing of an adequate algorithm depends on the asking of the application. The geometrical shape, the nature of the boundary, the proportion between the wave length and the sizes of the applicator, the properties of the materials, and others are factors that must be considered.

The modeling of microwave devices needs the theoretic knowledge of existing phenomena and the numerical methods in the frequency and time domains. Thus, the methods that characterize the time domain are based on the differential form of Maxwell’s equations depending on time, the best known being the method of finite differences (FDTD), and the best known method that characterizes the frequencies domain is that of finite elements (FEM) and the techniques regarding the global integral equations, the method of boundary elements (BEM).

The FEM Method is an instrument easily applicable to structures with an arbitrary geometrical shape, nonlinear behaviors (in the time domain), anisotropic materials and materials with losses, involving few matrix inversions and very simple limit conditions in closed structures. Nevertheless in unlimited problems there are requested absorbent limited conditions or infinite elements. Regarding the boundary problems, this can be opened. In this case except the global integration techniques, the infinite space can be modeled by an artificial limit that surrounds the discretised region.

The numerical methods that were applied divide the domain in subregions forming a network. The sensitivity of the result depends on the grade of division of the domain. Generally, using a compact network secures a correct result. However, a very large number of elements leads to the increase of the calculation time.

The study of the dielectric properties of the materials at microwave frequency, materials that must be processed, is essential for the projection of microwave installations. The size that described the behaviour of the dielectric under the influence of the microwave field is the complex permittivity, written $\varepsilon^*$ that has the expression:

$$\varepsilon^* = \varepsilon' - j \varepsilon''$$

where $\varepsilon'$ is the dielectric constant and $\varepsilon''$ is the loss factor that generates the energy quantity transformed in heat. The proportion $\varepsilon''/\varepsilon'$ is known as the losses angle tangent, written $\tan \delta$. Both $\varepsilon'$ and $\varepsilon''$ are dimensions depending on the frequency, $f$, the temperature, $T$, and the humidity in the material.

### 3. Microwave heating applications

The microwaves are used, in great part, for the thermic processing of materials like food, ceramics, wood, paper, rubber, textiles. They are also used for the biological heating of textures in biomedical applications. The results we present in this paper were obtained using a 3D firm soft, built on finite elements, because in comparison with a soft based on the method of finite differences, this can be applied also to the objects with a less regular shape.

Figure 1 shows a simulation of a food sample in a domestic oven, placed at the bottom of the cavity on a teflon scale. The present form of alimentary products was simplified in regular geometric shapes, making more easy the introduction of data in the soft. The list of conventional signs shows the complex component of the electric field from the closed multimode applicator, feeded through a wave guide placed sidewise as it can be seen in the figure.
The software allows the creation of any transversal section plane, to observe the distribution of the established field. Figure 1.b presents the same cavity as in figure 1.a, but due to the symmetry only half of the system was simulated; this leads to the reduction of the calculation time.

Figure 2 shows the results of a simulation made for a parallelepiped cavity with the dimensions $300 \times 391 \times 292$ [mm], and the dielectric material $200 \times 200 \times 25$ [mm], having the relative permittivity $\varepsilon_r = 2.5$. The simulation was made to MaxDeltaS = 0.03386 with 13 steps of adaptation, 41352 tetraedra, and the time that was necessary for the solving of the problem was 4h and 50min. The working frequency is 2.45 GHz.

By changing the feeding mode from the simple one to the one through more wave guides, it results a more uniform distribution of the electric field. The distribution of the electric field will determine the power density in the volume of the material, that is then transferred in a specific heat. Figure 3. a presents such a cavity with two guides keeping the same dielectric as that in figure 1. The position of the dielectric is also important when we desire a more uniform field; so, in figure 3.b it is shown the case in that the dielectric was lifted on the axis $0z$ with 100 mm. In figure 4.a it is shown the result of the simulation of a parallelepiped cavity, with the sizes $204 \times 84 \times 34$ [cm], used in industrial processes of drying of dielectric materials as sheets (cardboard, animal leather). Due to the symmetry and regular shapes, just half of the cavity was modelled, at the frequency 2.45 GHz, the dielectric having $\varepsilon_r = 5.7$. In figure 4.b we considered the same dielectric as in the figure 4.a, we just changed its position, from 2 to 3 cm on the axis $0z$. 

![Figure 2. The distribution of the electric component of the field through the wave guide and the dielectric](image)

![Figure 3. The CmplxMag_E distribution in the dielectric and port function of position](image)

![Figure 4. The distribution of the electric component of the field through the wave guide and the dielectric](image)
4. Conclusions

Heating in a microwave field of dielectric materials has more advantages than that with conventional methods, because as it can be seen in the results of the presented simulations, this is uniform, it is in the entire volume, and it is also quick. The distribution of the electric component of the electromagnetic field, the CmplxMag_E component, that is shown in different transversal sections through the wave guide and the dielectric, and then another representation of the same component in the base plane 0z. Analyzing the results we obtained, we can observe quite uniform and symmetrical values of the electromagnetic field. We must mention that such results were obtained after more adaptations of the problem. The high field regions are easily detected, and the applicator can be modified to eliminate them and to obtain a more uniform distribution.

REFERENCES