Microwave Applicator with Conveyor Belt System

Abderraouf Methlouthi[1,2], Olivier Rouaud[1,2] and Lionel Boillereaux[1,2]
[1]ONIRIS, CNRS, GEPEA, UMR6144, Nantes, F-44322 France
[2]Université Nantes Angers Le Mans, France,
*corresponding author: abderraouf.methlouthi@oniris-nantes.fr

Abstract: Industrial microwave ovens are widely used in agri-food and chemical applications. Resonant cavities are used to speed up chemical reactions and have the advantage to be small sized and efficient in terms of microwave distribution. These multimode cavities are considered as batch ovens where a small amount of products is treated. Rotating plates are added in the cavities to ensure a homogeneous power distribution. For continuous treatments, microwave tunnels can be used. In these ovens the microwave distribution is supposed to be homogeneous. Due to the difficulty to measure the electromagnetic field, this assumption is difficult to prove in the case of industrial plants. The aim of this study is to simulate the behavior of the electric field inside a microwave applicator with conveyor belt system using Comsol 3.5a. The numerical results are discussed and experimental validations (from a qualitative point of view) are presented.

Keywords: microwaves, finite elements, heat transfer

1. Introduction

Applicators with conveyor belt systems can be used in industry for multiple applications. Microwave applicators with conveyor belt systems are rapidly spreading due to the speed of the process and its efficiency [Metaxas & Meredith, 1986]. Conveyor belt carries load through the input and output ports of the industrial applicator. To improve thermal treatments, it is necessary to understand the different phenomena that occur inside the applicator. In case of microwave conveyors, it is difficult to predict the behavior of electric field inside the treatment zone. Thus, a numerical study is well suited to calculate electric field inside and predict its effect on loads. Many numerical techniques have been used to model microwave heating applicators with different loads. These methods include finite differences, finite elements, transmission line methods and others [Dibben D.C and Metaxas, 1994, 1997; Al-Rizzon et al, 2005; Dominguez-Tortajada et al, 2005; Yakovlev, 2006; Hallac, A and Metaxas, A.C, 2006].

This paper presents a numerical study of the electric field in an industrial microwave conveyor belt and its effect on load using COMSOL® code with qualitative experimental validation.

2. Material

The continuous industrial microwave applicator with conveyor belt is designed by MES®. Microwaves are generated by 6 magnetrons, each of them delivers a power of 1.2 kW at 2.45 GHz (figure 1). Magnetrons are disposed in quincunx to ensure homogeneous distribution of the electric field. Electromagnetic waves are sent through rectangular radiating waveguides at the top of the tunnel in TE10 mode. Each of the radiating waveguides is equipped with 5 slices through which microwaves are sent to the treatment zone (figure 2). Figure 1 presents a 3D simplified view of the loaded microwave tunnel with reduced microwave traps (for simulation considerations) and figure 3 presents detailed top plan view of the tunnel.

Figure 1. Loaded continuous microwave conveyor bels-system, 3D view

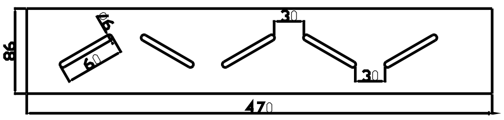

Figure 2. Down plan of one radiating waveguide showing slices, dimensions are in millimeter

Generators 1, 2 and 3 (radiating waveguides 1, 2 and 3 respectively) can only deliver full power and generators 4, 5 and 6 can deliver variable power thanks to their regulation systems. Due to technical problems, generator 1 is turned off. Treatment zone is a metallic enclosure with small entrance and exit for loading and unloading foodstuff. Because multiple reflections can occur in this cavity, the electric field can not be predicted by a simple analytical solution. The outer length of the cavity is 173 cm but the inner dimensions of the treatment zone are 150×45×45 cm3. Difference of dimensions between inner and outer sides of the treatment zone is due to armoring and for managing magnetrons positions.

Microwave traps are used for security reasons; actually, they are made of polyvinyl chloride (PVC) pipes, assumed to be transparent to microwaves, and filled with water. The water flow circulating in these pipes insures a full absorption of microwaves at the entrance and the exit of treatment zone with small temperature variation of water depending on the flow rate. These traps set a maximum height for the load, the entrance height is only 7 cm so treated foodstuff should be small enough to enter the treatment zone. The conveyor belt system has multiple speeds going from 0.35 m/min to 2.62 m/min and it is made of polytetrafluoroethylene (PTFE/Teflon). An air extractor is installed on the top of the treatment zone to avoid the penetration of steam inside the waveguides. Other equipments are added to the conveyor for multi-energy studies such as hot air generator and steam inlets but they are not used for the current study.

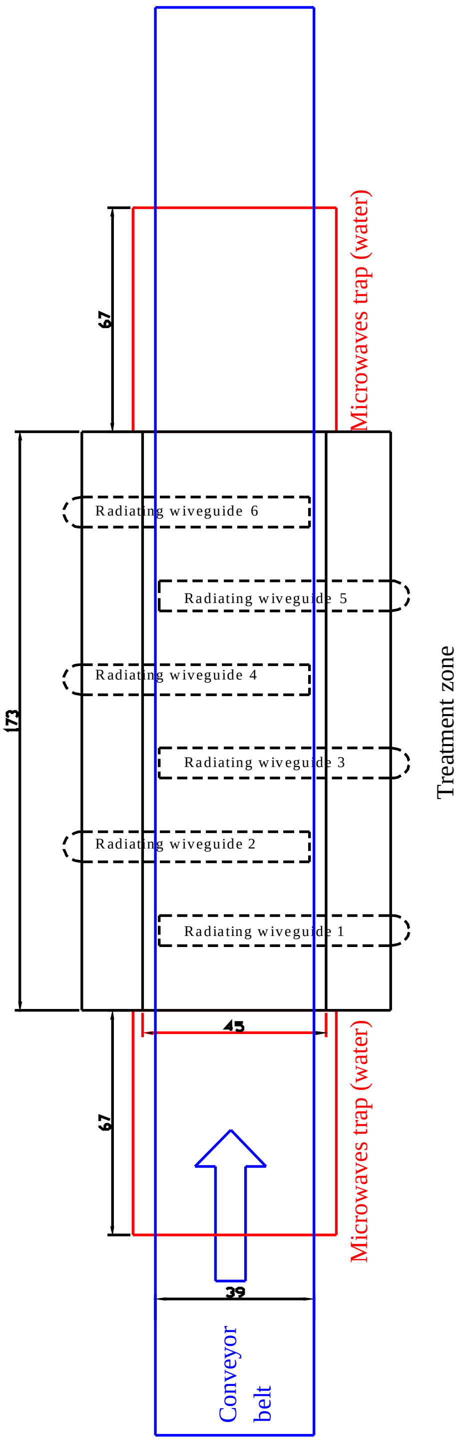

Figure 3. Continuous microwave conveyor belt system, top plan. Dimensions are in centimetres

3. Simulation

Numerical simulation for such a complex geometry is quite interesting due to difficulties of experimental validation. Actually, estimation of electric field inside treatment zone is difficult. Inside waveguides, microwaves are supposed to be at TE_{10} mode and positions of maximum values of electric field are supposed to be in front of slices to ensure a maximum transfer of energy to treatment zone.
For computing, COMSOL® multiphysics code is used. It is well suited for electromagnetic and radiofrequencies simulation problems coupled with other phenomena. Its only disadvantage is its need of memory for computing.
Magnetrons are assimilated to an electric transverse field (TE_{10}) at the entrance of the radiant waveguides. Microwave traps are computed as perfect match layer (PML) to consider the total absorption of microwaves by water flow, which explains the shortened length of the traps. For meshing, standard tetrahedral meshes are used with refinement near slices for more precision and inside loads due to difference in material.
Treatment zone and inside the radiant waveguides are set as air (dielectric constant equal to 1 and dielectric loss equal to 0) and the load used is agar gel at 2% which properties are listed on table 1. For simplification, properties of agar gel are considered constant.
Actually, properties depend on different factors such as density, temperature (Nelson 1992) which are fundamental for the behaviour of the load.

Table 1. Properties of agar gel

Properties	Description	Value
Cp	Heat capacity	4180 J/kg K
k	Thermal conductivity	0.6W/mK
ρ	Density	1070kg/m^3
ε’	Dielectric constant	73.6
ε’’	Dielectric loss	11.5

Two simulations are made to compare the electric field behaviour between two configurations: unloaded and loaded cavity. First computation is for the unloaded applicator. It was computed using COMSOL® multiphysics 3.5a with RF module installed in SUN workstation equipped with 2 dual core AMD® processors and 20Gbits RAM memory. A total of 582,720 tetrahedral mesh elements were used, which is equivalent to 3,820,358 freedom degrees. Due to hardware limitations, a stationary iterative solver was used, GMRES (generalized minimal residual method), which is an iterative method for the numerical solution of a system of linear equations. The method approximates the solution by the vector in a Krylov subspace with minimal residual. It was combined to Geometric Multigrid preconditioning method to speed up convergence. This preconditioning method uses successive over-relaxation vector as pre-smoother and post-smoother and as a coarse solver PARDISO (PARallel DIrect SOlver). The relative tolerance was set at 10^{-6}.
The second computation is for loaded applicator. Loads are agar gel blocs of 10×5×2 cm3 dimensions and 100 g weight each. A total of 22 blocs of agar at a distance of 8 cm between 2 successive blocs and lined up in 2 rows distant by 11 cm. To get the mesh independence, more meshes were needed for loads due to difference in material properties. A value of 0.025/√73.6 is set as a maximum dimension for a single mesh in load zones which makes a total of 2,434,999 meshes and 17,868,127 degrees of freedom. This configuration needs a workstation with 240Gbits RAM memory. For solvers, the same solver settings were used.
Figure 4 shows the meshed geometry in the case of loaded treatment zone.

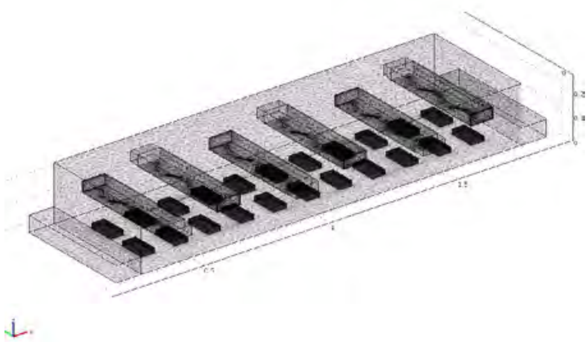

Figure 4. Meshed loaded geometry

Computation time for unloaded cavity is about 18000 seconds and for loaded cavity is about 52000. Due to hardware limitations, mesh independence proof wasn’t possible. A second computation is performed to evaluate the influence of the electric field on the product by studying the evolution of temperature inside the product. For these two computations, a stop heating condition was settled by stopping heating once the temperature reaches 100°C. We suppose also that heating occurs only by conduction inside the product.

4. Results

Figures 5 and 6 present the norm of electric field at 2 different cross sections and figures 7 and 8 present the total energy distribution at the same cross sections. Difference of length between the sections is due to the presence of microwave traps in the bottom of the applicator. These figures show the non uniformity of the electric field distribution in the treatment zone. We can also observe that electric field is more intense near the output of the applicator. This invalidates the hypothesis of considering the electric field inside a conveyorized applicator as uniform.

With the presence of load, which is composed mostly of water, the major part of energy is absorbed by agar gel. Differences between figure 5 and figure 6 show that conveyorized applicator is designed to produce higher electric field near application zone (slice at z=2cm coincides with the upper surface of load samples). Actually, electric field values at z= 2 cm can reach 2.77×10^4 V/m where at the same coordinates (x,y), at y= 10 cm they decrease up to 10^4 V/m.

For static simulation, the electric field distribution is non uniform but it is not the proof of non uniformity during continuous treatment. The difference between loaded and unloaded treatment zone is clearly seen through the figures. Loads absorb the total amount of microwave energy produced. At z= 10 cm, the electric field is more intense than near load samples.

The non uniform distribution of energy can be found in figure 9 that shows the temperature of each load and its distribution. Heat transfer was computed for a continuous heating during 150 s which is the average time to reach 100°C under real conditions starting from 12°C as initial temperature. Carried out experiments proved that 150 s is the necessary heating time needed to reach 100°C. Depending on their position, loads reach high temperatures or stay near the initial temperature. We observe also that the heart of the sample doesn't reach high temperatures

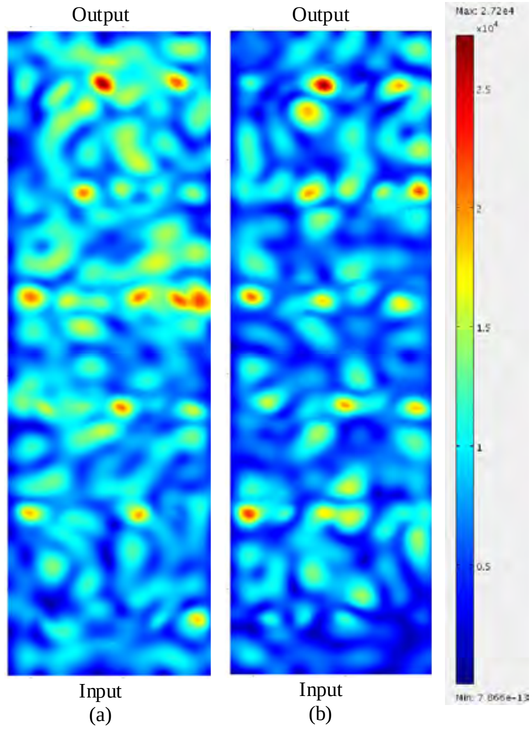

Figure 5. Electric field (V/m) distribution for unloaded (a) and loaded (b) treatment zone, slice at z=10 cm

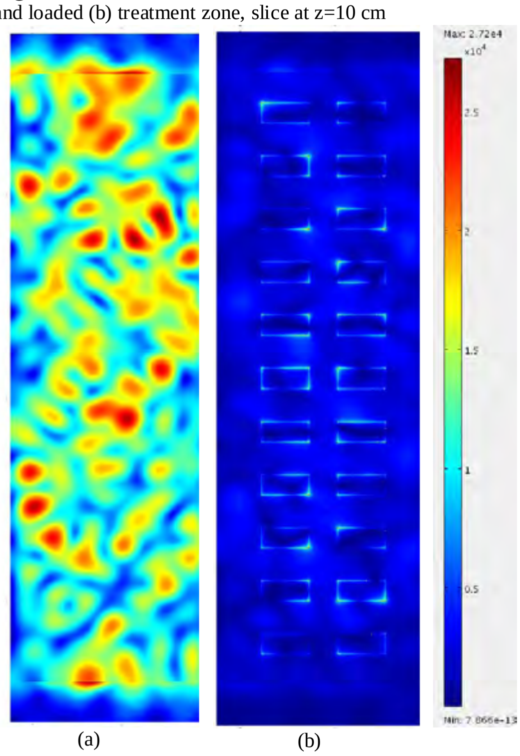

Figure 6. Electric field (V/m) distribution for unloaded (a) and loaded(b) treatment zone, slice at z=2 cm

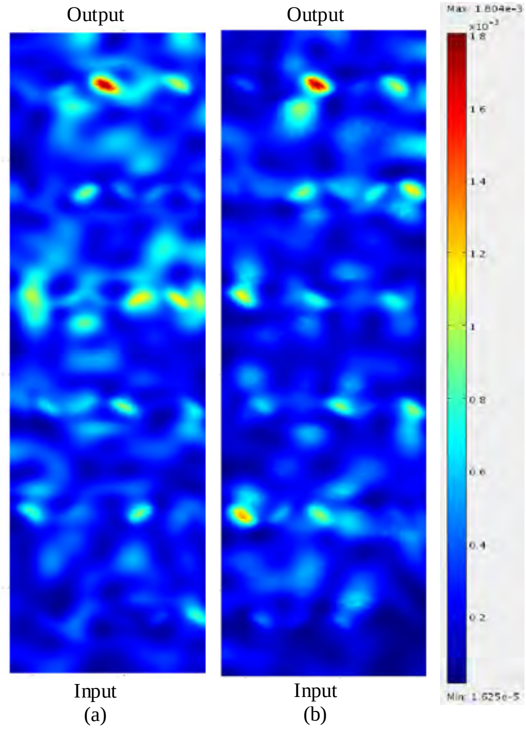

Figure 7. Total energy (j/m3) distribution for unloaded (a) and loaded(b) treatment zone, slice at z=10 cm

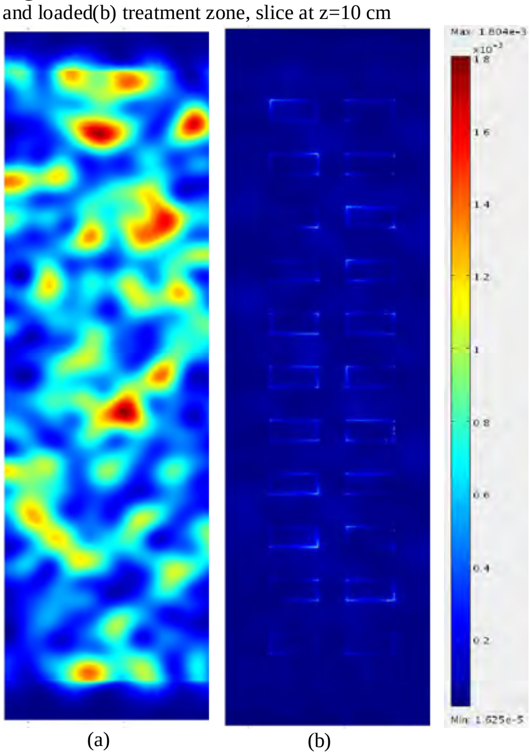

Figure 8. Total energy (j/m3) distribution for unloaded (a) and loaded (b) treatment zone, slice at z= 2 cm

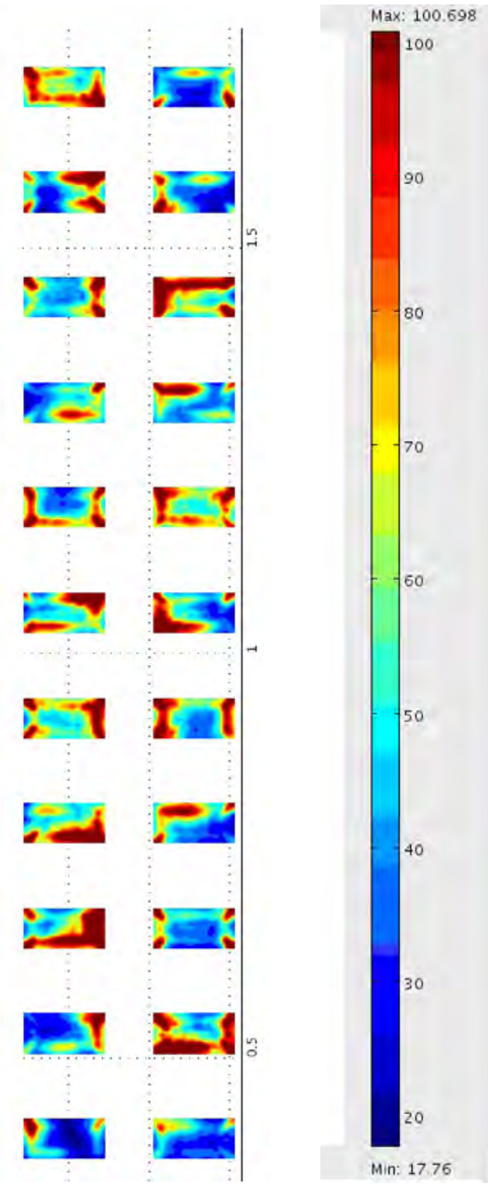

Figure 9. Temperature (°C) distribution inside loads after heating time of 150s, slice at z=1 cm.

while the outer sides are at higher temperature levels. The temperature evolution inside the different samples is linear and the unexpected result was the low level of temperature after 150s of treatment. Figure 10 shows the temperature rise for the 22 samples inside the treatment zone and it is evident that the temperature doesn't reach 100°C while it is the case for experiment results occurring under the same conditions.

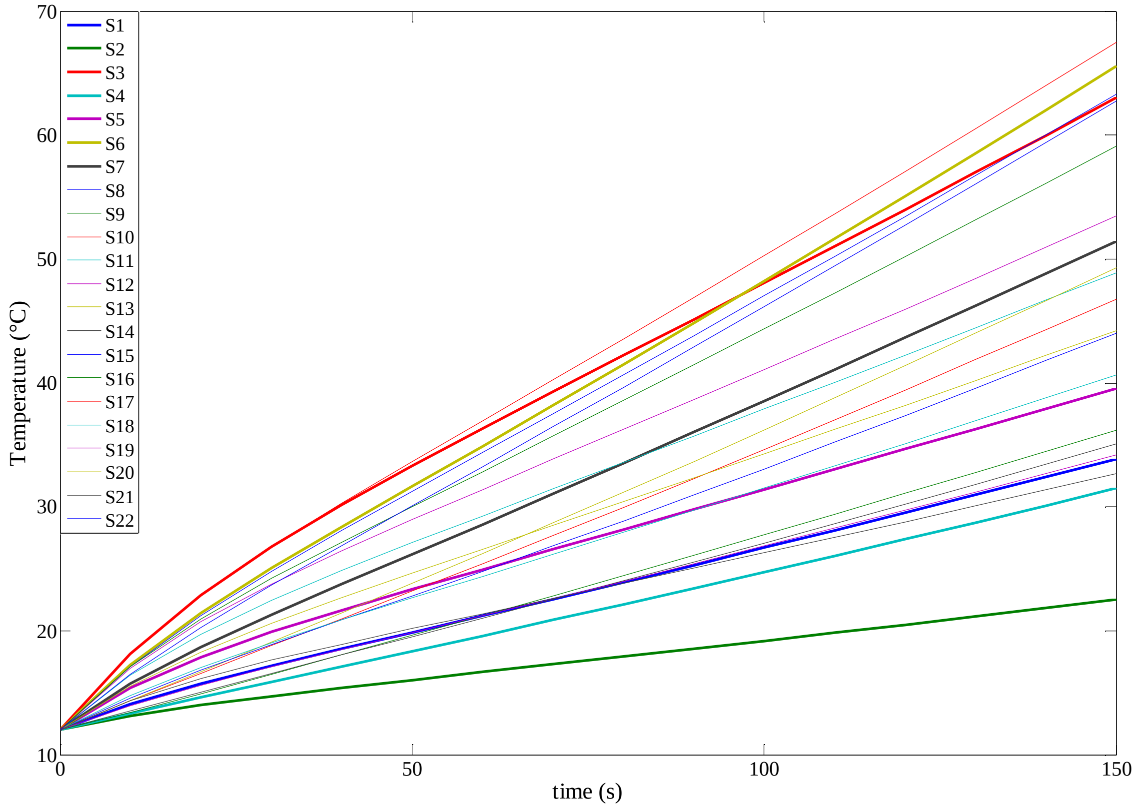

Figure 10. Temperature evolution for different samples inside treatment zone (samples are numbered from input to output from right to left (S1 is the first right sample starting from the input)

The difference between the experiment and the numerical result is due to the hypothesis of absence of mass transfer and non shape change of samples during treatments.

5. Conclusions

Computations of loaded and unloaded microwave applicator with conveyor belt system were carried out. The non uniformity of the distribution of electric field and total energy was proved, on one hand, by estimation of the electric field and total energy distribution in treatment zone and by the estimation of temperature distribution in loads on the other hand.

However, these computations under the assumption of null speed for the conveyor belt, the real challenge and most interesting computations are the continuous treatment at different speeds and their validation by experimental study which is the main subject of the current studies.

6. References

1. Al-Rizzon et al, a finite Difference Thermal Model of a Cylindrical Microwave Heating Applicator Using Locally Conformal Overlapping Grids: Part 1-Theoretical Formulation, *Journal of Microwave and Electromagnetic Theory*,**40(1)**, pp. 17- 29 (2005).

2. Dibben, D.C and Metaxas,A.C, Finite Element Time Domain Analysis of Multimode Applicators Using Edge Elements, *Journal of Microwave Power and Electromagnetic Theory*, **29 (4)**, pp. 224-251(1994).

3. Dibben, D.C and Metaxas,A.C, Frequency Domain vs Time Domain Element Methods for Calculation of Fields in Multimode Cavities,

IEEE Transactions on magnetics, **33(2)**, March, pp. 1468-1471(1997)
4. Dominguez-Tortajada et al, Load Matching in Microwave Heating Applicators by Means of the Genetic Algorithm in Optimization of Dielectric Multilayer Structures, *Microwave and Optical Techology Letters*, **47 (5)**, December, pp. 426-430(2005).
5. Hallac, A and Metaxas, A.C, Modeling of Industrial Conveyorized Applicators Using Higher Order Vector Finite Elements, *Journal of Microwave Power and Electromagnetic Theory*, **40(2)**, pp. 101-108 (2006).
6. Metaxas, A.C and Meredith, R.J, Industrial Microwave Heating, *IET (the Institution of Engineering and Technology), London* (1986).
7. Nelson, Stuart O., Measurement and applications of dielectric properties of agricultural products. *IEEE Transactions on Instrumentation and Measurement*, **41(1)**, February: 116-122 (1992).
8. Yakovlev, V., Examination of Contemporary Electromagnetic Software Capable of Modelling Problems of Microwave Heating, *Advances in Microwave and Radiofrenquecy Processing*, **Springer Verlag**, pp. 170-190 (2006).

7. Acknowledgements

Loaded treatment zone computation was accomplished thanks to the cooperation of Hervé Tortel of Institut Fresnel of Marseille who gave us the access to the 240GBits RAM workstation.
Current work has received the financial support of National Research Agency under the project ALIA-08.