MODELING AND THERMO-FLUID DYNAMIC SIMULATION OF A FRESH PASTA PASTEURIZATION PROCESS

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ABSTRACT

The present work aims to analyse a thermal process for pasteurization of fresh filled pasta, by means of Computational Fluid Dynamic (CFD) simulation. The pasta considered is “ravioli” filled of meat. Thanks to many studies on pasta proprieties (Saravacos and Maroulis, 2001 and de Cindio et al., 1992), some product parameters, such as thermal conductivity and heat capacity, have been determined.

All simulations have been performed using Ansys CFX code version 14.0 in a transient state (after 30s, 60s, 120s and 150s), to evaluate the pasteurization temperature at the core of the “ravioli” as a function of the process time. The heat exchange takes place in a pasteurization tunnel by means of water vapour at approx. 96°C.

Finally, experimental tests were performed in order to validate the simulation model of heat exchange. Results show a good agreement with the real pasteurization process and a good level of product quality.

Keywords: heat treatment, CFD simulation, fresh filled pasta, pasteurization process.

1. INTRODUCTION

The pasteurization process is one of the most important steps of the industrial packaging of fresh pasta. This phase should ensure a safe and healthy product. The pasteurization of the fresh filled pasta makes use of a heat treatment, with the aim of reaching a commercial sterility level of the food. The purpose is to reduce all vegetative forms of non-spore-forming pathogenic microorganisms. The timing and temperature of the treatment are established on the basis of the elimination of most heat resistant vegetative forms, such as Salmonella.

In this article, we consider a specific type of pasta, called "ravioli", filled of meat. The storage temperature of this product, throughout the food chain, is kept at 4 ° C ± 2 ° C. However, the presence of microorganisms in the product is inevitable: all technological operations can only reduce the number of microorganisms, but, overall, it remains impossible to completely eliminate them. To provide consumers with an acceptable safety level, the international standard EN ISO 11290-2 and a specific Report ISTISAN89/9 defined the maximum allowable level of contamination as *cfu* (Colony Forming Units) for fresh filled pasta, at the end of production process (Table 1).

MICROORGANISM	LIMIT	REFERENCE
Total microbial	max 10^6 cfu/g	Rep. ISTISAN 89/9
Staphylococcus Aureus	max $5x10^2$ cfu/g	Rep. ISTISAN 89/9
Clostridium Perfringens	max 10^3 cfu /g	Rep. ISTISAN 89/9
Salmonella	absent in 25 g	Rep. ISTISAN 89/9
Listeria Monocytogenes	max 100 cfu/g	EN ISO 11290-2
Bacillus Cerus	max 10^4 cfu/g	Rep. ISTISAN 89/9

Table 1- Maximum level of cfu for the production of fresh egg pasta (International standard EN ISO 11290-2, Report ISTISAN 89/9)

In order to understand the correct value of pasteurization, knowing the quality of raw materials is also paramount. In fact, the microbiological quality of fresh pasta depends not only on the hygiene of workers and environment where it is produced and preserved, but above all on the raw materials used to produce it and on the production technologies. Table 2 reports the maximum contamination level of the flour allowable for the production of fresh pasta (Pagani, 2007).

CBT	max 30-40.000 cfu/g
Yields	max 500 cfu/g
Molds	max 500 cfu/g
Salmonella	absent in 25 g
Staphylococcus	max 100 cfu/g
Enterobacteria	max 100 cfu/g
Fecal coliform	max 100 cfu/g
Bacillus cereus	absent in 1 g

Table 2 – Maximum contamination level of the flour for the production of fresh pasta

The fresh pasta is pasteurized to avoid the presence of pathogenic microorganisms and reduce the saprophyte micro flora to acceptable limits; as a result, it ensures a longer shelf life. During the heat treatment, the pasta filling contains a large amount of water, and, when the temperature increases, a partial evaporation occurs. The resulting water vapour remains entrapped inside the product. Thus, a particular way of cooking is generated, able to give the final product a typical taste.

In industrial processes, the heat treatment is obtained by putting the final products on a conveyor belt, moving inside a steam tunnel which operates at pressure close to 1 atm. Typical processing times are around a few minutes.

During the heat treatment, the vapour produced inside the product generates a water pressure that overcomes the external pressure. Thus, the dough shell is subject to a pressure gradient that deforms it and, under critical conditions, could break it. Thick shells could be used to prevent this undesired effect, but in practice this solution is never adopted because the dough shell should be very thin so as to enhance as much as possible the filler flavours. It should be noted that thin but resistant shells are necessary to obtain a good quality product (De Cindio et al., 2000).

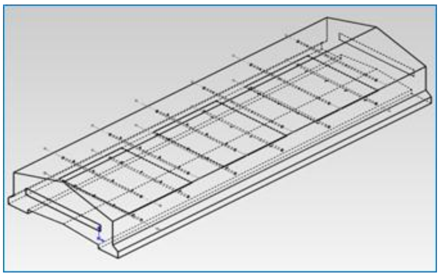

Figure 1. Geometry of pasteurizer

Based on these premises, many researchers try to optimize the pasteurization process of fresh pasta. A traditional approach makes use of experimental tests, changing the main parameters of the process, i.e. pressure, temperature and time (Alamprese et al, 2005; Alamprese et al, 2008; Rizzo et al., 2010).

In the last twenty years, in order to reduce the experimental cost, more and more research activities have been conducted through simulation tools. In particular, Computation Fluid Dynamic (CFD) simulation appears as one of the most used tools to model heat transfer process of food products (Zou et al, 2006, I and II;).

Some research activities about heat transfer in fresh filled pasta concern the simulation of drying phase (e.g., Migliori et al., 2005), using specific formulation for the heat transfer inside the pasta. No scientific works, however, have been found about the application of CFD to the pasteurization process of fresh filled pasta.

In this work, thanks to the support of a numeric solver, simulations were conducted to evaluate the temperatures reached inside the fresh filled pasta during pasteurization, as a function of time. Then the temperature values obtained from experimental tests were reported.

2. MATERIALS AND METHODS

2.1 Materials

The fresh filled pasta considered for the present study has a high moisture content (humidity of at least 24%) and water activity (Aw) between 0.92 and 0.97; for this reason, it can be right considered a perishable product. The main ingredients of the fresh pasta are semolina (or wheat flour), water, eggs and possibly fillings (meat, cheese, spinach, or herbs). A brief description to the recipe and nutritional table are reported respectively in Table 3 and Table 4:

Table 3
Recipe of "ravioli" with meat filling (4 persons)

Fresh pasta	350 g
Roast veal	150 g
Ham	30 g
Mortadella	30 g
Tomato sauce	400 g
Grated parmesan cheese	40 g
1 egg	
Nutmeg	
Salt	

Table 4
Nutritional table of "ravioli" with meat filling

Calories	290 kcal
Carbohydrates	34.5 g
Proteins	14.8 g
Fats	10.4 g

In order to perform CFD simulations, two main elements were considered: water vapour at 96°C and the final product . For the first one, properties are all known and can be easily retrieved from the software library. Conversely, for the food product, it was necessary to find (or compute) the correct properties.

In particular, the following parameters were set for the product : density, thermal conductivity and heat capacity. The density of fresh filled pasta is known, because it is provided by the manufacturing company ($\rho = 456.36$ kg/m^3); the thermal conductivity and heat capacity, instead, were derived from the available literature.

For the thermal conductivity, the following formulation was used (Saravacos & Maroulis, 2001):

$$k_d(x,T) = \frac{1}{1+x}\lambda_0 \exp\left[-\frac{E_0}{R}\left(\frac{1}{T}-\frac{1}{T_{rif}}\right)\right] + \frac{x}{1+x}\lambda_i \exp\left[-\frac{E_i}{R}\left(\frac{1}{T}-\frac{1}{T_{rif}}\right)\right] \tag{1}$$

where x is the water content of pasta, λ_i, λ_0, E_i, E_0 are used to describe the raw material (Table 5), T [°C] is the pasta temperature and T_{Rif} [°C] is a reference temperature, which is set at 60°C (Saravacos & Maroulis, 2001).

Table 5
Parameters for pasta thermal conductivity calculation (Saravacos & Maroulis, 2001)

λ_i [W m^{-1}K^{-1}]	0.8
λ_0 [W m^{-1}K^{-1}]	0.273
E_i [kJ mol^{-1}]	2.7
E_0 [kJ mol^{-1}]	0.0

For simplicity, this model was used to obtain an average value of k_d in the range of temperature and water content used in the process. By setting an average pasta temperature of 349 K and an average relative humidity of 24% in Eq. 1, the following value of k_d was obtained:

$$k_d = 0.38 \left[\frac{W}{m \cdot K}\right] \tag{2}$$

Similarly, the heat capacity C_p was computed as weighed average of the heat capacities C_i of the dough main components, i.e. water, starch, gluten and fat (Andrieu, Gonnet & Laurent, 1998):

$$C_p = \frac{\partial h}{\partial T} = \left[\frac{X}{(1+X)} C_{p,water} + \frac{1}{(1+X)} C_{p,solids}\right] \tag{3}$$

where $C_{p,\,solids}$ was derived as:

$$C_{p,solids} = y_{starch} C_{p,starch} + y_{proteins} C_{p,proteins} + y_{fat} C_{p,fat} \tag{4}$$

The following parameters were set for the computation:

Water

$$C_w = 4184 \left[\frac{J}{kgK}\right] \tag{5}$$

Starch

$$C_s = 5.737 \cdot T + 1328 \left[\frac{J}{kgK}\right] \tag{6}$$

Gluten

$$C_g = 6.329 \cdot T + 1465 \left[\frac{J}{kgK}\right] \tag{7}$$

Fat

$$C_f = 2000 \left[\frac{J}{kgK}\right] \tag{8}$$

The pasta composition was obtained from the data proposed in Table 6.

Table 6
Fresh filled pasta composition (Source: data provided by a company manufacturing fresh pasta)

Water	36,09%
Starch	40,70%
Gluten	13,53%
Fat	9,68%

The global C_p is thus calculated as:

$$C_p = 2494.64 \left[\frac{J}{kgK}\right] \tag{9}$$

The above values of d, k_d and C_p for the ravioli have been used in all CFD simulations.

2.2 Mathematical modelling

2.2.1 Simulation setting: geometry and mesh

Given the complex geometry and the large size of the pasteurizer, the simulations were conducted considering 1/3 the length of the pasteurizer (whose total length is 2400 mm).

The width of the pasteurizer, instead, is kept at the original size, because the angle of inclination of the "roof" (cf. Figure 2) was designed specifically to ensure that the condensation of steam does not run directly on the ravioli. Condensation flows along the walls to be deposited in a special section on the bottom of the pasteurizer.

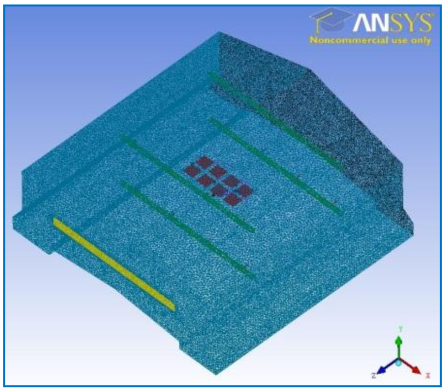

Figure 2. 1/3 of pasteurizer

The thermal analysis was performed on just two adjacent rows of product, each one containing 4 ravioli, although the industrial pasteurizer may contain a number of ravioli equal to 4/5 per 100 cm^2 of the conveyor belt. So, assuming an area of 3375 cm^2 (the size of the conveyor belt is 750x450 mm), the tape can contain up to 126 "ravioli".

In the present study, 8 "ravioli" are included in the model, to consider the impact between two adjacent ravioli and between two adjacent rows. Another reason for this choice is to not overload the mesh, which would compromise the reliability of the results.

The flow rates of steam were defined according to the load of dough in the pasteurizer. The size of the ravioli in the simulations complies with those used in subsequent experiments. The mesh created for this geometry is of tetrahedral type, with a gradient properly set to comply with the Courant number. This latter is of fundamental importance for transient flows. For a one-dimensional grid, it is defined as:

$$Courant = u\frac{\Delta t}{\Delta x} \qquad (10)$$

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 so that the Courant number is sufficiently small.

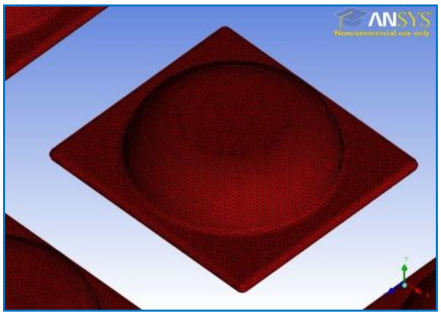

Figure 3. Surface Mesh on the "Raviolo"

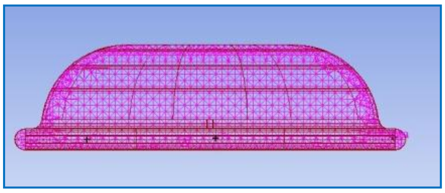

Figure 4. Volume mesh inside the "Raviolo"

2.2.2 Simulation setting: domain equations and boundary conditions

The 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:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho V) = 0 \qquad (11)$$

The momentum equation:

$$\left(\frac{\partial \rho V}{\partial t} + \nabla \cdot (\rho V \otimes V)\right)$$
$$= \nabla \cdot (-p\partial + \eta \cdot (\nabla V + (\nabla V)^t)) + S_M \qquad (12)$$

In this work, according to the materials used, two domains were created: a fluid (steam) and a solid (filled pasta).

For the energy equation of the fluid domain, the pasteurization process of “filled fresh pasta” was modelled using a “Total Energy” approach, i.e.:

$$\frac{\partial(\rho h_{tot})}{\partial t} - \frac{\partial p}{\partial t} + \nabla \cdot (\rho U h_{tot}) =$$
$$\nabla \cdot (\lambda \nabla T) + \nabla \cdot (U \cdot \tau) + U \cdot S_M + S_E \qquad (13)$$

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

$$h_{tot} = h + \frac{1}{2}U^2 \qquad (14)$$

The term $\nabla \cdot (U \cdot \tau)$ in eq. 13 represents the work due to viscous stresses and is known as the viscous work term. The term $U \cdot S_M$ represents the work due to external momentum sources. In this case, as in many applications, this term was neglected.

For the energy equation of the solid domain, CFX enables to create solid regions in which the heat transfer equations are solved, without considering the flow. Within solid domains, the conservation of energy equation can account for heat transport due to solid motion, conduction, and volumetric heat sources:

$$\frac{\partial(\rho h)}{\partial t} + \nabla \cdot (\rho U_S h) = \nabla \cdot (\lambda \nabla T) \qquad (15)$$

where h, ρ and λ are the enthalpy, density and thermal conductivity of the solid, respectively; U_s is the solid velocity (set at 0).

The boundary conditions set above are related to 16 inlet holes and 1 output section; in particular, a uniform orthogonal velocity input and a relative pressure for outlet are set. The wall was considered as adiabatic.

3 SIMULATIONS RESULTS

The simulations are carried out in transition state, to evaluate the variation of the pasteurization temperature inside the “ravioli” in function of time, in which the product is in contact with water vapour at 96 °C.

Four series of simulations were performed by setting different values of "Total Time", while keeping the "timestep" unchanged (cf. table 7).

Table 7
Total time and Timestep of simulations

Total Time	*Timestep*
30 s	0.01 s
60 s	0.01 s
120 s	0.01 s
150 s	0.01 s

From all the simulations carried out, it was observed that the product heats up with the increase of the time. The figures below show the pasteurization phase at different time intervals .

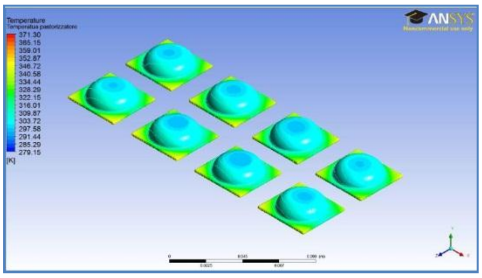

Figure 5. Simulation I - t = 30 s

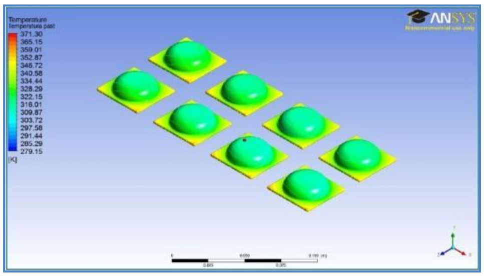

Figure 6. Simulation II - t = 60 s

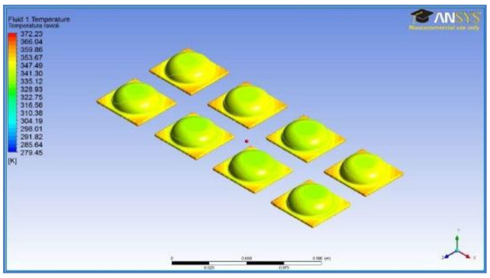

Figure 7. Simulation III - t = 120 s

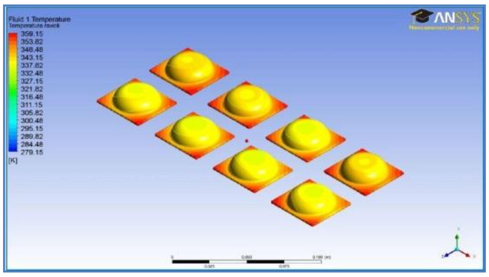

Figure 8. Simulation IV - t = 150 s

For each simulation, 8 points located at the core of each product were created. In these points, a chart to display the "pasteurization temperature ramp" was generated:

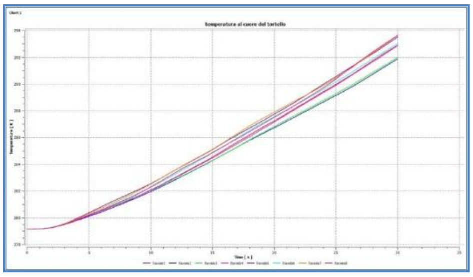

Figure 9. "Pasteurization temperature ramp" between 0 s < t < 30 s

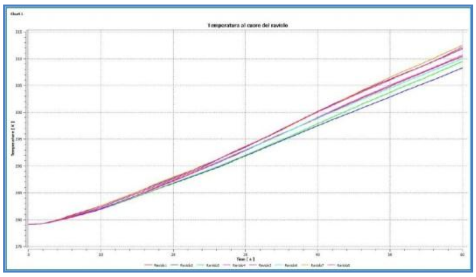

Figure 10. "Pasteurization temperature ramp" between 0 s < t < 60 s

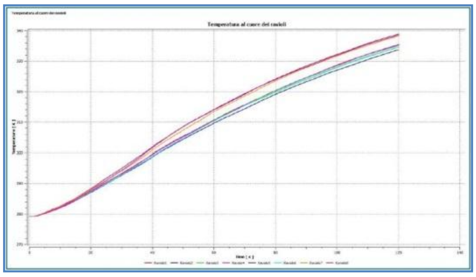

Figure 11. "Pasteurization temperature ramp" between 0 s < t < 120 s

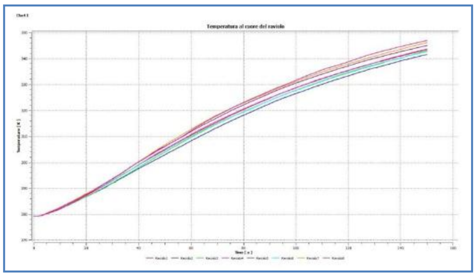

Figure 12. "Pasteurization temperature ramp" between 0 s < t < 150 s

From each simulation, with subsequent Microsoft Excel elaborations, it was possible to obtain all the temperatures calculated in the product volume. With those data, we were able to see the temperature trend in the product volume and not only in a specific point. From table 8 to table 11, the percentage of volume increase was observed. Values equal to 100% mean that the entire volume is located at a temperature higher or equal to the reference temperature set.

Table 8
% of volume for T greater or equal in respect of Tref (t = 30 s)

Tref	°C	K	%Volume
T0	15	288.15	100%
T1	25	298.15	85.06%
T2	35	308.15	42.58%
T3	45	318.15	22.84%
T4	55	328.15	9.19%
T5	65	338.15	1.86%
T6	75	348.15	0.04%

Table 9
% of volume for T greater or equal in respect of Tref (t = 60 s)

Tref	°C	K	%Volume
T0	15	288.15	100%
T1	25	298.15	100%
T2	35	308.15	99.99%
T3	45	318.15	71.38%
T4	55	328.15	33.09%

T5	65	338.15	12.98%
T6	75	348.15	1.75%

Table 10
% of volume for T greater or equal in respect of Tref (t = 120 s)

Tref	°C	K	%Volume
T0	15	288.15	100%
T1	25	298.15	100%
T2	35	308.15	100%
T3	45	318.15	100%
T4	55	328.15	100%
T5	65	338.15	87.03%
T6	75	348.15	22.92%

Table 11
% of volume for T greater or equal in respect of Tref (t = 150 s)

Tref	°C	K	%Volume
T0	15	288.15	100%
T1	25	298.15	100%
T2	35	308.15	100%
T3	45	318.15	100%
T4	55	328.15	100%
T5	65	338.15	100%
T6	75	348.15	56.24%

3.1 Summary of the simulations:

A summary of the tests conducted is reported below. In particular, table 12 shows the initial temperature (always constant), the temperature at the product core, the temperature at the base and the average temperature of the product, at four different time steps.

Table 12
summary of the simulations

	T_{start} [°C]	T_{inside} [°C]	T_{edge} [°C]	$\bar{T}$ [°C]
t = 30 s	6	20	61	41
t = 60 s	6	35	73	54
t = 120 s	6	67	82	75
t = 150 s	6	76	91	84

4 EXPERIMENTAL VALIDATION

4.1 Experimental tests

Experimental tests were performed to evaluate the accuracy and sensitivity of the results provided by the simulations described above. The tests were realized in a way as close as possible to the conditions implemented in the software. During the simulation, as mentioned, only 1/3 of the pasteurizer was considered, with a load of 8 ravioli disposed on two rows; furthermore, as done in the simulation phase, the ravioli are considered not in motion.

During the experimental tests, the same working conditions were set. The entire pasteurizer was used and 24 ravioli for test were loaded on the conveyor belt (i.e., a load three times higher). Moreover, on the basis of the travel time on the tape, it was possible to locate the ravioli in the same position as analysed during the simulation.

A temperature probe was inserted inside a product, with the purpose of recording the time-temperature trend. A series of tests to estimate an average trend of the temperature at the core of the product was performed.

The experimental results are reported in tables 13, 14 and 15:

Table 13
Experimental test 1

T_{start} = 7 °C	T_{inside} [°C]
t = 30 s	21.70
t = 60 s	47.10
t = 120 s	74.10
t = 150 s	82.10

Table 14
Experimental test 2

T_{start} = 6.20 °C	T_{inside} [°C]
t = 30 s	20
t = 60 s	41.80
t = 120 s	72.50
t = 150 s	83.50

Table 15
Experimental test 3

T_{start} = 6,5 °C	T_{inside} [°C]
t = 30 s	20
t = 60 s	38
t = 120 s	67
t = 150 s	77.50

4.2 Summary of the experimental tests:

As done for the simulation phase, a summary of the experimental tests performed is reported. In particular, figure 13 shows the "pasteurization temperature ramp" obtained in the experimental stage.

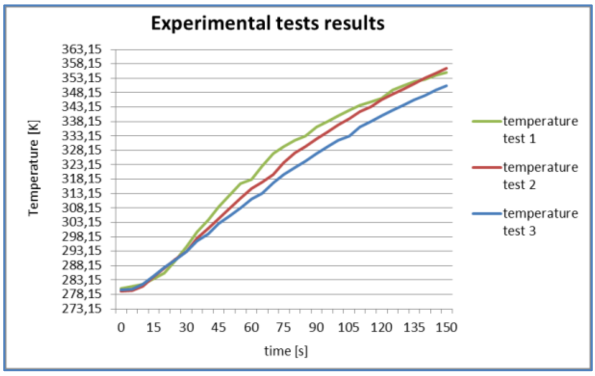

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Figure 13. "Pasteurization temperature ramp" from the experimental tests

4.3 Comparison

Three series of experimental tests were performed and the average value of temperature at the beginning of the experiment (t = 0s) and at the four time intervals analysed during the simulation (t = 30, 60, 120, 150s) was calculated.

An average value was derived from the experimental tests , so as to have a single curve for comparison with the simulation trend (cf. figure 14).

Table 16 shows the average values of experimental tests and compares them with the results provided by the software. The following values refer to the ones measured and calculated at the product core.

Table 16
Comparison between software and experimental results

	Average of experiments [°C]	Simulations [°C]	ΔError [°C]
T_{start} [°C]	6.57	6	0.57
t = 30 s	20.57	20	0.57
t = 60 s	39.53	36	3.53
t = 120 s	70.83	67	3.83
t = 150 s	78.92	74.5	4.42

Figure 14 shows the two trends. From that figure, it is immediate to observe a slight deviation between the results calculated by the simulator and those reported during the tests. This can be due to the fact that the pasteurization temperature of the industrial process was not always constant; conversely, some fluctuations were recorded. The temperature set for the simulations, instead, is fixed (96°C).

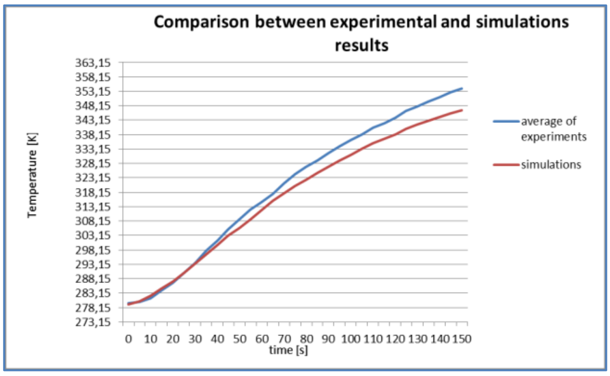

Figure 14. comparison between tests and software results

A further reason for deviation between experimental tests and simulations is that the real industrial scenario can be sensitive to many variables, since because each single product manufactured is different from another. For example, the consistency of the filling, the shape of the ravioli, the empty spaces inside them may vary. In addition, the initial temperature of the ravioli is never uniformly distributed and is not equal respect to another “ravioli”.

5 CONCLUSIONS

The present work aims to analyse a thermal process for pasteurization of fresh filled pasta, by means of Computational Fluid Dynamic (CFD) simulation. The pasta considered is “ravioli” filled of meat.

A simulation model was built under Ansys CFX code version 14.0. All simulations have been performedin a transient state (after 30s, 60s, 120s and 150s), to evaluate the trend of the pasteurization temperature at the core of the “ravioli” as a function of the process time. The real industrial process takes place in a pasteurization tunnel by means of water vapour at approx. 96°C.

Experimental tests were performed in order to validate the simulation model of heat exchange. Results show a good agreement with the real pasteurization process and a good level of product quality, with a little underestimation of the inner temperature of the ravioli, due to the higher temperature reached by the vapour during the tests (approx. 99°C).

Analysing and optimizing a pasteurization process by means of experimental tests can be expensive; hence, the availability of a simulation model able to reproduce this process can be helpful in practice for its optimization.

Future researches will be oriented toward obtaining better results, setting an higher temperature in the treatment room and considering the diverse initial temperature of different zone of the product.

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