CFD SIMULATION OF A RETORT PROCESS FOR FOOD VEGETABLE PRODUCTS

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ABSTRACT

This work aims at simulating a retort sterilization process of flexible packaging, performed in "autoclave". The retort sterilization is one of the most adopted processes in order to reduce the microbial load of packaged food.

Ansys CFD© software has been used in this study in order to simulate the heat transfer inside the retort room. Flexible packaging filled with a particular vegetable soup have been modelled. 3D geometrical configuration of the equipment has been also modelled in order to evaluate the sterilization level reached by each flexible packaging inside the retort room. In particular, the internal temperature of the most disadvantaged simulated product has been monitored during 5 minutes of the process in order to control the time/temperature trend.

Finally the model has been validated by comparing the simulation results with those obtained by experimental tests.

Keywords: *CFD; Food sterilization; Retort packaging; Heat treatment; autoclave, vegetable soup*

1. INTRODUCTION

Nowadays retort treatment using pressured saturated steam is used especially for food vegetables or soups, which are hardly sterilized by means of continuous processes.

The water is boiled at high pressure in order to create saturated steam, which must not condense on packaging surfaces of the treated products also at temperature higher than 120°C. The heat transmitted by the steam has to pass through the packaging in order to reach the inner part of the product. Moreover, air has to be removed from the sterilization chamber, avoiding formation of colder zones where the temperature may remain below the sterilization setting. At the end of the process it is necessary to dry the product to minimize the condensate content. A high presence of condensate steam may in fact damage the package and it may promote the growth of bacterial substrates. Metallic containers, jars, or some special carton beverages, such as Tetra Recart® or Combisafe®, could be adopted in this process.

Two types of heat transfer occur during this process: convection, and conduction. The convection rate can be considerably increased by inducing a forced convection by means of mechanical agitation of the trays. For this reason many retort rooms are designed to provide axial rotations or longitudinal movements of the product (Dwivedi and Ramaswamy 2010; Ramaswamy and Dwivedi, 2011). Thanks to these movements, it is possible to reduce the treatment time and to obtain higher quality products.

Literature widely explored the issue of retort process for vegetables and other food products (Durance, 1997; Teixera and Tucker, 1997), with the aim to understand the better setting of this technology (Simpson et al., 2007). Some authors tried to approach the problem experimentally (Dwivedi and Ramaswamy, 2010 b), but this approach requires an high cost of equipment and the impossibility to forecast the process behaviour, if something change. In recent years the development of the numerical simulation helped to overpass this problem and to identify the best thermal setting of the process (Miri et al., 2008). Among the different numerical approaches, Computational Fluid Dynamics CFD appeared as the most suitable in order to understand the evolution of the temperature inside the product during a retort process (Abdul Ghani et al, 2001; Abdul Ghani et al, 2003; Kızıltaş et al., 2010; Augusto and Cristianini, 2011). All of these letter studies simulated a 3D process considering the real configuration of the packaging, but none of them aims at considering the flow of vapour reaching the packaging inside a complex geometry like those of an "autoclave". Similar Studies have been performed in other food sector, like pasta (Bottani et al., 2013; Armenzoni et al, 2013) or refrigerated rooms (Ambaw et al., 2014), showing how is important the knowledge of the air/vapour flows for food processes.

Aim of this article is then to analyse the retort process considering a specific section of an Autoclave with a simultaneous treatment of 320 food packages. The product tested in this work is a pumpkin soup (a homogeneous product).

2. MATERIALS AND METHODS

2.1. Equipment

The handling system for the bricks loading and unloading interacts with the retort sterilizer. Using a coupling system, the baskets are inserted or extracted in a few minutes from the retort.

The retort system considered in this work (Figure 1) can contain until 6 baskets each composed from sixteen trays which contain 70 cartons per tray. This system is able to sterilize up to 6720 brick of 500 ml or 8640 containers of 390 ml per cycle.

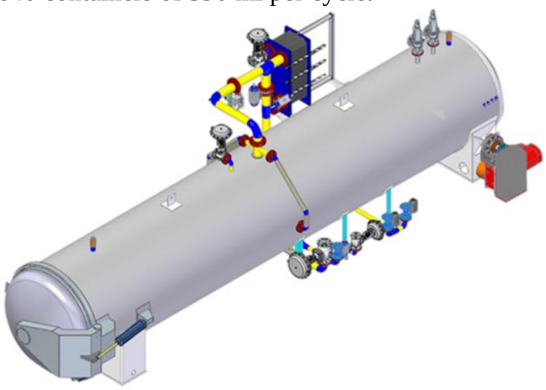


Figure 1: retort system considered in this study

The thermal cycle of the pumpkin soup lasts approximately 2 hours and it is composed by the following steps:

- Preheating phase: the internal temperature of the sterilizer rises up to 50°C at 2 bar;
- Heating phase: the internal temperature of the sterilizer rises up 110°C with an increased pressure up to 4 bars;
- Sterilization phase: inside the sterilizer the temperature reaches 130°C and the vapour is inserted with a pressure of about 4 bars; the product is handled in these conditions for a defined sterilization time;
- Pre-cooling phase: the sterilizer temperature drops to 105°C with a decreased pressure to 2 bar;
- Cooling phase: the whole system achieves an ambient temperature and pressure close to 1.5 bar;
- Discharge phase: when the system reaches the atmospheric pressure, the retort system can be opened to discharge the products.

At the end of the sterilization, all the cartons are discharged on a conveyor belts system and conducted to the secondary packaging operation.

From a technological point of view, the most critical phase is the sterilization one, especially in the 5 minute after the reaching of 85°C inside the product (usually after 1200s of treatment). This is the time range in which the simulations were performed (1200s-1500s).

2.2. Materials

The product considered in this study is a pumpkin soup, packaged in TetraRecart brick having a volume of 500ml. This packaging allows to be treated with a retort technology, having a particular heat resistance. The product is filled by means of a piston filler, which ensures a good accuracy and a limited head space (on average 13ml).

In order to perform CFD simulations, two main materials were considered: saturated steam water and pumpkin soup. Properties of the first one are well known and can be easily retrieved from the software library. Conversely, for the food product, it was necessary to find (or compute) the correct values for each physical property.

In particular, for the pumpkin soup, the following properties were considered: density, dynamic viscosity, thermal conductivity and heat capacity. The values of these properties were provided by a supporting company which, during experimental tests, has measured the corresponding data.

In order to perform the simulation, another material has been considered. In fact the thermal exchange became between vapour and the food liquid through a thin food package multilayer. In this type of packaging, paper is the material with greatest impact on heat transfer. For this reason only the paper layer was considered. All the features of each material are reported in Table 1.

Table 1: features of steam water, pumpkin soup and packaging paper

Saturated steam water		
Thermodynamic state	Mixture liquid/gas in equilibrium	
Molar Mass	18.02	kg/mol
Density	1.91	kg/m3
Reference pressure	4	bar
Reference Temperature	130	°C
Heat Capacity	1901	J/kgK
Thermal Conductivity	0.016	W/mK
Dynamic Viscosity	0.228	cp

Pumpkin soup		
Thermodynamic state	Liquid	
Density	1030	kg/m3
Heat Capacity	3350	J/kgK
Thermal Conductivity	0.48	W/mK
Dynamic Viscosity	0.085	Pa·s

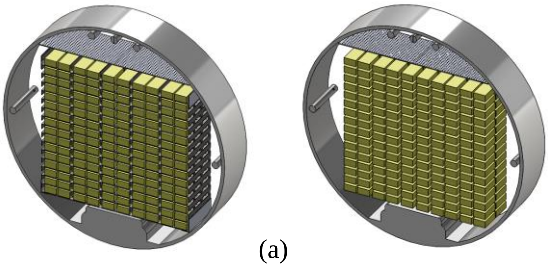
Food packaging paper		
Thermodynamic state	Solid	
Density	700	kg/m3
Heat Capacity	1321	J/kgK
Thermal Conductivity	0.21	W/mK

2.3. Mathematical modelling

2.3.1 Simulation setting: geometry and mesh

Given the large size of the retort sterilizer, the simulations were conducted considering a section of the whole system. Due to the complexity of the domain, it has been decided to approach the issue considering both the presence of the trays under the carton bricks, and a domain without trays (figure 2 a) and b)).

For each configuration, 320 bricks were loaded, considering however only 1 brick for the thermal analysis. As shown in Figure 3, the considered brick is located in the centre of the third layer starting from the bottom of the vessels.



(a) (b)

Figure 2: Configuration with (a) and without trays (b)

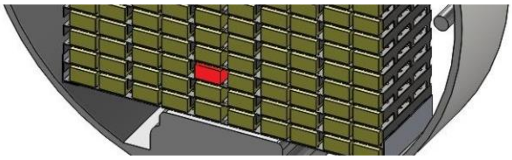


Figure 3. Focus on the analyzed brick

The fluid domain was obtained for both the two configurations using ICEM CFD, the modeller associated with ANSYS CFX. The volumes are divided into a finite number of cells, on which the analysis is carried out.

The meshes were created following a gradient that respects the Courant number. This number is of fundamental importance for transient flows. For a one-dimensional grid, it is defined as:

$$Courant = u\frac{\Delta t}{\Delta x}$$

where u is the fluid speed, Δt is the timestep and Δx is the mesh size. The Courant number calculated in Ansys CFX is a multidimensional generalization of this expression where the velocity and length scale are based on the mass flow into the control volume and the dimension of the control volume (Löhner, 1987). To allow a correct CFD simulation, the timestep must be chosen with the purpose of keep the Courant number sufficiently small.

The number of cells used in the simulations was determined starting from a coarse mesh, and gradually refined, evaluating the changes in the results. The mesh setting started from the definition of the external surface mesh (Figure 4) as suggested in Ansys solver modelling guide (Ansys, 2011). Table 2 reports the values of the surface mesh for each part.

Table 2: values of the surface mesh

Part	Size [mm]	Height [mm]	Height Ratio	Tetra Ratio
Wall	32	4	1.3	1.5
Open	16	4	1.3	1.5
Inlet	1	4	1.3	1.5
Brick	2	4	1.3	1.5
Trays	4	4	1.3	1.5
Pipe	4	4	1.3	1.5

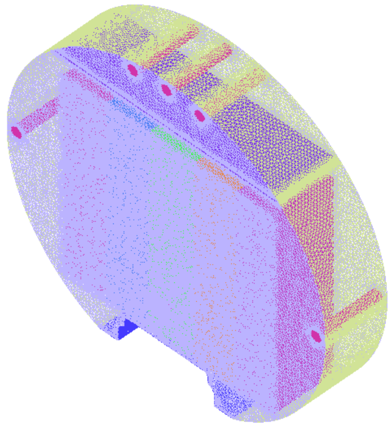
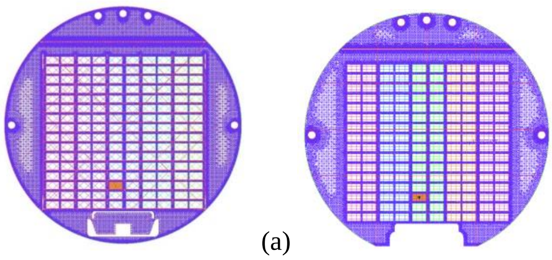


Figure 4. External mesh surface

The volume mesh was initially set by creating a uniform subdivision, and then thickened in the critical areas of the fluid volume. In particular, a finer mesh was used near the outlet section of the nozzle, where it can be expected that the shear rates would be higher and closer to the sterilizer walls in order to accurately simulate the flow boundary layer.

Figure 5 shows the generated mesh used for the calculation: an unstructured tetrahedral meshing scheme was used for each configuration.



(a) (b)

Figure 5: volume mesh of the configuration with trays (a) and without trays (b)

The final meshes were determined when the increase in quality of the mesh did not provide any significant improvements in the results. The overall number of cells created for the first mesh (Figure 5a) is about 12,500,000, while, for the second one (Figure 5b), the overall number of cells created is about 11,200,000.

2.3.2 Simulation setting: domain equations and boundary conditions

Three-dimensional, multiphase, two-fluid model simulations were developed to investigate the temperature trend inside the carton package. ANSYS CFX 14.5 software was used to solve the governing continuity, momentum and energy equations for the defined geometry and associated boundary conditions. The generalized transport equations solved are:

The continuity equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho V) = 0 \qquad (1)$$

The momentum equation:

$$\left(\frac{\partial \rho V}{\partial t} + \nabla \cdot (\rho V \otimes V)\right)$$
$$= \nabla \cdot (-p\partial + \eta \cdot (\nabla V + (\nabla V)^t)) + S_M \quad (2)$$

In this work, according to the materials used, three fluid domains were created: “autoclave”, “packaging paper” and “pumpkin soup”. ANSYS CFX uses the concept of domains to define the type, properties, and region of the fluid, porous, or solid. Domains are regions of space in which the equations of fluid flow or heat transfer are solved. This includes selecting the 3D bounding regions and choosing appropriate physical models for each domain. Packaging paper is created as an interface domain, between the “autoclave” and the “pumpkin soup” domains, to connect the two different domains with different properties and conditions. The interface between the surfaces is inserted as a solid layer. In this case a paper layer with thickness of 0.5 mm was created.

A “Thermal Energy” model is used to predict the temperature inside the pumpkin soup domain, i.e.:

$$\frac{\partial(\rho h_{tot})}{\partial t} + \nabla \cdot (\rho U h_{tot}) = \nabla \cdot (\lambda \nabla T) + \nabla \cdot (U \cdot \tau) \quad (3)$$

where h_{tot} is the total enthalpy, which can be expressed as a function of the static enthalpy h (T, p) as follows:

$$h_{tot} = h + \frac{1}{2}U^2 \quad (4)$$

The term $\nabla \cdot (U \cdot \tau)$ in eq. 3 is the work due to viscous stresses and it is known as the viscous work term. Inside the “autoclave” domain an isothermal heat transfer model was set. The isothermal model requires a uniform temperature for the fluid in absolute temperature terms. The temperature was fixed at 130°C. Being also the steam flowing in the “autoclave” domain at high velocity, a turbulent model has been adopted. One of the main problems in turbulence modelling is the accurate prediction of flow separation from a smooth surface. For this reason, the model adopted was the Shear Stress Transport (SST). The SST model, proposed by Menter (1994), is an eddy-viscosity model which is a combination of a k-ω model and k-ε model. The first is used in the inner boundary, while the second in the outer region and outside of the boundary layer. The SST model has been used in order to overcome the problems of both the methods. These features make the SST model more accurate and reliable for a wider class of flows than the standard k-ω and k-ε models. For the “pumpkin soup” domain the food product is instead in laminar flow.

The boundary conditions (Figure 6) are related to 10 inlet holes and 2 opening section; in particular, a uniform orthogonal velocity input and a relative pressure for outlet are set. The external wall was considered as adiabatic while the other brick not considered for the internal thermal process, were kept at 85°C. Table 3 resumes the boundary and initial conditions for the “autoclave” domain.

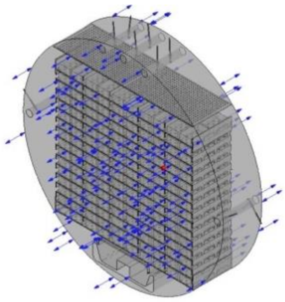


Figure 6. Boundary condition in CFX-Pre Solver

Table 3: Boundary and Initial conditions

Boundary conditions	
INLET	25 m/s
OPENING	3 relative bar
WALL	No slip wall and Adiabatic thermal condition
BRICK	No slip wall and initial temperature at 85°C

Initial conditions (t = 0)	
Pressure	3 relative bar
Velocity	0 m/s
“Autoclave” initial temperature	130°C
“packaging paper” initial temperature	85°C
“pumpkin” initial temperature	85°C

All the simulations were carried out in transition state, to evaluate the trend of the sterilization temperature inside the brick in function of the time. In particular for both configurations, a total time of 5 minutes with 0.5 seconds time-step were performed.

2.4. Experimental method

The tests have been performed to validate the simulations and to obtain a heat treatment able to ensure a healthy and safe product for the consumer. The tests have been developed according to the following phases:

1. Analysis of the product
2. Collecting samples
3. Positioning the temperature probes inside the package
4. Partially loading the retort
5. Controlling and analysing the samples by opening the cartons.

In the first phase, the chemical and physical parameters like the brix degree, pH, acidity, colour and texture were controlled. Then, some samples are collected to check the weight and the suitability of the welding performed by the machine. Then the thermocouples probes were inserted inside two containers and connected to a ELLAB data logger (Figure 7). The tests were carried out using temperatures probes located in two bricks previously considered as the most disadvantaged packages inside of the retort.

Figure 7. Thermocouples and ELLAB data logger

The most disadvantaged brick has been identified on the third tray in the center positions. After the probes connection, the retort sterilizer has been loaded with only a few hundred cartons, disposed in two sections as supposed in the simulation model.

At the end of the process, the carton analyzed were removed and opened to verify the real treatment obtained by the product.

3. SIMULATIONS RESULTS

The CFX-Post Solver was used to analyse velocities, temperatures and pressures fields inside the retort sterilizer and pumpkin soup domains. Different section planes were used to view the results of the process. Furthermore, a point located in the centre of the brick (the same point where the probe was put) was identified to monitor the temperature in the most disadvantaged zone of the whole system (Figure 8).

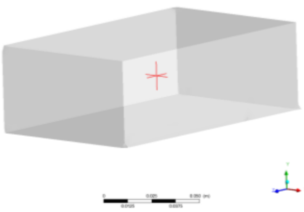


Figure 8. Point analyzed inside the pumpkin domain

For both simulations, the autoclave domain (Figure 9a) shows a constant temperature at 130°C. As regards the steam velocity, in the figures 9b), 9c) and 9d) the flows is in a range between 0-5 m/s.

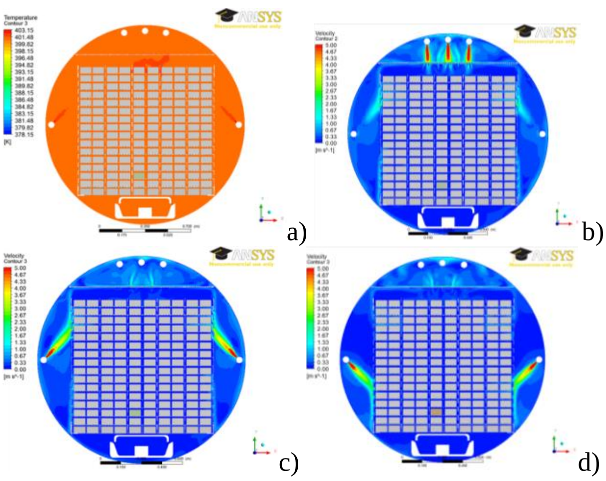


Figure 9: Temperature inside the sterilizer a); velocity inside the sterilizer at 3 planes: b) c) and d)

For each simulation, the temperatures inside the bricks were reported in separate paragraphs.

3.1. Simulation results of the configuration with trays

Analysing the temperature of the product in the configuration with trays, it was observed that the product heats up with the increase of the time. The figure below shows the temperature inside the brick during the sterilization phase at different time interval (between 0 to 5 minutes) in a range between 85 and 130°C.

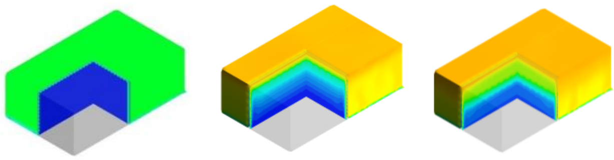


Figure 10. Temperature inside the brick at t=0 min, t=2,5 min, t=5 min

The temperatures were also analysed in function of the time in the previously defined point inside the product. Starting by 85°C, the heart of product reaches about 92.5°C after 5 minutes. This temperature trend is described in Figure 11

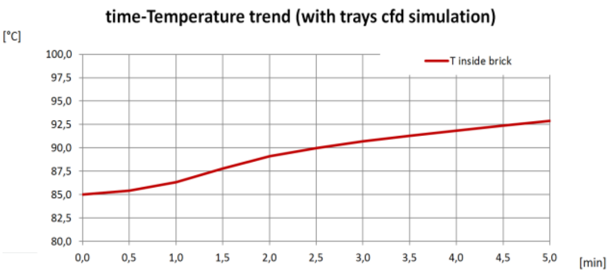


Figure 11 Time-Temperature trend in the previously defined point inside the brick

Thanks to Microsoft Excel elaborations, all the temperatures in the brick volume were obtained. With those data, we were able to see the temperature trend in the product volume and not only in a specific point.

The percentage of volume increase was reported in Table 4. Values equal to 100% mean that the entire volume is located at a temperature higher or equal to the reference temperature set.

Table 4% of volume with T greater or equal of Tref (at t = 2.5 min and t=5 min)

Tref (t = 2.5 min)

Tref	°C	K	%Volume
T0	85	358.15	100
T1	90	363.15	66.06
T2	95	368.15	54.20
T3	100	373.15	42.51

Tref (t = 5 min)

Tref	°C	K	%Volume
T0	85	358.15	100
T1	90	363.15	76.21
T2	95	368.15	64.37
T3	100	373.15	57.66

3.2. Simulation results of the configuration without trays

The same increasing of the temperature is shown by the food product with the configuration without trays. The figure below shows the temperature inside the brick during the sterilization phase at different time interval (between 0 to 5 minutes) in a range between 85 and 130°C. In the case without trays, the temperatures of the external layer are higher than before (Figure 12).

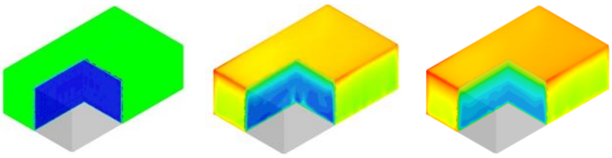


Figure 12. Temperature inside the brick at t=0 min, t=2,5 min, t=5 min

As before, the temperatures were analysed in function of the time in the previously defined point inside the product. Starting by 85°C, the heart of product reaches about 95°C after 5 minutes. Figure 13 describes this temperature trend.

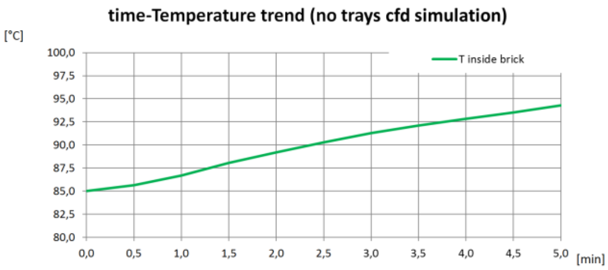


Figure 13 Time-Temperature trend in the local point inside the brick

As before thanks to Microsoft Excel elaborations, it was possible to calculate all the temperatures in the brick volume. As reported in Table 5, an increasing of percentage volume with higher temperature was observed respect the case without trays. Values equal to 100% mean that the entire volume is located at a temperature higher or equal to the reference temperature set.

Table 5 % of volume for T greater or equal in respect of Tref (at t = 2.5 min and at t = 5 min)

t = 2.5 min

Tref	°C	K	%Volume
T0	85	358.15	100
T1	90	363.15	79.76
T2	95	368.15	59.90
T3	100	373.15	46.31

t = 5 min

Tref	°C	K	%Volume
T0	85	358.15	100
T1	90	363.15	100
T2	95	368.15	78.66
T3	100	373.15	60.54

4. EXPERIMENTAL VALIDATION

4.1 Experimental tests

Following the prescription reported in section 2.4, an experimental test has been performed. Figure 14 reports the temperature trend in function of the time for the sterilizer room and inside the brick in the same point evaluated by the simulation during all the process.

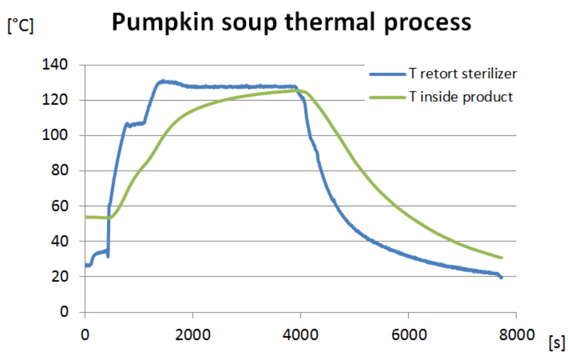


Figure 14: Temperature trend of the retort room and inside the brick

Figure 15 show instead the pumpkin soup and retort temperatures in the reference time (after 120s of treatment).

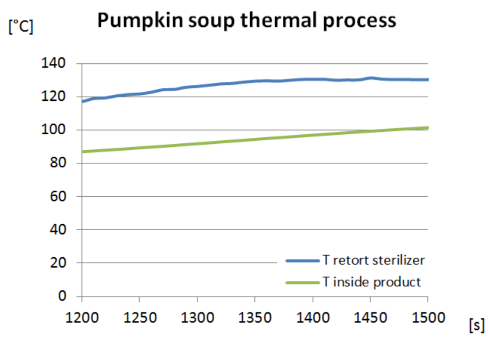


Figure 15 Temperature trend of the retort room and inside the brick in the reference time (1200-1500s)

During the reference time (1200-1500s), the temperature values in the retort sterilizer and inside the brick at step of 0.5min are reported in Table 6. The product temperature has been taken in the same point before analysed in the CFD simulation.

Table 6: experimental temperature inside the retort room and inside the brik (step of 0.5min)

Time [min]	**T retort sterilizer [°C]**	**T inside brick [°C]**
0,0	130,3	84,96
0,5	129,3	86,01
1,0	129,1	87,03
1,5	129,5	88,04
2,0	128,3	89,04
2,5	128,5	90,01
3,0	128,2	90,95
3,5	128,3	91,88
4,0	128,1	92,78
4,5	127,6	93,65
5,0	127,4	94,51

4.2 Comparison with simulation results

Table 7 and 8 compare the experimental values with them provided by the software simulations. The following values refer to the ones measured and calculated at the product core.

Table 7 Comparison between experimental values and those from the simulation with trays

Time [min]	Experimental Data [°C]	CFD simulations with trays [°C]	ΔError [°C]
0	84.96	84.96	0
1	87,03	86.33	0,70
2	89,04	89.08	-0,04
3	90,95	90.70	0,25
4	92,78	91.83	0,95
5	94.51	92.89	1,62

Table 8 Comparison between experimental values and those from the simulation without trays

Time [min]	Experimental Data [°C]	CFD simulations without trays [°C]	ΔError [°C]
0	84.96	84.96	0
1	87,03	86.71	0,32
2	89,04	89.17	-0,13
3	90,95	91.30	-0,35
4	92,78	92.81	-0,03
5	94.51	94.30	0.21

Figure 16 shows the comparison trend. From the figure, it is possible to observe a slight deviation between the experimental results and those calculated by the software with the configuration with trays. This could be due the absence of heat exchange between the trays and the bricks. Removing the trays the heat exchange happened on the whole package allowing a very good agreement between experimental and simulated data.

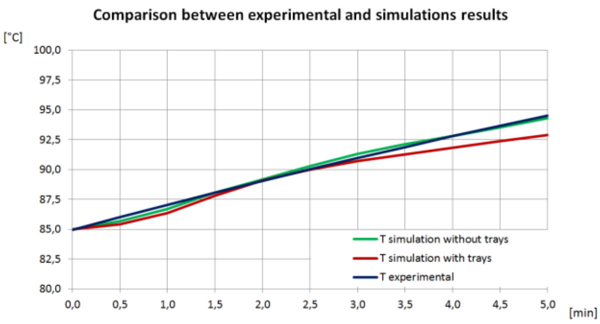


Figure 16. Comparison between the experimental test and simulation results

5 CONCLUSIONS

This work aimed to simulate a retort sterilization process of pumpkin soup packaged in flexible packaging. Ansys CFD© software has been used in this study in order to simulate the heat transfer inside the retort room. 3D geometrical configuration of the equipment has been modelled in order to evaluate the sterilization level reached by each flexible packaging inside the retort room. Until now any studies aims at considering the flow of vapour reaching the packaging inside a complex geometry like those of an “autoclave”. In this study, in particular, the internal temperature of the most disadvantaged point has been monitored during 5 minutes of the process in order to control the time/temperature trend. The simulations have been performed considering two configurations: one with trays and another without them.

The experimental validation has shown the better results obtained by the simulation without trays, having it the ability to better understand the behaviour of the heat exchange during the considered process.

Future research will be then address to better simulate the process considering also the heat exchange between the stainless steel trays and the paper packaging, in order to make the simulations results still more adherent to the real ones.

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