Methodology for the temperature balancing of an oven in the food industry

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Oven; temperature balancing; tortilla chips; crusting

ABSTRACT: The operation of an industrial oven for the production of tortilla chips was studied, with the aim of correcting the temperature variations along the width of the oven belts. This was performed by interventions of a practical nature and by physical adjustment of the ribbon burners with gas guiders and gas limiters. A methodology for their correct application was developed. These changes improved the quality of the crusting operation.

INTRODUCTION

The slow domestication of the maize, which have begun 8000-10,000 years ago[1] in Mesoamerican region from teosinte[1-4], was the sprout of an intense co-evolutional process that reached its peak with the flowering of the great civilizations of the New World, from the Olmecs (3,500 years ago) to the Mexica (700 years ago).[1,3,5-7]

In order to make the maize edible and digestible, pre-Colombian woman, as responsible for the collection, storage and preparation of the food[3], had to create and develop a technological process to removes the hard pericarp: the dried grains were cooked in a ceramic pot (*cazuela*) with a solution of wood ashes[8-9] or lime (about 1% of maize) at a ratio of 1:2 (m/v) to about 80 °C, between 20 and 45 minutes, and allowed to stand for the night[10]; the next day, the cooked maize (*nixtamal*) was washed with fresh water, two or three times, to remove the excess of lime[10], the pericarps and the impurities.[11] It was important that the grains weren't cooked with boiling water because they became gelatinous and too sticky.[12] This method of alkaline cooking (nixtamalization), besides causing the softening of the grain, and thereby facilitate pericarps removal, intensified its flavor and its nutritional value[12], preventing the development of diseases associated with malnutrition, such as pellagra or rickets.[2-3,6,13-16]

The pre-Colombian family, as today their descendants, consumed maize mainly in the form of tortillas[2,9,12-13,16-17], which represented about 80% of caloric intake[3]. To prepare them, the woman grinded the washed nixtamal on a rectangular mortar (*metate*) with a pestle (*metlapilli*), adding water to the dough to achieve the desired consistency. The masa was then shaped with the moist hands in discs (*tortilla*) of 15-20 cm of diameter, that were cooked in a ceramic plate (*comal*) until both sides became yellow.[12] In some regions of Mesoamerica, as in the Oaxaca region, due to the hot and humid climate[18], local people dehydrated tortillas in a ceramic oven (*comixcal*) to significantly increase its durability. If the tortillas were in the oven in its original form local people called it *tostadas*, if tortillas were cut into pieces (triangular or round) they called *totopos*.[14] With the introduction of the frying process in the indigenous diet after the Spanish colonization of Mesoamerica, in the sixteenth century, the local people began to fry the *totopos* in oil or butter[19] to enhance their flavor — the original tortilla chips.

Nowadays, the industrial process of tortilla chips is essentially an optimized interpretation of the various "unitary operations" created and developed by the pre-Columbian woman.[9,13-15,20]

The crusting operation is located in the tortilla chips process between the sheeter equipment, where the chips are cutted in triangular form, and the conditioner, where the chips are cooled and their moisture content stabilized. The crusting is realized in an oven that uses natural gas as fuel (NG), pre-mixed with air. It consists of three conveyor belts, progressively moving in opposite directions, and two turnarounds (Figure 1).

In the oven, the heat is transferred to the chips in three ways: **radiation:** from the infrared burners arranged above the top belt, that affects the top surface of the chip; **conduction:** heat from the ribbon burners arranged under each belt, transferred by contact of the chips with the belts; **convection:** heat from the air convection, that enters through the

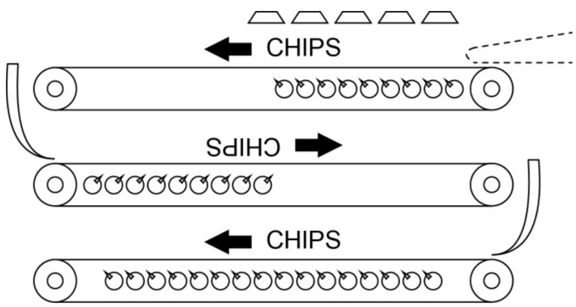

Figure 1. Direction and arrangement of the chips inside the oven (left side view).

openings in the bottom of the oven and exits in the chimneys at the top.

The control of the temperature variations along the width of the three belts (temperature balancing) of the oven ensures the qualities of the crusting operation and of the final product. The first method utilized in temperature balancing was the welding of the openings of the ribbon burners in areas where the temperature of the respective belt was higher. Over time, these small welds were damaged due to the intense heating and cooling, resulting in a temperature variations of the belts out of specification (exceeding 12 °C) and in the need to remake the whole process.

Currently, the preferred method for regulating the temperature variations of the belts is based on the introduction of gas guiders and gas limiters within the ribbon burners to control the flow of fuel therein (Figures 2, 3 and 4). If the temperature is higher on the right side of the oven, which is the inlet side of the gas-air mixture to the ribbon burners, gas guiders should be introduced to guide the heat to the left and to limit the heating of the inlet side; if the temperature is lower on the right side, gas limiters must be introduced to moderate the amount of mixture arriving at the left side and increase it at the inlet side.

Figure 2. 3D visualization of the ribbon burner (center) and of the materials for structural interventions in the oven (top: gas limiter; bottom: gas guider).

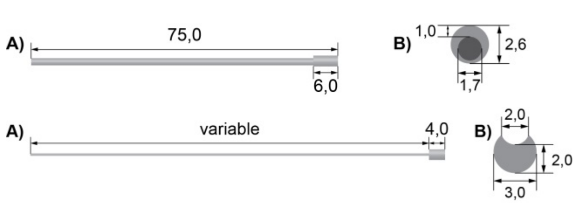

Figure 3. Dimensions of the gas guiders (top) and gas limiters (bottom), in centimeters: A) lateral view; B) frontal view.

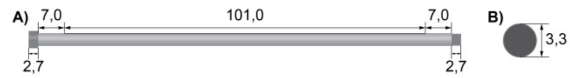

Figure 4. Dimensions of the ribbon burners, in centimeters: A) lateral view; B) front view.

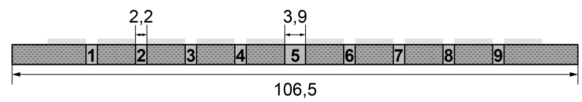

Figure 5. Width of the oven belts, in centimeters.

MATERIALS AND METHODS

The process to correct the temperature variations along the width of the belts involves measuring them with the oven in operation. The only way to realize it with precision, accuracy, speed and safety, is through the use of a thermometer which detects infrared radiation, since it operates without contacting the surface.

Before the measurements, the correct emissivity (0.9) of the material composing the surface of the belts (high-carbon steel) was introduced in the apparatus used: Fluke 566 infrared thermometer.

To compare the recorded temperatures, profiles of each belt were created: the intervals between the chips were numbered from left to right of the oven in the direction of product flow (Figure 6) and represented with the respective temperature in a graph. The measurements were made during the production of chips without defects and occupying the entire width of the oven belts.

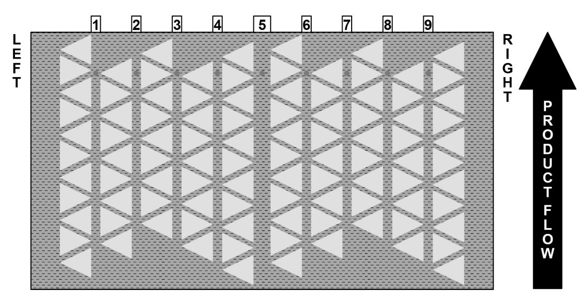

Figure 6. Numbering of the measurement intervals with respect to the product flow in the oven.

In order to avail the most of the length of the gas limiters, they must be introduced into the left side of the oven with a small weld in the inner end of the ribbon burner. Its application is recommended for the intervals 7, 8 and 9 (right side), and the metal rod of the limiter should be cutted with the proper length. For example, to increase the temperature in the interval 8, the limiter must have a total length of 87.8 cm (Table 1) and the intervention zone also includes the interval 9 (Figure 7).

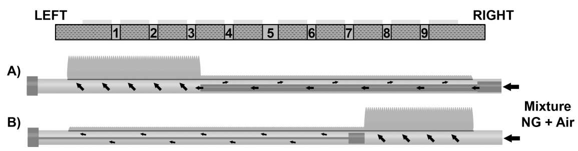

Figure 7. Flame effects by structural interventions in the ribbon burners: A) gas guider and B) gas limiter. In the top, the belt is divided in the respective intervals.

Table 1. Lengths of the gas guiders and gas limiters, depending on the interval where intended to act.

LEFT	Length (cm)						RIGHT
	1	2	3	7	8	9	
LIMITER	—	—	—	78,5	87,8	97,2	
	86,8	77,4	68,1	—	—	—	GUIDER

The gas guiders should be introduced into the right side of the oven, where is the entrance of natural gas-air mixture. Its use is recommended, in a general way, for the intervals on left side of the oven. However, like for the gas limiters, it is also possible to locate the flame effect in desired intervals: to act locally in the intervals 1 or 2 an extra tab should be welded to the material; to act in the interval 3 the material should be cutted. For example, to increase the temperature in the interval 3 the gas guiders should be cutted 6.9 cm (Figure 3 and Table 1) and the intervention zone also includes the intervals 1 and 2 (Figure 7).

RESULTS AND DISCUSSION

The whole process of temperature adjustment was performed in 17 operations, corresponding to 17 temperature profiles of the oven belts.

In Figure 8 is clearly observed that the three belts of the oven are out of specification of the maximum temperature variation (12 °C). It is notorious the existence of "cold zones" common to the three belts, characterized by generally being the minimum of the temperature function (intervals 3 and 7), and zones where the temperature range is higher, as the intervals 1 and 9, characterized by generally being the absolute maximum and minimum of the temperature function.

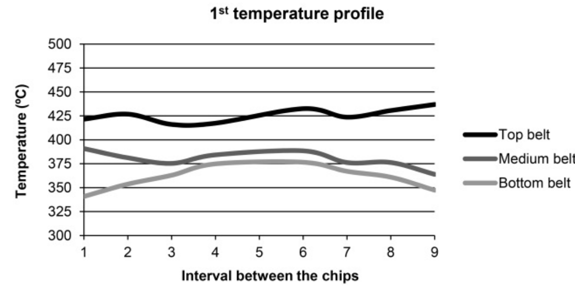

Figure 8. Temperatures observed in the 1st profile of each belt, depending on the interval between the chips.

To complement the visual information conveyed by the graphs, a rapid and efficient method to compare the variations of temperatures was developed (Table 2). The difference between the temperature of every interval and the average temperature of each belt was determined. This method immediately indicates the intervals where the temperature is low and needs to be increased (negative value), and where the temperature is high and need to be reduced (positive value), and it can also shows the convection profile inside the oven, from the bottom to the top. In the same table, the maximum and minimum temperatures of each belt were included, and the variation which is to be corrected.

The data from the interval 5 was neglected to create the temperature profiles and for determining the temperature variations along the width of the belts. This is related to the influence of the width of the interval 5, which is almost twice of the others, in the recorded temperature, and hence on comparisons of the results (Figure 5).

Observing the results obtained in the Tables 2 and 3 and in the Figures 8 and 9, the temperature profiles in the three belts evolved in the correct way, having the respective temperature variations inside the specification value (less than 12 °C).

Table 2. Results obtained in the 1st temperature profile.

Belt	Δtemperature[a] (°C)									$\bar{t}$[b] (°C)	t_{max} (°C)	t_{min} (°C)	Δt_{belt} (°C)
	Left			Center			Right						
	1	2	3	4	5	6	7	8	9				
Top	-4,1	1,1	-9,6	-8,3	24,7	6,8	-2,0	4,9	11,2	425,7	436,9	416,1	**20,8**
Medium	11,2	1,6	-4,2	4,7	18,6	8,9	-3,3	-3,3	-15,6	379,6	390,8	363,9	**26,9**
Bottom	-19,7	-6,8	2,4	14,3	24,1	16,0	6,6	0,4	-13,2	360,5	376,6	340,8	**35,7**

[a]Diference between the temperature of each interval and the average of each belt.
[b]Average temperature of each belt.

Table 3. Results obtained in the 17^{th} temperature profile.

Belt	Δtemperature (°C)									$\bar{t}$ (°C)	t_{max} (°C)	t_{min} (°C)	Δt_{belt} (°C)
	Left			Center			Right						
	1	2	3	4	5	6	7	8	9				
Top	-4,9	1,6	1,7	3,4	33,7	4,4	-4,1	-1,7	-0,4	467,3	471,7	462,3	**9,3**
Medium	-4,8	-1,1	-3,9	-0,7	18,2	2,4	-1,1	6,6	2,7	378,3	384,9	373,6	**11,4**
Bottom	-4,5	1,1	-3,1	-3,3	20,2	7,1	0,6	0,4	1,7	370,5	377,6	366,0	**11,6**

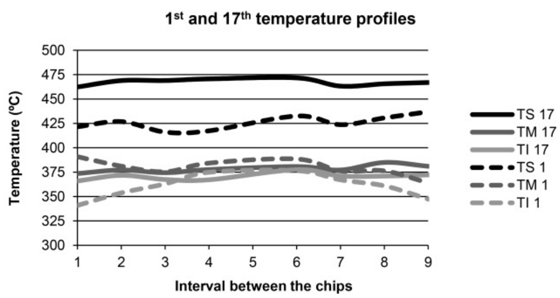

Figure 9. Comparison between the 1^{st} and 17^{th} temperature profiles.

Thus, based on the results of the 17 temperature profiles the following methodology was developed for the structural interventions in the oven:

1. Intervene in the desired number of ribbon burners, provided that they are equally spaced and that they are not continuous. Take into account the existence of gas guiders and gas limiters already in the oven, so that the installation is cycled in the ribbon burners;
2. Intervene preferably in the 2^{nd} half of the oven (with the exception of the top belt burners) so that the effects in the temperature are more perceptible to make the profiles;
3. Start the interventions in the bottom belt ribbon burners and then proceed to the above. The modification of the medium belt ribbon burners are accompanied by compensations in the top belt ribbon burners to prevent that the change of the temperature variation affects the correct chips production;
4. Enter gas guiders and gas limiters (or remove existing materials) until the temperature difference between the right and the left of the oven is minimized;
5. Introduce gas guiders and gas limiters, with the proper length, to correct the temperatures of the lateral intervals of the belts (Table 1).

Based on the evolution of the 17 temperature profiles of the oven belts, it was possible to arrange the interventions of a practical nature in descending importance:

1. To replace the damaged infrared burners: each one affects 3 °C in every interval of the top belt that is reached by radiation;
2. To clean the exterior of the ribbon burners and pilots: slightly improves the startup of the oven and the temperature distribution along the width of the belts;
3. To adjust the frequency of the exhaust fans to the specified values: influences the convection profile inside the oven, heating certain areas of the belts and cooling others;
4. To adjust the angle of orientation of the ribbon burners: there are variations due to constant vibration during the operation of the oven.

Based on the results of each structural intervention in the oven, it was possible to define the approximate effects of the introduction of one guide and one limiter. On their removal, the effect on temperature will be contrary:

Gas guider: in the intervals within the intervention zone increases 2 °C in the same belt and 2/3 °C in the upper belt; reduces 2 °C in the intervals 8 and 9 and 1 °C in the center (4, 5 and 6);

Gas limiter: in the intervals within the intervention zone increases 3 °C in the same belt and 1 °C in the upper belt; outside the zone reduces 1 °C overall and 1/3 °C in the center.

CONCLUSION

In this work the crusting operation in the industrial process of tortilla chips production was studied, which involved in-depth characterization of the equipment, with the aim of exposing their potential.

The correctness of the temperatures of the three oven belts was performed through interventions of a practical nature, such as replacing the infrared burners or improvements in equipment cleaning, and structural changes in ribbon burners. To achieve these goals the mapping of the temperatures of each oven belt were performed, to better define the material type (guiders and limiters), its quantity and the correct location for their application. The analysis of the evolution of the temperature profiles concluded that the two factors that influence the thermal variations in the belts are the damaged infrared burners and the exterior cleaning of ribbon burners, and they should therefore be checked with intense regularity. It is also important to ensure that the frequencies of the exhaust fans meet the specified values and that the orientation of the ribbon burners did not change significantly.

The improvements obtained with the correction of the temperature variations allowed a uniform distribution of the heat throughout the oven belts, benefiting the quality of crusting and the quality of tortilla chips. This permitted to produce better at lower cost, increasing the final yield. Or, paraphrasing the Engineer Luís Alves[21], the improvements judiciously capitalized the "raw material" called money handled in the "reaction" of crusting.

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