DETERMINATION OF THERMAL CONDITION OF PIZZA´S BAKING PROCESS

Bianca Sens dos Santos, bianca@labtucal.ufsc.br
Marcia B.H. Mantelli, marcia@emc.ufsc.br
Federal University of Santa Catarina, Departament of Mechanial Engineering, Bld. A3, Trindade, Florianópolis, Santa Catarina, Brazil, CEP 88040-900.

Abstract: *With technological energy development, different types of economic and ecological ovens, which replace the wood and electric ballast as energy sources, are being released to the market. The food industry aims for the development of better quality products (ovens), as well as the establishment of more efficient and better controlled processes (cooking). The understanding of the impact of these technologies in the cooking process and food quality isdirectly associated with their sensory properties. In this context, the main objective of this study is to evaluate the impact of different configurations of an oven in the quality of pizza, by setting up the best conditions for their cooking and by characterizing the predominant mechanisms of heat transfer. For this study, an oven prototype was built, consisting of a rectangular chamber (50cmx50cmx25cm), where internal plates were independently temperature controlled. A fan was coupled to the top region of the oven. The impact of different oven configurations on the pizza´s quality was studied on the basis of four factors: the presence or absence of heat transferred by radiation from thsurfaces of the oven, presence or absence of heat transferred by radiation from upper surface, presence or absence of forced convection and two materials, used in the oven bases: aluminum and stone. The quality standards evaluated for the pizza were: the edge texture, color, factor of safety in the food heating process and water loss. The temperature of the oven's surfaces was set on 523K (250°C) and the time of cooking at 10 min. The electrical fan frequency, when on, was set at 35Hz. It was observed that the forced convection contributed heavily to the improvement of all quality parameters evaluated. The color, measured by a scale built specifically for this purpose, increased by 92% when compared to pizzas baked without forced convection, the edge texture increased by 37%, the water loss by 98% and the safety factorby 934%. Statistically, the radiation provided by the upper and side surfaces presented the same influence over the edge texture, water loss and safety factor and the material of the baking tin presented influence only the safety factor, increasing it by 8%. Based on these results, the configuration set as the best one was: radiation from all surfaces, forced convection and use of stone on the base. With this configuration, three levels of the electrical fan frequency (5, 20 and 35Hz); three levels of temperature (150,250 and 350°C) and three different cooking times (3,5 and 10 minutes) were studied. The pizzas baked at 523K (250°C) for 5 minutes with the fan at 20Hz and the ones baked at 523K (250°C) for 10 minutes with the fan at 5Hz presented the best results for all quality parameters. The mechanisms of heat transfer were evaluated by the heat transfer coefficients, determined by the lumped capacitance method. The heat transfer mechanism predominant on pizza´s baking was radiation, followed by convection and conduction.*

Keywords: *baking oven; heat processing of food; mechanisms of heat transfer; lumped capacitance method.*

1. INTRODUCTION

The pizza is a product that has increased its space in consumer's preference. According to the Brazilian Association of Food, Hospitality and Tourism, São Paulo is the second largest consumer of pizzas in the world, losing only to New York. Currently, there are in São Paulo almost 6 thousand pizzerias, providing around 43 million pizzas a month to the city. Some of the reasons for the growth of the market and consequent increase in industrial production are relatively low cost of the product and ease of preparation for consumption. However, the popularization of pizza, for other products in the oven, is relatively recent and the quality of its mass remains an area little researched (WANG *et al.*, 2005).

The technology associated with the pizza´s baking is not well known. However, some phenomena can be explained by analogy to the bread baking, once the basic ingredients of the dough of these two products are almost the same. Factors that may influence the quality of the pizza during cooking are based on empirical knowledge and in studies with similar products. Although many studies involving alternative formulations for the pizza´s dough, fillings and packaging, among others, have been conducted, there are few objective indicators of quality available in the literature or legislation for this kind of product specifically (PINHO *et al.*, 2001).

The pizza is a heterogeneous food, which ideal baking conditions depends on factors related to both food (composition, physical properties, size, shape), and oven (type of oven, temperature). The dough of the pizza is a significant fraction of the product and its appearance, flavor and texture are important factors for their identification and acceptance by consumers.

In the process of dough baking, changes in the way heat is distributed inside the baking chamber can interfere with the quality and, consequently, the acceptability of the product. In the cooking of breads, for example, it is known that the forced convection inside the baking chamber is crucial in the quality of the product. This is the convection that will distributed better the water vapor injected into the chamber, responsible for the formation of crust and appropriate growth of the breads. In the case of biscuits, to be cooking at low temperatures, mainly involving radiation and conduction, and prolonged, ensuring sufficient time for the partial gelatinization of starch of the flour and drying of the biscuits. The barbecue is roasted primarily by radiation, from the embers of coal.

To design a cooking chamber with greater efficiency, it is necessary to have knowledge of physical and chemical processes involved in the cooking of food, setting up the ideal time and temperature to obtain a final product quality.

After the pizza, the oven is the main element in a pizzeria. Many pizzerias use, even today, a wood oven, others replaced by the ballast electric oven. However, with energy development, are emerging on the market different types of ovens. In general, the purpose of these ovens is to save energy and increase productivity, keeping, however, the quality of the product. The quality of bakery products is generally assessed by color, texture and flavor and microbiological security. Overall, the cooking of a food is the conversion of raw product to cooked, which is achieved with the use of heat. During cooking, the dough goes through several changes in order to obtain a product of desired quality, and it is this quality which limits the application of new technologies.

A clear example is the cooking of bakery products in microwave oven. Although the heating by microwave energy and be an economically efficient, the products have unacceptable texture, with a firm crust and the inner part too hard, small volume, excessive loss of water, poor development of crust and its color, main responsible for the taste of the product (SUMNU *et al*., 2004).

The jet impingement oven, whose technology is the use of jets of hot air directed on the areas of product, has been used successfully in the cooking of food, especially pizza, tortilla bread and various types of flat bread. However, in large-size products using this technology did not present good results. Technological innovations, such as the use of jet impingement oven or hybrid oven, combining technology and impingement by microwave heating have been used effectively in the food sector (WÂHLBY *et al*., 2000; PATEL *et al*., 2005).

The application of these technologies assist the food industry in the development of better quality products, as well in the establishment of more efficient processes and better control of existing processes. However, the successful application of new technologies for the cooking of bakery products is directly linked to understanding the process of conventional cooking and changes in dough during cooking, in addition to knowledge of the mechanisms of heat transfer in furnaces.

Numerous studies have investigated the development of the structure of bakery products. However, few have investigated the effect of different processes of cooking, that is, different profiles of temperature, mechanisms and rates of heat transfer to the product by linking it to changes in the quality and acceptance of the product.

The cycles of cooking are typically established without prior understanding of the process, requiring time for the necessary adjustments and a considerable amount of products with defects. Fahloul *et al*. (1995) cites the importance of measuring the flow of heat that reaches the food in understanding the process of cooking. The temperature is usually used to check if the cooking is appropriate, however, this measure is a direct relationship with only some attributes of the desired quality product. Many studies have been done to understand the individual contributions of different mechanisms of heat transfer in breads, biscuits and cakes in electric ovens, forced convection or gas.

Thus, understanding the impact of different conditions of cooking on changes in the product and the individual contributions of different mechanisms of heat transfer, associated with its sensory properties (texture, color, taste) and its microbiological security becomes an indispensable tool for the development of new technologies in this sector.

The determination of the thermal conditions of the pizza baking process was, then, motivated by interest in developing a modern alternative to replace the current pizza ovens, wood-fuel and electric. The electrical energy, the major source of energy used in ovens for baking pizzas, is becoming scarce and expensive. The wood, while inexpensive, has great environmental impact from its cutting and burning, which has motivated the government to the development and adoption of environmentally correct policies. In order to become more competitive, companies seek, also, for more efficient processes and increase productivity, considering, where possible, to lower cost energy sources. The Laboratory of Heat Pipes, LABTUCAL/UFSC, has conducted numerous studies aimed at optimization of thermal equipment used for baking food. In this sense, the use of thermosiphon presents as a thermal solution in this sector, allowing the physical separation, but not heat, and cooking chamber of combustion.

2. MATERIALS AND METHODS

2.1. Oven prototype

The construction of a prototype of a baking oven aimed to explore the process of pizza's baking and to determine the mechanisms of heat transfer prevailing during the baking. By baking the pizzas in this prototype, it is possible to verify the best conditions to obtain a quality product. The prototype built in LABTUCAL/UFSC consists of a rectangular chamber with 50 cm in length, 50 cm in width and 25 cm in height, with electrical resistance located between two plates of brass and set in the side surfaces, the upper surface (roof) and bottom (base). The capacity of this prototype is a pizza about 30 cm in diameter. The electrical resistances works independently of each other, allowing a better adjustment of each surface temperature. Usually the cooking is done in the ballast pizza ovens, supported on refractory stones or in conventional electric ovens, on forms of aluminum. For this study, two types of form will be tested: aluminum and stone. The fan, for forced convection inside the prototype, is positioned at the top surface and its frequency is variable. The prototype was covered with a layer of approximately 10 cm of glass wool, isolating it thermally. When it was necessary the blocking of radiation from the upper or side surfaces of the oven, it was used aluminum foil which emissivity was considered equal to zero.

2.2. Pizza

All pizzas analyzed had the same flavor (mozzarella) and were obtained from the same production lot. They were properly frozen for storage and, before use, were thawed until 283K (10°C).

2.3. Determination of thermal conditions of pizza's baking process

The determination of thermal condition of pizza's baking process was divided into three steps: a study of the influence of oven configuration on pizza's quality, including the choice of the best configuration for baking (step I), determination of oven operating conditions (step II) and determination of predominant mechanisms of heat transfer during the baking process (step III). The different *oven configurations* are given by different combinations of heat exchange by radiation between the oven side surfaces and the pizza, the heat exchange by radiation between the upper oven surface and the pizza, the presence or absence of forced convection and the type of base surface material surface in contact with the pizza. In turn, the different *oven operating conditions* are given by the combination the following factors: temperature, time of baking and frequency of the fan. The implementation of those steps was guided through the experimental planning and the quality was evaluated by the sensory and security quality requirements.

2.3.1. Study on the influence of the oven configuration on pizza's quality

The objective of this step was to obtain information on the influence of the configuration of the oven as the pizza and select the configuration that delivers a pizza and within the limits of acceptance of quality. To achieve this step, the time of cooking and temperature were set at 523K (250°C) and 10 minutes respectively. The factors studied were: (A) contribution of radiation by the upper surface of the oven, (B) contribution of radiation by the walls of the oven, (C) forced convection, and (D) material below the surface in direct contact with the pizza. The levels of these factors are presented in Tab. 1. The combination of different levels of each of these factors, by an experimental design, characterized different configurations of the furnace. In the total it will be 16 tests. The main effects and interaction between these factors were evaluated with respect to the quality of pizza (response) in terms of sensory and security quality. The Fig. 1 shows a sketch of this step.

Table 1. Factors studied in the 1st step and its levels.

Factors (k)	Levels of factors	
	(-1)	(+1)
A: Radiation by upper surface	No	Yes
B: Radiation by side surfaces	No	Yes
C: Forced Convection	No	Yes
D: Material of base	Aluminum	Stone

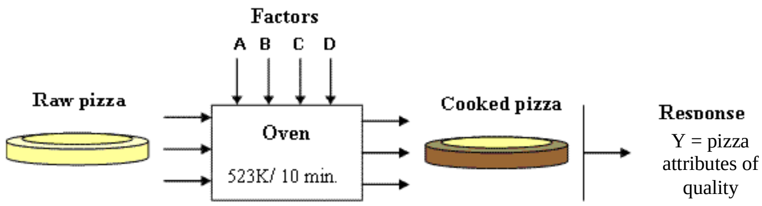


Figure 1. Scheme of the study on the influence of the oven configuration on pizza's quality.

2.3.2. Determination of oven operating conditions

The objective of this step is to determine the operating conditions of the oven with the oven configuration determined in the previous step. These conditions were determined with the following factors: oven's surface temperature (T), cooking time (t) and fan frequency (F_f). This last factor was studied only if the forced convection, studied in step I, has had significant influence on the quality of pizza. For each of these three factors were studied three levels presented in Tab. 2. The tests were initiated with the combination of lower levels of factors. The quality of the pizza was also evaluated according to sensory and security quality for each test. The Fig. 2 shows a sketch of such step.

Table 2. Factors studied in the 2nd Stage and its levels.

Factors (k)	Levels of factors		
	(1)	(2)	(3)
T: Oven's surface temperature (K)	423	523	623
t: cooking time (min.)	3	5	10
F_f: Frequency of the fan (Hz)	5	20	35

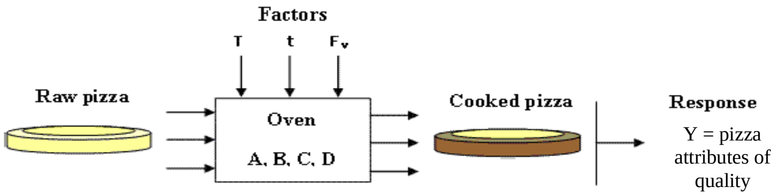


Figure 2. Schematic of the study for the determination of oven operating conditions.

2.3.3. Determination of predominant mechanisms of heat transfer during the baking process

The quantification of heat transfer mechanisms involved during the cooking of the pizza was made by the method of the global capacitance, using the technique of blocks, as it will be described. The technique of blocks is very simple and is based on the method of the global capacitance. It is all a block, initially at a uniform temperature $T_{block,i}$, placed inside a heated cavity , $T_{air}>T_{block,i}$. For this study will be used a block of aluminum (99.5% purity), with 0.31 ± 0.005 m in diameter and 0.013 ± 0.005 m in height, approximately the size of pizza. For this study will be assumed the ideal hypothesis that all cavity is fully insulated externally, and all heat dissipated by the electrical resistance is transferred to inside the cavity, warming their internal surfaces. Thus, all heat exchanges occur between the inside surfaces of the cavity, the block and the air. The heating of the air convection is through the areas. Thus, it will assume that the air temperatures are functions of the temperatures of all heated surfaces of the cavity. For t>0, the block will then be heated by the action of thermal radiation (q_{rad}, by exchanging heat with all surfaces of the cavity), by convection (q_{conv}, with the hot air that surrounds the block) and by heat conduction (q_{cond}, through the heated bottom of the cavity in contact with the block) until its temperature reaches the value of T_{air}, as it is shown on Fig. 3.

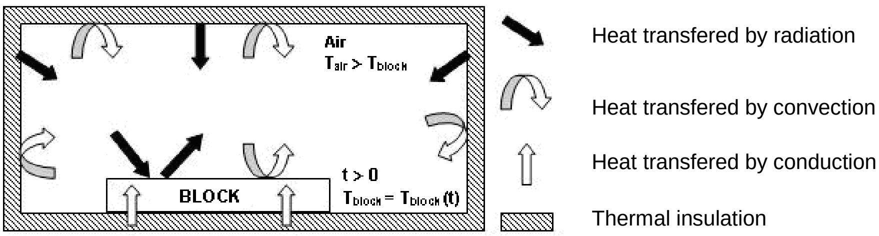


Figure 3 - Mechanisms of heat transfer involved in the block heating.

The essence of the method of global capacitance is the assumption that the temperature in the solid is spatially uniform at any instant of the transient process (INCROPERA; DEWITT, 1998). By this hypothesis it's considered that the gradients of temperature are negligible within the solid. To check this hypothesis the Biot number should be smaller than 0.1. If this really happens, the transient variation of temperature will be determined by the global balance of energy on the block. Taking the block of Fig. 3 as the volume control, if all surfaces are kept at the same temperature, T_s, a balance of energy shows that the accumulation of internal energy in the transient regime can be written as follows, based on rates of heat exchange:

$$q_{block} = mc_p \frac{dT_{block}}{dt} = A_{block}\varepsilon_{block}\sigma(T_s^4 - T_{block}^4) + A_{block}h_{conv}(T_{air} - T_{block}) + A_{block}\frac{(T_{pan} - T_{block})}{R''_{contact}} \quad (1)$$

where m is the mass of the block (equal to 2.675 kg), c_p is the aluminum specific heat at constant pressure (equal to 894.84 J/kgK), A_{block} is the upper surface area of the block (0.075m^2), ε_{bloco} is the emissivity of the block, h_{conv} is the convection heat transfer coefficient, t is the time and T_{block}, T_{pan} and T_{air} are the block, the inferior surface material in contact with the block and the air surrounding the block temperature, respectively. $R''_{contact}$ is the contact resistance between the pan and block. It should be noted that the pan is already inside the oven and is initially the same temperature as the air.

The first term of the Eq.(1) right side is the rate of heat transferred by radiation, the second term is the heat transferred by convection and the third one is the heat transferred by conduction. As the intention of this study is to estimate the contribution of different mechanisms of heat exchange during the baking of pizza and having in mind that the air temperature is a function of temperatures of all surfaces (including the temperature of the pan), it's convenient to define the rate of heat transfer by radiation and conduction in a manner similar to convection. The exchange of heat by radiation and conduction will then be rewritten in function of the temperature difference between the air and block.

$$q_{cond} \equiv A_{block} h^*_{cond} (T_{air} - T_{block}) \tag{2}$$

$$q_{rad} \equiv A_{block} h^*_{rad} (T_{air} - T_{block}) \tag{3}$$

Where, by comparison of Eq. (2) and Eq. (3) with Eq. (1),

$$h^*_{cond} = \frac{(T_{pan} - T_{block})}{R''_{contact}(T_{air} - T_{block})} \tag{4}$$

and

$$h^*_{rad} = \frac{\varepsilon_{block}\sigma(T_s^4 - T_{block}^4)}{R''_{contact}(T_{air} - T_{block})} \tag{5}$$

where h^*_{cond} and h^*_{rad} are the *modified* coefficients of heat transfer by conduction and radiation, respectively. Note that in the cases where coexist the transfer of heat by radiation, conduction and convection, the coefficient of heat transfer h_{conv}, h_{cond} and h_{rad} are additive.

For the measurement of modes of heat transfer by radiation, convection and conduction, it will be performed a series of experiments. The configuration and operation of the furnace conditions will be adjusted according to the findings for Steps I and II. Under these conditions the temperature as a function of time for a black block ($\varepsilon \approx 1$), for a polished block ($\varepsilon \approx 0$) and for the polished block supported on a layer of insulating material will be acquired. It will be considered that the black block heating will be given by heat transferred by radiation, conduction and convection. For the polished block, the heat will be transferred by convection and conduction. And, for the polished block supported on a layer of insulating material, it will be transferred by convection only. So, using Eq.(4) and Eq.(5), the Eq.(1) for the three blocks can be rewritten as follow:

$$q^{black}_{block} = mc_p \frac{dT_{black}}{dt} = A_{block} h^{black}_{global} (T_{air} - T_{black}) \tag{6}$$

$$q^{polished}_{block} = mc_p \frac{dT_{polished}}{dt} = A_{block} h^{polished}_{global} (T_{air} - T_{polished}) \tag{7}$$

$$q^{polished-insul.}_{block} = mc_p \frac{dT_{polished}}{dt} = A_{block} h_{conv} (T_{air} - T_{polished}) \tag{8}$$

where

$$h^{black}_{global} = h_{conv} + h^*_{cond} + h^*_{rad} \tag{9}$$

and

$$h^{polished}_{global} = h_{conv} + h^*_{cond} \tag{10}$$

The coefficients of heat transfer can be estimated by integration of Eq.6, 7 or 8, since the condition $t=0$ and $T(0)=T_0$ to the final condition. Thus we have:

$$\frac{T - T_{air}}{T_0 - T_{air}} = exp\left[-\left(\frac{hA_{block}}{mc_p}\right)t\right] \tag{11}$$

The h can then be determined by plotting the curve $ln\left[(T - T_{air})/(T_0 - T_{air})\right]$ as a function of time, t, where:

$$\tau = -\frac{hA_{block}}{mc_p} \tag{12}$$

is the curve slope obtained. Isolating h in Eq. (12), it has an average value for the heat transfer coefficient.

2.4. Sensory quality determination

The sensory quality was determined based on three attributes: color of pizzas, texture of edge and loss of water.

2.4.1. Color determination

The pizza's color was evaluated by comparing the images of pizza baked under certain baking conditions and a standard color scale (from 2 to 16), developed specifically for this purpose in previous studies. (SANTOS, 2009). Based on the planning of the tests of steps I and II, the pizzas were baked in duplicate. The images were properly taken and encoded, and then were submitted to 10 trained judges. For the acceptance of pizza's color the average of responses should be between 6 and 10.

2.4.2. Texture edge

Based on the planning of the tests of steps I and II, the pizzas were baked in duplicate, then the edge of the pizza was cut and divided into samples of approximately 1 cm^2. The samples were submitted to judges in small plastic cups sealed with aluminum foil and these, properly encoded.

The texture of the edge was evaluated in terms of its hardness. For this study, the hardness was defined as the force needed to compress the sample between the molar teeth in the first bite, causing a deformation. The texture of the edge of each pizza was evaluated by 25 judges in sensory analysis, using a *just right scale* with five categories: 1-well below the ideal (very soft), 2-less than ideal (soft), 3-ideal, 4-above the ideal (hard), 5-well above the ideal (very hard). For the acceptance the index of texture should have at least 50% of ideal responses.

2.4.3. Loss of water

The loss of water during cooking was evaluated by the difference in mass between the raw pizza and immediately after cooking, using an analytical balance. It is considered that the difference in weight between the raw and cooked pizza is due only to loss of water, being the others volatile components disregarded.

2.5. Security quality determination

The safety of food from the microbiological point of view can be assessed by the *integral lethality of the process*, called $F_{process}$ value. The $F_{process}$ value can be understood as the time in minutes, equivalent to the thermal processing led to a constant temperature of reference. The reference level of thermal destruction, the F_{Tref} value, is defined as the time that the food must be processed at a certain temperature of reference for a specific reduction in the number of microorganisms. The microorganism of higher thermal resistance, namely *Bacillus cereus*, is used for this study and a value F_{Tref} of 14.8 minutes is obtained, in pervious study (SANTOS, 2009), for the reference temperature of 363K (90^{o}C). The integral lethality of the process for each configuration and condition of the oven operation was obtained by Equation (13). For the acceptance of the cooking process the $F_{process}$ value must be equal or greater than the F_{Tref} value.

$$F_{process} = \int_0^t 10^{\frac{T(t)-T_{ref}}{Zm}} dt \qquad (13)$$

where *T(t)* is the temperature of pizza dough as function of the time, *t*, and Z_m is a thermo bacteriology parameter of the microorganism. For the *Bacillus cereus* the value of Z_m is 10,5^{o}C.

3. RESULTS AND DISCUSSIONS

3.1. Study on the influence of the oven configuration on pizza's quality

With the responses of step I, it was made a statistical analysis by analysis of variance. In practical terms, the analysis of variance is now performed to check whether or not significant effect of the factors involved in this study and their interactions on the quality attributes studied. For the analysis of experimental data obtained it was used MINITAB, a statistical program (MINITAB INC., 2007). A rapid procedure to determine the effect of factors and their magnitude on a specific response is through the graph of normal probability for the standardized effects. In this graph, no significant effects tend to be on the line passing through the origin of the standardized effect, while the significant ones to be apart. A significant factor influencing a parameter means that, when this factor varies from its lowest to its highest level, will cause a significant change in the value of this parameter. This influence can be positive or negative when, respectively, increase or decrease the value of the parameter. If positive, is located to the right of the continuous graph of the probability for the normal effects, if negative, to the left. The Fig.4 shows these graphs for color, edge texture, loss of water and values of $F_{process}$.

From the results for the 1st step it can be found that, among the factors studied, the forced convection was the greatest factor of influence on all the quality parameters evaluated for the pizza. The forced convection strongly contributed to the increase of all the quality parameters evaluated.

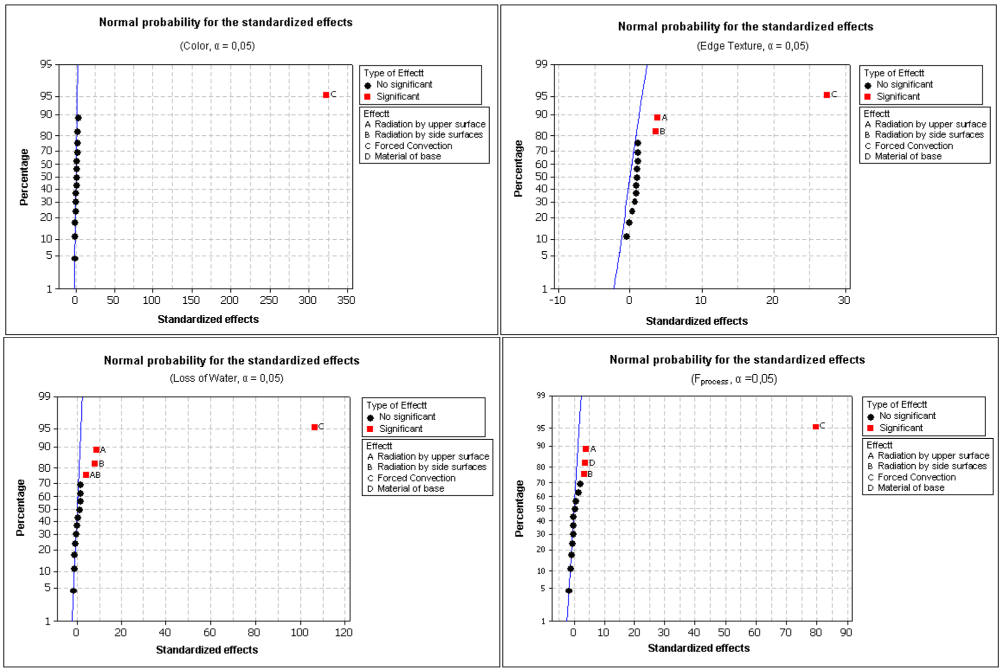


Figure 4. Normal probability for the standardized effects graphs.

The color data in which forced convection was present showed an average value of 15.3 for the color average, placing them in the rejection of the scale. Tests in which forced convection was not induced showed the average value of 8 for the color, such samples are within the zone of acceptance of the scale. It shows an increase of 92% for the color when forced convection is used. The Fig.5 shows the difference between the color of baked pizzas under the same conditions of time and oven temperature with and without the induction of forced convection. As the forced convection didn't have interaction with other factor, the average for the edge texture using forced convection was 4.3 against 3.1 with no forced convection, showing an increase of 37%. For the loss of water an average of 14.6 with forced convection and 7.4 without, an increase of 98%. And finally, the average of $F_{process}$ values with convection was 84.4 min. and without convection it was 8.2 min., an increase of 934%. The increased speed of the air inside the oven promotes an increase in heat and mass transfer by convection, thus the surface of the pizza reaches temperatures greater than those achieved in non-convective ovens. As the intensity of the *Maillard* reaction, the main reaction of browning of bakery products during the cooking, strongly depends on the temperature and moisture content of the product, turning the fan on cause an intensification of the *Maillard* reaction.

Figure 5. Pizzas obtained from step I with and without forced convection.

Neither the main effects of radiation by the upper and side surfaces and the effect of the pan, nor the effects of interaction of these factors were significant for the pizza's color, being indifferent to the chosen level each.

To the edge texture and loss of water during cooking in addition to convection, radiation by the roof and the walls had a positive effect. However, it was observed that the settings using only the superior radiation or only radiation by side surfaces caused no significant difference in its values, for both levels of forced convection. But, the loss of water was higher when it was used radiation from both surfaces. For the values of $F_{process}$ all factors had positive effect. The use of the form of stone has increased by 8% in the number of decimal reductions when compared to the use of the form of aluminum. For the pizzas baked without forced convection, for all combinations of other factors, not achieved the $F_{process}$ value of 14.8 min., minimum required this study.

Thus, given the comments above, the configuration of the oven that will be used for the 2_{nd} step will be: forced convection, radiation by roof and walls and use the form of stone.

3.2. Determination of oven operating conditions

The Tab. 3 presents the data obtained on step II. The signs $F_{process}$, C, ET and WL means $F_{process}$ value (min.), color, edge texture (percentage of ideal responses, %) and water loss (%), respectively.

Table 3. Data obtained for $F_{process}$ value, color (C), edge texture (ET) and water loss (WL).

Temperature	Baking time												Fan frequency
	3 min.				5 min.				10 min.				
	$F_{process}$	C	ET	WL	$F_{process}$	C	ET	WL	$F_{process}$	C	ET	WL	
423 K (150°C)	0,0	2,1	0,0	1,0	0,0	2,2	0	1,5	0,0	3,9	24	2,8	5 Hz
	0,0	3,8	16	2,0	0,0	4,0	48	3,1	0,0	6,2	68	4,3	20 Hz
	0,0	4,3	28	2,9	0,0	4,5	56	4,3	0,5	7,6	76	5,9	35 Hz
523 K (250°C)	0,0	4,0	24	3,2	0,1	6,2	68	3,6	6,1	7,7	60	6,6	5 Hz
	0,0	6,3	84	4,0	4,9	8,2	84	6,1	12,0	13,6	12	10,3	20 Hz
	0,0	7,6	64	6,9	4,4	12,5	32	9,5	21,8	14,3	0	12,3	35 Hz
623 K (350°C)	0,0	12,4	0	7,6	0,4	13,5	0	9,9	17,1	16,0	0	12,8	5 Hz
	0,4	14,4	8	9,6	6,7	16,0	0	13,2	-	-	-	-	20 Hz
	-	-	-	-	-	-	-	-	-	-	-	-	35 Hz

By Tab.3 it is noted that only two of operating conditions settings are in agreement with the requirements of acceptance: color average between 6 and 10, texture should have at least 50% of ideal responses and $F_{process} \geq 14.8$. Those two conditions are those in oven at 523 K with fan operating at a frequency of 5Hz for 10 minutes and those baked in oven at 523K with the fan 20Hz for 5 minutes. For convenience and economy, will be used the operation condition with less time for cooking to characterize the thermal conditions of the process of cooking the pizza, i.e. temperature of the surfaces of 523K, 20Hz fan frequency and 5 minutes for time baking. Some tests, indicated by "-", were not made because the tests preceding them already obtained too dark color.

3.3. Determination of predominant mechanisms of heat transfer during the baking process

The Fig. 6 shows the three blocks used for this step: polished, polished supported by the insulating layer and black block.

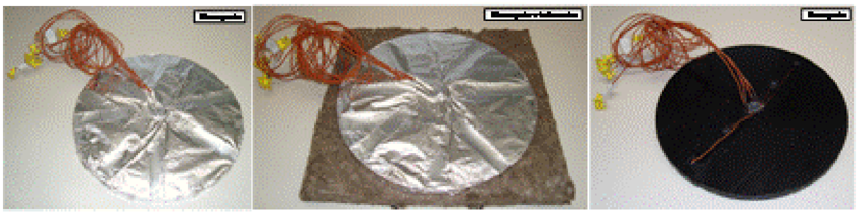


Figure 6. Blocks used for the determination of predominant mechanisms of heat transfer.

By heating each one of those blocks on the set operating conditions of oven found on the step II (523K, 20 Hz), it was obtained three curves of temperature, showed on Fig. 7. Those tests were made in duplicate, but here it will be shown only one of the results to exemplify.

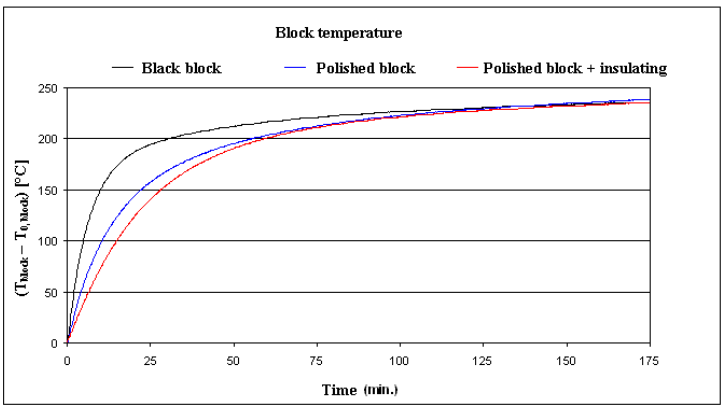


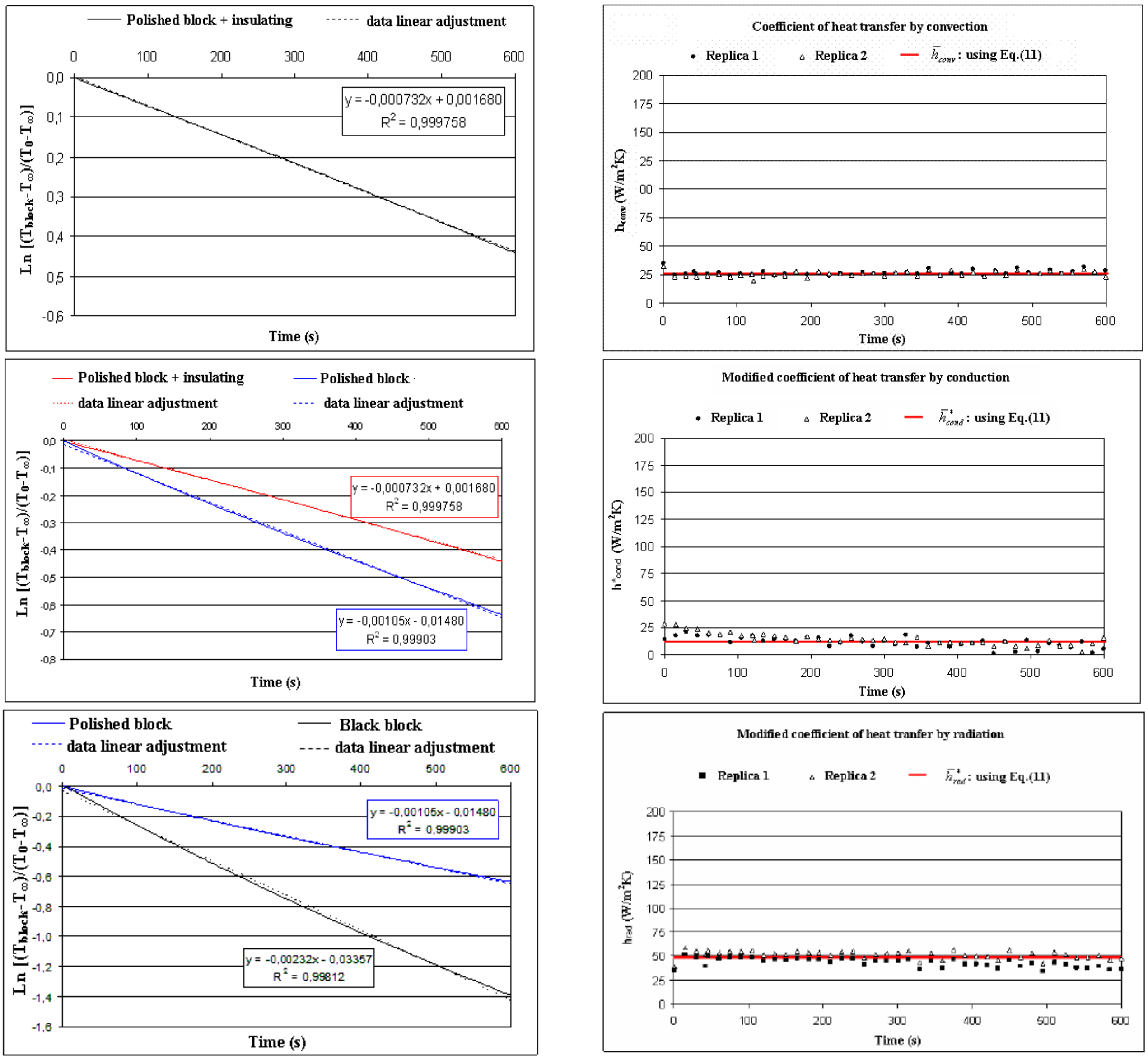
Figure 7. Temperature against time for the three blocks.

As it was expected the curve for the black block presented the greater slope and the polished block over the insulating layer curve presented the lower slope. With the data from each one of the blocks it was plotted the logarithmic curves of dimensionless temperature versus time, showed on Fig. 8 (a).

The angular coefficients of the curves were used to calculate the heat transfer coefficients by Eq. (11). The dimensionless temperatures were presented to the 10 minutes (600s) for heating the block. It was also estimated the values of h during the process of block heating by using the Fourier equation for transient convective heating, $q = mc_p \dfrac{dT}{dt} = A_{block} h(T_{air} - T_{block})$ and the definition of derivative involving limit, where, for small intervals of time, $\Delta t \to 0$:

$$h = \frac{mc_p}{A_{block}\left(T_{air} - T_{block}\right)} \lim_{\Delta t \to 0} \frac{Tblock\left(t + \Delta t\right)}{\Delta t} \approx \frac{mc_p}{A_{block}\left(T_{air} - T_{block}\right)} \frac{\Delta T_{block}}{\Delta t} \tag{14}$$

With the data obtained for the three blocks using the Eq. (11) Eq. (14) fot _t =15 s were calculated the values of heat transfer coefficients for the polished block with the insulating (h_{conv}), for the polished block ($h_{global}^{polished}$) and for the black block (h_{global}^{black}). With some algebraic manipulations for Eq. (9) and Eq. (10) the values of f h_{rad}^{*} and h_{cond}^{*} are obtained. The values for h_{conv}, h_{cond}^{*} and h_{rad}^{*} during heating of the block are shown on Fig.8 (b).



(a) (b)

Figure 8. (a) Logarithmic curves of dimensionless temperature versus time for the polished, black and polished over the insulating layer blocks, (b) Coefficients of heat transfer to the block during the heating.

Note that the Eq. (11) gives the average values for the coefficients of heat transfer. Those average values are indicated by the red line on Fig.8 (b). For convection it was obtained h_{conv} =26.2 ± 0.5 W/m^{2}K. For conduction, h^*_{cond} =12.6 ± 1.5 W/m^{2}K and, for radiation, h^*_{rad} = 48.6 ± 3.6W/m^{2}K. Calculating the average of data obtained from Eq. (14) it is obtained h_{conv} =26.3 ± 2.3 W/m^{2}K, h^*_{cond} =13.0 ± 5.29 W/m^{2}K and h^*_{rad} = 50.6 ± 4.1 W/m^{2}K. Also for radiation the modified coefficient of heat transfer was calculated by Eq (5), using the average temperature of the oven's surfaces. The value obtained was 25.8± 4.1 W/m^{2}K.

By the results can be concluded that the predominant mechanism of heat transfer in the pizza's baking process was radiation, followed by convection and conduction. The conduction mechanism was of less influence during the baking of pizza. This is due, probably, to the low contact between the pan and block, featuring a high thermal resistance of contact between them. It can be noted too that the average values for the coefficient of thermal exchange by radiation calculated with the average temperature of the oven's surfaces are approximately 50% lower than those calculated by the technique of blocks (Eq. 11 and Eq.14). The use of technique of blocks to calculate the portion of heat transferred by radiation to the block appears to be better. This difference on the values can be explained because while the use of average temperature of the surfaces does not take into account the contribution of the hotter regions to the radiation, the block black absorbs all the energy that reaches it, even considering the heat delivered to a greater or lesser intensity in such regions.

4. CONCLUSIONS

The objectives of this study were achieved successfully. By the first step, Study on the influence of the oven configuration on pizza's quality, it was seen that the forced convection was the factor with greater influence on all the attributes of sensorial and security quality for the pizza. Both, the sensorial and security quality, must be evaluated together for the food cooking processes. By the second step, determination of oven operating conditions was chosen the better conditions of temperature, time and fan frequency for the pizza´s baking process. The combination that respect the quality requirements were that one using 523K (250°C), for 5 minutes and with 20Hz of fan frequency. Finally, under those conditions the predominant mechanisms of heat transfer between the oven and the pizza were determinate by the technique of blocks. This technique proved to be effective to estimate the contribution from the different mechanisms of heat transfer.

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6. RESPONSIBILITY NOTICE

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