NUMERICAL SIMULATION OF THE MICROWAVE PASTEURIZATION PROCESS OF SOME FOOD LIQUIDS

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ABSTRACT: *The paper deals with numerical simulation by finite element method of microwave pasteurization process. The comparative study is focused on two liquids: milk and apples juice. Information regarding the state of the concerning the characteristics of pasteurization process and its dedicated installations are presented. The computerized results obtained from numerical simulation agree with experimental results from the state of the art, validating the models. These emphasize that microwave pasteurization process is very efficient in the removing the pathogen components in very short time, keeping the nutritive elements under conditions of industrial applicability.*

KEYWORDS: microwave, pasteurization, temperature, numerical simulation

1. INTRODUCTION

Milk is one of the foods that can be consumed in its natural state, being the only food product, with the exception of honey, whose only function in nature is to serve as food. It can be defined as the fresh, whole secretion obtained by complete milking of healthy mammals [1].

Juices are products that fully preserve the nutritional value of fruits and vegetables, their taste and aroma [6].

Microwaves are believed to inactivate enzymes and kill microbes mostly through conventional thermal mechanisms [7].

The products are subjected to the thermal treatment of microwave heating in a pressurized chamber to ensure the long-term preservation of the products.[2]

Spoilage of fruit juices is generally limited to enzymes and microorganisms [8]. Pasteurization of fruit juices is intended to perform two important functions: inactivating unwanted enzymes and destroying spoilage microorganisms [9]

The heat treatment applied to the milk must ensure the destruction of the turbeculosis bacillus and all pathogenic microbes, so that the milk meets the hygienic-sanitary norms provided by the standard [3].

Most studies were used to investigate the possibility of shelf life, improvement of pasteurized milk, application microwave energy to inactivate milk pathogens, or uneven temperature distribution during microwave treatment [4].

Pasteurization is the process by which the development of microorganisms in food is slowed down. The process is named after the person who created it, the chemist and microbiologist Louis Pasteur. The first pasteurization test was carried out by Louis Pasteur and Claude Bernard on April 20, 1862. The process was originally conceived as a way to prevent the acidification of wine and beer [1].

Thermal treatments are: thermalization, low pasteurization of milk (LTLT), high pasteurization of milk (HTST), ultrapasteurization, sterilization, sterilization in containers [10].

- **Low pasteurization of milk LTLT – Low Temperature, Long Time**

It is an old method and consists of heating the milk to 63°C and keeping it at this temperature for 30 minutes [1].

- **High pasteurization of milk HTST - High Temperature, Short Time**

The process requires reaching 72-75°C and holding it for 15-20 seconds, followed by cooling [1].

- **Thermalization**

The process consists of preheating the milk to a temperature closet o that of pasteurization to inhibit the growth of bacili [1].

- **Ultrapasteurization**

Aseptic processing is used to sterilize a wide range of food liquids including milk, juice or fuit concentrate, creams, yogurts or ice creams. Several high pasteurization treatment systems have thus been implemented with two or more heating steps, applying steam injections or infusions for the last fraction of a second when the temperature reaches 150°C, followed by rapid evaporation and cooling with heat exchangers [1].

- **Sterilization**

Sterilization of milk is based on the principle of thermoabiosis, which means the destruction with the help of heat of all microorganisms (vegetative forms and spores) in milk in a closed container, in order to avoid reinfestation after sterilization. Total sterilization can only be achieved in the case of long-term treatments and at very high temperatures for milk. The initial method of sterilization, still used, consists in the thermal treatment of milk in containers, at about 115-120°C for 20...30 minutes [1].

- **Sterilization in containers**

The canister sterilization process is a food preservation method in which the product and the container are sterilized together, simultaneously. This process takes place by putting food products into sealed containers, such as cans or bottles, and then they are heat-treated at high temperatures, usually between 110-121°C, for a certain period of time [1].

2. MICROWAVE PASTEURIZATION INSTALLATIONS

Microwave pasteurization systems:

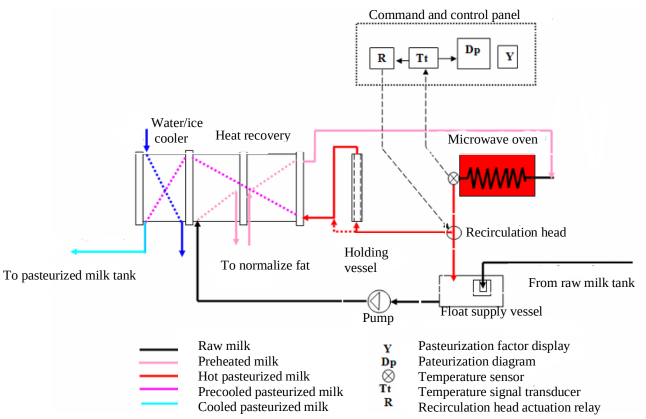


Figure 1. Scheme of the microwave milk pasteurization installation[2]

Figure 1 shows how, at start-up, the liquid to be pasteurized will be taken from the storage container (valve) with a pump whose initial flow rate will be adjusted and will be introduced into the exchanger-heat recovery, to raise the temperature, from the storage temperature, to a temperature of about 54-57°C, duet to the heat given off by the pasteurized liquid, which returns through the exchanger. With this temperature (54-57°C), the liquid enters the microwave chamber, where the temperature is raised to the pasteurization level (65-85°C) [3]. From the microwave enclosure, the heated liquid passes into a holding vessel. From the holding vessel, the liquid re-enters the heat exchanger (providing heating of the unpasteurized liquid) from which it leaves cooled, and is collected in a pasteurized liquid storage container (valve for pasteurized liquid). The efficiency of pasteurization is influenced by factors, such as: the temperature, the irradiation factor that depends on the power of the microwave field and the time the milk is kept in this field. The effiiciency was demonstrated by performing the following tests in parallel: the phosphatase test and microbiological tests both by the classic method and with the help of PETRIFILMS. The efficiency is very good for the maximum temperature of 68°C [3]

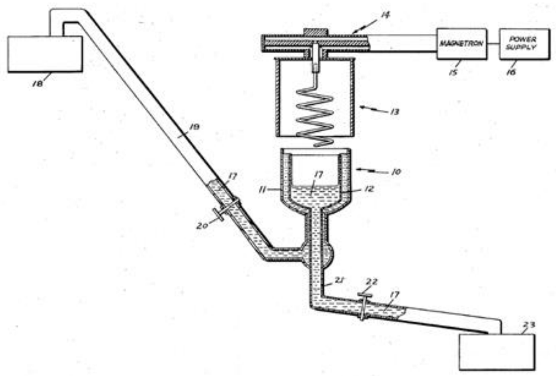


Figure 2. Scheme of the microwave pasteurization installation of fruit juices[5]

From figure 2 we extract the fact that a special microwave applicator, consisting of a magnetron connected to a helical radiator or director, was built to expose the juice to the energy of the microwave oven and to direct and concentrate this energy from the area of the inner bowl of counter-flow system. Thus, a controlled flow of concentrate can be passed through this bowl, irradiated for a predetermined period of time and transferred to a container. It was experimentally determined that the enzymes and microorganisms in the juices are not activated during the irradiation process, the juice preserving its quality, appearance and taste. While the concentrate enters the container, it can be cooled in preparation for the final storage process in boxes. The counter-flow device used allows a high degree of energy to be recovered, and due to the fact that the microwave irradiation is selective and takes place in the juice and not in the glass of the bowls, a high degree of efficiency is obtained from this process. At the same time, due to the fact that there is no heat exchange between a hot surface and the concentrate, as in conventional exchangers, the energy absorption is not dependent on an existing heat differential between a surface and the concentrate. Thus, the danger of overheating, which has always been a problem in deactivating enzymes with heat exchangers, is avoided and the possibility of the formation of an unpleasant taste in the processed juice is cancelled [5].

3. NUMERICAL SIMULATION OF THE MICROWAVE PASTEURIZATION PROCESS OF MILK AND APPLE JUICE

3.1. Description of numerical simulation stages

In order to model and simulate the operation of a microwave oven, the finite element method (numerical simulation) was used with Comsol Multiphyisics 4.2.

Stage 1: Choosing the calculation module: Microwave Heating Frequency Transient, described in figure 3.

Stage 2: Model parameterization: The microwave heating model of a food, namely milk and apple juice, uses the following parameters, represented in figure 4.

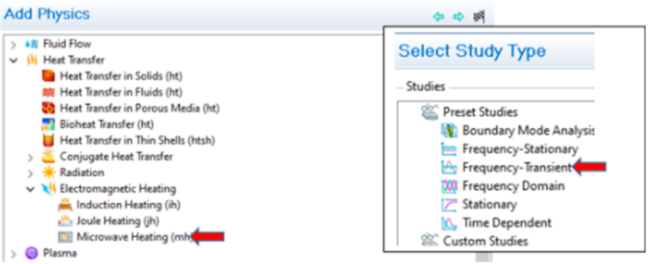
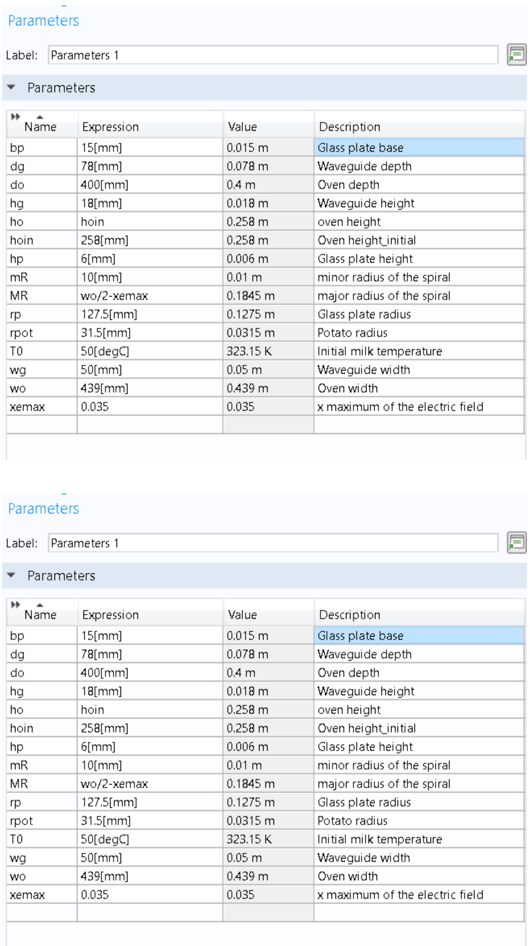


Figure 3. Choosing the calculation module



Parameters

Label: Parameters 1

Parameters

Name	Expression	Value	Description
bp	15[mm]	0.015 m	Glass plate base
dg	78[mm]	0.078 m	Waveguide depth
do	400[mm]	0.4 m	Oven depth
hg	18[mm]	0.018 m	Waveguide height
ho	hoin	0.258 m	oven height
hoin	258[mm]	0.258 m	Oven height_initial
hp	6[mm]	0.006 m	Glass plate height
mR	10[mm]	0.01 m	minor radius of the spiral
MR	wo/2-xemax	0.1845 m	major radius of the spiral
rp	127.5[mm]	0.1275 m	Glass plate radius
rpot	31.5[mm]	0.0315 m	Potato radius
T0	50[degC]	323.15 K	Initial milk temperature
wg	50[mm]	0.05 m	Waveguide width
wo	439[mm]	0.439 m	Oven width
xemax	0.035	0.035	x maximum of the electric field

Parameters

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Name	Expression	Value	Description
bp	15[mm]	0.015 m	Glass plate base
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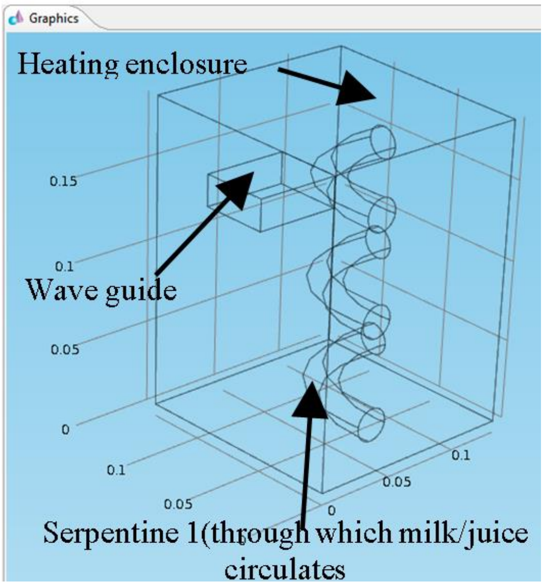
Figure 4. Model parameters for milk/ apple juice

Stage 3: Geometrizing the model: The microwave heating enclosure will be made following the steps in figure 5.

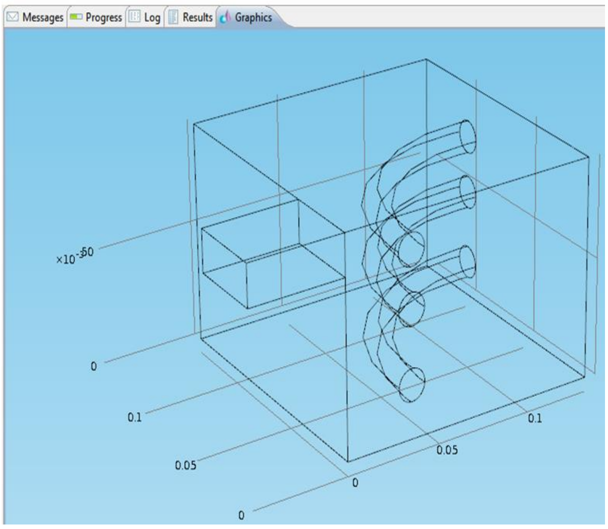
Since the models are very large, they have approximately 30000 nodes it was decided to model a quarter of the microwave heating oven with different geometries for milk and juice.

Stage 4: Allocate the necessary materials with the specific properties of the calculation module, as follows:

- air – for the inside of the microwave oven, including the waveguide, figure 6;
- food material – milk/apple juice – for coils 1,2,3, figure 7;
- copper – for the oven walls, figure 8;
- silicone – for the walls of the coils, figure 9.

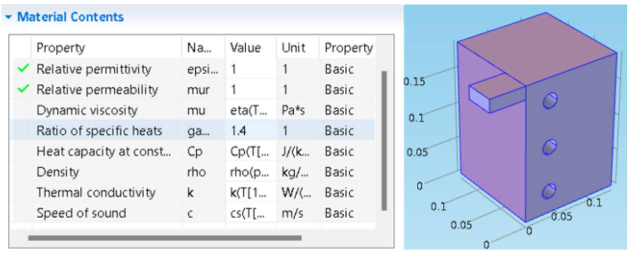


a) The components of the model



b) a quarter of the geometry

Figure 5. Creating geometry

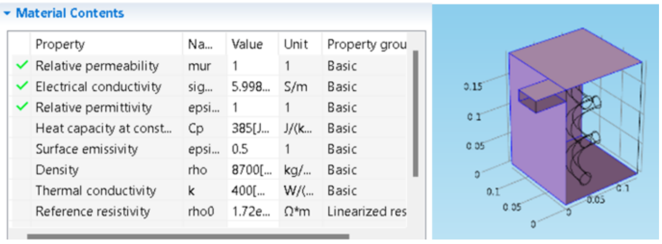


Property	Na...	Value	Unit	Property
Relative permittivity	epsi...	1	1	Basic
Relative permeability	mur	1	1	Basic
Dynamic viscosity	mu	eta(T...	Pa*s	Basic
Ratio of specific heats	ga...	1.4	1	Basic
Heat capacity at const...	Cp	Cp(T[...	J/(k...	Basic
Density	rho	rho(p...	kg/...	Basic
Thermal conductivity	k	k(T[1...	W/(...	Basic
Speed of sound	c	cs(T[...	m/s	Basic

Figure 6. Allocation of materials – air – microwave oven and wave guide

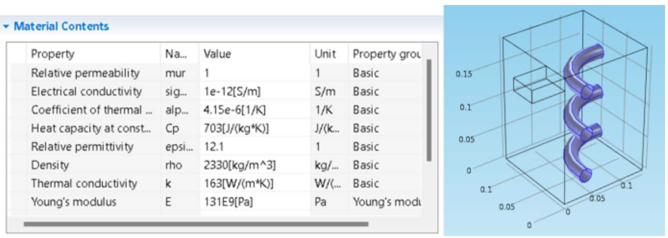
Property	Na...	Value	Unit	Property gr
Electrical conductivity	sig...	5e-1	S/m	Basic
Relative permittivity	epsi...	70-15j	1	Basic
Relative permeability	mur	1	1	Basic
Thermal conductivity	k	0.6	W/(...	Basic
Density	rho	1030	kg/...	Basic
Heat capacity at const...	Cp	3890	J/(k...	Basic

Figure 7. Allocation of materials – milk/apple juice – for coils 1,2,3



Property	Na...	Value	Unit	Property grou
Relative permeability	mur	1	1	Basic
Electrical conductivity	sig...	5.998...	S/m	Basic
Relative permittivity	epsi...	1	1	Basic
Heat capacity at const...	Cp	385[J...	J/(k...	Basic
Surface emissivity	epsi...	0.5	1	Basic
Density	rho	8700[...	kg/...	Basic
Thermal conductivity	k	400[...	W/(...	Basic
Reference resistivity	rho0	1.72e...	Ω*m	Linearized res

Figure 8. Allocation of materials – copper – for the oven walls



Property	Na...	Value	Unit	Property grou
Relative permeability	mur	1	1	Basic
Electrical conductivity	sig...	1e-12[S/m]	S/m	Basic
Coefficient of thermal ...	alp...	4.15e-6[1/K]	1/K	Basic
Heat capacity at const...	Cp	703[J/(kg*K)]	J/(k...	Basic
Relative permittivity	epsi...	12.1	1	Basic
Density	rho	2330[kg/m^3]	kg/...	Basic
Thermal conductivity	k	163[W/(m*K)]	W/(...	Basic
Young's modulus	E	131E9[Pa]	Pa	Young's modu

Figure 9. Allocation of materials – silicone – for the walls of the coils

Stage 5: Boundary conditions: Boundary conditions for oven microwave heating apply:

- initial milk/apple juice temperature, parameter T0=50[°C], figure 10;
- the condition of propagation of electromagnetic waves without the usual heat transfer inside the microwave oven, figure 11;
- the microwave emission port – is the entry surface in the waveguide, figure 12;
- impedance condition related to copper walls, figure 13;
- the condition of a perfect magnetic conductor related to the plane symmetry, after which the model was created which ensures the transmission of microwaves also in the other half of the oven not modelled, figure 14.

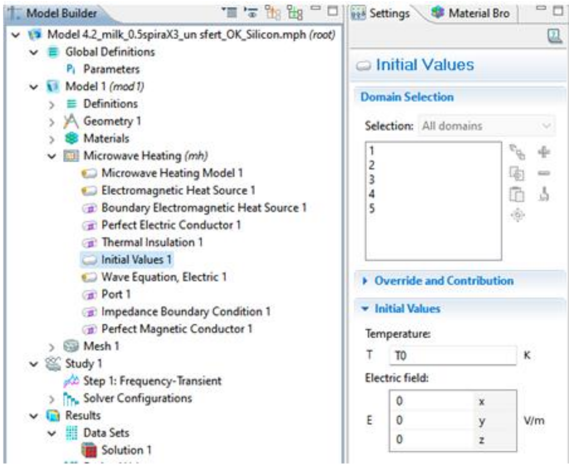


Figure 10. Setting the initial temperature

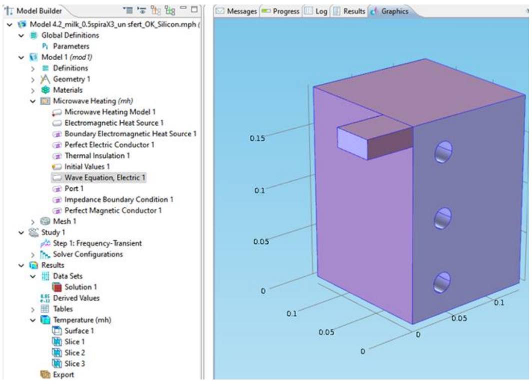


Figure 11. The condition of propagation of electromagnetic waves

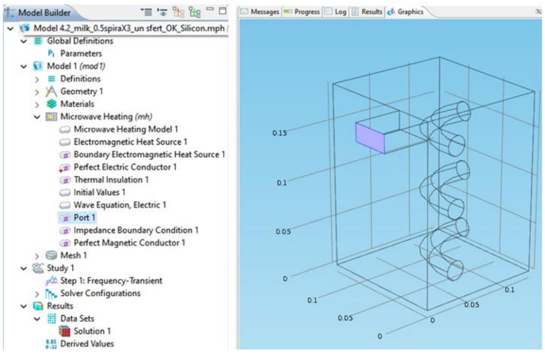


Figure 12. The port of the microwave emitters

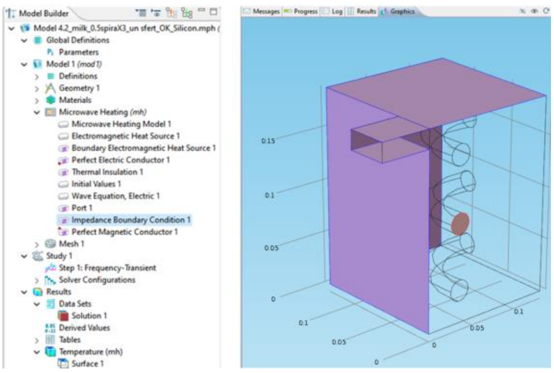


Figure 13. The impedance condition

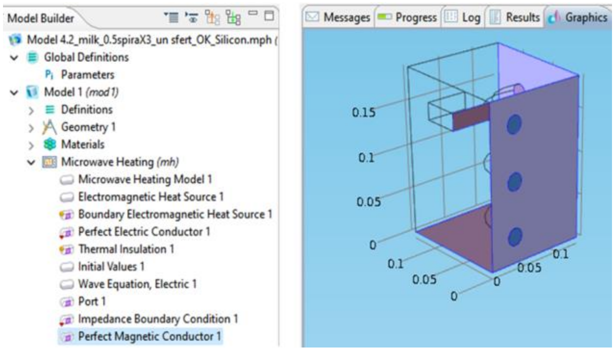


Figure 14. The condition of perfect magnetic conductor

Stage 6 and 7: Discretization of the model: Free tetrahedral elements with finer discretization are used the heated material, in the area of interest, represented in figure 15. To save computing resources, the maximum 6 [mm] is set.

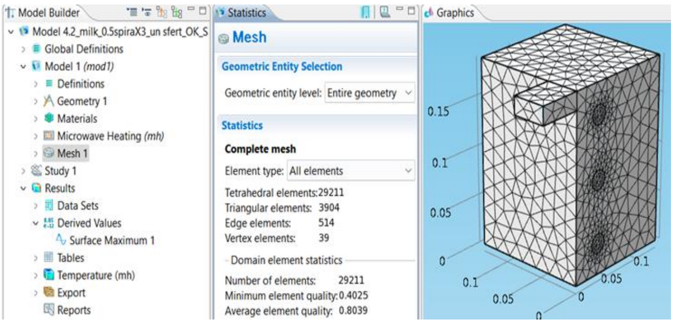


Figure 15. Discretization, statistics and model quality

3.2. Simulation results

The maximum value of the electric field intensity in a cross section along the Oz axis close to the section made in order to simplify the geometry is 14196 V/m for milk and 44687 V/m for apple juice, figure 16 and figure 17.

Standing waves are formed. The liquids pass through the areas of maximum intensity/belly (red or dark blue color) of interest for pasteurization process.

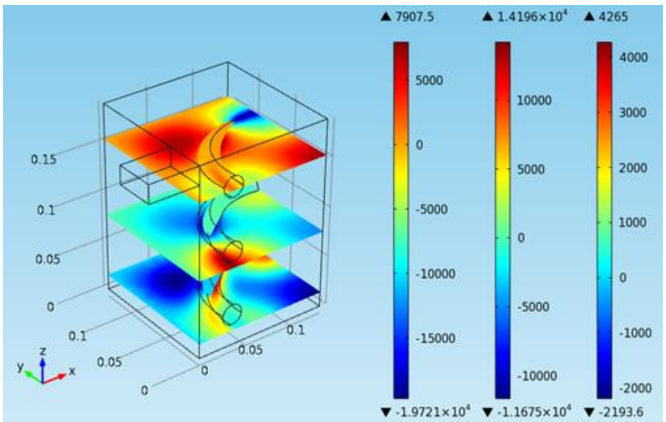


Figure 16. Distribution of the electric field and its values for milk

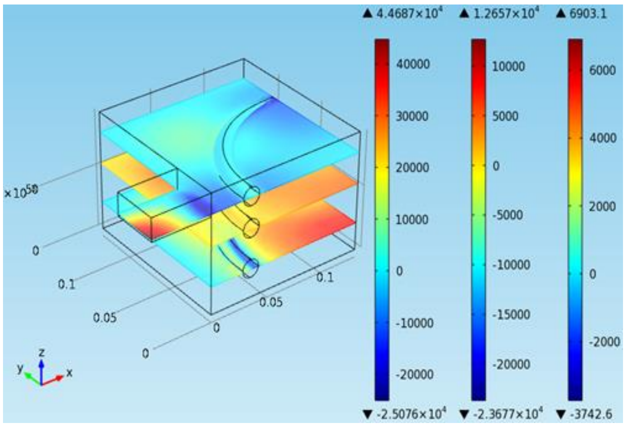


Figure 17. Distribution of the electric field and its values for apple juice

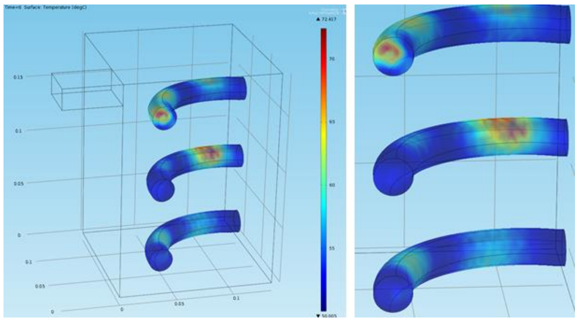


Figure 18. Temperature distribution (pasteurization of milk) after 6 seconds exposure, isometric view

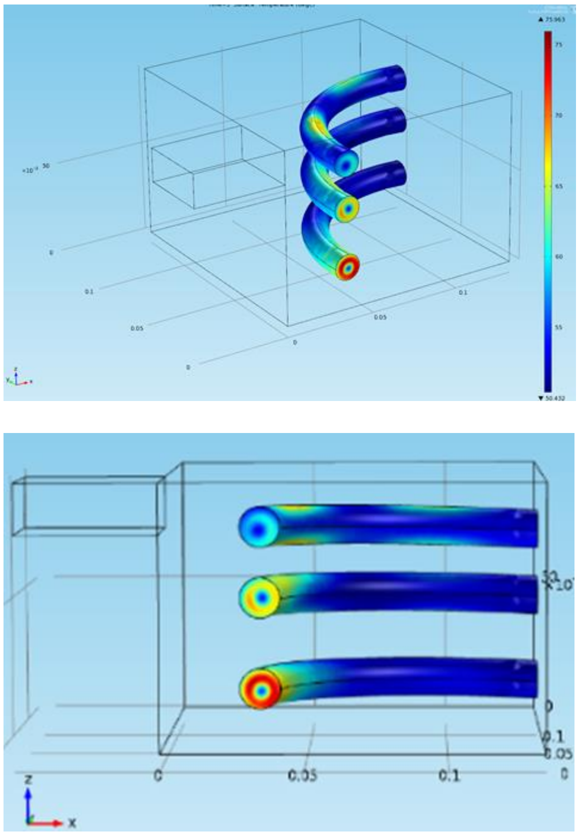


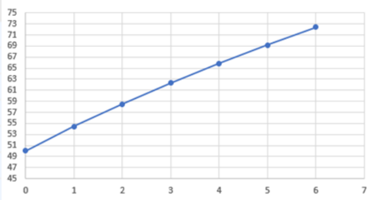
Figure 19. Temperature distribution (pasteurization of apple juice) after 5 seconds exposure, isometric view

The maximum, respectively minimum value of the temperature on the surface of the coils is 72.417°C, respectively 50.005°C (for milk) and 75.963°C, respectively 50.432°C (for apple juice), figure 18 and figure 19.

It can be observed that the maximum temperature is at the coordinates (x – 0.0992; y – 0.0894; z – 0.0283 – for milk) (x – 0.0329; y – 0; z – 0.0254 – for apple juice).

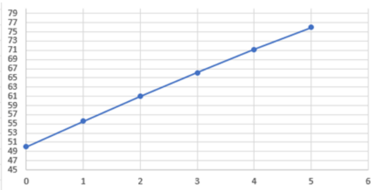
Figure 20 shows the maximum values of the temperatures of milk and apple juice at different time periods.

Time	Temperature (degC)
0	50.0065
1	54.4263
2	58.5033
3	62.2854
4	65.8263
5	69.2192
6	72.457



a. Maximum temperatures at different time periods for milk

Time	Temperature (degC)
0	50.0058
1	55.6315
2	61.0053
3	66.1685
4	71.15
5	75.963



b. Maximum temperatures at different time periods for apple juice

Figure 20. Variation of the maximum temperatures of the heated liquids

4. CONCLUSIONS

The numerical model presented, made through a three-dimensional simulation based on symmetry, following the economy of computing resources, offers a spatial vision of the components of the electromagnetic field represented by the intensity of the electric and magnetic field as well as the power distribution. Also, the thermal modelling performed provides valuable information both about the heating mode and the temperature distribution in the liquids subjected to microwave heating.

In the present case, analyzing the data extracted from the numerical simulation, it was found that the maximum temperature values reached are 72.417°C for 6 seconds for milk, respectively 75.963°C for 5 seconds for apple juice, which shows the high efficiency and productivity of the pasteurization process. The modelled installation provides for heat recovery and its use for preheating liquids. Knowing these temperatures ranges, we can conclude that the food pasteurization process takes place (milk, respectively apple juice), but at the same time those components that have a beneficial effect after consuming the respective foods are not affected/destroyed.

Future research will be directed towards the physical realization of the models and their optimization.

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