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An Analysis of Air Flow in the Baking Chamber of a Tunnel-Type Electric Oven

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Abstract: The baking process in tunnel ovens can be influenced by many parameters. Among these, the most important can be considered as: the baking time, the volume of dough pieces, the texture and humidity of the dough, the distribution of temperature inside the oven, as well as the flow of air currents applied in the baking chamber. In order to obtain a constant quality of bakery or pastry products, and for the efficient operation of the oven, it is necessary that the solution made by the designers be subjected to modelling, simulation and analysis processes, before their manufacture, and in this sense it can be applied to the Computational Fluid Dynamics (CFD) numerical simulation tool. In this study, we made an analysis of the air flow inside the baking chamber of an oven. The analyzed oven was used very frequently on the pastry lines. After performing the modelling and simulation, the temperature distribution inside the oven was obtained in the longitudinal and transverse planes. For the experimental validation of the temperatures obtained in the computer-assisted simulation, the temperatures inside the analyzed electric oven were measured. The measured temperatures validated the simulation results with a maximum error of 7.6%.

Keywords: tunnel-type oven; CFD analysis; baking room temperatures; vorticity

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1. Introduction

Baking, even if it is located towards the end of the processing line, is a very complex operation through which the starch-based semi-finished products (bread, pretzels, cookies, etc.) undergo numerous physical, chemical, and biochemical changes, including volume expansion, starch gelation, protein denaturation and coagulation, and the Mayllard reaction [1–4]. These changes occur depending on the baking time, the applied temperature and the speed of heat application, and if these parameters vary, the physical, chemical and bio-chemical transformations will change significantly [5–10]. The temperature applied in the baking process varies depending on the ingredients used in the preparation of the semi-finished products, and their baking time depends on both the temperature inside the oven and also shape and size for semi-finished products [11,12]. Through baking, the porous structure of the dough turns into a core and the outer surface into a crust [13]. In [14] it is shown that the heating of the semi-finished products takes place due to the transmission, primarily, to the outer layers of the dough of heat from the inside of the oven. When the temperature of the layers in the peripheral area of the semi-finished products reaches the water boiling point, the force due to the water vapor pressure will maintain the expansion process of the dough until the end of the process [14,15]. Heat transfer from inside the oven to the dough pieces is directly influenced by the temperature of the oven hearth and the environment inside the baking chamber [14]. Also, the temperatures of the semi-finished products when being fed inside the oven. Traditionally, the time and temperature of the baking process in an electric oven are controlled, but the presence of airflow affects the temperature distribution inside the oven [16]. In [17], a study was performed to identify the parameters that influence finished products' quality. Among other things, parameters such as baking time, volume of dough pieces, texture and humidity of the dough, baking temperature and the flow of air currents applied inside the oven were observed. Electric ovens for baking starch-based semi-finished products can be described as thermally insulated chambers which are utilized for drying, heating, baking or cooking food [18]. The improper placement of heat sources inside the electric oven can cause heat transfer imbalances, leading to temperature variations in the baking chamber. These imbalances will result in an uneven distribution of crust color and moisture content over different areas in the depths of products [19]. During the process, as a result of water removal from the semi-finished products, the air inside the baking chamber retains moisture [4]. Therefore, it is necessary to remove it through the vents because the variation of humidity is responsible for the quality defects of the finished products [20]. In order to obtain an optimal baking process, in industrial practice, the semi-finished products are baked in ovens at a constant temperature [21]. During baking, heat transfer takes place through radiation, conduction and convection. Among these, radiation is that which is more frequently used. Radiation is transmitted heat from the heating sources located inside the oven and from the hot metal surfaces. Convection occurs when air, coming into contact with the heating source and hot metal parts of the oven, transfers heat to the baking surface of the product, and from here a conduction transfer takes place inside the product [3,20,22–24]. It should be noted that the process of thermal convection can be natural or forced.

In order to obtain products of a constant quality and for an efficient operation of the oven, it is necessary that the solution made by the designers be subjected to modelling, simulation and analysis processes, before their manufacture, and in this sense the Computational Fluid Dynamics (CFD) numerical simulation tool can be applied [3,25,26]. CFD is often used to simulate many processes in the food industry, such as: mixing, ventilation, refrigeration, baking, drying, etc. [27–29]. The use of the CFD numerical simulation combined with additional models has been studied by the authors of [25] on a forced thermal convection oven. The study aimed to determine the degree of browning of the bread by applying the developed model and to improve baking performance. The objective of [25] was to optimize the design of forced convection ovens by using time-dependent 3D numerical simulations. The baking process is influenced by a number of variables in the case of electric ovens with forced thermal convection: the correct maintenance (at the values set by the operator) of the temperatures in the baking chamber, the thermal conductivity of the materials from which the electric oven is made, the baking time, the temperature distribution in the baking chamber, as well as the humidity at feeding. One of the important parameters that influences baking is the air circulation in the baking chamber. This parameter influences the temperature distribution in the volume of the baking chamber. Forced thermal convection is the forced movement of a fluid caused by an external force moving it (pump, fan, level difference, etc.) [30].

The authors of [31] also proposed to use numerical simulation to study heat transfer by natural convection. They believed that such a simulation provides helpful information for the robust design of an oven and its performance evaluation. The authors of [3] aimed to study the temperature profile inside of a household electric oven using CFD numerical simulation. Three different models of radiation (the Discrete Transfer Radiation Model, the Surface-to-Surface Radiation Model and the Discrete Ordinates Radiation Model) were proposed in the study from [3] to determine the core and crust temperatures of the finished product. The proposed CFD model was able to provide information on the optimum temperature for air inside the oven, the baking time and starch gelatinization. Similarly, by using a CFD numerical simulation, the authors of [32] proposed a model that could predict both the temperature of the air inside the oven and of the dough during the baking process. Also, in [33], the authors proposed an algorithm that aimed to reduce the baking time of semi-finished products in a forced convection oven. The data provided by computer-aided modelling can be of real use for the efficient design of furnaces and the energy improvement of the process. The results of the research in [34] regarding the temperature distribution show the need to perform modelling and temperature analysis in the baking room of an oven. After applying the modified geometry of the oven in the model proposed by the authors of the paper, an improvement in the temperature distribution in the baking room was obtained, limiting these variations to ±2 K.

This paper aims to study the temperature profiles and air currents inside a small-capacity electric tunnel-type oven. The computer-assisted simulation was validated with the experimental data for the temperatures recorded in four points inside an electric oven.

The article has the following structure: the materials and methods section, in which the concepts of designing the computer-assisted simulation as well as the mathematical equations that were the basis of this study are presented; the results and discussions section, where the results of the analysis are presented and discussions are made on these results, as well as the experimental validation of the simulation; and the conclusions section, in which the major conclusions of the study are presented and recommendations are made.

2. Materials and Methods

In the case of electric ovens, forced thermal convection is performed by two fans, most often powered at 220 V, which forcefully introduce hot air into the baking chamber. In the case of electric oven Zanolly SYNTHESIS 06/40V E (made by Zanolli Srl from Verona, Italy) [35], analyzed in this paper, baking temperature is achieved by four electrical heaters arranged as follows: two electrical heaters above the movable hearth of the oven and two electrical heaters under the hearth.

The purpose of the present study was to simulate the flow of hot air inside the above-mentioned electric oven, according to the methodology presented in Figure 1.

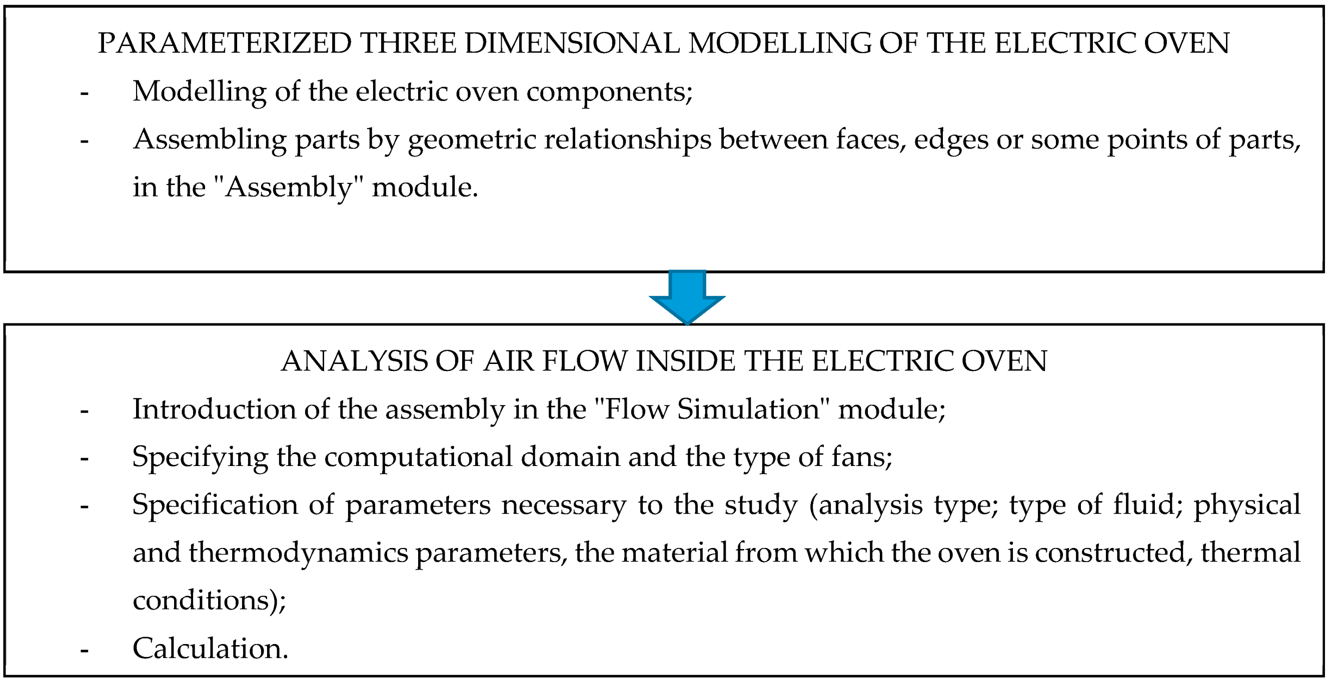


Figure 1. Methodology of analyzing the air flow through the electric oven.

Firstly, we made 3D geometric models of the oven Zanolly SYNTHESIS 06/40V E's components. The 3D modelling was performed with the parameterized design program Solid Works Premium 2016 S.P. 0.0 (produced by Dassault Systems, Vélizy-Villacoublay, France), in the "Parts" module.

Figures 2–4 present different views of the obtained models and the interface of the Solid Works program.

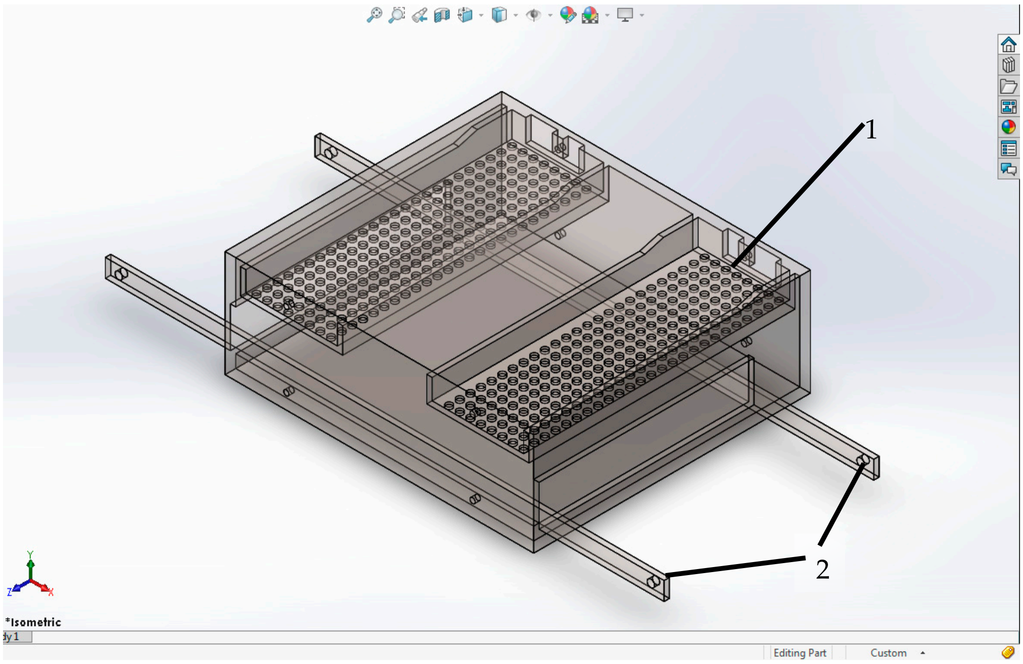


Figure 2. Baking chamber. 1. air flow holes; 2. conveyor guides.

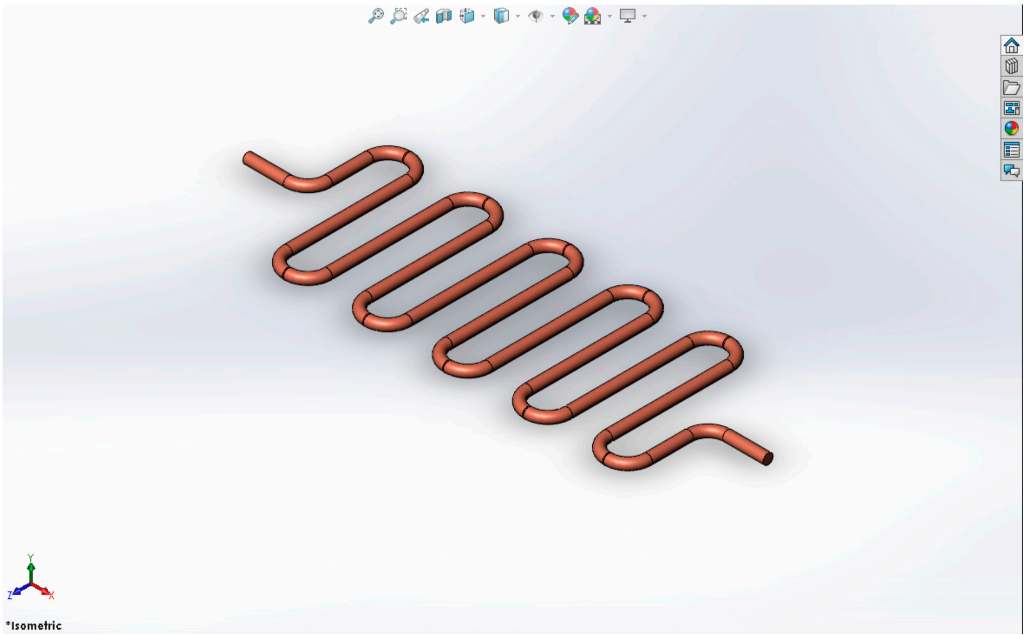


Figure 3. Electrical resistance for heating.

The components were assembled in the "Assembly" module. The assembly was performed by introducing geometric relationships between the entities of the parts (faces, edges and points).

After making the assembly, it was introduced in the "Flow Simulation" module to perform the analysis of air flow inside the baking chamber. As only the flow of air inside the oven was concerned, all connections to the external environment (the product supply and outlet ports, as well as the air supply openings for the fans) were closed with the help of lids, as shown in Figure 5.

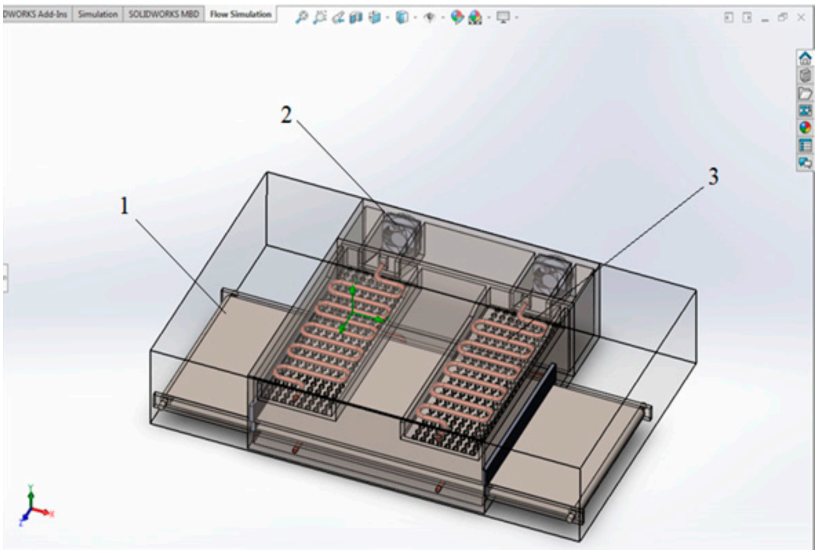


Figure 4. The assembly used in airflow analysis. 1. conveyor; 2. fan; 3. electrical resistance for heating.

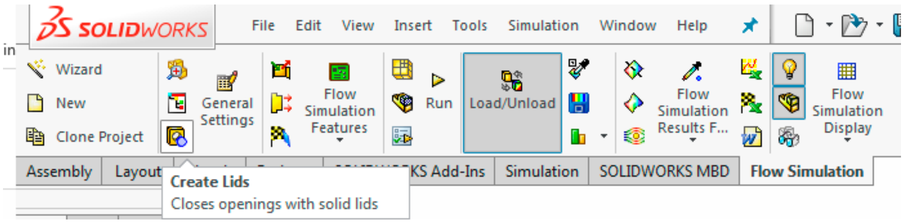


Figure 5. The option to make the lids from the "Flow Simulation" module of the analysis program.

After isolating the inner volume of the chamber, the type of analysis was chosen, as well as the physical parameters, the type of fluid, and the material from which the baking chamber was made. Also chosen were the initial thermodynamic parameters and the thermal conditions of the process; see Figures 6–9.

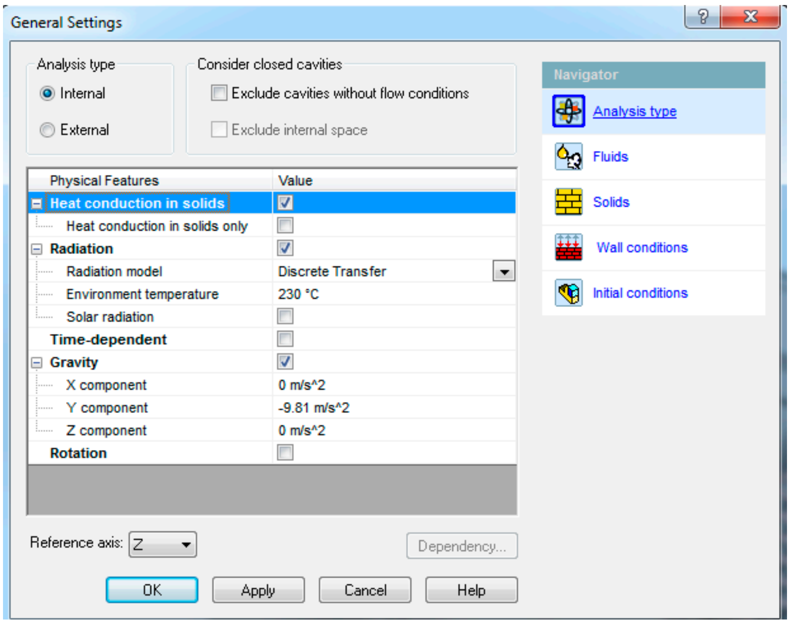


Figure 6. Choosing the type of analysis in the "Flow Simulation" module.

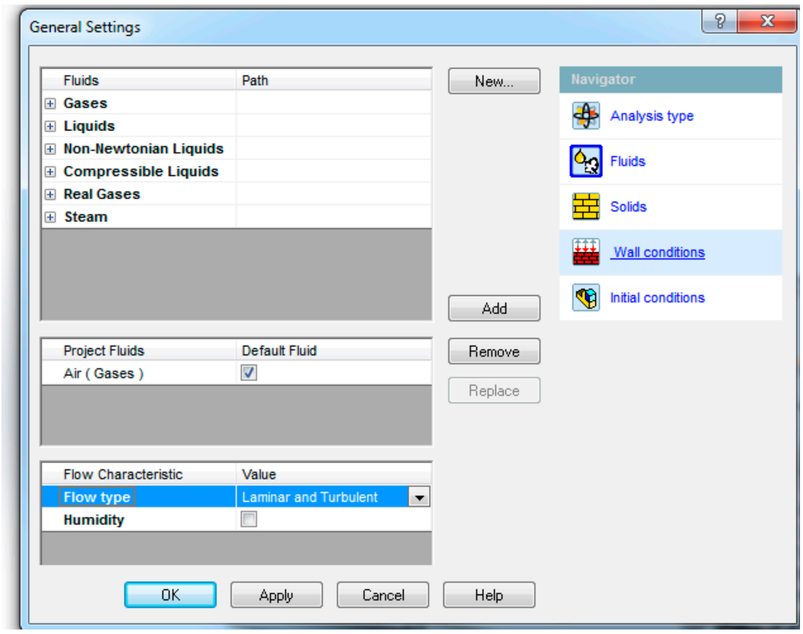


Figure 7. The choice of the fluid circulating inside the baking chamber, as well as the flow characteristics in the "Flow Simulation" module.

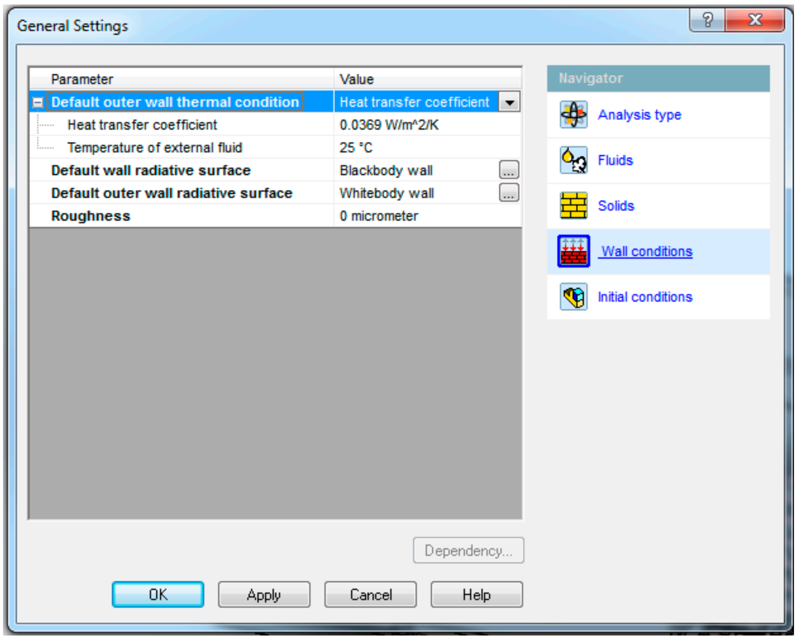


Figure 8. Choosing external parameters in the "Flow Simulation" module.

Figure 8 shows that in the case of external conditions, there was set a heat transfer coefficient calculated at 0.0369 W/m^{2}K. The coefficient was calculated with the relation [36]:

$$\alpha_T = \alpha_0 \frac{273 + C}{T + C} \left(\frac{T}{C} \right)^{3/2} \quad (1)$$

where: α_T is the coefficient of thermal conductivity at temperature T; α_0 is the fluid conductivity at 273 K (for air α_0 = 0.0234 W/m^{2}K); T is the absolute temperature (for this analysis it was considered 230 °C for the temperature inside the oven; this value can be adjusted); C is the characteristic constant of each gas (for air C = 122 K) [36].

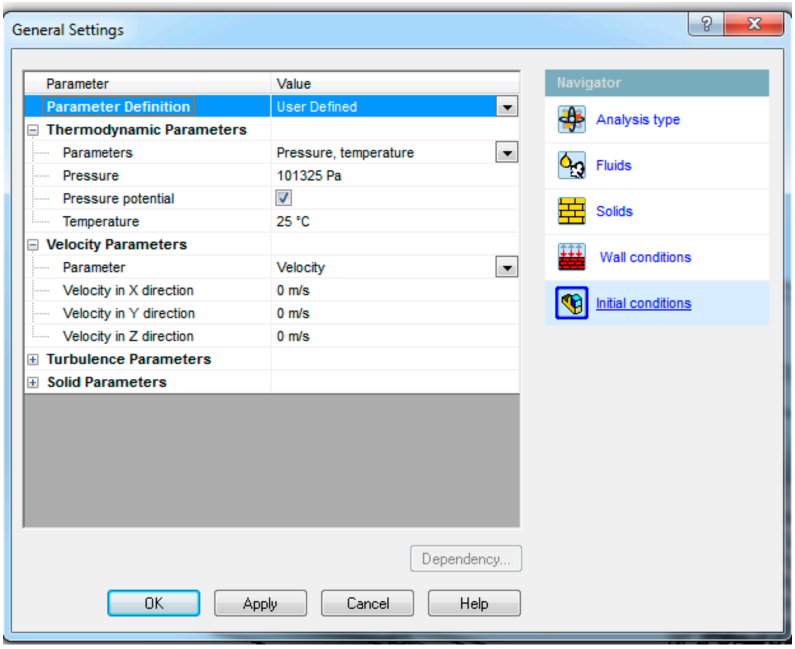


Figure 9. Choosing the initial conditions in the "Flow Simulation" module.

At the same time, we set the wall conditions for the computational domain. Thus, in the feeding and discharge areas of the baking chamber, as well as in the air supply areas of the fans (i.e., where the lids were placed), the normal atmospheric pressure and the ambient temperature of 25 °C were set as analysis conditions (Figure 10).

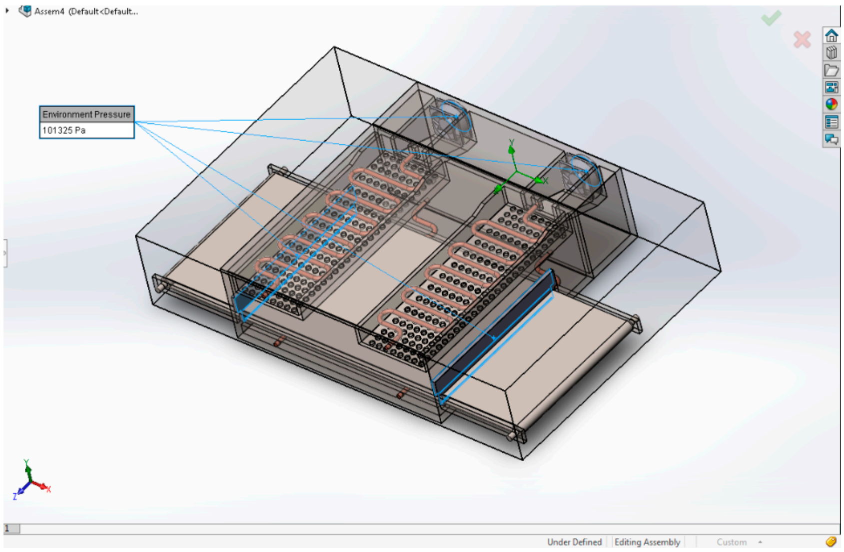


Figure 10. Conditions at the borders of the computational domain.

Then, on the surfaces of the blades of the two parametrically shaped fans, we set the virtual characteristics of an axial fan, Comair Rotron, powered in an alternating current, model SU/A (50 Hz). This fan was chosen because the features were the same as the characteristics of the actual fan, mounted on the electric oven, on which the experimental validation was done, but which was not found in the SolidWorks program library. Both fans had been set to introduce air into the electric oven baking chamber. Figure 11 shows the arrangement of the fans, and Figure 12 shows the variation of the air flow with the pressure difference of the chosen fan.

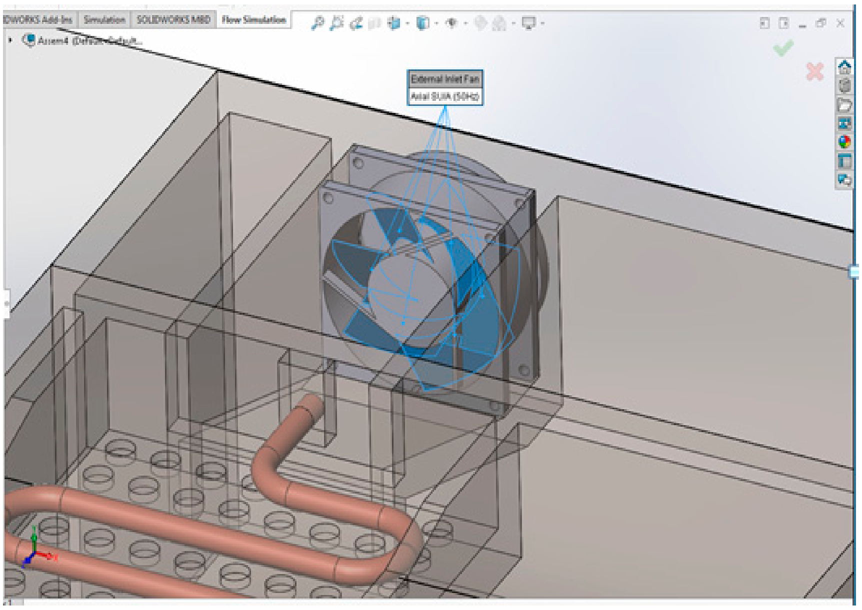


Figure 11. The way the fans are placed.

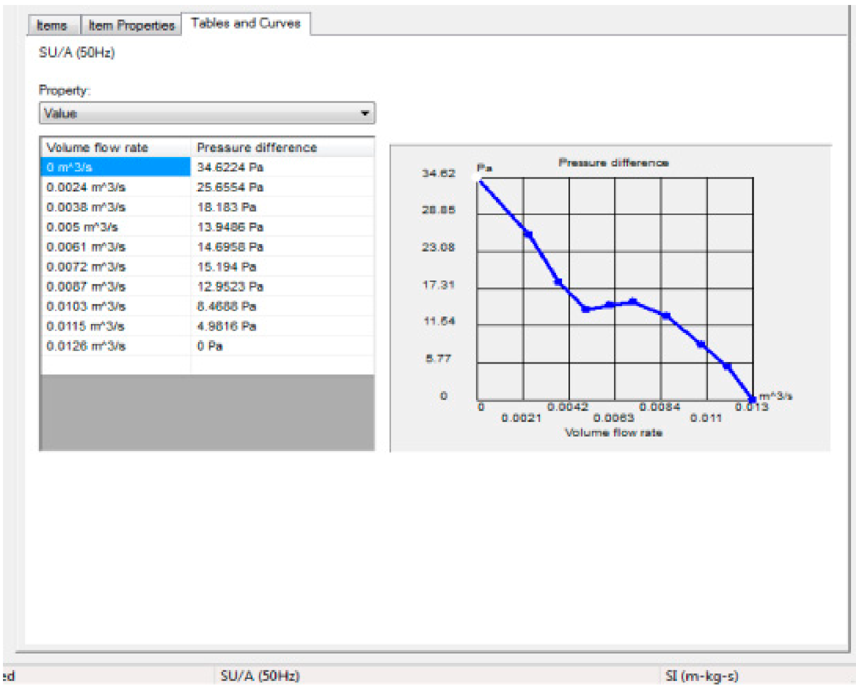


Figure 12. The variation of the air flow with the pressure difference of the chosen fan.

After setting the fan parameters, the heat sources inside the baking chamber were set.

For all four heaters in the oven assembly, the values for the rate of heat generation were set as follows: for the electric heaters above the conveyor, a value of 1100 W was entered, for the electrical resistance under the conveyor from the supply area of the oven, we set a value of 1700 W, and for the electrical heater in the outlet area under the conveyor, a value of 1750 W was set. These values were determined experimentally by the authors for the same oven and presented in the paper [6].

Before running the analysis, the fineness of the finite volume network in the computational domain was also set. Figure 13 shows the finite volume network.

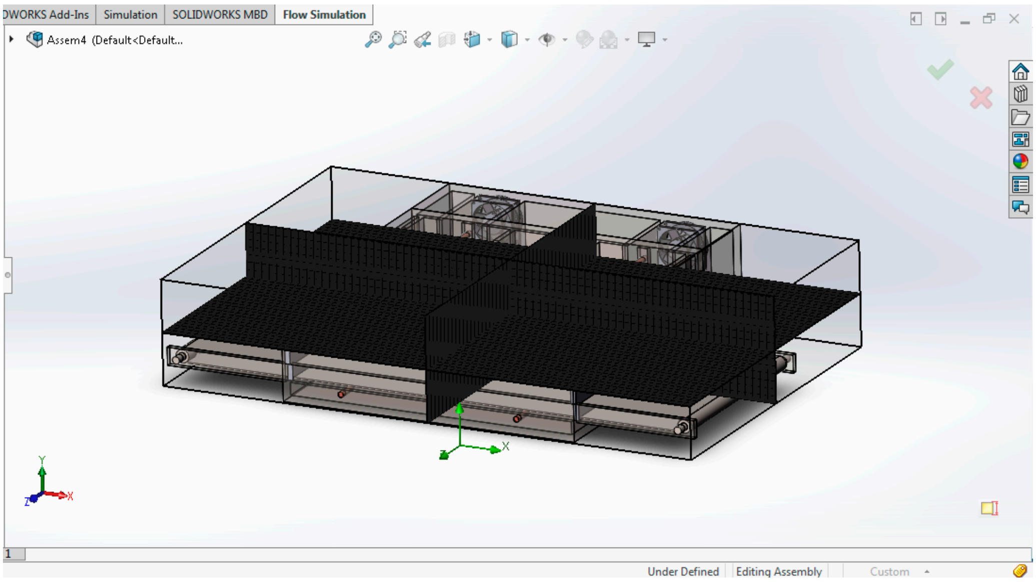


Figure 13. Computer's finite element network settings.

The Navier–Stokes equations (Equation (3)), which are used in almost all CFD flow models, were the basis for this study. By solving Navier–Stokes equations, we can predict the pressure and the velocity of one type of fluid in a certain enclosure geometry [37–39]. We used these equations together with the continuity equation (Equation (2)) by conserving momentum. The conservation of mass was represented by the continuity equation.

After solving the equations, values obtained could be applied to any point in the flow of the fluid, and so all flow details could be resolved anywhere in the flow area of an enclosed geometry. In the research literature, scholars often combine those equations with some additional equations (such as the energy equation).

$$\frac{\partial p}{\partial t} + \nabla(\rho v) = 0 \tag{2}$$

$$\rho\frac{\delta v}{\delta t} = -\nabla p + \rho g + \mu\nabla^2 v \tag{3}$$

where: ρ is the fluid density (for air ρ =1.184 kg/m^3); v—fluid velocity (for analysis the air velocity was determined at v = 2.4 m/s); p—atmospheric pressure (p = 1 atm); μ—fluid dynamic viscosity (for air μ = 1.84 $\times$ 10^{-5} kg/ms) [40].

3. Results

After performing the analysis, the program recorded in its own database the circulation of air and temperature inside the baking chamber. The simulation results took into account the initial conditions set and presented above. Thus, Figure 14 shows the distribution of air currents inside the oven, through several views.

Figure 15 shows the temperature distribution inside the oven for some characteristic sections.

From Figure 14, it can be seen that in the middle area of the oven there were created air vortices which caused the temperature in the middle area of the conveyor in the longitudinal plane to decrease to a value of 170–180 °C, under the conditions in which the operating mode requires a baking temperature of 230 °C. This is mainly due to the entrainment of cold air currents, which enter the baking chamber and are entrained in the vortex movement inside. This phenomenon can also be observed in the temperature distribution at the level of the conveyor belt (Figure 15). Chhanwal, N. et al. and Kokolj, U. obtained the same results in their paper [5,23].

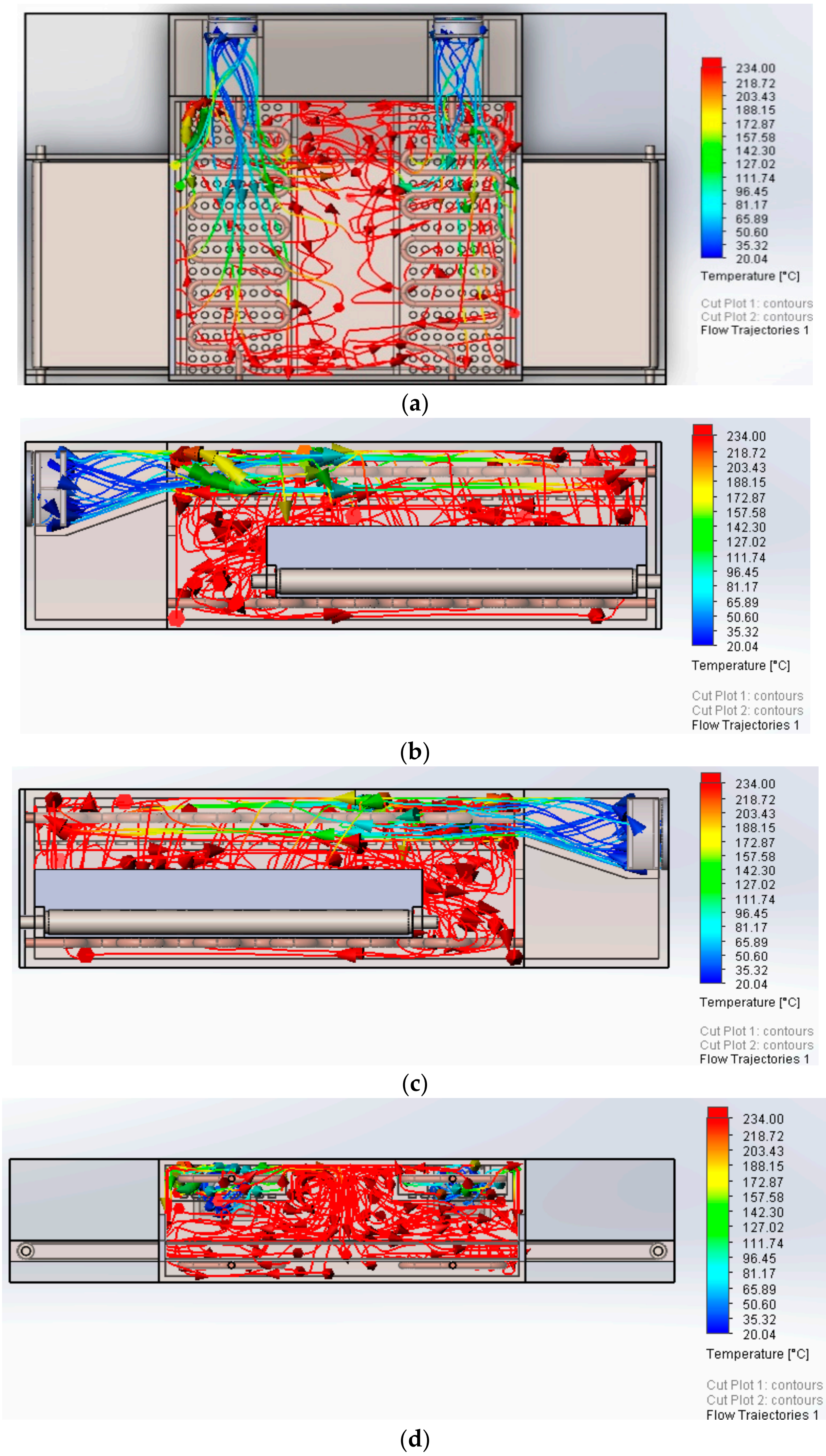
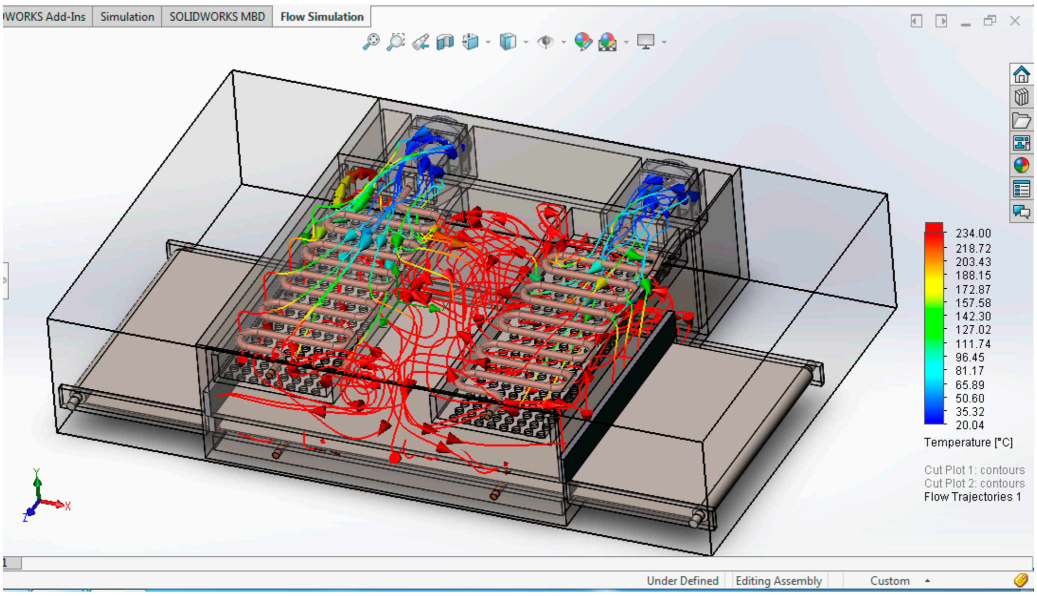
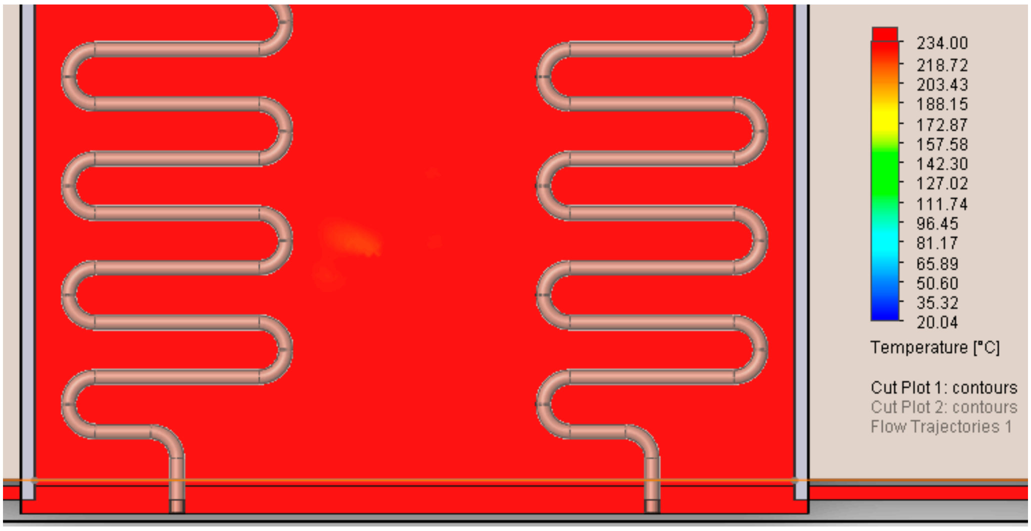


Figure 14. *Cont*.

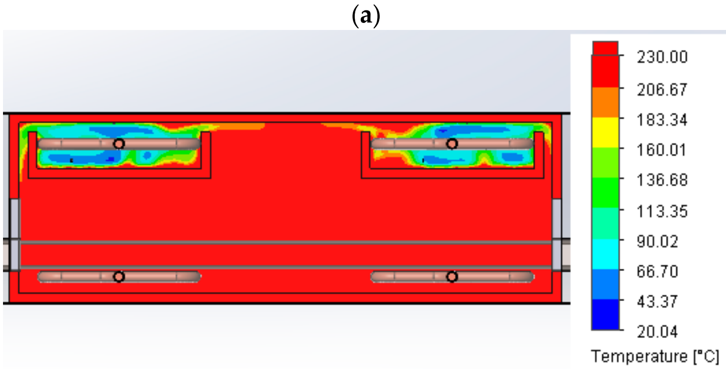


(**e**)

Figure 14. Distribution of air currents inside the baking chamber: (**a**) top view; (**b**) view from the feeding area with baking product; (**c**) view from the outlet area of the baked product; (**d**) front view; (**e**) isometric view.

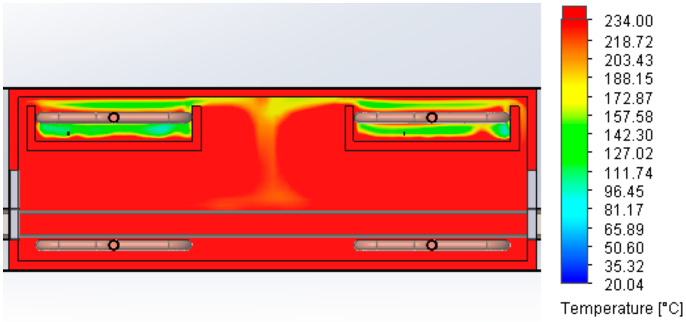


(**a**)

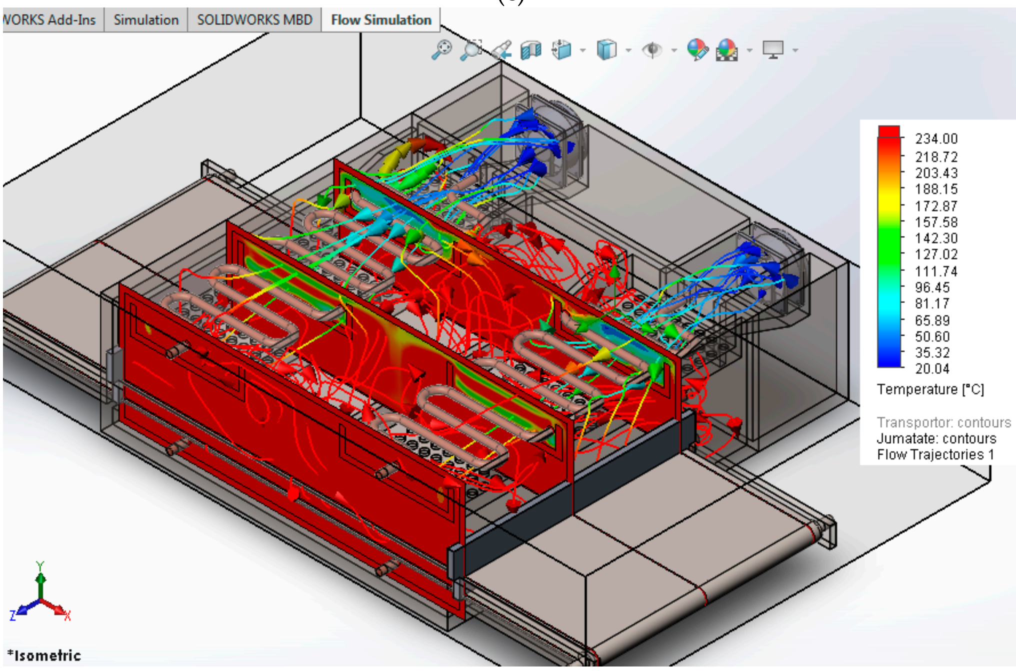


(**b**)

Figure 15. *Cont.*



(**c**)



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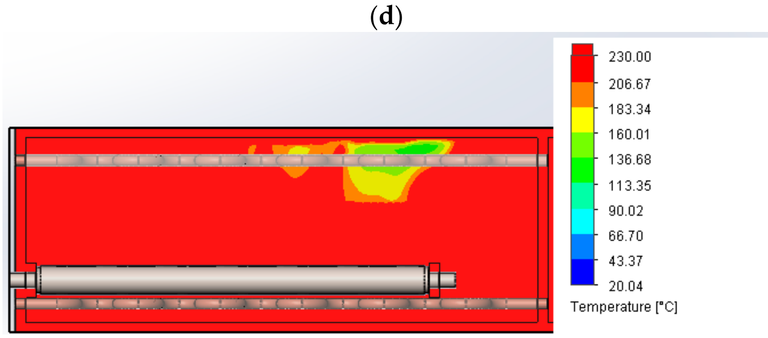
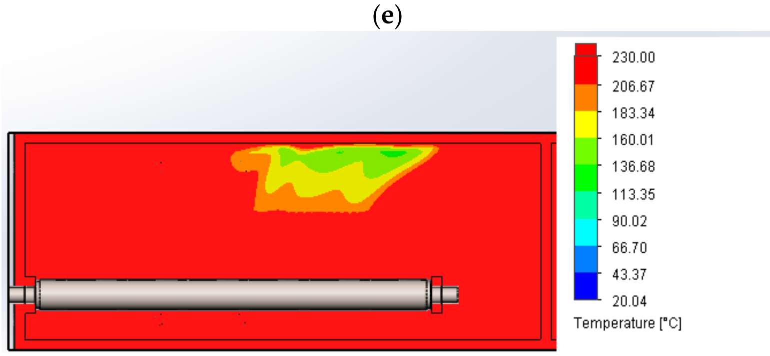
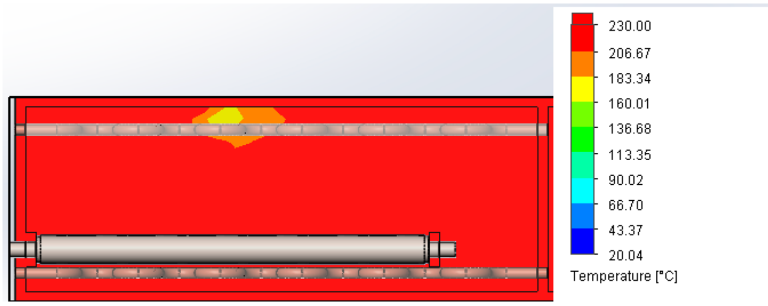


(**e**)

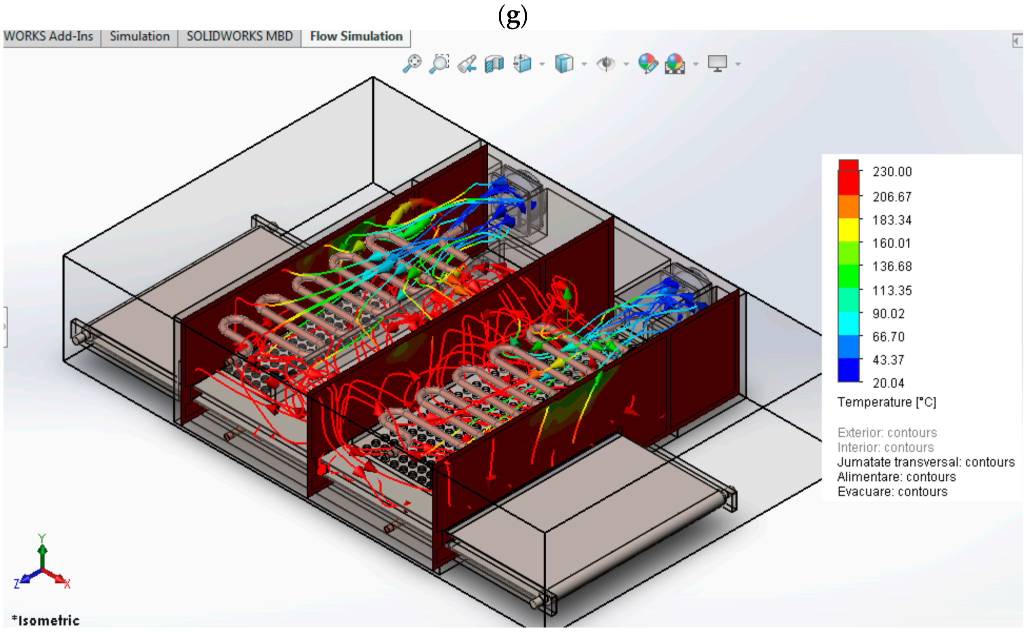


(**f**)

Figure 15. *Cont.*



(**g**)



(**h**)

Figure 15. Temperature distribution in the oven for some characteristic sections: (**a**) temperature distribution at the conveyor belt level; (**b**) temperature distribution in the supply area of air in the baking chamber (longitudinal section); (**c**) temperature distribution in the area opposite to the air supply in the baking chamber (longitudinal section); (**d**) temperature distribution in the three areas shown above along with the trajectories of the air currents (isometric view); (**e**) temperature distribution in the feeding area of the baking chamber (cross section); (**f**) temperature distribution in the outlet area of the baking chamber (cross section); (**g**) temperature distribution in the middle zone of the baking chamber (cross section); (**h**) temperature distribution in the three areas shown above along with the trajectories of the air currents (isometric view).

Also, it was found that the temperature distribution in the three longitudinal planes was different. In the air supply area (sucked in by fans from the outside environment and fed into the baking chamber), the temperatures were distributed between 20 °C and 230 °C and would increase as the air advanced in the baking chamber to the opposite wall where the temperature distribution was in the range of 160–230 °C, here, however, the temperature of 230 °C was predominant.

It was noted in Figure 16 with Sketch 1, the longitudinal line of the conveyor inside the baking chamber located on the opposite side of the air supply, with Sketch 3, the longitudinal line located in the middle area of the conveyor inside the baking chamber, and with Sketch 2, the longitudinal line located near the feeding area with air inside the baking chamber. All three lines were located on the surface of the conveyor and were used to collect data on the variations of the heat transfer coefficient (Figure 16a), air temperature (Figure 16b), air pressure (Figure 16c) and the specific heat of the air (Figure 16d) along the length of the baking chamber. Figure 17 shows the three lines used to collect the numerical values that define the variation curves in Figure 16.

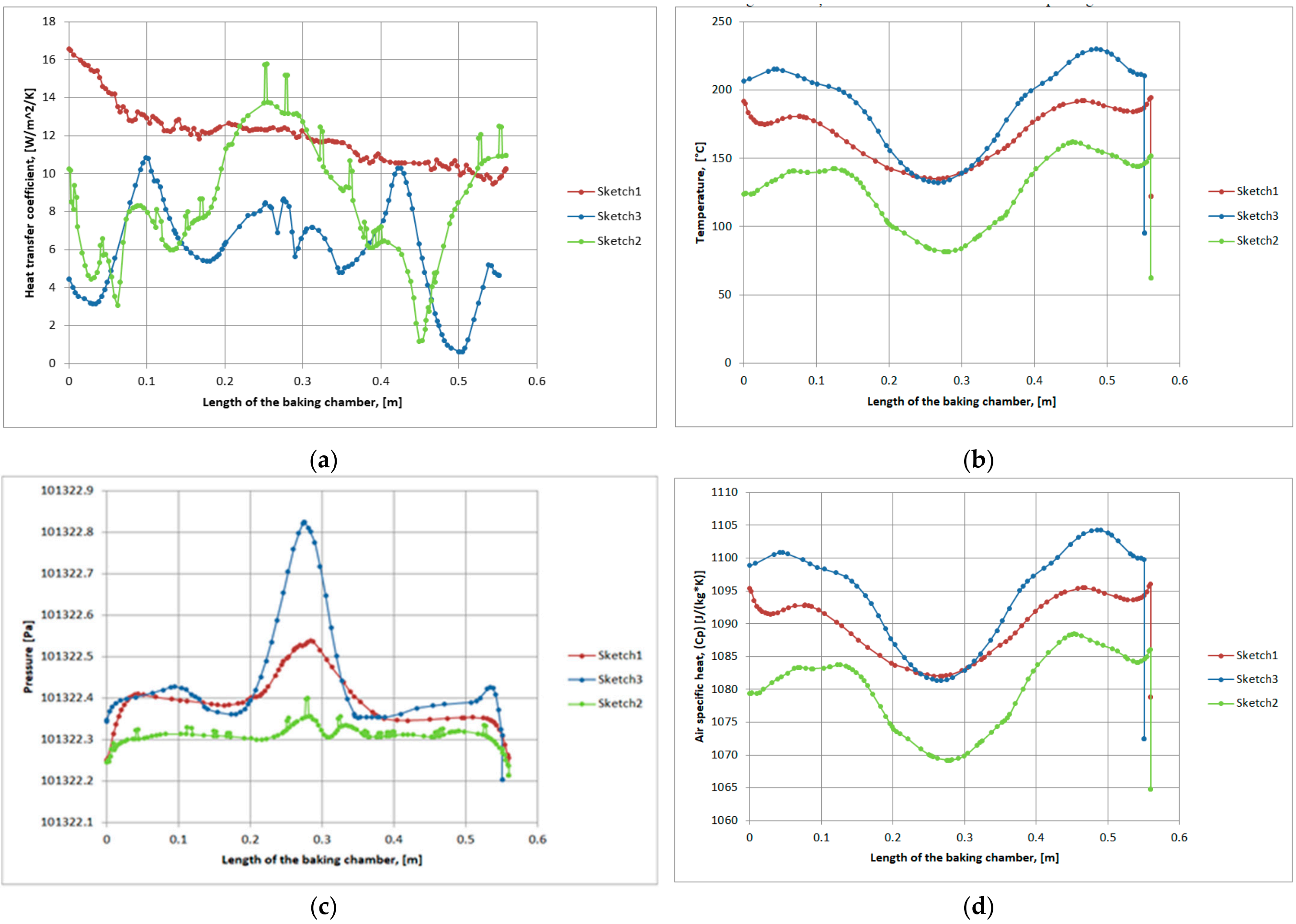


Figure 16. Variation along the length of the baking chamber from some physical parameters: heat transfer coefficient (**a**), air temperature (**b**), air pressure (**c**) and specific heat (**d**).

Figure 16b,c shows that in the middle area of the conveyor (Sketch 3), as the air pressure increases, the temperature inside the baking chamber decreases, with the phenomenon being explained somewhat above.

Also, the specific heat of the air increased from 1004 J/kgK (the value that air has at 20 °C, [41]) up to 1104 J/kgK. This phenomenon was also observed by Rek, Z et al. in [26].

Some steps can be taken to avoid heat loss in the middle area of the oven. It is recommended that the air introduced into the oven should be preheated before being fed into it (but not before the air is sucked in by the fans). And, also, to break the vortices that form inside the oven which drive the cold air to the middle zone of the oven and to the surface of the conveyor. A mechanical solution could be the use of some deflector plates, mounted in the areas of maximum intensity of air vorticity, used to breakdown the vortices.

Vorticity is defined in the literature as a mathematical concept used in fluid mechanics that reflects the intensity of the circulation or rotation of a fluid and is most often represented by the angular velocity of rotation [42].

In the case of the analyzed electric oven, the vorticity (on the three areas presented above) is represented in Figure 18. It can be seen that the vorticity has higher values in the area opposite to the air supply because here the air current hits the vertical wall of the baking chamber and begins to create vortices. Also, it can be observed here that the maximum value of vorticity appears again in the area near the middle of the baking chamber along its length. The results are similar to those obtained by the authors of [25], in which the authors showed a temperature and vorticity gradient with variations identical to the one in this article. It should be mentioned, however, that in the study in [25], this gradient was beneficial to the working process of the oven analyzed, and while it was not in the oven used in this article, this is why we recommend mounting deflector plates in this area.

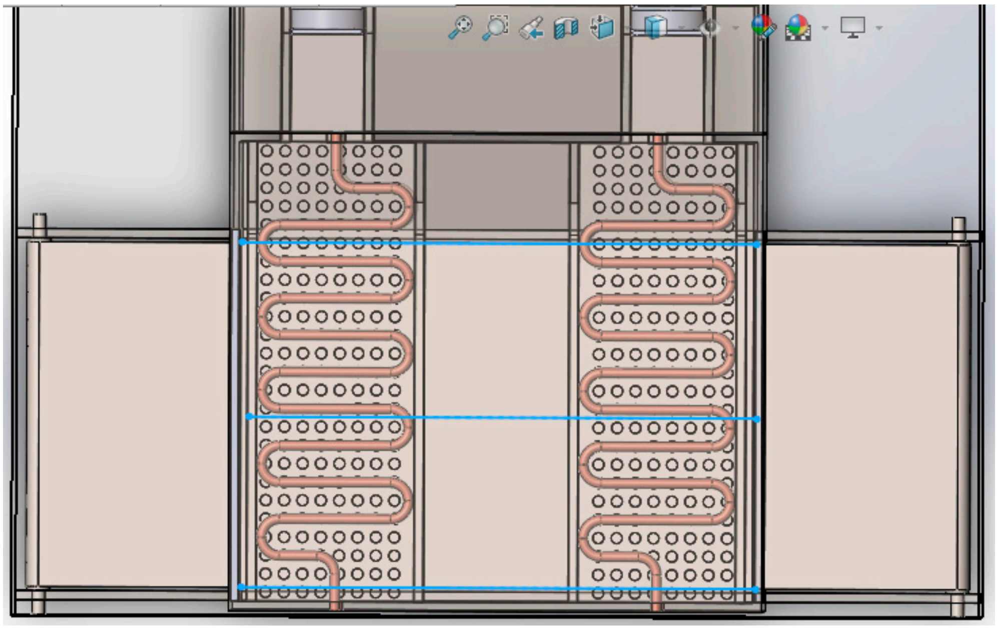


Figure 17. The lines used to collect the numerical values defining the curves of variation of the heat transfer coefficient, the air temperature, the air pressure and the specific heat of the air along the length of the baking chamber.

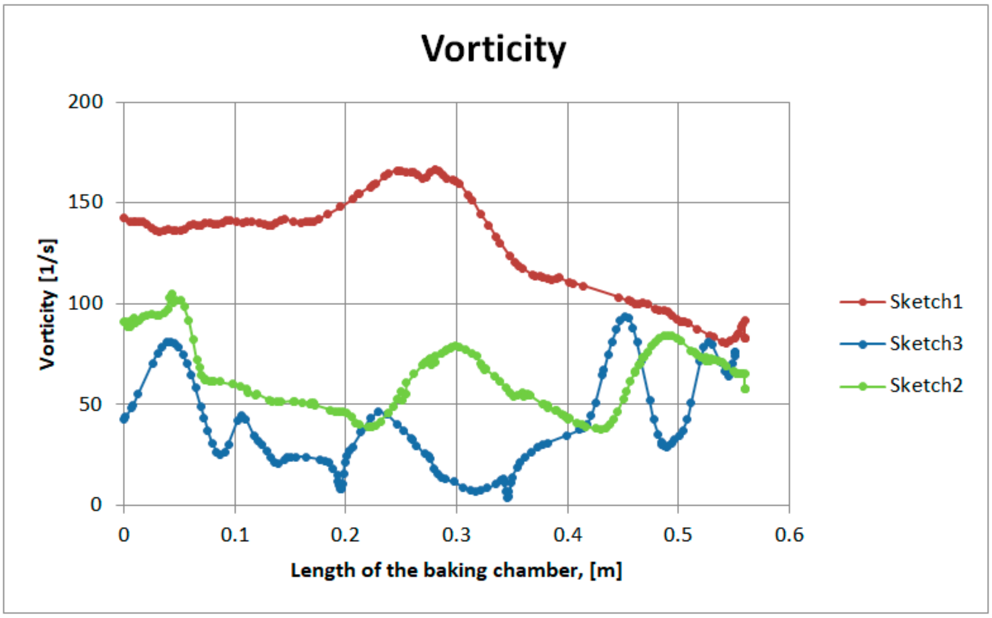


Figure 18. Variation of vorticity along the length of the baking chamber.

Figure 19 shows with Line 1 the transverse line of the conveyor in the oven outlet area, with Line 3 the transverse line located in the middle area of the conveyor, and with Line 2 the transverse line of the conveyor in the supply area. This figure shows the variation data of the heat transfer coefficient, air temperature, air pressure and air-specific heat in the transverse plane of the baking chamber.

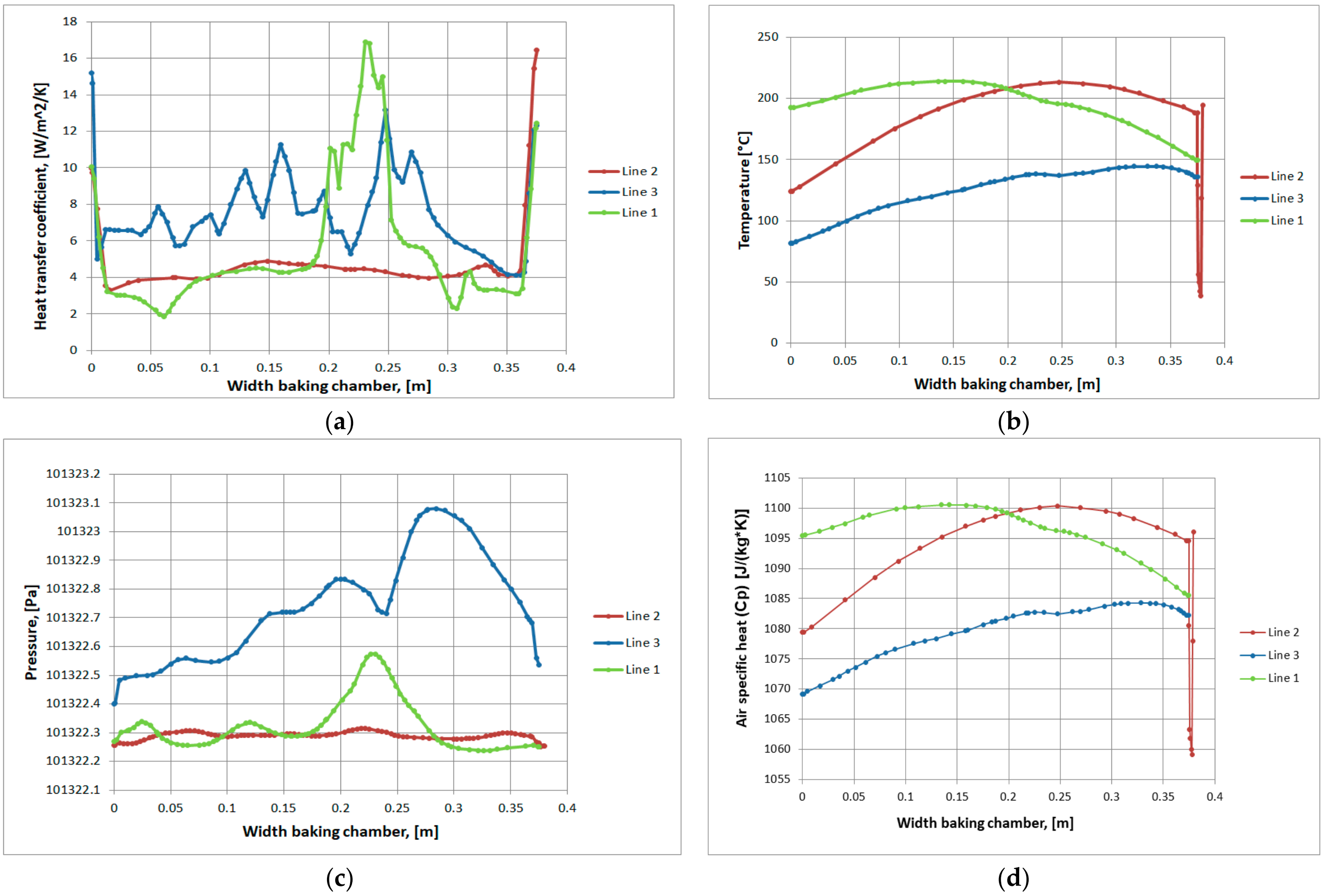


Figure 19. Variation across the width of the baking chamber for some physical parameters: heat transfer coefficient (**a**), air temperature (**b**), air pressure (**c**) and specific heat (**d**).

Figure 20 shows the vorticity variation across the width of the baking chamber in the three areas mentioned above. It can be seen that, for the supply area, the maximum values were close to the area of the first fan. In the case of the discharge zone, the vortex variation curve shows maximums towards the left and right ends of the discharge surface, with the vortices being small in the central zone. And, in the case of the line in the middle area of the baking chamber, in width, the maximum was reached at about 0.24 m from the outer wall.

The quality of the baking process is mainly influenced by two factors: the constant maintenance of the set baking temperature and the baking time (the time the product spends inside the baking chamber). The first factor can influence the second. Thus, if the temperature were evenly distributed, both longitudinally and transversely, in the baking chamber, and was kept constant at the set value, it is possible that the baking time would be reduced, which would lead to an increase in the productivity of these types of electric ovens.

The non-uniformity of the temperature and the presence of eddies of significant sizes which were constant, are similar to the results of [43], research based on the application of numerical simulation analysis methods inside a forced convection oven, in which the authors proposed adjusting the structure of the deflectors inside the baking chamber and demonstrated that they bring a significant improvement in temperature uniformity compared to the original deflector.

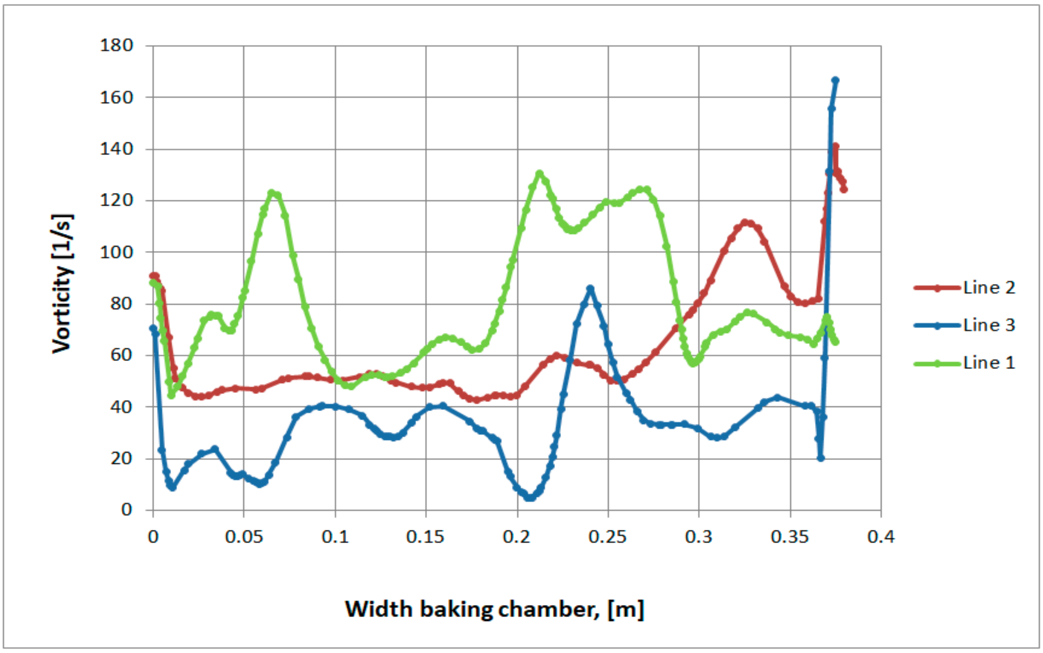


Figure 20. Projection of vorticity on the width of the baking chamber.

To guarantee an efficient distribution of air flow, thus ensuring a fast baking process, the authors of [44] identified the best furnace design or configuration by studying three furnace design geometries with different fan rotor positions. However, we consider that a preheating of the air with a low-power electric resistance would guarantee a uniformity of temperature in the baking chamber. If this is corroborated the installation of deflector plates in the areas shown above in the article, to break the vortices created, a high efficiency of baking processes can be ensured at constant temperatures.

The design of the fan cover of a bakery oven was studied by the authors of [25] through a methodological proposal and validation involving the combination of computational fluid dynamics and numerical computations to obtain accurate results. The results of the study show that the use of simulation in the design stage gives engineers the opportunity to quickly and efficiently examine new design concepts, which leads to the acceleration of the project development process.

4. Validation of the Air Flow Simulation inside the Baking Chamber of the Analyzed Electric Oven

In order to validate the values of the temperatures obtained during the simulation of the air flow inside the baking chamber of the electric oven, a series of measurements were made with the help of the Extech MP530 MultiPro True RMS multimeter (made by Extech Instruments, Waltham, MA, USA) and an ordinary laboratory thermocouple.

The measurements required a thermocouple that was introduced into the baking chamber of the oven, and the parameters of the operating mode were set according to the simulation of the air flow inside the baking chamber. Measurements were made in sets of five at four important points inside the baking chamber (according to Figure 21), and the results for each point were mediated. Thus, the following average temperature values were obtained: for the lower input area, the temperature value was 214 °C (A_1); for the output area on the lower midline, the temperature value was 226 °C (A_2); for the upper-middle zone, the temperature value was 249 °C (A_3); and for the lower middle area, the temperature value was 249 °C (A_4). The obtained temperatures validate the simulation results with a maximum error of 7.6%, a lower value than the one obtained by Suvanjumrat and Loksupapaiboon in [45], which was 8.99% for the analysis on a batch furnace.

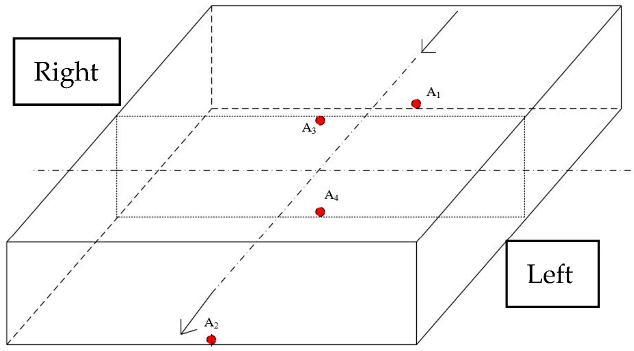


Figure 21. Diagram of the baking chamber of the electric oven and the areas where the temperature measurements were made. A_1—down feeding area; A_2—lower evacuation area; A_3—upper middle area; A_4—lower middle area.

5. Conclusions

Following the simulation performed with the help of the Solid Works program, the "Flow Simulation" module, we obtained values for some physical parameters (heat transfer coefficient, specific heat, air pressure, air temperature, vorticity) on the length and width of the baking chamber for the air flow inside the electric oven.

The novelty of this article consists in the fact that a study was carried out on an electric furnace that had not been analyzed in this way before, following which recommendations were made for construction and operation.

Some steps can be taken to avoid heat loss in the middle area of the oven. It is recommended that the air introduced into the oven be preheated before being fed into it (but not before the air is sucked in by the fans). And, also, to break the vortices that form inside the oven and that drive the cold air to the middle zone of the oven and to the surface of the conveyor. A mechanical solution could be the use of some deflector plates, mounted in the areas of maximum intensity of air vorticity, used to breakdown vortices. Those recommendations were determined by computer-aided modelling-simulation.

We recommend to the builders of forced-convection tunnel-type electric ovens to perform CFD analyses in the design phase of the ovens in order to avoid possible design mistakes. It was demonstrated in this paper, through experimental validation, that the temperature distribution, longitudinally and transversely in the baking chamber at the level of the conveyor, is verified by computer-assisted simulation with a maximum error of 7.6%.

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References

1. Marcotte, M. *Heat and Mass Transfer during Baking*; WIT Press: Billerica, MA, USA, 2007; Volume 13, pp. 241–265.
2. Mohd Jusoh, Y.M.; Chin, N.L.; Yusof, Y.A.; Rahman, R.A. Impact of Humidified Baking on Crust and Crumb Properties of Open Bread during Storage. *Food Sci. Technol. Res.* **2013**, *19*, 29–37. [CrossRef]
3. Chhanwal, N.; Anishaparvin, A.; Indrani, D.; Raghavarao, K.S.M.S.; Anandharamakrishnan, C. Computational fluid dynamics (CFD) modeling of an electrical heating oven for bread-baking process. *J. Food Eng.* **2010**, *100*, 452–460. [CrossRef]

4. Clair-Thompson, S.S. Heat Flux and Humidity Affect Oven Performance. 2016. Available online: https://www.bakingbusiness.com/articles/44913-heat-flux-and-humidity-affect-oven-performance (accessed on 22 July 2023).
5. Sabovics, M.; Straumite, E.; Galoburda, R. The influence of baking temperature on the quality of triticale bread. In Proceedings of the 9th Baltic Conference on Food Science and Technology FOODBALT 2014 Conference Proceedings, Jelgava, Latvia, 24–26 April 2014; pp. 228–233.
6. Munteanu, M.G.; Voicu, G.; Ferdeș, M.; Constantin, G.A.; Stefan, E.M.; Gheorghiță, N.E.; Duțu, I.C. Experimental Research on Energy Consumption in Baking Bagels. In Proceedings of the ISB-INMA TEH—Agricultural and Mechanical Engineering International Symposium, Bucharest, Romania, 30–31 October 2014; pp. 641–646.
7. David, A.P.; Burnete, N. Theoretical premises of the mathematical modeling of the bread baking process. *Agricultura* **2009**, *1–2*, 69–70.
8. Khater, E.; Bahnasawy, A. Heat and Mass Balance for Baking Process, Khater and Bahnasawy. *J. Bioprocess Biotech.* **2014**, *4*, 1000190. [CrossRef]
9. Ahrne, L.; Andersson, C.-G.; Floberg, P.; Rosén, J.; Lingnert, H. Effect of crust temperature and water content on acrylamide formation during baking of white bread: Steam and falling temperature baking. *LWT* **2007**, *40*, 1708–1715. [CrossRef]
10. Azmi, M.M.Z.; Taip, F.S.; Kamal, S.M.M.; Chin, N.L. Effects of temperature and time on the physical characteristics of moist cakes baked in air fryer. *J. Food Sci. Technol.* **2019**, *56*, 4616–4624. [CrossRef] [PubMed]
11. Olugbade, T.O.; Ojo, O.T. Development and performance evaluation of an improved electric baking oven. *Leonardo Electron. J. Pract. Technol.* **2018**, *33*, 189–206.
12. Moldoveanu, G.; Niculescu, N.I.; Mărgărit, N. *The Baker's Book*; Technical Publishing House: Bucharest, Romania, 1973; pp. 124–126.
13. Voicu, G. *Bakery Process and Equipment*; Bren Publishing House: Bucharest, Romania, 1999.
14. Qdidactic. Available online: https://www.qdidactic.com/stiinta-tehnica/nutritie/coacerea-painii354.php (accessed on 23 July 2023).
15. Mis, A.; Nawrocka, A.; Dziki, D. Identification of Baking Expansion Phases of Leavened Dough Using an Experimental Approach. *Food Bioprocess Technol.* **2016**, *9*, 892–903. [CrossRef]
16. Shahapuzi, N.S.M.; Taip, F.; Aziz, N.A.; Ahmedov, A. Effect of oven temperature profile and different baking conditions on final cake quality. *Int. J. Food Sci. Technol.* **2015**, *50*, 723–729. [CrossRef]
17. Nurul, A.S.; Farah, S.T.; Siti, M.M.K.; Norashikin, A.B.A. Effects of temperature and airflow on volume development during baking and its influence on quality of cake. *J. Eng. Sci. Technol.* **2014**, *9*, 303–313.
18. Morakinyo, A.T.; Omidiji, B.; Owolabi, H. Development and optimization of operational parameters of a gas-fired baking oven. *Leonardo J. Sci.* **2017**, *31*, 45–64.
19. Bakerpedia. Oven Temperature. Available online: https://bakerpedia.com/processes/oven-temperature/ (accessed on 8 July 2023).
20. Shane, B.W. Physicochemical Transformations in Low-Moisture Dough during Baking. Ph.D. Thesis, The University of Guelph, Guelph, ON, Canada, April 2013.
21. Gundu, R.; Datta, A.K.; Jayashree, G.C. Optimization of Bread Baking Parameters in Conventional Oven. *J. Agric. Eng. Res.* **2012**, *49*, 54–57.
22. Coman, G. Heat and Mass Transfer. Available online: http://www.tmt.ugal.ro/Items/staff/Coman_Gelu/Docs/Coman-TC-Curs.pdf (accessed on 2 July 2023).
23. Chukwuneke, J.; Nwuzor, I.C.; Anisiji, E.O.; Digitemie, I.E. Design and Fabrication of a Dual Powered Baking Oven. *Adv. Res.* **2018**, *16*, 1–8. [CrossRef]
24. Khatir, Z.; Paton, J.; Thompson, H.; Kapur, N.; Toropov, V.; Lawes, M.; Kirk, D. Computational fluid dynamics (CFD) investigation of air flow and temperature distribution in a small scale bread-baking oven. *Appl. Energy* **2012**, *89*, 89–96. [CrossRef]
25. Kokolj, U.; Škerget, L.; Ravnik, J. The Validation of Numerical Methodology for Oven Design Optimization Using Numerical Simulations and Baking Experiments. *J. Mech. Eng.* **2017**, *63*, 215–224. [CrossRef]
26. Rek, Z.; Rudolf, M.; Zun, I. Application of CFD Simulation in the Development of a New Generation Heating Oven. *J. Mech. Eng.* **2014**, *58*, 134–144. [CrossRef]
27. Norton, T.J.; Sun, D.-W. Computational fluid dynamics (CFD)—An effective and efficient design and analysis tool for the food industry: A review. *J. Food Sci. Technol.* **2006**, *17*, 600–620. [CrossRef]
28. Norton, T.; Tiwari, B.; Sun, D.-W. Computational Fluid Dynamics in the Design and Analysis of Thermal Processes: A Review of Recent Advances. *Crit. Rev. Food Sci. Nutr.* **2013**, *53*, 251–275. [CrossRef]
29. Padhi, M.R. A Review on Applications of Computational Fluid Dynamics (CFD) in the Food Industry. *PJAEE* **2020**, *17*, 10159–10169.
30. Badea, A. *Basics of Heat Transfer and Mass*; Romanian Academy: Bucharest, Romania, 2004.
31. Mistry, H.; Dey, S.; Bishnoi, P.; Castillo, J.L. Modeling of transient natural convection heat transfer in electric ovens. *Appl. Therm. Eng.* **2006**, *26*, 2448–2456. [CrossRef]
32. Salish, K.; Pushpadass, H.P.; Franklin, M.E.E.; Mitra, H.; Muniandy, S.; Ghosh, B.C. Three-dimensional computational fluid dynamics modelingof baking of chhana podo (milk cake). *J. Food Process Eng.* **2021**, *44*, e13587. [CrossRef]

33. Khatir, Z.; Thompson, H.; Kapur, N.; Toporov, V.; Paton, J.; Lawes, M. The application of computational fluid dynamics (CFD) and oven design optimization in the british bread-baking industry. In Proceedings of the 8th International Conference on CFD in Oil & Gas, Metallurgical and Process Industries SINTEF/NTNU, Trondheim, Norway, 21–23 June 2011; pp. 1–7.
34. Dhanuskar, V.D.; Pachghare, P.R. Modeling and Analysis of Temperature Distribution in the Industrial Gas Fired Powder Coating Oven using Computational Fluid Dynamic (CFD). *Int. J. Innov. Res. Sci. Eng. Technol.* **2017**, *6*, 10503–10509.
35. Wang, F.C.; Sun, X.S. Thermal Expansion of Flour-Water Dough Measured with a Dynamic Mechanical Analyzer. *Cereal Chem.* **1999**, *76*, 87–91. [CrossRef]
36. Gavrila, L. Heat Transfer through Conductivity. Available online: http://cadredidactice.ub.ro/gavrilalucian/files/2011/05/fdtou-curs-09.pdf (accessed on 8 July 2023).
37. Jonuskaite, A. Flow Simulation with SolidWorks. Bachelor's Thesis, Plastics Technology, Arcada University of Applied Sciences, Helsinki, Finland, 2017.
38. Yang, X.; Wu, L.; Zhang, H. A space-time spectral order sinc-collocation method for the fourth-order nonlocal heat model arising in viscoelasticity. *Appl. Math. Comput.* **2023**, *457*, 128192. [CrossRef]
39. Jiang, X.; Wang, J.; Wang, W.; Zhang, H. A Predictor–Corrector Compact Difference Scheme for a Nonlinear Fractional Differential Equation. *Fractal Fract.* **2023**, *7*, 521. [CrossRef]
40. Evans, P. Properties of Air at Atmospheric Pressure. 2015. Available online: https://theengineeringmindset.com/properties-of-air-at-atmospheric-pressure/ (accessed on 8 July 2023).
41. Ovidius University of Constanța. Available online: http://idd.univ-ovidius.ro/tutorials/cursuri/FIM/ING9/11Anexa1.pdf (accessed on 9 July 2023).
42. Holton, J.R. Vorticity. In *Encyclopedia of Atmospheric Sciences*; Academic Press: Cambridge, MA, USA, 2003; pp. 2500–2504.
43. Yang, Z.; Cheng, D.; Su, B.; Ji, C.; Haung, J.; Li, H.; Zhang, K. Study on the optimization of temperature uniformity in the oven under the forced convection mode. *Sci. Rep.* **2023**, *13*, 12486. [CrossRef]
44. Olawale, I.; Adetokunbo, A.A.; Rahman, A. Isothermal Air Flow Investigation in Industrial Baking Oven of Different Impeller Locations using Computational Fluid Dynamics (CFD) Approach. *J. Eng. Sci.* **2021**, *17*, 73–91.
45. Suvanjumrat, C.; Loksupapaiboon, K. Improvement of thermal distribution in the rubber-glove former conveyor oven by OpenFOAM. *Eng. J.* **2020**, *24*, 109–120. [CrossRef]